The Economics of Electric Vehicles for Passenger Transportation

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Contents

Contents

Foreword

Electric mobility is gaining momentum, especially in Europe, China, and the United States, which account for more than 90 percent of the world's electric vehicle (EV) fleet. But this report, *The Economics of Electric Vehicles for Passenger Transportation,* shows that electric vehicles could be increasingly relevant for low- and middle-income countries (LMICs).

While many advanced countries see electric mobility primarily as a way to decarbonize the transport sector, the rationale for electric mobility adoption in LMICs is much wider. It brings the potential to reduce local air pollution, improve the quality of public transportation, provide last-mile connectivity, reduce dependency on imported fuels, and provide new opportunities to participate in vehicle supply chains. Yet, electric mobility adoption does not address all malaises of transport and development such as road safety, congestion, land management, or urban planning. Therefore, electric mobility adoption must be part of a comprehensive program to promote sustainable and inclusive urban mobility.

Electric vehicles (EVs) will eventually come to dominate the passenger transport systems of all countries, but the timing of this transition will be determined by the economic and financial realities of each case. For some countries, it already makes economic sense to pursue electric mobility, even though EVs can cost 70 percent more than conventional vehicles. That is because the operating benefits EVs bring to the table – such as lower maintenance and fuel costs – often offset the higher capital cost, making them a feasible option in the medium-term.

Factoring in the broader health and environmental benefits makes the economic case even stronger. Regardless of how a country generates electricity, EVs emit less carbon per vehicle-kilometer compared to conventional vehicles. These reductions only become more pronounced as the power sector decarbonizes. For LMICs with serious urban air pollution problems, the value of local environmental benefits associated with electric mobility adoption even exceeds that of global climate benefits. After performing an analysis based on these criteria, this report finds that, in half of the countries studied, global policy targets aiming for 30 percent of new passenger vehicles to be electric by 2030 makes economic sense for many LMICs.

Efforts to accelerate an electric mobility transition should target the most viable market segments. The case for electric two-wheelers and three-wheelers is particularly strong in almost every country studied, in view of their relatively low capital cost. The case for electric buses is expected to strengthen as technology evolves and countries adopt efficient procurement and management practices. As of now, for more than half of LMICs studied, the electrification of buses is an attractive proposition, when externality benefits are included and when vehicles are deployed on busy, high-volume routes.

Once a country decides that accelerating electric mobility uptake makes sense, there are several ways governments can be proactive. Accelerating adoption requires coordination across sectors and a combination of strategic, transport, energy and financial policies. The evaluation of the timing and chief motivations should guide the policy design Nonmonetary incentives such as promoting leasing and consumer financing all show promise and are cost-effective. But also governments need to invest in robust charging infrastructure, which can be up to six times more effective at encouraging EV purchases than subsidies. Thus, the ultimate success of electric mobility adoption involves additional public investment, and in some countries, it also means reductions in fiscal revenues due to the foregone oil taxes. Governments may need to plan to anticipate the fiscal implications.

And while most of the pieces of puzzle could seem to be in place, ultimately making the proposal attractive for users is essential. That might demand setting in place financial and procurement schemes such as pooling demand and transferring power and benefits to buyer rather than to providers or by creating financing mechanisms to reduce the risk of new buyer and spread higher capital costs. Electric mobility is an agenda of increasing relevance to LMICs – although each one will need to find its own way. Like many transitions, while the trajectory is uncertain the ultimate destination is clear.

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Abbreviations

2W/3W	two-wheeler /three-wheeler
BaaS	battery as a service
BAU	business as usual
BEV	battery electric vehicle
CAFC	corporate average fuel consumption
DSO	distribution systems operator
EPM	Electricity Planning Model
EV	electric vehicles
FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles
GC	grand challenge
GCC	Gross Cost Contracting
GDP	gross domestic product
GJ	gigajoule
GNI	gross national income
HEV	hybrid electric vehicle
HOV	high occupancy vehicle
IBT	increasing block tariffs
ICCT	International Council on Clean Transportation
ICE	internal combustion engine
ICEV	internal combustion engine vehicle
IEA	International Energy Agency
IMF	International Monetary Fund
IRENA	International Renewable Energy Agency
LMIC	low- and middle-income countries
NREL	National Renewable Energy Laboratory
OECD	Organisation for Economic Co-operation and Development
PHEV	plug-in hybrid electric vehicles
PM	Particulate Matter
PPP	Purchasing Power Parity
PV	photovoltaic
SDS	Sustainable Development Scenario
SIDS	Small island developing states

TCO	total cost of ownership
TOU	time of use
TTW	tank-to-wheel
UNEP	United Nation Environment Program
WTT	well-to-tank

Note: *All dollars are in U.S. currency unless otherwise specified.*

Key Messages and Policy Recommendations

Electric mobility has garnered growing interest and significant momentum across several major global markets—often motivated by transport sector decarbonization. Together, Europe, China, and the United States account for more than 90 percent of the world's electric vehicle fleet. For many OECD countries, electric mobility is seen primarily as a lever for transport sector decarbonization, given that many of the other relevant policy options have already been exhausted.

This report finds that electric mobility is also increasingly relevant for low- and middle-income countries. As of today, electric mobility for passengers is a comparative rarity across low- and middle-income countries (LMICs). In some of the LMIC leading markets, such as Brazil, India, and Indonesia, electric vehicles account for less than 0.5 percent of total sales. There are signs that this situation is changing. India, Chile, and Brazil are leading the way in electrifying their bus fleets in their largest cities by introducing innovative financing practices and improved procurement practices. Battery swapping schemes are taking off in Asian and East African countries to lower the upfront cost of two-and three-wheelers. Original modeling for this report suggests that established global policy targets, such as 30 percent of new passenger vehicles to be electric by 2030, would make economic sense for many LMICs under a wide range of possible scenarios.

The potential benefits of electric mobility for low- and middle-income countries go well beyond those associated with decarbonization. Electric mobility for passengers in LMICs not only can certainly bring significant decarbonization benefits, but also has the potential to contribute to several other important development agendas—notably inclusive mobility, local air quality, energy security, and industrial policy.

- **Promoting inclusive mobility**. Life-cycle costs for some types of electric vehicles are becoming lower than those associated with conventional alternatives. Moreover, the proliferation of cost-effective two-wheel and three-wheel electric vehicles may bring transportation within reach of lower income populations. Electric two- and three-wheelers are already popular in many low-income markets for transporting people and goods. In rural areas, low-cost electric motorbikes, in combination with solar photovoltaic systems, reduce dependence on expensive or hard-to-obtain gasoline, facilitate access to markets and other opportunities, and help solve the first or last mile problem when using public transit. As electric vehicles move toward capital cost parity with their conventional counterparts, such benefits will be further accentuated.

- **Improving local air quality**. Deteriorating local air quality is a serious health issue in many large cities across the developing world, and is responsible for 7 million fatalities globally each year. Switching to electric passenger vehicles reduces emissions of the most harmful particulate matter by as much as a factor of 10 per passenger kilometer traveled. Not only is electricity sometimes the cleaner fuel, but the fact that it is generated in remote locations also moves remaining pollution away from vehicle tailpipes in crowded cities.

- **Bolstering energy security**. Many countries rely on imported oil products to power traditional petrol and diesel-based vehicles. Fuel imports can absorb a significant amount of foreign exchange and often leave balance of payments vulnerable to oil price shocks. To the extent that countries generate electricity from renewable energy, or even other indigenous fossil fuels, introducing electric mobility can bring significant benefits in terms of enhanced energy security and associated macroeconomic resilience. For example, countries such as Ethiopia and Nepal, which import fuels but can generate electricity almost entirely from indigenous hydropower, could significantly reduce their reliance on oil by switching to electric mobility.

- **Democratizing manufacture**. The manufacture of motor vehicles based on internal combustion engines is relatively complex, and hence not widespread, with just five countries accounting for 60 percent of global production. Although the manufacture of batteries for electric vehicles also remains highly concentrated globally, the greater simplicity of electric vehicles themselves, as well as the considerable commoditization of many key components, suggests the possibility of much greater scope for domestic production (or at least assembly) in many LMICs. An early indication is the innovative start-ups emerging in Kenya, Uganda and Rwanda, providing affordable alternatives for electric two-wheelers and already exploring lower cost options for electric buses and trucks.

However, the transition to electric mobility raises many complex choices and policy questions, many of which have never been considered from an LMIC perspective. Much of the policy literature on electric mobility takes the perspective of higher-income countries. However, the transport policy context in LMICs differs sharply from that in HICs in light of the disparities in age, performance, and composition of the baseline vehicle fleet. For the first time, this report undertakes a detailed analysis of the adoption of electric passenger mobility across a broad cross-section of 20 LMICs, as well providing a wide-ranging review of emerging country experiences. This overview briefly answers some of the most pertinent policy questions and draws out the main policy recommendations. More comprehensive analysis is provided within the report, while the associated *Electric Mobility Scoping Tool* can be adapted and applied to any country to gain deeper customized insights into the most appropriate policy trajectory in each case.

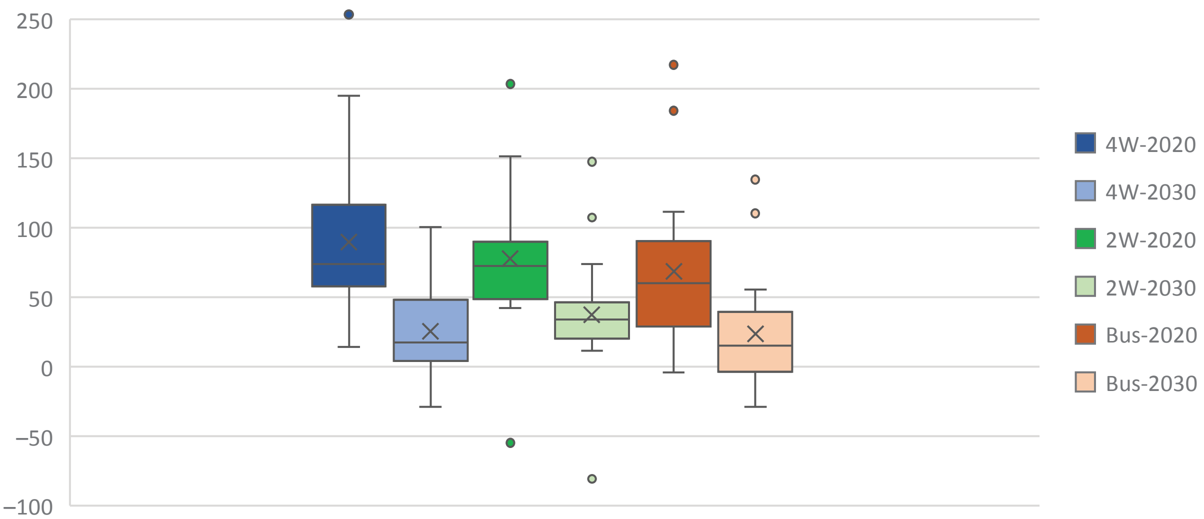
Addressing Questions

Policymakers are asking many questions about the relevance of electric mobility. Using the original research for this report, it is possible to clear up several common misconceptions about the case for electric mobility and to shed light on the many related questions that arise.

Question 1: Is the higher capital cost of electric vehicles compensated by lower life-cycle costs?

Capital cost premiums associated with electric vehicles are substantial, but declining. Electric passenger vehicles are significantly more expensive to purchase than conventional internal combustion engine vehicles. The magnitude of the capital cost premium varies according to the type of electric vehicle. As of the early 2020s, the largest premiums of around 80 percent are associated with four-wheel and two-wheel electric vehicles, and slightly lower premiums of around 60 percent with electric buses (figure 1). Some 30 percent of the cost of purchasing an electric vehicle is associated with the battery. Given rapid technological progress, the cost of batteries has been falling on average at 7 percent per annum. As a result,

FIGURE 1. Vehicle Capital Mark-up of BEV over ICE (%)



Source: World Bank, *Electric Mobility Scoping Tool*, 2022.
Note: BEV = battery electric vehicle; ICE = internal combustion engine (vehicle).

the cost premiums associated with electric vehicles are expected to fall to the 25 to 40 percent range by 2030 (figure 1), and will eventually reach cost. Nevertheless, uncertainties continue to surround the evolution of battery prices, which are closely linked to the availability and price of the rare earth minerals (such as lithium) used for their manufacture.

Charging infrastructure is another significant capital cost associated with the adoption of electric passenger vehicles. Although electric two-wheelers can largely be charged from regular power sockets, other types of electric vehicles require more specialized charging infrastructure. This includes both private charging points, at home or at work, as well as public facilities to ensure that electric vehicles can recharge while roaming. The associated investments are largest in the case of electric buses, which require more significant charging infrastructure given their greater power needs. Overall, investments in charging infrastructure typically amount, on average, to some US$2,500 on average per four-wheel vehicle and US$25,000 per electric bus.

Once purchased, electric vehicles are significantly cheaper to operate given their simpler and more efficient motors. Because much less can go wrong with an electric vehicle than with a fuel-based vehicle, maintenance is more straightforward, amounting to a typical saving of US$5,000 over the life cycle of a typical four-wheel vehicle. Electric vehicles are also less costly to run because they are much more energy efficient than their conventional counterparts (see question 3), amounting to a typical saving of around US$10,000 in the economic cost of energy over the life cycle of a typical four-wheel vehicle. Such underlying economic advantage is further accentuated by the fact that many LMICs tax petrol while subsidizing electricity, generating even larger financial savings for electric vehicle owners (see question 7).

In addition, the ongoing externality benefits resulting from reduced emissions of carbon and various local air pollutants can sometimes be the deciding factor for electric mobility. These bring an estimated economic value of approximately US$5,000 over the lifetime of a vehicle (see questions 3 and 4). For a significant number of countries, electric mobility is attractive solely for the lower operating costs, even without taking externality benefits into account. However, the number of countries for which electric mobility looks economically attractive increases significantly when externality benefits are included.

Question 2: Can consumers afford the capital cost differential associated with electric vehicles?

Until electric vehicles reach capital cost parity, higher purchase costs will be a significant barrier to uptake. In many countries, the capital cost premiums for private two-wheel and four-wheel vehicles do not represent much more than 10 percent of gross national income (GNI) per capita, suggesting that they might potentially be affordable with some consumer financing. In a significant number of countries, however, the capital cost premium of electric four-wheelers is prohibitively large—ranging from 20 to 100 percent of GNI per capita which is potentially an insurmountable barrier for many consumers.

Many OECD countries have tried to offset higher capital costs with vehicle purchase subsidies, but financing mechanisms are likely to be a better solution in the developing world. Subsidies for the purchase of electric vehicles, mainly four-wheel, are widespread in many market-leading countries. These subsidies have proved to be very costly, about US$12,000 per induced vehicle purchase. Moreover, such subsidies are likely highly regressive, given that four-wheel electric vehicles are expensive and have been adopted mainly by higher-income consumers. As a result, such subsidies are unlikely to be a good use of public funds in LMICs, particularly because those higher capital costs often pay for themselves over time as consumers enjoy lower operating costs. What may prove more cost-effective and scalable for LMICs is to develop financing mechanisms to allow consumers to spread the higher capital costs of electric vehicles over time. These could be consumer credit lines or adoption of vehicle (or battery) leasing models. For instance in India, the government offers a first-loss partial credit guarantee to financial institutions to unlock commercial financing availability at concessional rates for the purchase of electric two- and three-wheelers.

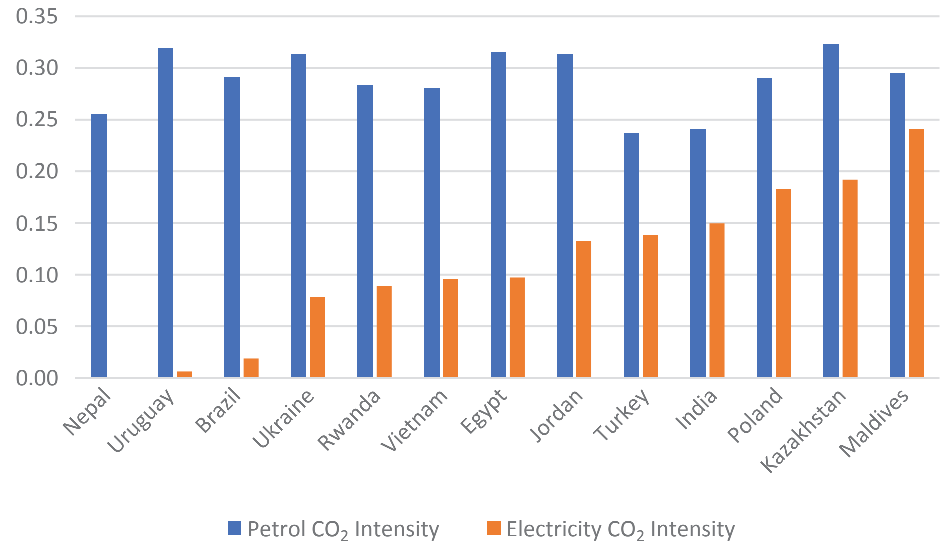
Leasing EVs can be effective in mitigating ownership risks faced by consumers and transferring them to leasing companies, which may be better equipped to manage them. Battery as a Service (BaaS) is one of the emerging business models in which the purchase of the battery—the costliest component of electric vehicles—is decoupled from the vehicle itself and a combination of battery leasing and swapping reduces the upfront vehicle cost, key barrier to EV adoption for low-income populations. This model has been observed in China, India, Thailand, and increasingly, Africa. Similarly, leasing schemes have been introduced to make the adoption of electric buses more palatable. In Chile, the business model for electric buses separates service provision from fleet ownership, with the utility becoming an asset owner and investor that leases buses to operators. Indeed, the use of Mobility as a Service (MaaS) models in the context of electric vehicles provides a practical way of shifting the burden of higher capital costs to firms with potentially easier access to credit and having consumers pay gradually per trip or via monthly subscriptions.

Question 3: Does it make environmental sense to electrify transportation before the power grid is fully decarbonized?

Electric vehicles offer a major energy efficiency advantage, particularly in the context of LMICs with highly inefficient fleets of conventional vehicles. Electric motors are much more efficient than internal combustion engines, which lose a great deal of energy in the form of heat and noise. This advantage remains, even accounting for significant energy losses in the generation, transmission, and distribution of electricity. When it comes to LMICs, the efficiency advantage is further accentuated by the low baseline efficiency in the motorized fleet due to the prevalence of older vehicles and the relatively lax fuel efficiency standards. When all these factors are accounted for, electric vehicles require only about a quarter to a third of the energy needed by existing internal combustion engine vehicles to move one passenger-kilometer.

Given its greater energy efficiency, electric mobility is typically advantageous in carbon terms even before the power grid is fully decarbonized. Countries vary greatly in terms of the current carbon intensity of their power generation mix. However, due to the much higher level of energy efficiency associated with electric vehicles, electric vehicles are almost always less carbon intensive than their conventional counterparts *per vehicle-kilometer travelled* (figure 2). Of course, this advantage only becomes further accentuated as the power sector pursues the necessary decarbonization trajectory over time. For example, countries like Kazakhstan and Poland, which generate electricity primarily from fossil fuels, can increase the externality benefits of electric mobility by 50 and 90 percent respectively as a result of shifting toward renewable sources of electricity.

FIGURE 2. Comparative Carbon Intensity of Petrol and Electricity ($kgCO_2$/vkm)



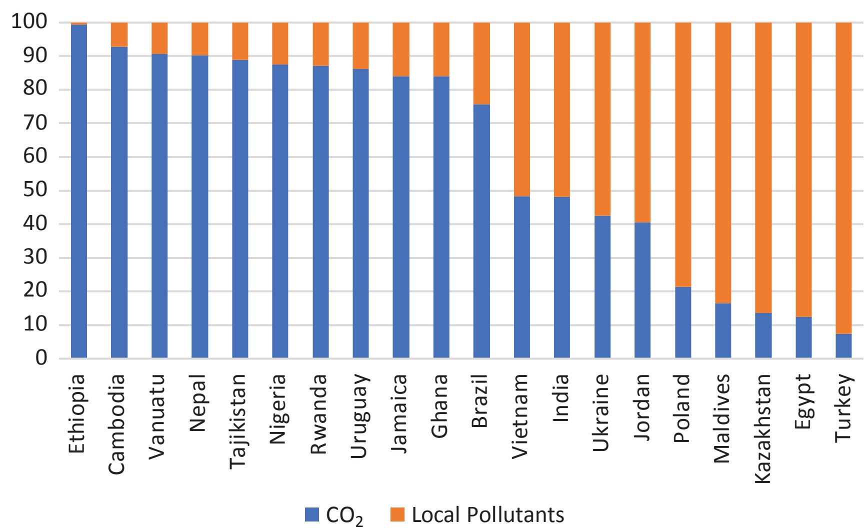
Source: World Bank, *Electric Mobility Scoping Tool*, 2022.

Question 4: How important are local environmental benefits in relation to global ones?

Electric mobility also carries a huge advantage in the reduction of local air pollutants. Electric vehicles emit just a fraction of the local air pollutants—NOx (nitric oxide), SOx (sulfur oxide), PM10 (particulate matter)—associated with internal combustion engines per unit of energy consumed. This advantage is further accentuated to around an order of magnitude when the energy efficiency differential is considered. In addition, local air pollutants associated with power generation are typically emitted at relatively remote locations where power plants are situated. The associated human health damage factor is therefore much lower than when the equivalent pollution is emitted from a vehicle tailpipe on a congested urban street.

For some emerging economies, the environmental benefits associated with reducing local air pollution are even more significant than those associated with mitigating global climate change. The relative importance of local and global environmental benefits of switching to electric mobility varies considerably across LMICs (figure 3). For countries such as Egypt and Turkey, which still rely significantly on fossil fuels for power generation and face major urban air pollution challenges, the environmental benefits associated with electrifying passenger transportation are primarily local in terms of improved urban air quality.

FIGURE 3. Environmental Benefits of Switching to Electric Mobility (% on total gains)



Source: World Bank, *Electric Mobility Scoping Tool*, 2022.

Conversely, for countries such as Ethiopia and Nepal, which have exceptionally clean hydropower and less pressing urban air pollution problems, the environmental benefits associated with electrifying passenger transportation are primarily global in terms of reduced carbon emissions.

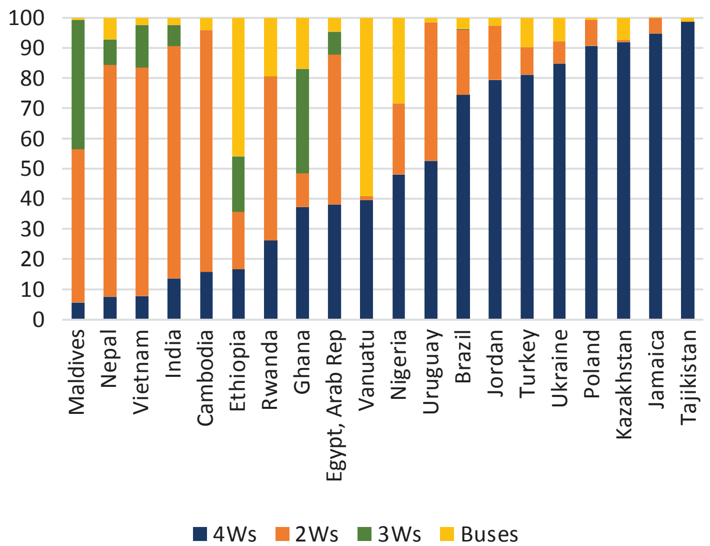
Question 5: Should countries prioritize electrification of certain vehicle categories, and, if so, which?

The case for electric vehicle adoption varies significantly across vehicle categories, with vehicle capital cost and lifetime mileage being critical factors. Passenger transport electrification is evolving in very distinct ways for the two-wheelers, four-wheelers, and buses. As a result, in any given country, electrification may make sense much sooner for some types of vehicles than for others, suggesting the importance of a differentiated approach. Broadly speaking, vehicle types with relatively small absolute capital cost differentials and/or relatively high lifetime mileage are likely to be the most attractive. Because the disadvantage of electric vehicles comes from higher capital costs, it follows that the least expensive vehicles may be among the first to become attractive. Similarly, because the advantage of electric vehicles stems from operating cost savings, it follows that the most intensively used vehicles are those likely to present the most favorable balance of costs and benefits.

Thus, electrification of transport is particularly attractive for two-wheelers, electric buses, and possibly high mileage four-wheel fleets such as taxis and equivalents. In just about every LMIC studied for this report, two-wheelers were advantageous to electrify, in view of their relatively low capital cost. Furthermore, for a majority of LMICs studied, the electrification of buses was also an attractive proposition, particularly once externality benefits were included. The case is strongest for electric buses deployed on routes that involve intensive usage of the vehicle, to allow operating cost savings to accumulate. By contrast, the case for electric four-wheelers was only compelling in a handful of the LMICs studied, albeit slightly better for intensively used commercial fleet or passenger vehicles, such as taxi or ride-sharing services, which may capture higher operating cost savings.

Vehicle fleet compositions vary hugely across low- and middle-income countries, and this needs to inform the adoption strategy. Whereas four-wheel vehicles tend to dominate passenger fleets in many high-income countries, the story can be quite different across the developing world (figure 4). In many Asian countries—such as Cambodia, India, Nepal, and Vietnam—two-wheeled vehicles account for as much as 60 to 80 percent of passenger-kilometers, making their electrification particularly relevant. Across African countries—such as Ethiopia and Ghana—buses account for some 40 percent, which again may be a good case for electrification. By contrast, in many upper-middle-income countries—such as Brazil and Turkey—four-wheel vehicles account for more than 80 percent of passenger-kilometers traveled, leaving the case for

FIGURE 4. Prevalence of Types of Vehicles (% of total VKT)



Source: World Bank, *Electric Mobility Scoping Tool*, 2022.

electric mobility not so strong. This underscores the importance of understanding a country's vehicle fleet composition when designing a vehicle electrification strategy.

Question 6: What will the impact of electric mobility be on the electric power system?

The overall energy demand associated with adopting electric mobility is not large relative to the scale of the power system in most countries. Electrification of passenger transport will certainly create additional demand for electricity. Yet demand growth is expected to be quite manageable in most cases due to the energy-efficient nature of electric vehicles, and the relatively slow transformation of the vehicle fleet. Across the 20 LMICs studied for this report, the adoption of a 30 percent target for new vehicle electrification by 2030 was found to boost electricity demand by no more than a fraction of 1 percent. Nevertheless, exceptions may arise in some low-income countries where power infrastructure is embryonic. Simulations conducted for several countries in the Sahel suggest that modest electrification of the two-wheel fleet could already place pressure on scarce electricity supplies.

The time profile of electric vehicle charging could potentially exacerbate peak demand. More concerning than the aggregate effect on electricity demand is the time profile associated with vehicle charging.

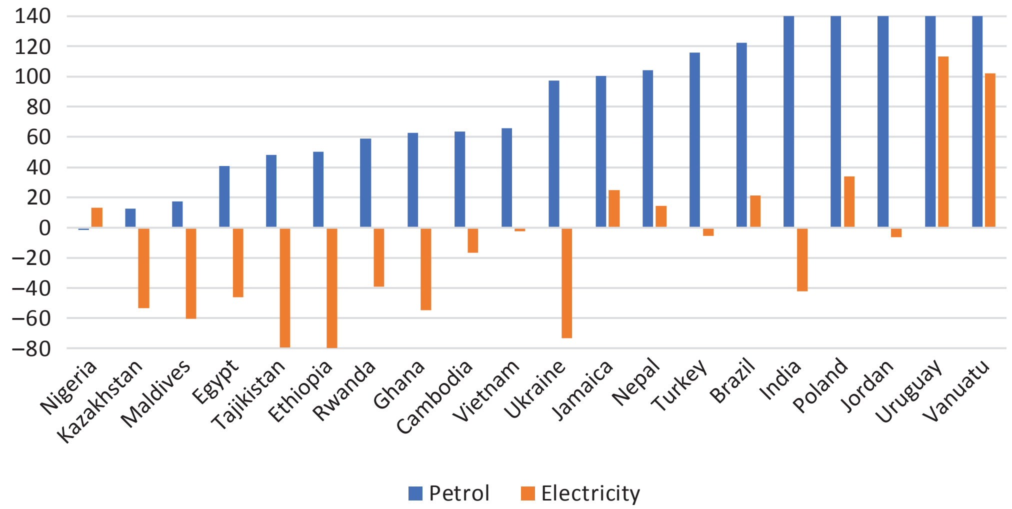
For private vehicles at least, charging will quite likely take place at home at the end of the day, carrying the risk of further accentuating the evening demand peak. This is potentially costly to accommodate, given that peak demand for electricity—rather than total energy needs—is the main driver for power infrastructure investment. Moreover, many power utilities lack the pricing tools to incentivize a shift in charging behavior toward off-peak periods, such as the middle of the night.

Question 7: How do taxes and subsidies affect incentives for the adoption of electric vehicles?

Energy taxes and subsidies materially affect the operating cost savings associated with electric mobility. Many countries either tax energy (because of negative environmental externalities) or subsidize energy (because it is a basic need). Moreover, different kinds of energy, notably liquid fuels and electricity, may be treated quite differently from a fiscal perspective. As noted, one of the main advantages of electric vehicles is reduced energy consumption and associated costs. This underlying economic advantage will be distorted by the presence of taxes and subsidies for liquid fuels and electricity.

Most LMICs studied tend to heavily tax petrol and diesel while generously subsidizing electricity, to the point of over incentivizing electric vehicle adoption. Typical tax rates on petrol range run to

FIGURE 5. Tax and Subsidy Rates for Petrol and Electricity (% on cost)



Source: World Bank, *Electric Mobility Scoping Tool*, 2022.

between 40 and 140 percent over cost; subsidies to electricity amount to around 40 percent of the price (figure 5). Such a fiscal regime favors the adoption of electric vehicles by widening the cost differential between liquid transport fuels and electricity. Although pricing petrol and diesel more expensively than electricity may be legitimate, given related larger environmental costs, analysis suggests that the price differential is often larger than what would be warranted economically by the different environmental impact. Of course, a fiscal regime that taxed electricity while subsidizing petrol would have the opposite effect of disincentivizing the adoption of electric vehicles and could represent the situation in some oil-exporting countries that heavily subsidize fossil fuels.

The fiscal regime affecting vehicle purchase also plays a role in shaping incentives for uptake. Whereas many OECD countries have introduced significant subsidies to encourage purchase of electric vehicles, these are a rarity across LMICs. In about half the countries studied, the fiscal treatment of electric vehicles and their conventional counterparts does not differ. In the other half of the countries, vehicles based on internal combustion engines are penalized with a surcharge of about 20 percentage points above their electric equivalents, based on a combination of taxes and import duties. Nevertheless, fiscal incentives—even where they exist—are not typically large enough to reverse the capital cost disadvantage of electric vehicles.

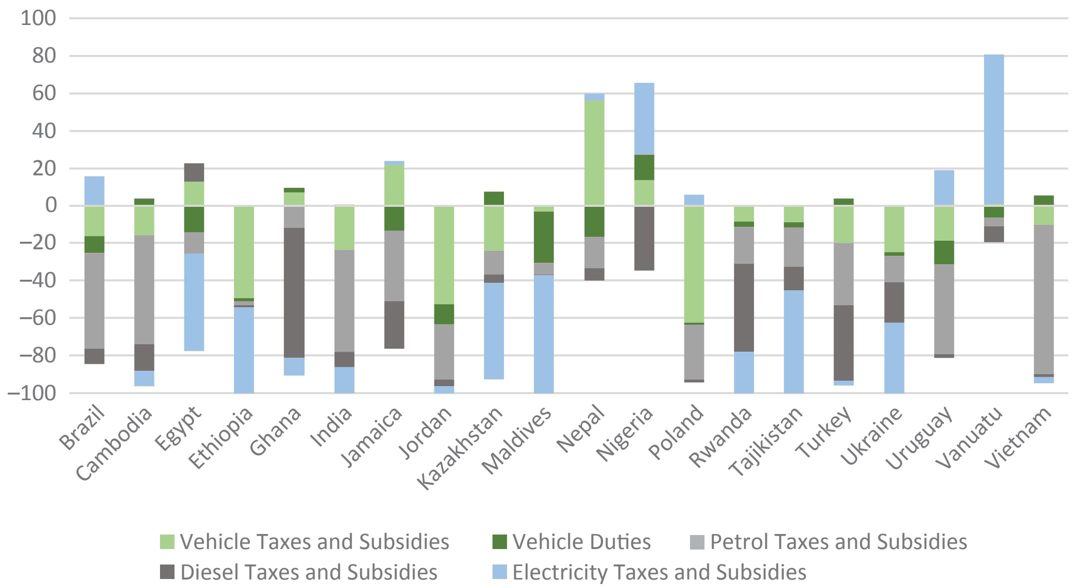
Question 8: What are the fiscal implications of an accelerated transition to electric mobility?

Absent any fiscal reforms, adoption of electric mobility is expected to reduce net fiscal receipts. As noted, internal combustion vehicles and associated liquid transport fuels are generally more heavily taxed than electric vehicles and associated electricity usage. The inevitable consequence is that a shift toward electric mobility will decrease tax receipts from conventional transport and increase subsidies to the electricity sector (figure 6). This could be expected to lead to some overall deterioration in the public finances, particularly for countries that rely on fuel taxes as a significant source of fiscal revenue. The transition might also prejudice the financial sustainability of power utilities—already precarious in many LMICs—if these are not fully compensated for providing additional electricity to vehicle owners at below-cost recovery rates. In addition to its negative impact on the net fiscal position, the electric mobility transition will also give rise to public expenditure needs (see question 9).

Question 9: What are the investment needs associated with electric mobility and who bears them?

The investment needs associated with the transition to electric mobility are significant. Broadly, two types of investments are needed to support adoption of electric mobility. The first is the incremental capital

FIGURE 6. Relative Fiscal Impact of Electric Mobility by Tax Stream (% of total impact)

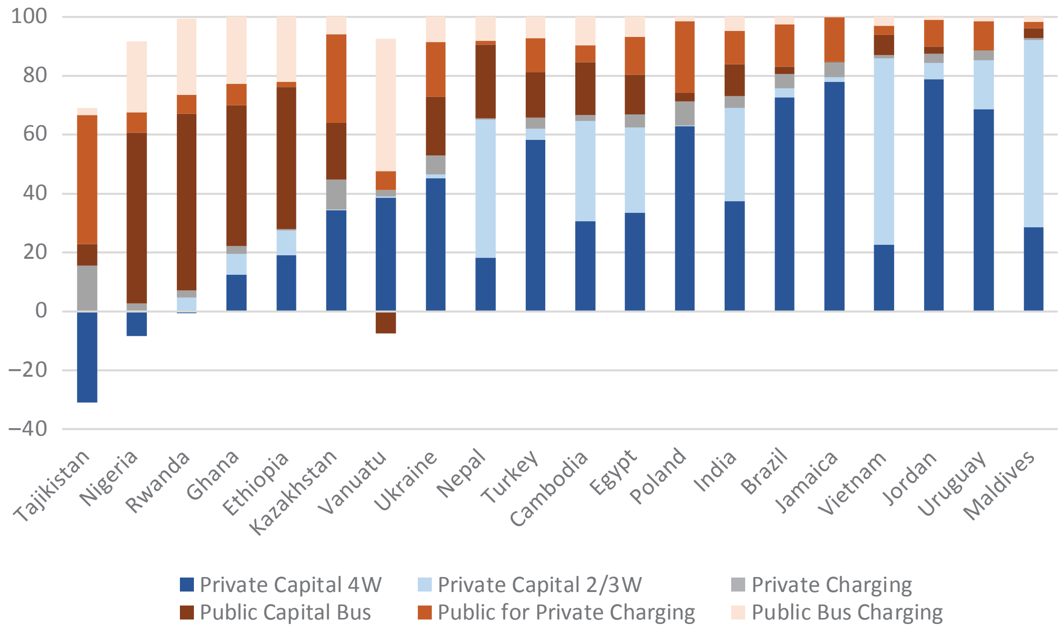


Source: World Bank, *Electric Mobility Scoping Tool*, 2022.

cost associated with the purchase of electric vehicles, which is currently substantial, but can be expected to decline toward zero over time. The second is the charging infrastructure needed to support the use of electric vehicles, comprising a range of facilities, from private chargers located in homes and offices to public charging stations on the road, to specialized charging arrangements at bus depots. Despite considerable variation in the magnitude of investment needs across countries, a figure of around 0.25 percent of gross domestic product per annum is representative.

The burden of investment falls mainly on the public sector in some countries and mainly on the private sector in others. The incremental investment cost of personal two-wheel and four-wheel electric vehicles and associated home charging infrastructure will fall on private individuals. Whereas the public sector must bear the additional cost of purchasing electric buses and their associated charging infrastructure, as well as provision of public charging facilities for private users of electric vehicles. The relative size of public and private investments needed varies hugely across countries (figure 7). In countries where public transport is dominant, the investment burden falls primarily on the public sector. Elsewhere, most of the investment needs to be undertaken by private actors. Understanding these differences is critical in designing a suitable financing strategy.

FIGURE 7. Additional Investment Needs by Public and Private Shares (% on total needs)



Source: World Bank, *Electric Mobility Scoping Tool*, 2022.

Question 10: Could carbon finance play a role in financing the electric mobility transition?

Electric mobility can sometimes provide a cost-effective way of carbon abatement. In almost half of the countries studied, electric mobility can deliver carbon abatement at negative cost—meaning that its adoption is more than justified by the other associated benefits, so that carbon savings essentially 'come for free'. In many other countries, however, adopting electric mobility would only make economic sense if the price of carbon exceeded US$100 per ton. The relevance of electric mobility as a carbon abatement strategy, then, depends heavily on context.

Carbon financing could potentially cover a significant portion of public investment needs. At present, there is little or no experience with harnessing carbon finance to support electric mobility. If it were possible to capture such finance at a price of US$40 per ton, however, simulations suggest that the resulting revenues would be enough to cover a substantial percentage (around a quarter) of the associated incremental government investment needs in electric buses and public charging infrastructure. The same cannot be said for private investment in four-wheel vehicles, where carbon finance is not able to contribute a material share of the incremental investment.

Recommendations

Several useful policy recommendations flow from the answers to the questions posed. These fall into several categories: strategic context (recommendations 1–4), pertinent to the transport sector (recommendations 5–9), pertinent to the energy sector (recommendations 10–13), and related to financing (recommendations 14–16).

Strategic Recommendations

Recommendation 1: Identify the primary motivation for pursuing electric mobility. As noted at the outset, reasons for pursuing electric mobility are numerous, particularly in LMICs. These include promoting inclusive mobility, improving local air quality, reducing carbon emissions, bolstering energy security, and democratizing manufacture of vehicles. In any given country, one or more of these objectives may weigh more heavily than others. Countries need to articulate why they are adopting electric mobility because doing so will help to guide and inform their strategic approach. For example, a country motivated by industrial policy may need to press ahead sooner than otherwise to gain a first mover advantage in manufacture, whereas a country motivated by decarbonization need only advance once the associated implicit carbon price drops below a certain level.

Recommendation 2: Position electric mobility within an integrated national strategy for sustainable mobility. Even when decarbonization is an important reason for pursuing electric mobility, countries need to recognize that electric mobility is just one of several approaches to decarbonizing the sector and of a wider national strategy for sustainable mobility. Transport decarbonization will generally require a combination of measures to *avoid* emissions through demand management, to *shift* traffic to less carbon-intensive transport modalities such as public transportation and railways, and to *improve* the carbon footprint of all transportation modes. Electric mobility is just one way to *improve* the sector's carbon footprint and may not necessarily be the most cost-effective one. It will need to be considered alongside other *improve* measures, such as motorization management to improve the overall fuel efficiency of the conventional fleet, as well as combined with other measures designed to *avoid* and *shift* emissions.

Recommendation 3: Evaluate the case for and timing of electric mobility at the country level. A strong conclusion from this study is that the economics of electric mobility for passenger transport depend on context.

The balance of benefits and costs varies substantially across countries in line with their characteristics. For example, in general, the case looks to be stronger in countries that are net oil importers, enjoy relatively low-cost purchase of vehicles, and have vehicle fleets that are not dominated by four-wheelers. Furthermore, the case for electric mobility is generally improving over time, due to technological change, and the moment when it starts to make economic sense will differ from one country to another. The *Electric Mobility Scoping Tool* developed for this report provides an agile and practical way of conducting a first-order assessment at the country level. More detailed analysis for the 20 countries covered in the report is provided in the *Country-at-a-Glance* appendix.

Recommendation 4: Establish mechanisms for institutional coordination. The transition to electric mobility is complex, calling for coordination across a wide range of institutions, which may not necessarily have any history of close collaboration. For a start, both transport and electricity sectors need to work closely together to ensure that power infrastructure is increasingly aligned with transportation demands. Further, although electric mobility may be a national policy objective, much of the implementation will need to take place at the city level. For instance, an urban municipality's decision to electrify transport may prejudice national revenues from gasoline tax, while a national decision to accelerate electric mobility may impose significant investment needs at the local level.

Transport Sector Recommendations

Recommendation 5: Target adoption of electric mobility toward most promising vehicle segments. Countries should avoid blanket approaches to electric mobility and consider instead the electrification of each vehicle segment individually because the strength of the case may vary substantially. Two-wheelers (with their relatively low capital costs and negligible charging infrastructure requirements) are typically the first vehicle category for which electric mobility becomes attractive, followed by buses and lastly four-wheelers. Taking this into account, countries may wish to sequence transport electrification efforts accordingly. Further, because the benefits of electric mobility stem from operating cost savings, the crucial issue is mileage. The higher the vehicle mileage, the sooner electric mobility is likely to become attractive. This points to a case for prioritizing, within each vehicle segment, those sections of the fleet associated with the most intensive usage. For instance, taxis, ride-sharing vehicles, and other commercial four-wheel fleets may become suitable for electrification before less-intensively used private family cars.

Recommendation 6: Prioritize use of public funds for subsidization of charging infrastructure. The expansion of electric mobility is subject to a coordination, chicken-and-egg type of problem: demand for electric vehicles depends on the availability of charging infrastructure, and the case for building charging infrastructure depends on demand for electric mobility. Breaking out of this vicious circle is therefore a priority area for public intervention. Clear economic evidence indicates that subsidizing construction of public charging stations is a far more cost-effective approach to encouraging the uptake of electric vehicles than subsidizing the purchase of those vehicles directly. Indeed, the subsidy cost per additional electric vehicle sale induced is just US$4,000 for charging stations, versus US$12,000 for vehicle purchase incentives.

Recommendation 7: Facilitate battery swapping models. A simple way of keeping down the cost of electric vehicles and the associated battery charging activities is to swap fully batteries in and out of vehicles, exchanging flat batteries for fully charged ones. Associated business models are already springing up across Africa and Asia, but the scale-up of this promising approach calls for further regulatory standardization to ensure widespread compatibility between types of batteries and electric vehicles.

Recommendation 8: Facilitate recycling of batteries for electric vehicles. The most critical bottleneck for the development of electric vehicles is batteries. Batteries not only remain relatively costly to produce, but also are subject to a high degree of market concentration and hostage to bottlenecks in the supply chain of the rare earth minerals (such as lithium) from which they are made. As the stock of electric vehicle batteries in circulation starts to expand, it will become increasingly feasible to recycle batteries extracting further value from their mineral content. However, this depends on a suitable policy environment being in place to facilitate recycling through the establishment of regulatory standards and procedures at the national and international level, as well as associated manufacturing facilities jointly set in place with regulations that extend producer responsibility to battery recycling.

Recommendation 9: Adopt demand pooling mechanisms to reduce procurement cost of buses. Similar challenges arise for public transit authorities, which may struggle to afford the capital cost premium associated with electric buses. In these cases, experience shows that the aggregation of demand across multiple urban jurisdictions to form larger procurement lots can be an effective way of reducing the unit cost of purchasing electric buses. India, for example, has achieved cost reductions of up to 30 percent. This may involve national-level coordination of electric bus procurement across cities, or in smaller countries even supranational coordination, potentially facilitated by regional or multilateral institutions.

Energy Sector Recommendations

Recommendation 10: Integrate demand for electric mobility into power sector planning. As electric mobility becomes increasingly widespread, its implications for the power sector will become more material. Given the long lead times involved in power sector investments, it is important to start integrating projected transportation demand into the planning process along the entire electricity supply chain, starting with generation, moving on to transmission, and focusing on local distribution, where hotspots and bottlenecks are likely to arise. This should provide a clearer sense of the cost implications of electrifying transport for the power sector.

Recommendation 11: Adopt electricity demand management measures to shift charging demand away from peak periods. The cost implications of electrifying transport for the power sector depend on charging behavior and the extent to which it is concentrated in existing system peak periods, which highlights the importance of adopting measures to manage electricity demand, with a view to shifting the timing of vehicle charging. The many ways of doing so include simple measures such as providing consumers with information to encourage more efficient behavior and introducing battery swapping arrangements to spread charging activity over time (recommendation 8). Ultimately, smart charging infrastructure that allows the grid operator to influence when vehicles charge (V1G), and potentially even integrate vehicle batteries as energy storage resources at the system level (V2G) can resolve this issue—though not without significant investment. In the meantime, one of the most powerful demand management tools available is energy pricing (see recommendation 12).

Recommendation 12: Reform electricity tariff structures to provide incentives for more efficient charging behavior. Electricity tariff structures can be complex and across the developing world are dominated by time-invariant rising block tariff structures. Such schemes can penalize electric vehicle ownership by pushing charging into higher-priced consumption bands. At the same time, they do nothing to encourage vehicle owners to charge during off-peak periods. Greater reliance on time-of-use pricing, where flat linear tariffs vary by time of day, would be better suited to systems where electric vehicles make up a growing portion of demand. However, implementing such pricing schemes calls for significant investments in smarter metering infrastructure.

Recommendation 13: Reform energy prices to ensure suitable incentives for electric vehicle adoption. The absolute level of electricity prices relative to that of liquid transport fuels will have an important impact on the incentive for electric vehicle adoption in the first place. As noted, taxing petrol and diesel while subsidizing electricity may over incentivize electric vehicle adoption, and vice versa. Ideally, the relative prices of transportation and electricity should reflect the relative burden of environmental pollution associated with each of them.

Finance Recommendations

Recommendation 14: Support creation of financing mechanisms to spread higher capital costs. Capital cost premiums for electric vehicles may persist into the medium term, making them difficult for private consumers to afford. This would be especially true for the low-income consumers who might otherwise benefit from electric two-wheelers. Rather than introduce relatively costly and potentially regressive subsidies for the purchase of electric vehicles, LMICs would be better advised to support creating financing mechanisms so that the higher capital costs can be spread over time. This could be done several ways, from providing credit lines on relatively soft terms to introducing leasing arrangements for vehicles and/or batteries, to adopting innovative (ESCO-type) models where an intermediary bears the cost of vehicle purchase in return for a share in the operating cost savings.

Recommendation 15: Tap into carbon finance to offset public investment needs. Depending on the country context, electric mobility could in some cases prove to be a zero or low-cost approach to carbon abatement. Moreover, analysis suggests that carbon credits could in principle cover a material proportion of the incremental investment cost, particularly well-suited to critical areas of public investment, such as the development of charging infrastructure or the purchase of higher-cost electric buses. As of today, however, there has been little or no experience with designing carbon transactions in a manner suitable for supporting the development of electric mobility. Claiming carbon credits via results-based climate financing could be an option to explore more systematically.

Recommendation 16: Examine fiscal implications of electric mobility and make adjustments as needed. As noted, given the shifting patterns of demand for vehicles and associated fuels, the transition to electric mobility is unlikely to be fiscally neutral. On the contrary, given prevalent patterns of taxation and subsidization for vehicles and energy, the electrification of the transport sector is likely to erode established fiscal revenue bases, notably fuel taxation. While a certain amount of fiscal incentive may be helpful to catalyze the transition in the early stages; over time, the fiscal architecture will need to adapt to this new reality.

Like many transitions, while the trajectory is uncertain the ultimate destination is clear. Electric mobility is an agenda of increasing relevance to LMICs given its potential to contribute to multiple development challenges. However, each country will need to find the right moment and the right reasons for electrifying its transport sector. Many factors will shape the electric mobility transition in each country, including the nature of the vehicle fleet and the wider energy supply situation. But for most countries it will make sense to target smaller and/or higher mileage vehicles first, channel scarce public resources toward development of charging infrastructure, provide mechanisms for consumer finance, and coordinate closely with the electricity sector.

CHAPTER 1

Why Is Electric Mobility a Development Issue?

Why Is Electric Mobility a Development Issue?

Mobility is essential for economic and social development but in its current form the transport sector in most countries is not sustainable. Pollution is among the most severe problems brought on by the transport sector, causing an estimated 7.8 million years of life lost annually which translates into about US$ 1 trillion in health damages globally (Annenberg et al. 2019). Transport is also a major driver of global warming, responsible for about a quarter of global greenhouse gas emissions from burning fossil fuels (IEA 2020). Given the vast vehicle stock in industrialized countries and continued rapid motorization in low-and middle-income countries (LMIC), the need to decarbonize transport is urgent. Electric vehicles (EVs) will contribute toward this goal, complementing other sustainability priorities such as a modal shift to nonmotorized and public transport. Like other major technological changes, EVs will be disruptive—triggering major changes in transport-related sectors, which are a large economic force and major employer in most countries. These disruptions will certainly play out over the next few decades. Good public policy can ensure a smooth transition. Countries should therefore prepare for and promote the electric mobility transition as one critical element in an overall shift toward a sustainable transport and energy system. For the purpose of this report, EV refers to a battery electric vehicle (BEV) or a plug-in hybrid electric vehicle (PHEV). It does not include hybrid electric vehicles that cannot be plugged in.

Almost 130 years after the earliest electric vehicles emerged, the electrification of transport is approaching a tipping point (Sperling 2018). Numerous automobile firms have announced a shift to producing EVs mostly or even exclusively, and they face stiff competition from newly formed electric-only companies. Countries, regions, and cities have announced bans on the registration or operation of internal combustion engines in the near future (Wappelhorst 2020). Further technology advances and scale economies are quickly reducing the cost of key components in electric vehicles—notably the battery pack. For some vehicle types and in some markets, EVs already have a lower total cost of ownership than internal combustion engine vehicles (ICEVs). Examples are fleet vehicles or two- and three-wheelers that provide essential shared transport services in many lower income countries. Effective policies can accelerate these trends.

Like any major technological change, the electric mobility transition will create winners and losers. It will shrink a massive and complex fossil fuel-based infrastructure built over more than a hundred years that delivered unimagined mobility for people and goods. The shift will affect how vehicles are built and traded and how they are fueled and serviced. Opportunities for smart entrepreneurs and businesses will be numerous.

Many firms, though, will experience painful adjustment or leave the sector, and labor-market turnover could be considerable. Jobs will likely be lost in automobile production beyond those already experienced to automation. In other areas, such as building a charging infrastructure, new jobs will be created. Whether these disruptions will cause widespread social hardship will depend on the effectiveness of public policies that can mitigate harm.

Electrification is only one of the ways to decarbonize the transport sector. EVs address the pollution problem but not other transport sector externalities, such as congestion, road safety, or the large amount of land that transport infrastructure requires. Electrification is therefore only one element in a comprehensive sustainable transport policy that involves such measures as reducing unnecessary travel; making nonmotorized travel and public transit safer, cheaper, and more convenient; and shifting goods transport from trucks to rail or ship where possible.

This chapter discusses the broader development implications of the electric mobility transition. It argues that electric mobility will have important environmental, economic, and social impacts in low- and middle-income countries where EV uptake has so far been low or absent (see, for example, Dane, Wright, and Montmasson-Clair 2019). The focus, as in the report overall, is on passenger road transport. The electric mobility transition will take time, although major technological shifts often occur more quickly than anticipated. Not all countries will or should immediately make EVs a priority. Waiting for technology to advance and costs to come down will sometimes make sense. But all countries should develop an electric mobility strategy. The following chapters in this report will discuss when is an appropriate time to start implementation and how to facilitate the transition to electrified transport with effective public policies.

Rapid Motorization, Environmental Concerns and Technological Change Drive the Electric Mobility Transition

Mobility is a fundamental need and, all else equal, people prefer personal transport. Owning a vehicle makes it easier to access services, jobs, and other opportunities. A vehicle is also an aspirational purchase and status symbol. More than 1.2 billion vehicles—passenger cars, buses, motor coaches, trucks, and tractors—were in use globally in 2018 (World Road Statistics 2020).F1F Most years, the car population grows by more than 4 percent, the largest increases in the East Asia and Pacific region. As vehicle ownership in high-income countries is close to saturation levels, two-thirds of the increase in car ownership will occur in countries that are not members of the Organization for Economic Co-operation and Development (OECD) (Sims et al. 2014). This rise in the global fleet could be enormous. If China (166 vehicles per 1,000 population in 2018) were to reach motorization rates like those of Australia or Poland (about 720), 770 million vehicles would be added. India (about 25 vehicles per 1,000) reaching the same level would add another 940 million[1] (World Road Statistics 2020). In principle, increased vehicle ownership could yield enormous personal and societal benefits, which is why many governments encourage car ownership. Those benefits come with considerable social costs, however.

Vehicles using internal combustion engines cause local pollution that has immediate effects on the health of the local population and climate pollution that contributes to global warming. Local air pollution from transport is associated with health conditions such as heart and lung disease, cancer, complications during pregnancy, and adverse birth outcomes (Health Effects Institute 2010). Specifically, burning gasoline or diesel fuel releases nitrogen oxides (NO_x), carbon monoxide (CO), ozone, sulfur dioxides (SO_x) and volatile organic compounds (VOCs). NO_x and VOCs combine to form coarse (PM10) and fine (PM2.5) particulate matter. Exposure to particulate matter can also affect mental health (Braithwaite et al. 2019). Although severe health impacts are cumulative and not immediately felt, air pollution is visible. This has helped motivate governments to tighten air quality controls, most prominently in urban China (World Bank and EV100 2022; World Bank and Development Research Center of the State Council 2014). Commuters, cyclists, pedestrians, and residents living near busy urban roads or transport corridors are most affected by air pollution (Cepeda et al. 2017). One estimate puts the global annual deaths from traffic related PM2.5 and ozone exposure at 385,000 in 2015, which equates to 11.4 percent of total deaths attributed to such pollution (Annenberg et al. 2019). Poorer countries with older vehicle stocks and laxer emission controls experience higher air pollution exposure, as do households with low socioeconomic status. Poorer households are more likely to live near pollution sources including heavily trafficked roads. Poorer children spend more time outside, and their households cannot afford mitigation options such as air purifiers. Satellite data analysis in Dar es Salaam, Tanzania, for example, suggests that areas of high traffic volume and associated air pollution tend to coincide with low-income neighborhoods (Dasgupta, Lall, and Wheeler 2020). Higher air pollution exposure, combined with higher susceptibility to poor health, results in major health disparities driven by environmental factors (Hajat, Hsia, and O'Neill 2015).

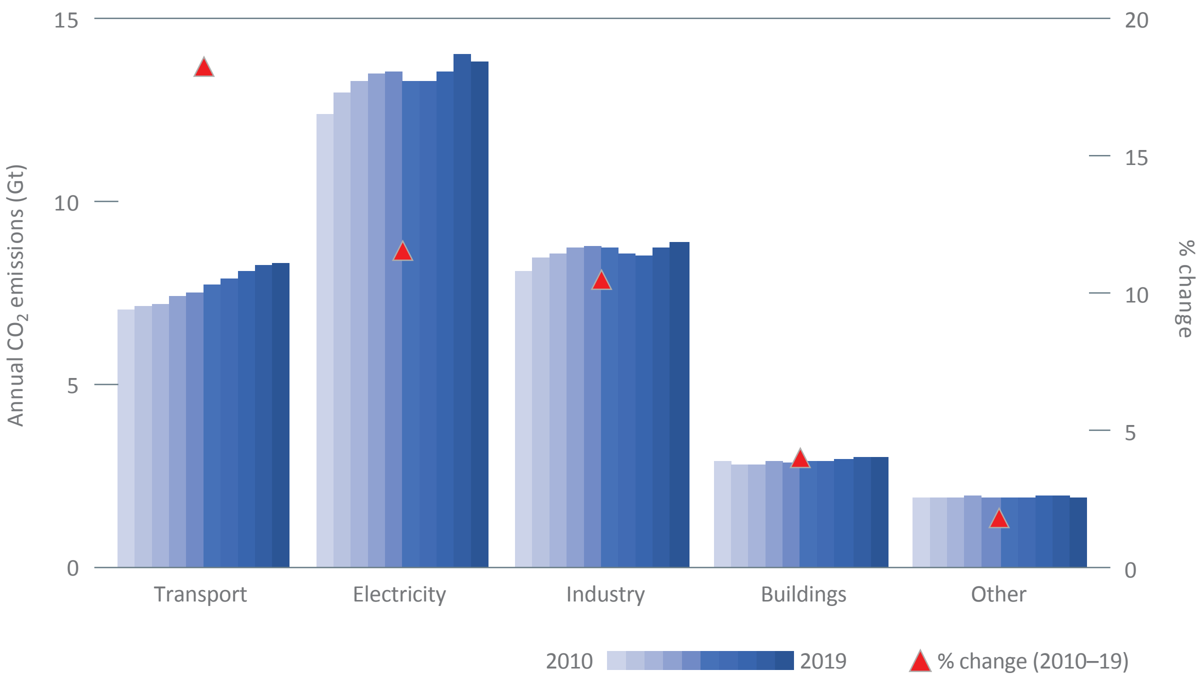
Combustion of fossil fuels also produces carbon dioxide (CO_2), which is the main contributor to global warming, as well as other pollutants with high warming potential, such as nitrogen oxides or black carbon. In 2019, oil supplied more than 90 percent of the total energy consumed by the transport sector. This generated almost 8.5 $GtCO_2$ (emissions fell to 7 $GtCO_2$ in 2020 during the COVID-19 pandemic) or about a quarter of all global greenhouse gas emissions (IEA 2021a). These emissions have been rising fast as improvements in fuel

1. World Bank staff estimate based on World Road Statistics data

efficiency are more than offset by more and bigger vehicles and higher travel volumes. In fact, the transport sector is the only major sector whose greenhouse gas emissions have steadily risen during the last decade (figure 1.1). In 2019, they were almost three times as high as in 1970, 70 percent coming from road transport, which grew even faster than transport overall (IPCC 2021).

Electrification of transport, using clean, renewably generated electricity is possible today because of major improvements in several technology sectors. Three are especially important: vehicle technology, especially batteries and electric motors; digitalization of production and management of vehicles and charging infrastructure; and electricity production and the shift from dirty to clean power. Powerful and efficient batteries are the most important technology advance. Batteries account for about one-third of the total price of an electric vehicle (König et al. 2021), but their cost is rapidly falling. Learning rates—how much the price falls with a doubling of production—are between 20 percent and 27 percent (Ziegler and Trancik 2021). The real price of lithium-ion cells (scaled by energy capacity) has declined by about 97 percent since their commercial introduction in the early 1990s. Batteries, in combination with highly efficient motors and regenerative braking, allow for a far

FIGURE 1.1. Annual Carbon Dioxide Emissions by Sector



Source: IEA 2021a

better use of energy inputs. More than two-thirds of the energy used by ICEVs is wasted as heat, whereas EVs use more than three-quarters of the power delivered through the grid (U.S. Department of Energy 2011).

Digitalization is the second relevant area of technological change because EVs are much simpler in terms of their mechanical components but rely on more complex electronics. An EV may contain more than 100 semiconductors to manage batteries, sensors that control powertrain and drivetrain management, and various safety and communication components. Digital technologies are also essential in new vehicle production facilities. Because EVs are fundamentally different, car companies have built new, highly automated factories. Electric charging infrastructure also relies on information and communications technology—from automatically matching a connected car to the driver's charge account to making EVs part of the electric grid of the future by allowing them to draw and supply electricity depending on demand, electricity prices and owner preferences.

Finally, massive innovation has also benefited the greening of electricity production. Powering EVs with clean energy is one of the most important factors in determining how climate-friendly an electric vehicle will be. Fueling mobility with electricity could eventually make a complex supply infrastructure for fossil fuels obsolete. Getting gasoline or diesel to the pump requires exploration, extraction, transportation, refining, and distribution of oil products. All this happens over large distances across the globe. Historically, according to the International Monetary Fund, the fossil fuel industry has been able to offset some of these high costs with large subsidies—US$5.2 trillion, some 6.5 percent of global gross domestic product (GDP) in 2017 (Coady et al. 2019; see also Mahdavi, Martinez-Alvarez, and Ross 2020). Costs of renewable electricity generation have fallen sharply (table 1.1). Learning rates for wind and solar equipment are particularly steep and costs per kilowatt (kW) are now often lower than those for fossil fuel generated power (IRENA 2020a). Rather than annually burning through more than a million years of photosynthesis embedded in fossil fuels, ways to produce most of the world's annual energy use—including for mobility—from just a year's worth of solar radiation are now realistic scenarios (Carbon Tracker 2021).[2]

TABLE 1.1. Power Generation Costs from Solar and Wind Power Technologies

	Concentrated solar	Photovoltaic	Onshore wind	Offshore wind
Percent power cost reduction 2010–2021	79	88	48	19

Source: IRENA 2020b.

2. With the exception of geothermal, practically all renewable energy is ultimately produced by incoming solar radiation that powers pressure gradients generating wind as well as the hydrologic cycle.

The Electric Mobility Transition Will Have Environmental, Economic, and Social Impacts

Because turnover of the vehicle stock takes time, the impact of the electric mobility transition will be felt gradually in all areas of the transport sector. This transition is under way in many high-income and some emerging economies and will eventually also gather momentum in middle- and even low-income countries. The transition will need to be largely market driven, although policies will initially facilitate and accelerate the switch to electric vehicles. As the electric mobility transition unfolds, it will affect three areas critical for LIMCs: the environment, the economy, and social welfare. These are also three pillars of development: sustainability, growth, and inclusion. Sustainability is the main driver of the transition, but the economy will be central to its success because the electrification of transport affects several important supply chains and markets: for vehicles and parts, for raw materials, and for fuels that will be phased out and those that will replace them. Changes and disruptions in each of these markets can have social implications, especially in relevant labor markets, where some types of jobs will disappear and others be created.

Environmental Impacts

The prospect of lowering the transport sector's environmental footprint is the main motivation for increasingly ambitious policies to promote EVs. For developed countries, and from a global perspective, reduction of CO_2 emission is a chief priority and a motivation strong enough to pursue rapid adoption of EVs. For developing countries, however, the most pressing and evident motivations are linked to reduction of local pollutants, improvement of the associated health issues, and more generally the need for better air quality and noise reduction. Expected lower costs of owning and operating an EV is a useful side effect that will reinforce the electric mobility transition.

Local air pollution (principally NO_x, PM, and SO_2) and global climate pollution (CO_2) are both generated along the entire vehicle-related supply chain, from vehicle production to fuel supply and vehicle operation and eventual disposal. Well-to-tank emissions occur in the production of fuels such as gasoline and diesel and in electricity generation. Fossil fuels require extraction, transport, refining, and distribution. Electricity generation also still depends largely on fossil fuels. Operation of ICEVs causes tank-to-wheel (TTW) emissions that are strictly regulated in many countries, for instance, through the EURO standards in the European Union. TTW emissions can be estimated using information about the age of the vehicle stock and average distances traveled per year. Industry lifecycle analyses have generated estimated emissions from production and disposal of vehicles (European Commission et al. 2020).

Absolute emission reductions from increased use of EVs depend on the size of countries and vehicle fleet composition. For instance, under a realistic EV adoption scenario, as described in chapter 2, India could achieve average annual CO_2 emission reductions of 87 million tons, and Vanuatu could avoid 18,000 tons. The power generation mix determines local pollution. Egypt and India both depend heavily on fossil fuels. Egypt, though, would see large reductions in SO_2 emissions because it uses natural gas for 70 percent of its electricity generation, whereas coal-dependent India would see growing SO_2 emissions with increased generation to power EVs. In relative terms, Vietnam would see the greatest average annual CO_2 emission reductions—about 28 percent. Other countries with large emission reductions are Nepal and Uruguay, both of which use renewables for power generation almost exclusively.

For economic analysis, air and climate pollution estimates are converted to monetary costs. For climate pollution, this is the social cost of carbon—formally, this is the discounted cost of damages that will be caused by, say, a ton of CO_2 equivalent. A more practical way to think about this is as an estimate of the price or tax on emissions that would be required to trigger sufficient changes to achieve climate goals such as those in the Paris agreement. The High-Level Commission on Carbon Prices and World Bank guidelines recommend a carbon price of US$40 to US$80 per ton of carbon dioxide equivalent in 2020, rising to US$60 to US$100 by 2030. Local air pollution has more immediate effects on human health. An extensive literature on health impacts details a range from reductions in productivity to increased mortality. Damages are most severe in lower-income countries (Roy 2016; World Bank 2022a). The economic costs of such impacts are typically estimated using the concept of the value of a statistical life, which quantifies essentially how much, on average, people are willing to pay to reduce their mortality risk. Average annual savings (reductions in damage costs) from lower CO_2 emissions are highest in India, at more than US$2 billion, and in Egypt from PM10 reductions, at almost US$1.8 billion.

Economic Impacts

For well over 100 years, automobile manufacturers have built internal combustion engines. As both policies and economics start to favor electric vehicles, manufacturers have begun to retool their production facilities. The industry is highly concentrated. In 2019, 61 percent of global motor vehicle production—more than 56 million vehicles—happened in just five countries: China, Germany, India, Japan, and the United States (OICA 2019). The top 10 countries account for 80 percent. Brazil, Mexico, Thailand, Russia, and Turkey also have large automobile production sectors. Most production facilities are owned by large, multinational companies. The top five global manufacturers produced 43 percent of vehicles, the top ten more than 65 percent. Five Chinese car companies are the only manufacturers from a middle-income country among the top 20.

Vehicle Supply Chains

These manufacturers have the deep pockets needed for the research and development to design complex vehicle components and build large production facilities. Electric vehicles, however, have fewer moving parts and do not require components such as transmissions, fuel systems, or catalytic converters. This has several implications. The impact of the shift will be large for firms building complex gas or diesel engines, but perhaps even greater for suppliers of parts and components that are not needed in EVs. International firms have built local supplier networks in countries where they manufacture or assemble vehicles. Thus, a drop in demand for car components could affect suppliers in countries such as Mexico or Turkey. Production of key EV components such as motors and batteries, in contrast, is still highly concentrated. Most lithium-ion battery cells today are manufactured in China, although additional large manufacturing is done in Hungary, Japan, South Korea, and the United States.

As vehicle manufacturing shifts from complex engine systems to assembly of mostly standardized electric motors and battery packs, value-added in vehicles will come from clever integration of components. This leaves scope for new entrants that may be competitive even with smaller production runs and could be an excellent opportunity for manufacturers or assembly plants in low- and middle-income countries. In fact, the big auto manufacturers and powerhouse technology firms are already teaming with local car assemblers in Africa, Asia, and Latin America to bolster EV assembly lines (Arroyo-Arroyo and Vesin 2021). Innovative start-ups are emerging in Kenya, Rwanda, and Uganda to come up with affordable EV alternatives, particularly for 2Ws but also affordable options for buses and trucks in which the vehicle body is repurposed and an electric powertrain installed. Kenya's Opibus is an example of such start-ups.

Stricter climate policies will favor manufacturing locations with access to cleaner energy. EV battery production is a good example. The smaller its carbon footprint, the greater will be the environmental benefit of an EV relative to an internal combustion engine (ICE) vehicle. The production of a conventional gasoline car produces about 5 metric tons of CO_2 emissions and consumes approximately 100 gigajoule (GJ) of energy, whereas the production of a BEV (assuming a 24 kWh battery) produces more than 8 metric tons of CO_2 emissions and consumes about 180 GJ of energy. The lithium-ion battery alone accounts for an average 3 metric tons of the CO_2 emissions (Helms, Kämper, and Lambrecht 2015). Given the current power mix in different countries, battery cell manufacturing in China currently generates 1106 g CO_2eq per kWh capacity, 745 g in Japan, 663 g in the United States, 634 g in South Korea and 468 g in the EU (Meyer et al. 2018). Battery production with a higher share of renewables in the power mix will have an advantage in places with strict climate policies, including possible border tax adjustments on the embedded CO_2 content of imports.

A quick transition to electric mobility in industrialized countries could accelerate exports of used ICE vehicles to low- and middle-income countries. The volume of such exports is already large (UNEP 2020). In 2018, the EU, Japan, and the United States exported almost 4 million used cars, of which more than 80 percent went to low- and middle-income countries. The EU was the source of more than half of the total, including 1 million exported to Africa, followed by Japan (27 percent) and the United States (18 percent). Africa, where used light-duty vehicles account for 60 percent of the total growth of the vehicle fleet, was the largest importing region (40 percent), followed by Eastern Europe (24 percent), the Asia Pacific (15 percent), the Middle East (12 percent), and Latin America (9 percent). Among countries, Serbia, Nigeria, and the United Arab Emirates imported the largest number of used cars from the three major exporting regions (see table 1.2).

TABLE 1.2. The 10 Largest Import Markets for Used Vehicles, 2018

Rank	Market	Number of Imports
1	Serbia	260,078
2	United Arab Emirates	238,810
3	Nigeria	238,760
4	Ukraine	173,011
5	Libyan Arab Jamahiriya	161,814
6	Bosnia and Herzegovina	132,586
7	Tanzania	125,845
8	Georgia	125,745
9	New Zealand	101,034
10	Chile	91,827

Source: UNDP 2020.

Used vehicles are not necessarily more polluting or less safe than the existing vehicle fleet in an importing country. For instance, Japan has strict vehicle inspections and many drivers replace their cars after only about four years of service (UNEP 2020). But many of the exported cars are older or poorly maintained and sometimes emission controls have been removed to recover valuable metals from catalytic converters. By sending such cars to lower-income countries, wealthier regions clean up pollution at home by shifting it to other parts of the world rather than reducing it overall. This increases local pollution in poorer countries and makes no contribution to limiting global greenhouse gas emissions similar to shifts in heavy industry in the 1990s and 2000s (Peters et al. 2011).

Adoption of electric vehicles should therefore be complemented by efforts to keep highly polluting cars off the road elsewhere. Many countries already use a range of policy tools to manage the used vehicle trade. Of 146 countries analyzed in the UNEP report, 18 ban used-car imports outright. Most of these are middle-income countries with significant domestic vehicle manufacturing, including Brazil, China, India, Indonesia, Thailand, Turkey, and South Africa. If those vehicles are produced to low standards, however, import bans may well keep cars built to higher standards elsewhere out of the market. Age limits are used by 66 countries to keep older vehicles out and 28 countries have modest vehicle emission standards. However, 100 countries have no emission standards for imports. Some countries use selective bans (such as of diesel vehicles), some require labeling of emission performance, and many use fiscal tools such as age-based taxation or progressive excise taxes based on greenhouse gas emissions or engine size. Finally, some countries have exceptions for hybrid electric or electric cars. The UN Environmental Program report concludes that 81 of 146 countries have weak or very weak policies, and that 47 have good or very good policies to manage used vehicle imports. As results from the analysis in this report suggest, high shares of cheaper used ICEV imports can slow down the adoption of electric vehicles. Policies of the type listed here can help accelerate the electric mobility transition.

Supply Chains for Batteries

A successful transition to electric mobility implies a sharp rise in the demand for raw materials required to produce EV components. This raises the question whether a sufficient, secure, and sustainable supply of critical raw materials will be available at a price that ensures at least cost parity between EVs and ICEVs. Essential raw materials to produce current EV batteries include lithium, nickel, cobalt, manganese, and graphite. Other raw materials are important inputs for fuel cells (such as platinum), electric motors (rare earth elements), and for expanding electric grids and charging infrastructure (copper). Global known resources of these materials exceed projected demand significantly, even when considering a parallel rise in demand from other uses (NOW 2020a). Global reserves—the share of resources that can be economically extracted—generally also appear sufficient under current scenarios. The projected demand increases may strain supply chains, however. In the IEA Sustainable Development Scenario the demand for lithium, graphite, cobalt, nickel, and manganese for EVs will see a growth of between 16 times and 42 times—42 times, 25 times, 21 times, 41 times, and 16 times, respectively—between 2020 and 2040 (IEA 2021b).

Reserves of key raw materials are concentrated in a small number of countries most of which are developing countries (table 1.3). The Democratic Republic of Congo accounted for about 70 percent of global cobalt production in 2019, and South Africa and Brazil have 60 percent of the world reserves of manganese (IEA 2021b; USGS 2021). Most of these raw materials are not refined and processed locally. More than 50 percent of global refining of copper, cobalt, lithium, and nickel is located in China (NOW 2020a). The country also produces about 80 percent of refined rare earth minerals. With such levels of concentration, disruption of mining or processing operations in a single country has global repercussions.

TABLE 1.3. Major Sources of Raw Materials for Batteries and Fuel Cells

Cobalt	Australia, Canada, Cuba, Dem. Rep. of Congo, Philippines, Russia
Copper	Australia, Chile, China, Dem. Rep. of Congo, Peru, United States
Graphite	Brazil, China, Turkey
Lithium	Argentina, Australia, Bolivia, Chile, China, Russia, United States, Zimbabwe
Manganese	Australia, Brazil, South Africa, Ukraine
Nickel	Australia, Brazil, Canada, China, Cuba, Indonesia, New Caledonia, Philippines, Russia
Platinum	Russia, South Africa, Zimbabwe

Source: NOW 2020a; USGS 2021.

A second concern relates to the social and environmental impacts of mining operations. This is particularly important because a significant portion of the mining reserves are in developing countries with poor governance, weak environmental and social safeguards, and a deficient track record of enforcement of existing policies. Poorly managed, revenue from resource extraction comes with high hidden costs. Cobalt mining in the Democratic Republic of Congo has raised substantial environmental, community, and human rights issues (Amnesty International 2016). Much of cobalt is extracted in so-called artisanal mines where miners have no access to protective equipment and basic social protections. Reports about child labor have also been made. Major global customers have reacted and try to ensure that cobalt used in their products was mined under socially responsible conditions. Other parts of the supply chain remain less discriminating. Mining almost always raises environmental concerns and mining for materials that are essential for the energy transition are no exception (Sovacool et al. 2020). Lithium mining consumes large amounts of water. In South America, it occurs in areas that are water stressed, creating potential conflicts between industrial and community use (see Liu and Agusdinata 2020).

Finally, recycling and reuse of batteries is both a challenge and an opportunity for developing countries. The disposal of used batteries can be an environment hazard. Their recycling and reuse offer an opportunity to recover expensive and scarce rare minerals and minimize the social and environmental impacts of mining operations. It would also open business opportunities when setting in place battery recycling facilities and leasing and repurposing schemes. A main challenge is to set in place and enforce directives to promote battery recycling. This might call for international regulations and agreements. Unfortunately, the global experience on country-specific regulations and directives to promote battery recycling is limited.

Supply Chains for Maintenance and Fueling

Beyond vehicle cost and fuel, the third major cost factor for vehicle ownership is operations and maintenance. This includes insurance, taxes and registration, fuel or electricity, as well as servicing and repairing a vehicle. In modern vehicles, repairs typically involve swapping entire component groups. The automotive aftermarket includes the manufacturing, sales, and installation of additional or replacement parts by original equipment manufacturers, specialized automotive suppliers, and generic manufacturers. One estimate put the global size of this market at US$760 billion in 2015 with expected growth rates averaging 3 percent per year (Breitschwerdt et al. 2017). An increase in electric vehicles will reduce the size of this market. EVs have fewer moving parts and fewer parts overall. Service intervals are longer. Complex and repair-intensive parts like radiators, pistons, or fuel pumps are absent. Regenerative braking reduces wear of brakes and brake pads. Only tires tend to wear out more quickly because of the larger weight of EVs and the greater torque of electric motors. Overall, both BEVs and PHEVs are expected to incur about half the maintenance costs of ICE vehicles (Harto 2020).

The transition to electric mobility will also change the business model of the fueling infrastructure, especially gas stations, which number well over 100,000 each in the United States and China and about 40,000 in Brazil.

EVs can in principle be charged anywhere grid access is available (24/7 Wall St. 2020; Deloitte 2019). Private charging happens at single or multifamily homes or at the workplace including for commercial vehicle fleets. Public charging includes charge points at public parking lots such as at retail locations, at decentralized charge points along urban streets, and—as with current gas stations—at charging hubs within towns and cities or along major transport corridors.

The split between public and private charging depends on many factors, one study predicts that by 2030, private charging in Germany will account for 76 percent to 88 percent of the total (NOW 2020b). On that basis, the study expects a required ratio of EVs to public charging points that will rise from 11:1 in 2021 to 20:1 in 2030 as private charging infrastructure expands. These ratios are place specific. Areas with large apartment buildings will require a larger share of public chargers than less dense suburbs. A larger proportion of public chargers will also be needed in countries where electricity access is not universal. The EV charging business model also includes the battery-as-a-service approach in which the private sector of LMICs can engage in providing battery leasing and swapping services. This approach will, first, keep demand on the power grid under control and the provision of charging stations decentralized, but second, it can significantly reduce the capital cost of EVs when separating the cost of the vehicle from that of the battery, transferring the cost of obsolesce and depreciation from users to the private sector that can mitigate by economies of scale.

Changes in maintenance costs and fueling infrastructure directly affect the economics of EV adoption. Lower maintenance needs directly reduce the total cost of ownership for EVs. Estimates derived from the analysis in chapter 2 suggest that annual per vehicle savings depend on local factors including the vehicle fleet composition, and could be into the order of US$977 for Ethiopia and US$864 for Ghana. The shift away from gasoline and diesel requires investments in private and public charging facilities. The scenarios estimate that India will need to build more than 2 million chargers by 2030 at a cost of US$4.4 billion. Vietnam will need to spend about US$275 million and Nigeria US$175 million. These costs are at least partially offset by cost savings in the fossil fuel supply chain. Savings are highest for buses, so countries like Ethiopia which have a larger proportion of buses in new vehicle registrations see the largest annual per vehicle savings of about US$11,650.

Fossil Fuel Supply Chain

As electricity replaces oil as a transport fuel, demand for oil should in principle drop—along with its price—leaving only the lowest cost producers in the market. How quickly this transition could occur is uncertain. A range of factors affect the uptake of alternative fuels, including technology, policy, and consumer preference. Even in the most ambitious climate mitigation scenarios, such as IEA's Net Zero Scenario (IEA 2021a), oil demand does not drop substantially in the near future due to oil use for non-energy purposes; oil use with carbon capture, usage, and storage in industrial applications; and continued oil use in applications like aviation.

In fact, many forecasts predict that oil demand in passenger transport will remain flat or decline only modestly in the next 10 to 20 years (Kah 2018; Hensley, Knupter, and Pinner 2018). This is because passenger vehicles accounted for only 23 percent of global oil demand in 2017. Trucks, ships, and planes, where electric options are limited, consume 29 percent of all oil used. Industry, petrochemicals, power, and other sectors account for the remainder. Biofuels are an alternative but expensive and come with their own environmental drawbacks. As economies grow, increasing demand for industry and other modes of transportation could more than offset the amount of oil displaced by electricity in the passenger vehicle market. Furthermore, even if the share of electric vehicles increases, a rapid growth of the vehicle fleet in countries with rising incomes may well lead to a net increase of ICEVs and higher emissions in the short to medium term, especially if the vehicle miles traveled also rise.

Once EVs eventually start to reduce oil demand, public revenue could decline in oil producing countries. Many small oil and gas producers in Latin America, the Middle East, North Africa, and Sub-Saharan Africa did not significantly contribute to climate change historically but are economically the most vulnerable to such income losses. Countries can pursue two broad strategies to reduce their risk (Peszko et al. 2020). The first is to use current resource revenue to diversify economic activities by investing more in education and innovation, ecosystems services, and boosting their social capital and institutions. The second is to foster climate cooperation within the international community to enable a more comprehensive structural transition toward a low-carbon economy and to compensate the most vulnerable population groups that are negatively affected by the transition. Oil-importing countries will experience positive impacts because large oil imports can have disruptive effects on current account balances and heighten macroeconomic uncertainty when prices fluctuate (Yalta and Yalta 2017). A study for the UK predicts that replacing imported oil products with domestically produced renewable energy for mobility will benefit household incomes and promote GDP expansion and employment (Alabi et al. 2020).

Electricity Supply Chain

Although fossil transport fuel demand should eventually fall, the shift to EVs will increase electricity consumption. Analysis for this report confirms other estimates that EVs are unlikely to cause a substantial increase in electricity demand in the near to medium term. Assuming a 30 percent share of sales by 2030 for electric cars and buses and of 70 percent for electric two- and three-wheelers by 2030, electricity demand will increase by less than 5 percent for most countries studied—a small increase that can be absorbed by existing power systems or by modest capacity increases. In some countries with severe power generation constraints, such as the Sahelian countries, the impact on power generation can be massive and not feasible in the short term even if only 2Ws and 3Ws shift to electric.

EV adoption, however, could have a significant impact on the shape of the electricity load curve if charging is uncoordinated and mostly occurs during early evening peak hours. This can threaten the stability of the power grid, require more reserve capacity, and increase overall system costs. Chapter 4 of this report reviews policies to prepare power systems to cope with these impacts.

Although EVs produce zero tailpipe emissions on the road, upstream emissions could be substantial. EVs will be greenest where damage from ICE vehicles is high and the electric grid is relatively clean. Where electricity is generated from coal, electric cars and buses can sometimes cause more harm than ICE vehicles (Holland et al. 2016). This does not apply to electric two-wheelers. Even when using electricity from fossil fuels, such as coal, they have 20 to 30 percent lower climate impacts than conventional motorcycles. When powered with renewable energy, their climate change impact is reduced by 60 to 80 percent (Cox and Mutel 2018). More generally, when powering EVs with electricity derived from fossil fuels, pollution is shifted from densely populated urban areas to areas around large power plants, mines, and waste disposal sites (Hendryx, Zullig, and Luo 2020; Cropper et al. 2021). Coal burning emits more harmful pollutants than any other fuel source; further, disposal of coal ash, which is often poorly regulated, exposes nearby residents to heavy metals that can contaminate drinking water supplies. The burden is often on the poorest. But electrifying transport still makes sense even when much of the power comes from fossil fuel sources. Vehicle electrification in China does not currently reduce CO_2 emissions because of the country's coal-intensive grid (Peng et al. 2018). More than 41,000 premature deaths, however, would still be avoided annually by shifting air pollution from dense urban to sparsely populated rural areas. Any reduction of coal in the power mix increases the number of lives saved.

Social Impacts

The electric mobility transition is a significant technological change, and such shifts are often accompanied by some degree of social impact. Disruptions in the markets for vehicles, fuels, and transport-related services will affect labor markets in these sectors. The magnitude of these impacts is uncertain because the electric mobility transition will have ambiguous macroeconomic effects and play out over a long time, especially in lower-income countries, where vehicles tend to stay on the road for 15 to 20 years. Published studies therefore show mixed results, some expecting net job gains and some predicting employment reductions. The overall sense is that job losses in some areas will be offset by gains in others. The extent of these adjustments is unknown, but even significant churning in the labor market can create social hardship for many.

The clearest labor-market consequences will be in vehicle manufacturing and mostly in high- or upper-middle-income countries. An early estimate by Ford found that simpler EV assembly could reduce capital investments by half and labor input by thirty percent compared to ICEV manufacturing (Ford Motor Company 2017). These estimated job losses match those predicted in a detailed study for Germany, where the automobile industry currently employs more than 800,000 people. The study expects a baseline fall of employment of 27 percent between 2017 and 2030 simply due to productivity increases. A 25 percent share of EVs would result in overall labor force reductions of 37 percent; a 40 percent share for a reduction of 40 percent; and an 80 percent share for a reduction of just over half of current employment (National Platform 2020). Additional job losses are likely in vehicle maintenance and services and in the fossil fuel supply chain. All of these are also large employers in low and middle-income countries (see table 1.4).

Battery-related employment will not compensate for losses in manufacturing traditional power trains and components. Cell production is highly automated. Only an estimated 40 jobs per GWh battery capacity are created in battery cell and module production, but more than 200 additional jobs are in the upstream value chain including materials, R&D, and manufacturing machinery (Thielmann et al. 2020). Job gains can be expected in the electricity supply sectors and in construction, the maintenance of charging infrastructure,

TABLE 1.4. Potential Employment Impacts in the Transition to Electric Mobility

Driver	Mechanism	Employment impact
Vehicle production	EVs have fewer parts and new EV manufacturing capacity will maximize automation potential. Same with battery cell production which will be highly automated and concentrated in a few places.	Decrease
Maintenance	Frequency and cost of maintenance and service will be lower than for ICE vehicles. Smaller aftermarket.	Decrease
Fuel	Reduction in gasoline and diesel supply activities, refining, and gas station operations.	Decrease
Charging infrastructure	Investments to increase electricity supply and construction, installation and maintenance of charging stations could compensate for the loss of jobs in the fossil fuel sector.	Increase
Purchase price	Initially higher purchase price could reduce demand for cars. But EVs are expected to become cheaper than ICEVs which could increase vehicle demand.	Ambiguous
Lower per km costs	Increased vehicle usage could have positive employment impacts especially in transport-intensive sectors.	Increase
Total cost of ownership	Savings from car usage could increase demand for other goods and services.	Increase
Reduced pollution	Fewer health effects reduce demand for health services, yield health care cost savings, and increase productivity and demand for other goods and services.	Small increase

Source: Adapted from FTI Consulting 2017.

and continued digitalization in the transport sector (Pek et al. 2019). Additionally, as the costs of purchasing and operating EVs are expected to fall below those for ICEVs, savings by consumers and commercial vehicle owners increase expenditures for goods and services in other sectors.

Regardless of the net impact on jobs, LMICs will buffer the impact of the EV transition by embracing early interventions that encourage training in newly demanded technologies. Growing the renewables sectors, requires local labor and creates jobs in construction and routine maintenance, thus it presents an opportunity for low-skilled workers. Fewer than 20 percent of workers in clean energy production and energy efficiency in the United States have at least a bachelor’s degree (Muro et al. 2019). Public renewables investments have high employment multipliers: 24.6 jobs created per US$1 million invested in low-income developing countries, 15.6 jobs in emerging economies, and 6.6 jobs in advanced economies (Moszoro 2021).

Although the greatest development benefits of the electric mobility transition relate to sustainability and growth, the transition can also contribute to inclusion. electric mobility will benefit the poor and other marginalized or disadvantaged population groups if it can make transport cleaner, more accessible, more affordable, or more convenient. Most directly, reductions in local pollution will benefit people living near high-volume transport corridors. Prioritizing electric bus operation in congested, low-income areas can reduce exposure to air and noise pollution for poorer people (Sclar et al. 2019). If costs of electric vehicles can be reduced below the cost of gasoline or diesel vehicles, as many expect, mobility can also become more affordable. Electric two- and three-wheelers are already popular in many low-income markets for transporting people and goods. In rural areas, low-cost electric motorbikes, in combination with solar photovoltaic (PV) systems, reduce dependence on expensive or hard-to-obtain gasoline, facilitate access to markets and other opportunities, and help solve the first or last mile problem when using public transit (Rajper and Albrecht 2020). Although support for electric vehicles in industrialized countries currently favors already well-off residents, targeted policies can promote benefits for the poorer parts of the population by focusing electric mobility support on smaller, cheaper vehicles and the infrastructure that supports them.

A Sustainable Transport System Requires More Than Electrifying Vehicles

The shift to electric mobility is a core element of strategies to mitigate global warming and reduce local pollution. Simply replacing ICE vehicles with EVs, however, does not address other persistent transport-related problems such as congestion, safety, and access. Residents in cities globally suffer from traffic congestion. According to INRIX (2018), US drivers lost an average of 97 hours due to congestion at a cost of US$1348 per driver, some US$87 billion total. Congestion is often worse in low- and middle-income countries, where road construction and traffic management have not kept pace with motorization. Drivers in Bogotá lost 254 hours, those in Moscow lost 210 hours in traffic during 2018. Additional losses and environmental impacts come from fragmentation and inefficiencies among transport operators in many markets that cause delays and poor use of capacity.

Road safety is another costly transport externality. Traffic accidents cause more than 1.4 million deaths and 50 million serious injuries every year, 93 percent of which are in developing countries (World Health Organization 2018). The World Bank estimates that this reduces the GDP of low- and middle-income countries by between 1 percent and 5 percent (World Bank 2022b). Ensuring equitable access to transportation options is another critical goal of sustainable and inclusive transport strategies. An estimated one billion people live more than 2 kilometers from an all-weather road and one in six women avoid searching for a job because they fear harassment during transit. Switching to electric vehicles will not address any of these issues.

More fundamental shifts in how transport is organized must therefore accompany the electrification of vehicles. Avoid-Shift-Improve is a simple sustainability framework used in the transport sector. The first priority is to make the overall transport system more efficient, primarily by avoiding unnecessary or unnecessarily long trips. In urban areas, land use planning that creates mixed-use neighborhoods reduces the trip to work, shopping, or entertainment which also promotes local economic development. Moving more activities such as work or education online, as was involuntarily during the COVID-19 pandemic, also reduces commuting and therefore congestion.

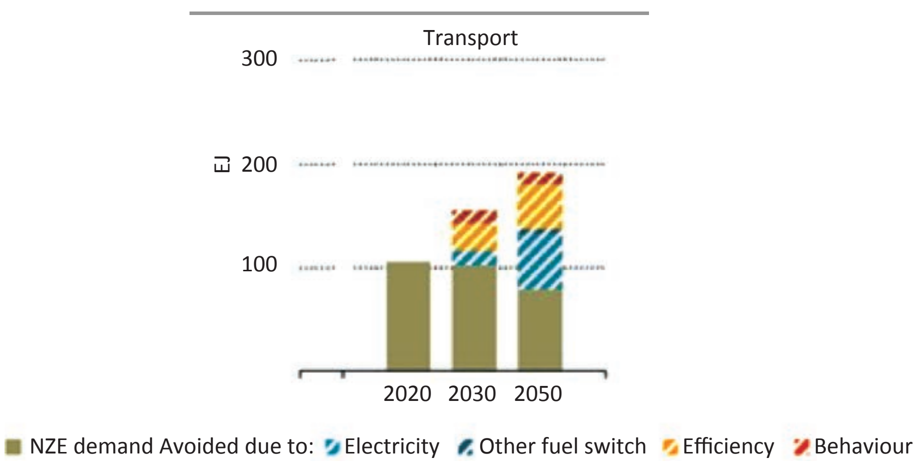
The second priority is to increase trip efficiency by encouraging modal shifts: from energy-intensive modes such as personal cars to nonmotorized transport or mass transit. Residents will dispense with personal cars only if convenient and affordable alternatives are readily available. Wide and safe sidewalks and bike lanes encourage nonmotorized travel for shorter distances. Efficient public transit gives commuters incentives to use buses and light rail. Transit-oriented development is now used by progressive cities around the world to increase the use of public transport. It involves planning and design of urban areas that creates compact, mixed-use, pedestrian and bicycle-friendly developments around public transit hubs (Salat and Ollivier 2017). Singapore plans to have 80 percent of the population living within a 10-minute walk from a train station by 2030, which would allow 75 percent of peak-hour trips to be made by public transport (Singapore Land Transport Authority 2013).

The third priority is to improve the efficiency of vehicles across transport modes. ICEV engines have become ever more fuel-efficient, but more people buy bigger cars, offsetting these gains. As electrification will take time, climate goals cannot be achieved without major additional efficiency measures for the ICE fleet. In the IEA Net Zero scenario, such measures contribute more emission benefits by 2030 than electrification of vehicles (see figure 1.1). So far, the trend toward larger, heavier vehicles is also evident in the EV market, where many EVs replace relatively fuel-efficient ICE cars rather than heavily polluting clunkers. One study for the United States found that EVs replaced ICEVs whose fuel-economy was 4.2 mpg better than average and 12 percent of EV buyers replaced hybrid vehicles (Xing, Leard, and Li 2021).

According to United Nations estimates, behavioral changes triggered by avoid and shift strategies—traveling less and switching to more sustainable modes—can reduce about 15 percent of the CO_2 emissions required to meet the Paris climate target of preventing global average temperature to rise above 1.5°C (UNFCCC 2020). Although the behavioral contribution to CO_2 emission reductions seems minor, by 2030 it can more than halve the share of EVs in the global vehicle fleet that would be required to get to net zero emissions—from 45 percent to 20 percent (IEA 2021a). Further, these behavioral changes will deliver many additional social and environmental benefits, including lower congestion, greater road safety, more equitable access to transport, and decreased land consumption.

Transport sustainability has many aspects and decarbonization of the transport sector that supports global climate goals will require a multidimensional approach that involves all aspects of the Avoid-Shift-Improve

FIGURE 1.1. Energy Consumption and Avoided Demand in Transport Sector



Energy efficiency plays a key role in reducing energy consumption across end-use sectors

Notes: CCUS = carbon capture utilisation and storage. Other fuel switch includes switching to hydrogen-related fuels, bioenergy, solar thermal, geothermal, or district heat.

Source: IEA 2021b.

framework. An efficient and well-planned transition to electric mobility will play an important role. Industrialized countries have the financial and technical resources to promote a quick shift, but it will be much more difficult for lower-income countries to develop an effective and affordable electric mobility strategy. When to embark on this transition and how to design and implement an EV strategy are discussed in the chapters that follow.

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CHAPTER 2

The Economics of Electric Mobility

The Economics of Electric Mobility

While electric mobility of passenger transportation holds considerable promise for the future decarbonization of the transport sector, many policymakers are trying to understand whether it makes sense for their countries and, if so, when and how to pursue such a transition. The economics of electric mobility addresses several important questions. Is the higher capital cost of electric vehicles (EVs) compensated by lower running costs? Would it be preferable to wait until technological change and global scale further bring down the costs of electric vehicle technology? Should countries prioritize electrification of certain vehicle categories, such as two-wheelers or buses? Does it make sense environmentally to electrify transportation before the power grid is fully decarbonized? Can the move toward electric mobility be justified purely in terms of mitigating local air pollution? To what extent do the wide array of taxes, import duties, and subsidies levied on vehicles as well as on transport fuels and electricity services materially distort consumer choices between EVs and those powered by internal combustion engines (ICE)? Even if electric vehicles are socially desirable, will private actors have the incentive or the financing capacity to adopt them without explicit public mandates?

This chapter introduces a simple economic framework for answering all these questions based on an understanding of the costs and benefits of the transition toward electric mobility. The framework examines this issue at a national scale, while exploring how conclusions may differ across vehicle categories. Specifically, it evaluates the net social cost of reaching an illustrative national electric vehicle target of 30 percent of cars and buses entering the national fleet being electric by 2030 and more than 70 percent of two- and three-wheelers—known as the 30×30 scenario. Net social costs are calculated as the difference between the lifetime (public and private, capital and operating) cost of the vehicle fleet that meets the electric vehicle policy, compared to the lifetime cost of a baseline scenario—called business as usual (BAU)—in which the passenger vehicle fleet continues to evolve according to historic trends without any explicit policy to mandate EVs.

Most of the discussion focuses on the central 30×30 scenario, but sensitivity analysis is also presented for several alternative scenarios. In the green grid scenario, a country's power generation mix undergoes further decarbonization by accelerating deployment of renewables in line with what the International Renewable Energy Agency's (IRENA's) Global Renewables Energy Outlook takes to be technically feasible.[1] This increases the externality benefits associated with the adoption of electric mobility. In the Scarce Minerals scenario, the cost of batteries declines more slowly than anticipated due to global shortages of rare earth minerals and associated higher prices, a mounting concern among industry analysts. In turn, the Fuel Efficiency scenario explores to what extent the case for electric mobility is diluted by efforts to improve the fuel efficiency of ICE vehicles. The Efficient Bus scenario explores the possibility of further optimizing municipal management of bus fleets to secure savings in procurement and extend bus mileage to maximize operational benefits in line with industry best practices. Finally, the Taxi Fleet scenario explores the implications of focusing electrification of four-wheelers on higher mileage vehicle fleets such as taxis, as opposed to private family cars.

The economic nature of the analysis calls for stripping out all taxes, duties, and subsidies to examine the true underlying costs. In addition, the impact on both local environmental externalities relating to urban air pollution and global externalities associated with carbon emissions must also be incorporated to provide a full economic picture. However, comparing the economic results with those from a parallel financial analysis that does not make either of these adjustments is nonetheless instructive. Throughout, results are further disaggregated by vehicle category to shed light on how the net costs or benefits of electric vehicle adoption may vary across types of vehicles. The overall framework is microeconomic and does not consider wider macroeconomic repercussions.

The economic framework developed in this chapter is simultaneously applied to a diverse sample of 20 low- and middle-income countries to shed light on how the answers to the fundamental economic questions of electric mobility differ across country contexts. Furthermore, a typology is used to permit a wider generalization of results to countries outside this sample based on their characteristics. In particular, the economics of electric mobility are found to be quite sensitive to various country attributes including the prevalence of four-wheelers in the national vehicle fleet, whether a country is a net fossil fuel exporter, and the relative cost of purchasing vehicles in a country.

Overall, the results suggest that the economic case for the electrification of transport is already strong in close to half of the countries studied and is improving over time as technological change brings down the cost of vehicles. In general, electric two-wheelers are economically advantageous in almost all of the

1 Based on IRENA analysis, the target renewable energy share for 2030 by region is defined as 60 percent for East Asia, 55 percent for the European Union, 85 percent for Latin America and the Caribbean, 27 percent for the Middle East and North Africa, 60 percent for North America, 66 percent for Oceania, 52 percent for the rest of Asia, 42 percent for the rest of Europe, 53 percent for Southeast Asia, and 67 percent for Sub-Saharan Africa.

countries studied, but electric four-wheelers do not make sense in all but a handful, even when they operate in commercial fleets. Electric buses also offer economic and financial advantages in about three-quarters of the countries studied, which increase when more efficient management practices are adopted. Although the capital cost differentials of electric vehicles remain significant, in many instances they are more than compensated over time by lower maintenance and energy costs as well as reduced pollution externalities. Results are robust to further greening of the power grid or more pessimistic assumptions about declining battery costs. By and large, fiscal distortions are found to overly favor electric mobility given widespread taxation of petrol and subsidization of electricity, meaning that accelerating electric mobility adoption is likely to reduce net fiscal revenues in the near term. The investment needs associated with such a transition are not insignificant. Carbon finance could make a substantial contribution to the financing of public investment needs, but private investments in more expensive EVs may pose affordability challenges in the context of low- and middle-income countries.

Evaluating Electric Mobility at the Country Scale

The economics of electric mobility at the country level can be evaluated by comparing the present value of all the lifetime capital and operating costs of the new vehicles entering the fleet as of 2030 under two scenarios. The first, referred to as the 30×30 scenario, incorporates an electric mobility policy target such that 30 percent of all new vehicles purchased should be electric by 2030. The baseline (BAU) scenario captures the situation in which no policy target is imposed for electric vehicles and vehicle purchase decisions continue to reflect historic trends. This framework is represented by the equation in figure 2.1.

For exposition, it is useful to further decompose this overall difference in costs between the two scenarios into four components (see the alternative element in figure 2.1): the difference in vehicle fleet capital costs (adjusting for taxes and subsidies), the difference in vehicle fleet operating costs (including maintenance as well as running fuel or electricity and once again adjusting for relevant taxes and subsidies), the additional charging infrastructure required to support a higher penetration of EVs, and the reduction in vehicle fleet externalities. The decomposition makes it possible to understand which of these differences is primarily responsible for driving the results.

Because this is an economic analysis, taxes and duties must be subtracted from all capital and operating costs and subsidies must be added back in. This makes it possible to understand the actual underlying relative costs of these two scenarios, as well as the extent to which fiscal policies may be responsible for distorting the choice between them, by comparing results with and without taxes and subsidies. Regarding the valuation of

FIGURE 2.1. Framework for Evaluating Economics of Electric Mobility at National Scale

$$\Delta\ NSC = PV_{30x30}\ (Economic\ Cost) - PV_{BAU}\ (Economic\ Cost)$$

$$\Delta\ NSC = PV_{30x30}\ (CC + OC + CI - T + S + EX) - PV_{BAU}\ (CC + OC + CI - T + S + EX)$$

Or alternatively

$$\Delta\ NSC = \Delta PV\ (CC - T_{cap} + S_{cap}) + \Delta PV(OC - T_{ope} + S_{ope}) + \Delta PV\ (CI) + \Delta PV\ (EX)$$

Capital — *Operations* — *Charging Infrastructure* — *Environmental*

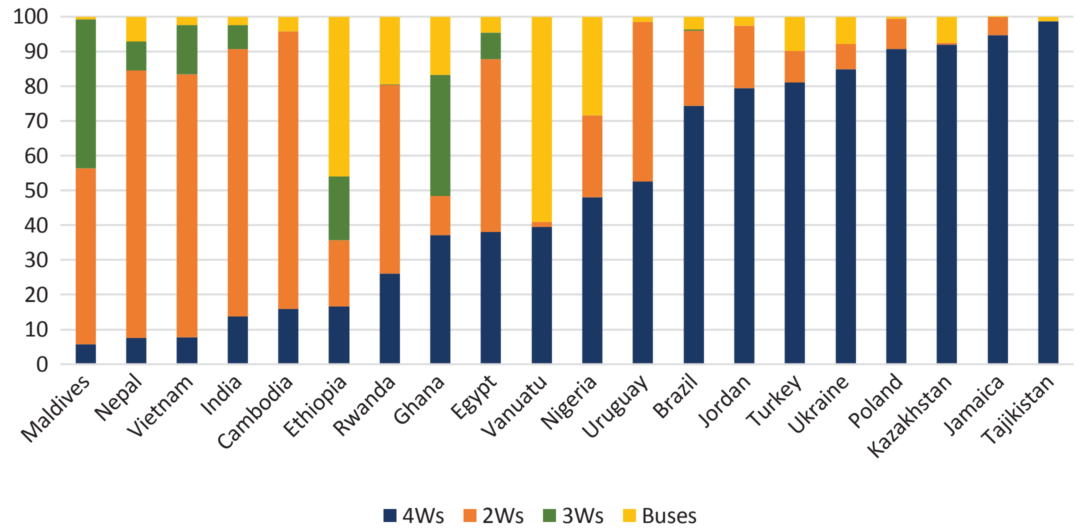
Δ: difference between 30x30 Scenario and BAU — *PV: present value of costs*
NSC: net social cost — *CC: vehicle capital costs* — *OC: vehicle operating costs*
T: taxes — *S: subsidies*
CI: Charging infrastructure — *EX: environmental externality costs*

externalities, a value of US$40 per ton by year 2020 is used for carbon, which is the lower bound of the World Bank's official guidance on the shadow value of carbon, and it gradually rises to US$50 per ton by 2030. In the case of local externalities, the damage coefficients are country specific and reflect local damages drawing from the World Bank's Carbon Pricing Assessment Tool. To calculate the present value of the cost differences, a discount rate of 6.6 percent is used. Again, this is in line with World Bank official guidance that the discount rate should be set at twice the projected growth in real per capita income in the developing world to reflect the social rate of time preference.

Comparing Vehicle Fleet Capital Costs

The composition of vehicle fleets varies widely across countries (figure 2.2). In particular, the prevalence of 4W cars ranges from under 10 percent of total passenger vehicle-kilometers traveled in Vietnam to almost 100 percent in Jamaica. The significance of 4W cars broadly increases with a country's national income but may also reflect a country's transport culture. For instance, Tajikistan (a low-income country) depends entirely on four-wheel cars, whereas in Uruguay (a high-income country) only 50 percent of its vehicle kilometers are traveled in four-wheelers. Where four-wheelers are not dominant, some countries—primarily low- and middle-income ones in Asia such as Cambodia, Maldives, Nepal, and Vietnam—depend primarily on

FIGURE 2.2. Prevalence of Types of Vehicles (% of total VKT)

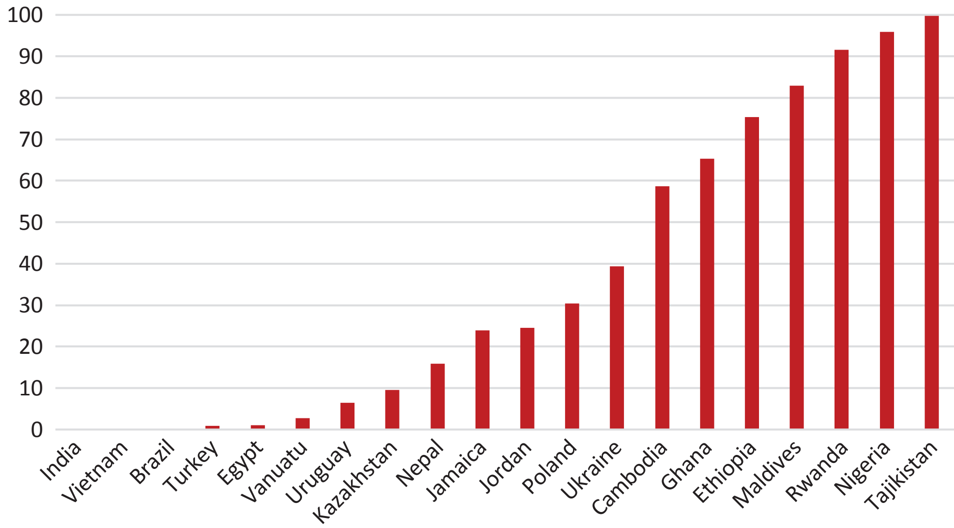


Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

two-wheel motorbikes and sometimes three-wheel rickshaws for 60 to 80 percent of their total passenger vehicle-kilometers. Conversely, several low- and middle-income African countries—such as Ethiopia, Nigeria, and Rwanda—rely on buses to provide 25 to 50 percent of their total passenger vehicle-kilometers. Given that the economics of electric mobility differ widely across vehicle types (see following discussion), the nature of a country's fleet composition will significantly affect the economics of electric mobility adoption and is an important factor to consider.

Another relevant consideration is reliance on secondhand vehicle imports. Recent work by the UN Environment Programme has highlighted the extent to which low- and middle-income countries, particularly those in Africa, import a large share of their vehicles secondhand from high-income countries (UNEP 2020). Academic research confirms that in a country like Uganda, the average age of imported vehicles exceeds 10 years and the average price is to the order of US$5,000 (Forster and Nakyambadde 2021a, 2021b). Of the 20 countries studied for this report, as many as seven from across Africa and Asia import more than half of their cars secondhand (figure 2.3), which has implications for the adoption of relatively new electric vehicles, suggesting a significant time lag before such vehicles become available in the global secondhand market on an affordable basis.

FIGURE 2.3. Reliance on Secondhand Vehicle Imports (% of Total Fleet)

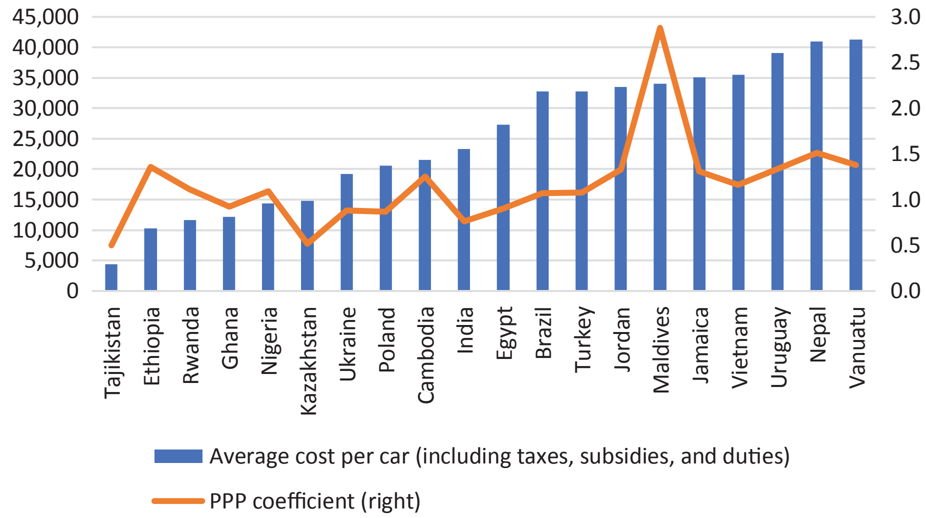


Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

All these factors contribute to the average cost of a “new” vehicle in a country, as do the specification of the vehicles purchased, the extent to which vehicles are domestically manufactured, and country-specific factors such as vehicle shipment costs that may affect the relative cost of imports. Figure 2.4 illustrates how the weighted average cost of one standardized vehicle addition to the fleet ranges from under $15,000 in the Sub-Saharan African countries to around US$40,000 in Nepal, Uruguay, and Vanuatu. These differences broadly follow the magnitude of the Purchasing Power Parity (PPP) adjustment factor for vehicles shown on the chart in orange. These differences are driven by the types of vehicles imported (whether two- or four-wheelers), whether the vehicles are secondhand, and whether the country faces some intrinsic cost disadvantage for the import of vehicles (remoteness and logistical complexity).

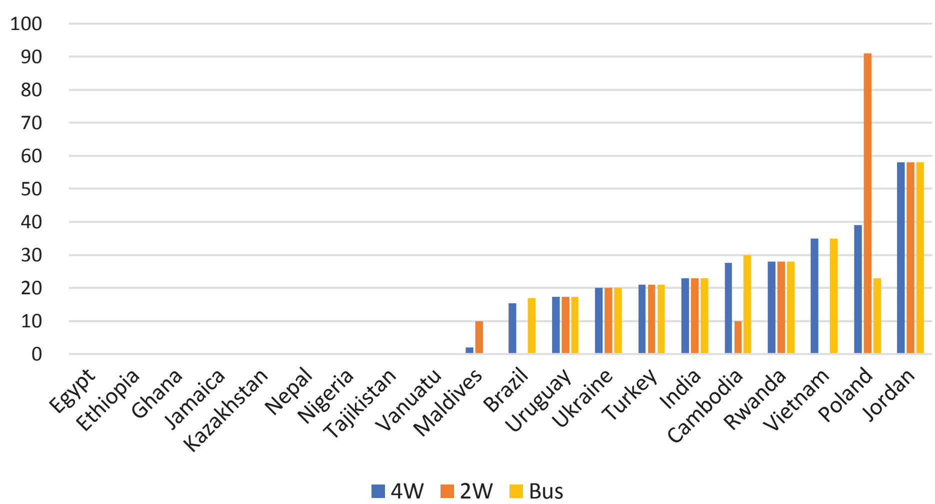
Purchased vehicles (whether new or secondhand) are often subject to significant taxes and import duties, whereas EV purchases are occasionally subsidized. Although these fiscal incentives are not considered in the *economic* analysis, they play an important role in the *financial* analysis. Understanding how high the vehicle tax burden is overall and to compare to what extent the tax burden on electric vehicles and those with internal combustion engines is even-handed or rather privileges one type of vehicle over another. In general, tax rates across vehicle types fall in the 15 to 25 percent range. Almost half the countries do not apply any differential taxation to petrol internal combustion vehicles (ICEVs) versus battery electric vehicles (BEVs) (figure 2.5).

FIGURE 2.4. Average Cost of 4W Vehicles, 2020 (US$)



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

FIGURE 2.5. Tax Rate Differential of ICE Vehicles over BEVs (%)



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

More widespread is the practice observed in various other countries—India, Jordan, Poland, Rwanda, Turkey, Ukraine, Uruguay, and Vietnam—of taxing ICEVs at least 20 percentage points higher than equivalent BEVs.

Finally, the relative capital cost of the 30×30 scenario relative to BAU is summarized in table 2.1. Throughout the chapter, the results of the economic analysis are expressed on a normalized per million passenger kilometer basis, meaning that the total incremental costs of the transition to the 30×30 scenario are aggregated across the entire national fleet, and then divided by the total number of passenger-kilometers delivered by the incremental vehicles added to the fleet expressed in millions. As a point of reference, 1 million passenger-kilometers is a typical level of service provided by a private car across the entirety of its life cycle. Similarly, the results of the parallel financial analysis are normalized as the change in life-cycle costs per vehicle, allowing results to be disaggregated by vehicle category. The aggregate results of the financial analysis are also expressed in terms of differential cost per million passenger-kilometers to allow for a ready comparison with the results of the economic analysis.

In addition to presenting results for each of the 20 countries modeled, table 2.1 also includes results for various typologies of interest, which are based on the relevant subset of the 20 countries fulfilling those characteristics.[2] This supports wider inferences about countries not included in the sample by providing an understanding of three factors. First is how results are influenced by the composition of the vehicle fleet—whether car dominant or mixed, if car vehicle miles traveled (VMT) accounts for more than 80 percent of the total VMT. Second is the country's net oil exporting status (if net importer or exporter). Third is the relative cost of vehicles, depending on whether the PPP index for vehicles produced by the World Bank's International Comparisons Program is above or below one (ICP 2017).

The economic analysis indicates that in just about every country a capital cost premium is associated with purchasing EVs. Moreover, this premium is substantial—of the order of US$10,000 to 20,000 per million passenger-kilometers (the typical operating life of a family car). In percentage terms, the 30×30 scenario presents a capital cost premium of the order of 10 percent over BAU, though this declines toward 5 percent when fiscal advantages are taken into account.

The only exception is Tajikistan, where a modest capital cost advantage is associated with electric vehicles because the country relies heavily on imported secondhand vehicles. Because BEVs depreciate more rapidly than ICEVs, secondhand imports are cheaper, thereby reducing the capital cost of the transition. The capital cost premium is much larger for certain countries, notably Brazil, Jamaica, Jordan, Nepal, Poland, Turkey, Uruguay, and

[2] For the most part, the variables defining these typologies are not highly correlated with one another. However, the degree of correlation (correlation coefficient -0.2 to -0.4) between being a net oil exporter and having a carbon-intensive power grid is moderately negative, as it is between having a car-dominated fleet and relatively expensive vehicle purchase costs.

TABLE 2.1. Vehicle Capital Cost Advantage of Electric Vehicles at Year 2030

	in $/Mpaxvkm			% of BAU values	
	a	b	c = a + b		
	Cost advantage (economic analysis)	Net taxes and subsidies (fiscal wedge)	Cost advantage including fiscal wedge (financial analysis)	Cost advantage (economic analysis)	Cost advantage including fiscal wedge (Financial analysis)
Brazil	(21,880)	13,052	(8,828)	(8.3)	(2.4)
Cambodia	(12,724)	2,148	(10,576)	(16.4)	(8.1)
Egypt	(13,010)	254	(12,756)	(8.9)	(6.7)
Ethiopia	(4,692)	5,798	1,106	(16.8)	2.1
Ghana	(6,241)	(1,106)	(7,348)	(9.4)	(9.4)
India	(12,207)	10,051	(2,156)	(12.9)	(1.7)
Jamaica	(27,919)	(2,864)	(30,784)	(8.7)	(6.2)
Jordan	(41,124)	37,438	(3,685)	(15.2)	(0.8)
Kazakhstan	(8,347)	2,470	(5,877)	(5.6)	(3.2)
Maldives	(9,370)	8,399	(970)	(29.7)	(1.4)
Nepal	(39,111)	(27,515)	(66,626)	(52.2)	(30.3)
Nigeria	(6,511)	(976)	(7,488)	(10.3)	(9.8)
Poland	(26,712)	57,784	31,072	(5.4)	5.0
Rwanda	(5,112)	2,781	(2,331)	(12.2)	(3.9)
Tajikistan	1,351	1,290	2,641	2.4	3.8
Turkey	(31,494)	3,930	(27,563)	(11.1)	(6.2)
Ukraine	(11,376)	10,595	(781)	(6.0)	(0.3)
Uruguay	(37,121)	37,615	493	(12.1)	0.1
Vanuatu	(3,915)	3,616	(299)	(2.1)	(0.1)
Vietnam	(22,595)	1,291	(21,305)	(27.6)	(15.8)
Typologies					
Car dominant	(23,287)	16,361	(6,926)	(8.11)	(1.73)
Mixed fleet	(13,055)	7,907	(5,148)	(13.71)	(3.90)
Net oil exporter	(18,329)	9,905	(8,424)	(8.26)	(2.76)
Net oil importer	(14,465)	9,452	(5,013)	(12.35)	(3.07)
High-cost vehicles	(21,642)	6,582	(15,060)	(11.87)	(5.56)
Low-cost vehicles	(12,597)	10,577	(2,021)	(11.11)	(1.34)

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
Note: BAU Scenario Minus 30×30 Scenario (average over fleet additions). $/Mpaxvkm: dollar per million passenger vehicle kilometers.

Vietnam—where it ranges between US$20,000 and US$40,000 per million passenger-kilometers. In terms of the country typology, the capital cost premium is approximately twice as large for countries with car dominated fleets, net oil exporters, and high-cost vehicles. As noted in the case of Tajikistan, another factor driving the magnitude of the capital cost differential is the extent to which countries rely on the import of secondhand vehicles.

Reporting the fiscal wedge makes it possible to establish the extent to which the tax and subsidy regime supports EVs. Overall, more than half of the countries studied operate a fiscal regime for vehicles that favors the purchase of electric vehicles, Maldives and Poland standing out for their explicit subsidy of US$2,000 and $6,000 per car, and Uruguay for its sizable tax advantage. However, several countries—Ghana, Jamaica, Nepal, and Nigeria—stand out for applying a relatively punitive combination of taxes and duties on the purchase of EVs that amount to anywhere between US$1,000 and US$30,000 per million passenger-kilometers. In fact, Ethiopia, (especially) Poland, Tajikistan, and Uruguay are the only countries where the fiscal wedge is large enough to completely offset the capital cost premium associated with purchasing EVs, so that on average they appear to be cheaper financially to consumers. In terms of country typology, the largest fiscal wedge in favor of EVs is in countries with car-dominated fleets.

Finally, disaggregating the economic and financial analysis by vehicle category is illuminating (see table 2.2). Table 2.2 shows that, in the case of four-wheel EVs, in only a handful of countries (India, Maldives, Nigeria, Poland, Rwanda, Tajikistan, Ukraine, and Uruguay) are cheaper these to purchase than their ICE counterparts. Poland is the only country that offers a significant financial advantage, on average US$1,096 per vehicle. On the other hand, two-wheel EVs are more expensive than ICEVs except in Poland, albeit by a relatively modest sum amounting to no more than US$200 per vehicle in many cases. When it comes to electric buses, the financial premium is significant, to the order of US$10,000 per vehicle. However, Uruguay stands out for having electric buses US$10,000 cheaper than conventional ones in financial terms, thanks to a taxation policy that hugely favors electric buses with a 6 percent vehicle purchase tax versus 23 percent for diesel buses.

Comparing Vehicle Fleet Operating Costs

The two main components of vehicle fleet operation are fuel and maintenance costs. It is well known that maintenance costs of EVs are significantly lower than those associated with ICEVs. This is due to the much simpler nature of the motors involved (recall chapter 1).

As countries adopt more electric vehicles, they will reduce their use of liquid transportation fuels, such as petrol and diesel, and satisfy more of their transportation energy demand from electricity. How this affects the transportation sector's energy bill depends on the relative unit energy cost of transportation. This can usefully be broken down into two components: the cost per unit of energy delivered by electricity versus fossil fuels and the energy consumption per unit of transportation, reflecting the relative energy efficiency of EVs versus ICEVs (figure 2.6).

TABLE 2.2. Vehicle Capital Cost Advantage of Electric Vehicles at Year 2030

	US$/vehicle					
	Electric buses		2W		4W	
	Cost advantage (economic analysis)	Cost advantage including fiscal wedge (financial analysis)	Cost advantage (economic analysis)	Cost advantage including fiscal wedge (financial analysis)	Cost advantage (economic analysis)	Cost advantage including fiscal wedge (financial analysis)
Brazil	(6,136)	2,055	(125)	(97)	(1,983)	(819)
Cambodia	(9,621)	(5,694)	(154)	(160)	(1,397)	(1,033)
Egypt	(12,107)	(15,412)	(202)	(237)	(1,100)	(783)
Ethiopia	(3,375)	1,952	(172)	(75)	(1,173)	(367)
Ghana	(7,738)	(9,212)	(71)	(82)	(290)	(331)
India	(14,027)	(10,400)	(199)	(44)	(1,412)	134
Jamaica	(5,219)	(7,393)	(305)	(435)	(2,010)	(2,203)
Jordan	(9,111)	(7,913)	(451)	(253)	(2,895)	(90)
Kazakhstan	(11,639)	(12,365)	(107)	(85)	(459)	(231)
Maldives	(5,501)	32	(231)	(63)	(2,011)	324
Nepal	(18,705)	(22,958)	(694)	(1,375)	(5,593)	(9,222)
Nigeria	(6,418)	(7,468)	(12)	(13)	308	383
Poland	(12,412)	(6,325)	(29)	73	(886)	1,096
Rwanda	(7,116)	(4,971)	(32)	(12)	18	406
Tajikistan	(6,226)	(6,130)			115	198
Turkey	(12,982)	(10,699)	(368)	(355)	(2,172)	(1,917)
Ukraine	(10,558)	(7,804)	(128)	(65)	(712)	170
Uruguay	249	10,385	(404)	(304)	(2,866)	483
Vanuatu	996	1,318	(351)	(464)	(2,473)	(745)
Vietnam	(14,234)	(6,006)	(348)	(395)	(3,004)	(1,755)
Results by Typology						
Car dominant	(10,383)	(6,088)	(161)	(128)	(1,591)	(394)
Mixed fleet	(11,162)	(8,647)	(225)	(123)	(1,426)	(62)
Net oil exporter	(6,736)	(4,966)	(114)	(89)	(1,731)	(711)
Net oil importer	(12,164)	(8,975)	(227)	(124)	(1,430)	(60)
High-cost vehicles	(8,325)	(5,005)	(314)	(372)	(2,056)	(1,104)
Low-cost vehicles	(13,255)	(10,738)	(198)	(58)	(1,232)	219

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
Note: BAU scenario minus 30×30 scenario by type of vehicle (average over fleet additions).

FIGURE 2.6. Decomposition of Changes in Energy Bill for motor transportation

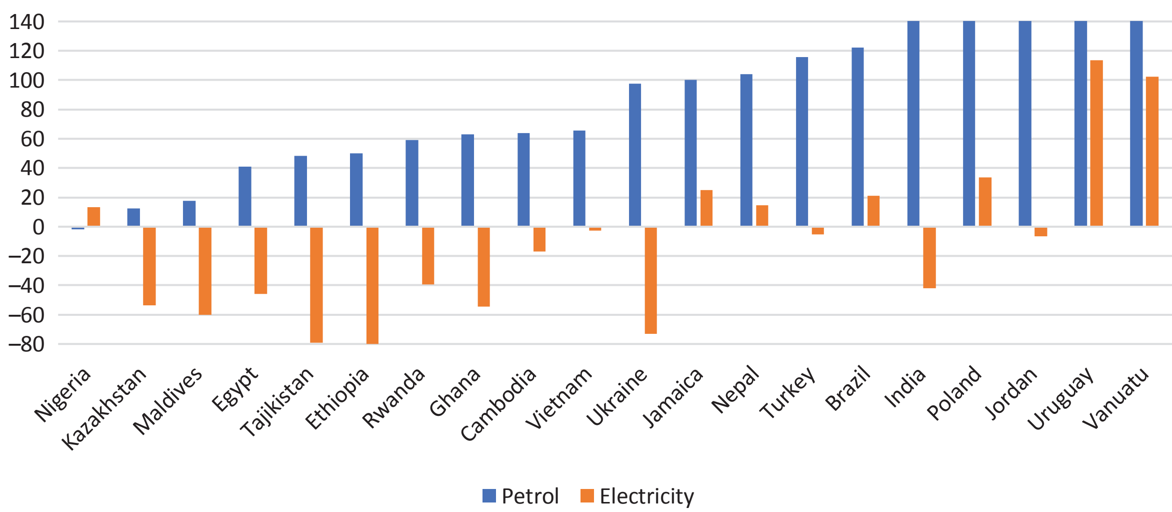
$$\Delta CE = \Delta PE \times \Delta EFF$$

Δ: difference between variables under 30x30 scenario versus BAU
CE: unit energy cost of transportation (US$/vehicle-kilometer)
PE: unit energy price (US$/Joule)
EFF: energy efficiency coefficient (Joules/vehicle-kilometer)

Variation in the price of both electricity and liquid fuels across countries is considerable. For example, in this sample, the price of electricity varies between US$0.02 per kilowatt-hour in Ethiopia to US$0.40 per kilowatt-hour in Vanuatu, whereas the price of liquid fuels varies between US$0.50 per liter in Kazakhstan to around US$1.40 per liter in Vanuatu.

One important reason for such variations in the price of energy across countries are a wide range of tax and subsidy policies that distort the relative cost of electricity and fossil fuels and need to be removed prior to economic analysis (figure 2.7). Most striking is that across most countries, petrol is taxed while electricity is subsidized. Taxes on petrol are typically in the 40 to 140 percent range, whereas subsidies to the electricity

FIGURE 2.7. Tax and Subsidy Rates for Petrol and Electricity (% on cost)



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

sector are typically between 40 and 80 percent. This pattern of fiscal policy tends to favor BEVs over ICEVs *beyond what the underlying economic costs would suggest* by substantially altering the relative prices of these alternate energy sources. In effect, petrol is *twice* as expensive relative to electricity than would be the case in the absence of both the distortionary taxes and subsidies.

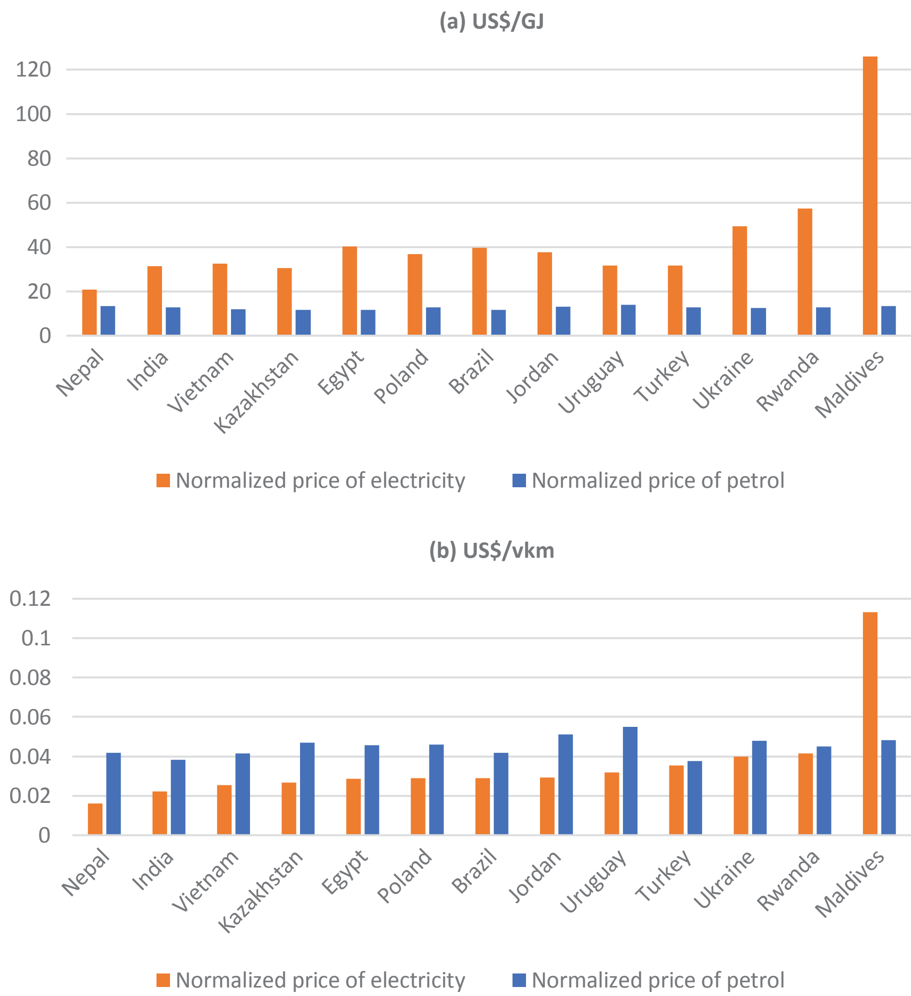
Once tax and subsidy distortions are removed, electricity and liquid fuel prices can be normalized into consistent units so that the underlying economic costs can be compared (figure 2.8a). Across countries, electricity is approximately twice as expensive as liquid fuels on a per unit of energy basis. This is not entirely unexpected given that liquid fuels are a raw form of energy, whereas electricity is a more extensively processed form of energy to which more economic value has been added through the production and delivery process.

While electricity may typically be a more expensive form of energy per unit, the actual cost of using electricity for transportation may still be lower to the extent that EVs are more energy efficient than ICEVs powered by liquid fuels (recall chapter 1). In fact, whereas EVs consume only 0.70 to 1.00 megajoules per vehicle-kilometer, ICEVs powered by liquid fuels consume between 3.00 and 5.00megajoules per vehicles kilometer, depending on the vintage and fuel efficiency standards of the vehicle fleet. This makes EVs several times more energy efficient than ICEVs (figure 2.9). In most low- and middle-income countries, petrol vehicles consume four to five times more energy per vehicle-kilometer than electric vehicles, and diesel vehicles consume three to four times as much. Even in a country such as Turkey, where ICEVs are relatively fuel efficient, they still consume two to three times more energy per vehicle-kilometer than EVs.

Overall, this means that the normalized cost of using electricity to power transportation is significantly lower than that for fossil fuels in terms of dollars per vehicle-kilometer (figure 2.8b). For even though electricity is twice as expensive as liquid fuels on a per unit of energy basis, only about a quarter of the energy is needed when vehicles are powered by electricity rather than fossil fuels. Thus the energy efficiency advantage of EVs more than offsets the apparent cost disadvantage of electricity (figure 2.8a and b).

The relative operating cost of the 30×30 scenario relative to BAU is summarized in tables 2.3 and 2.4. Clearly, vehicle maintenance costs are always reduced under the 30×30 scenario, reflecting the simpler nature of EVs and saving around US$5,000 to US$6,000 over a typical vehicle lifetime. Similarly, for almost every country, the net cost of fuels is lower under the 30×30 scenario, by around US$5,000 to US$15,000 over a typical vehicle lifetime. Even though electricity is being a more expensive form of energy, it is more than compensated by the greater energy efficiency of EVs, bringing overall fuel costs down. The only countries where energy becomes more expensive for EVs are small island developing states (Vanuatu and particularly the Maldives), which is due to exceptionally high costs of electricity there, electricity generated primarily from imported oil in small, inefficient plants.

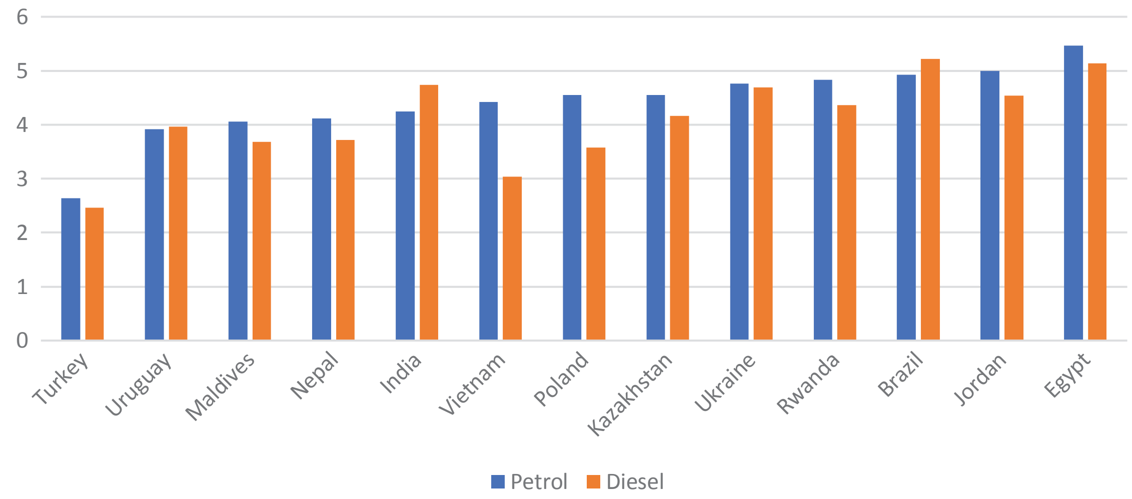
FIGURE 2.8. Normalized Energy Cost of Electricity and Liquid Fuels in Alternative Units



Source: World Bank Economics of Electric Mobility Scoping Tool, 2022

In almost every country, the fiscal regime for fuels and electricity works substantively in favor of electric mobility, reflecting the preponderance of petrol and diesel taxes on the one hand and electricity subsidies on the other (see figure 2.7). This adds to a substantial fiscal advantage over the lifetime of a vehicle, between US$20,000 and US$30,000 per million passenger vehicle kilometers in most cases. The most striking case is the Maldives, where electricity is both very expensive and heavily subsidized, amounting to a fiscal advantage in favor of EV owners amounting to almost US$19,000 per million passenger vehicle-kilometers. Vanuatu is the only country with a sizable fiscal wedge that works against electric mobility, reflecting that electricity is relatively expensive

FIGURE 2.9. Fuel Consumption per Vehicle-Kilometer for Electricity and Liquid Fuels (MJ/vkm)



Source: World Bank Economics of Electric Mobility Scoping Tool, 2022

and more heavily taxed than liquid fuels. Nigeria also stands out as the only country where the fiscal wedge is close to being neutral between the operation of electric vehicles and those based on internal combustion engines. Overall, the nature of the fiscal wedge means that the financial case for operating EVs is even stronger than the economic one, with the percentage operating cost advantage being 5 to 15 percent in economic terms and 10 to 30 percent in financial terms (table 2.3).

It is also of interest to consider how the financial savings in vehicle operating costs work out across categories of vehicles (table 2.4). The results are broadly as expected. The operational cost savings are larger for larger vehicles, reflecting their higher energy consumption. Over the life cycle of the vehicle, these financial operating cost savings typically amount to US$15,000 to US$30,000 for an electric bus, around US$2,000 for an electric four-wheeler, and usually well under US$1,000 for an electric two-wheeler.

Comparing Infrastructure Costs

An additional expense associated with electric vehicles is the need to develop charging infrastructure of adequate density to allow EVs to circulate freely and recharge their batteries as needed. As noted in chapter 1, inadequate development of charging infrastructure can be a barrier to EV uptake; ensuring that investment in charging infrastructure keeps pace with the desired expansion of the electric vehicle fleet is necessary.

TABLE 2.3. Vehicle Operating Cost Advantage of Electric Vehicles at Year 2030

	US$/Mpaxvkm					as % of BAU values	
	a	b	c = a + b	d	e = c + d		
	Cost advantage maintenance	Cost advantage energy	Cost advantage (economic analysis)	Net taxes and subsidies (fiscal wedge)	Cost advantage including fiscal wedge (financial analysis)	Cost advantage (economic analysis)	Cost advantage including fiscal wedge (financial analysis)
Brazil	*5,567*	*5,287*	10,855	*22,491*	33,346	6.7	12.8
Cambodia	*5,178*	*14,077*	19,254	*14,561*	33,815	12.0	17.0
Egypt	*5,053*	*10,247*	15,300	*9,911*	25,211	11.5	19.1
Ethiopia	*1,838*	*5,082*	6,920	*5,561*	12,480	3.4	6.0
Ghana	*2,826*	*8,020*	10,846	*10,452*	21,298	5.7	8.7
India	*5,465*	*17,752*	23,217	*33,058*	56,275	20.1	33.9
Jamaica	*4,483*	*5,895*	10,378	*19,857*	30,235	5.6	11.4
Jordan	*5,356*	*7,187*	12,543	*21,794*	34,337	6.2	12.3
Kazakhstan	*5,448*	*2,834*	8,283	*10,303*	18,586	4.8	10.1
Maldives	*1,784*	*(13,074)*	(11,290)	*19,141*	7,851	(11.9)	8.3
Nepal	*7,174*	*25,545*	32,720	*13,587*	46,307	21.6	24.8
Nigeria	*2,888*	*7,962*	10,850	*(136)*	10,714	5.5	5.2
Poland	*10,379*	*4,460*	14,838	*22,621*	37,459	5.2	9.1
Rwanda	*2,523*	*3,833*	6,356	*22,329*	28,686	3.2	9.5
Tajikistan	*2,228*	*6,209*	8,437	*9,883*	18,321	3.9	7.4
Turkey	*8,699*	*7,824*	16,523	*19,197*	35,720	8.7	14.2
Ukraine	*4,628*	*6,008*	10,636	*29,139*	39,774	5.0	14.3
Uruguay	*7,251*	*21,964*	29,216	*37,342*	66,558	14.9	18.2
Vanuatu	*7,386*	*(165)*	7,221	*(43,645)*	(36,424)	3.2	(14.4)
Vietnam	*9,186*	*21,892*	31,078	*25,160*	56,238	22.6	32.2
Typologies							
Car dominant	6,642	5,655	12,297	21,836	34,133	6.6	12.3
Mixed fleet	5,572	16,923	22,494	28,798	51,292	18.1	30.5
Net oil exporter	5,058	5,669	10,726	18,338	29,064	6.4	11.6
Net oil importer	5,891	16,247	22,137	28,945	51,082	16.9	28.5
High-cost vehicles	6,431	10,715	17,145	19,670	36,815	10.3	16.1
Low-cost vehicles	5,538	16,251	21,789	30,299	52,088	17.4	29.9

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
Note: BAU Scenario minus 30×30 Scenario (average over fleet additions).

TABLE 2.4 Vehicle Operating Cost Advantage of Electric Vehicles at year 2030

	US$/vehicle					
	Electric buses		2W		4W	
	Cost advantage (economic analysis)	Cost advantage including fiscal wedge (financial analysis)	Cost advantage (economic analysis)	Cost advantage including fiscal wedge (financial analysis)	Cost advantage (economic analysis)	Cost advantage including fiscal wedge (financial analysis)
Brazil	15,207	35,389	361	1,033	650	2,174
Cambodia	20,299	30,141	334	631	613	1,102
Egypt	27,579	39,691	265	393	880	1,819
Ethiopia	6,809	12,269	129	255	376	664
Ghana	13,212	26,651	290	521	413	784
India	27,370	53,731	680	1,777	983	2,167
Jamaica	15,966	39,896	458	1,046	700	2,077
Jordan	14,088	21,975	434	1,469	633	1,774
Kazakhstan	6,043	15,721	413	702	572	1,239
Maldives	(29,435)	4,442	(234)	225	(948)	213
Nepal	29,789	34,723	449	786	1,276	1,842
Nigeria	5,222	5,335	254	229	1,043	996
Poland	11,529	20,452	82	244	470	1,212
Rwanda	5,825	28,203	148	553	246	1,127
Tajikistan	10,114	21,455			505	1,099
Turkey	17,814	29,214	376	825	583	1,667
Ukraine	14,748	49,983	301	1,027	491	2,004
Uruguay	27,870	29,497	751	1,807	1,250	2,986
Vanuatu	7,367	(39,076)	283	866	227	(407)
Vietnam	34,576	40,132	605	1,158	942	1,565
Results by Typology						
Car dominant	15,675	32,329	344	953	578	1,779
Mixed fleet	21,224	37,531	634	1,572	964	2,066
Net oil exporter	9,378	17,848	350	948	657	2,021
Net oil importer	22,990	41,529	631	1,566	835	1,916
High-cost vehicles	13,776	21,392	524	1,073	680	1,965
Low-cost vehicles	25,380	49,150	644	1,660	849	1,928

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
Note: BAU Scenario minus 30×30 scenario by vehicle type (average over fleet additions)

Multiple types of charging infrastructure would be needed to support the 30×30 scenario. Private individuals would need to invest in home charging infrastructure for their private vehicles, which would need to be complemented by a certain ratio of office charging facilities as well as public charging facilities allowing for rapid charging on the go. In addition, municipalities would need to invest in charging infrastructure for the electric bus fleet. All the relevant assumptions on the unit cost of charging stations, as well as the target density are summarized in table 2.5.

TABLE 2.5. Model Assumptions on EV Charging Infrastructure

Mode	Charger type	Unit costs (US$)	Density (chargers per 1,000 vehicles)
Car	private chargers	875	1,000
	workplace chargers	1,051	325
	public slow chargers	9,713	100
	public fast chargers	29,140	11
Bus	workplace chargers	30,000	500
	public fast chargers	50,000	250
3W	public chargers	37	166
2W	regular charger	0	/

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

The estimates for the cost of charging infrastructure associated with the 30×30 scenario are reported in table 2.6. The additional costs are typically around US$5,000 per million passenger vehicle-kilometers. About 60 percent of the costs of charging infrastructure are associated with providing public charging stations for four-wheelers (and other) privately owned vehicles. A further 20 percent is associated with investments in home-based charging that need to be made by EV owners. The remaining 20 percent is associated with charging electric buses.

Finally, EV adoption also calls for significant investments in power infrastructure, both in the generation and distribution tiers (as described in chapter 4). However, because the overall increment in electricity demand associated with the 30×30 scenario is marginal, well under 1 percent of total electricity consumption in the countries studied, it is assumed that these costs are fully captured through power purchases of EVs. They will be clarified in the discussion of investment needs.

Comparing Externality Costs

Transportation gives rise to carbon emissions, as well as local air pollutants—including SO_x, NO_x, and particulate matter (PM). In fact, emissions of the two are highly correlated. This is true whether transportation is powered by liquid fuels or electricity. Whether a switch to electric vehicles presents an environmental advantage depends on two factors: the relative pollution intensity of the two sources of energy and the relative energy efficiency of the

TABLE 2.6. Charging Infrastructure Cost Advantage at Year 2030

	in US$/Mpaxvkm			
	a	b	c	d = a + b + c
	4W private charging	4W and 3W public charging	Bus public charging	Cost advantage (economic analysis)
Brazil	*(1,367)*	*(4,051)*	*(693)*	(6,111)
Cambodia	*(316)*	*(911)*	*(1,482)*	(2,709)
Egypt	*(752)*	*(2,207)*	*(1,148)*	(4,107)
Ethiopia	*(36)*	*(108)*	*(1,368)*	(1,512)
Ghana	*(234)*	*(682)*	*(2,101)*	(3,017)
India	*(582)*	*(1,717)*	*(724)*	(3,024)
Jamaica	*(1,826)*	*(5,349)*	*(13)*	(7,188)
Jordan	*(1,436)*	*(4,242)*	*(480)*	(6,158)
Kazakhstan	*(1,587)*	*(4,705)*	*(900)*	(7,192)
Maldives	*(77)*	*(222)*	*(164)*	(463)
Nepal	*(182)*	*(529)*	*(3,541)*	(4,252)
Nigeria	*(311)*	*(885)*	*(3,134)*	(4,330)
Poland	*(3,338)*	*(9,871)*	*(563)*	(13,772)
Rwanda	*(185)*	*(524)*	*(2,054)*	(2,762)
Tajikistan	*(892)*	*(2,500)*	*(139)*	(3,530)
Turkey	*(1,568)*	*(4,700)*	*(2,930)*	(9,198)
Ukraine	*(1,104)*	*(3,176)*	*(1,457)*	(5,737)
Uruguay	*(1,445)*	*(4,335)*	*(562)*	(6,341)
Vanuatu	*(274)*	*(789)*	*(5,566)*	(6,629)
Vietnam	*(265)*	*(784)*	*(705)*	(1,754)
Typologies				
Car dominant	(1,640)	(4,860)	(1,141)	(7,641)
Mixed fleet	(543)	(1,599)	(865)	(3,007)
Net oil exporter	(1,176)	(3,480)	(1,093)	(5,750)
Net oil importer	(683)	(2,016)	(889)	(3,589)
High-cost vehicles	(898)	(2,667)	(1,286)	(4,852)
Low-cost vehicles	(698)	(2,057)	(784)	(3,540)

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
Note: BAU scenario minus 30×30 scenario (average over fleet additions)

FIGURE 2.10. Decomposition of Changes in Carbon Emissions from Motor Transportation

ΔCIT = ΔCIE x ΔEFF

Δ: difference between variables under 30x30 scenario versus BAU
CIT: carbon intensity of transportation (CO_2/vehicle-kilometer)
CIE: carbon intensity of energy (CO_2/Joule)
EFF: energy efficiency coefficient (Joules/vehicle-kilometer)

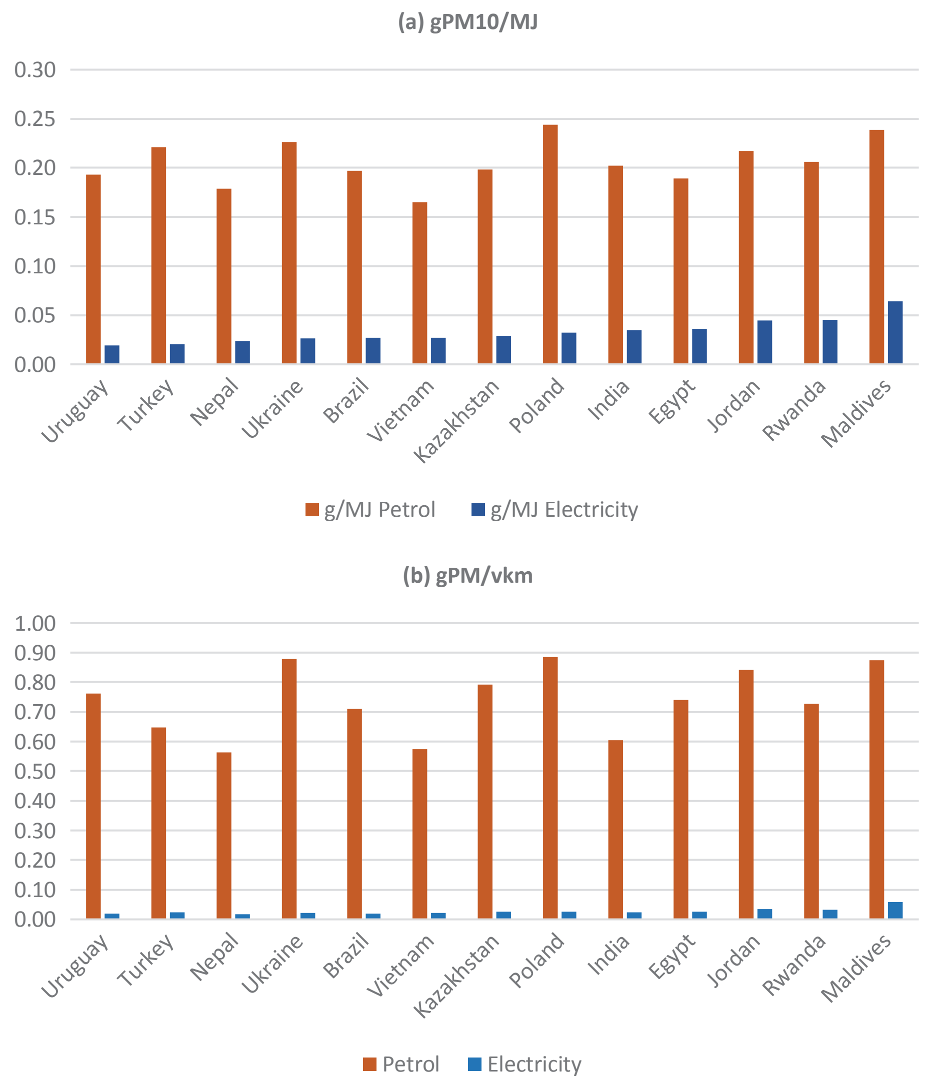
two types of vehicles (figure 2.11). A related factor is exposure, which depends on the proximity of the polluting source relative to vulnerable human subjects.

The pollution intensity of electricity generation varies widely across countries. In the case of local pollutants, such as particulate matter, petrol emits far more pollution per unit of energy produced (0.15 to 0.25 gPM10/MJ) than any of the electricity systems (no more than 0.05gPM10/MJ), even for power systems still heavily based on fossil fuels (figure 2.11, panel a). This means that electricity is unambiguously preferable to liquid fuels in terms of local pollution. When the energy efficiency advantage is additionally taken into account and the PM intensity expressed relative to units of travel, electricity becomes cleaner than petrol by an order of magnitude (figure 2.11, panel b), see figure 2.10 for details.

In the case of carbon emissions, however, the relative carbon intensity of energy from petrol versus electricity varies hugely depending on the composition of the generation mix (figure 2.12). At one end of the spectrum, hydro-reliant countries, such as Ethiopia, Nepal, and Uruguay, produce negligible externalities from power generation. At the other end, small islands that depend on oil (such as the Maldives and Vanuatu) together with larger countries that depend on coal (such as India and Poland) produce substantial externalities from power generation. Thus, the carbon intensity of petrol-based internal combustion engines tends to lie around 0.08 gCO_2/kJ, whereas the carbon intensity of electricity varies from close to zero all the way up to around 0.25 gCO_2/kJ (figure 2.12). One way of thinking about this is that the carbon intensity of liquid transportation fuels is broadly equivalent to the carbon intensity of a power grid that relies heavily on natural gas, such as those of Ghana or Nigeria.

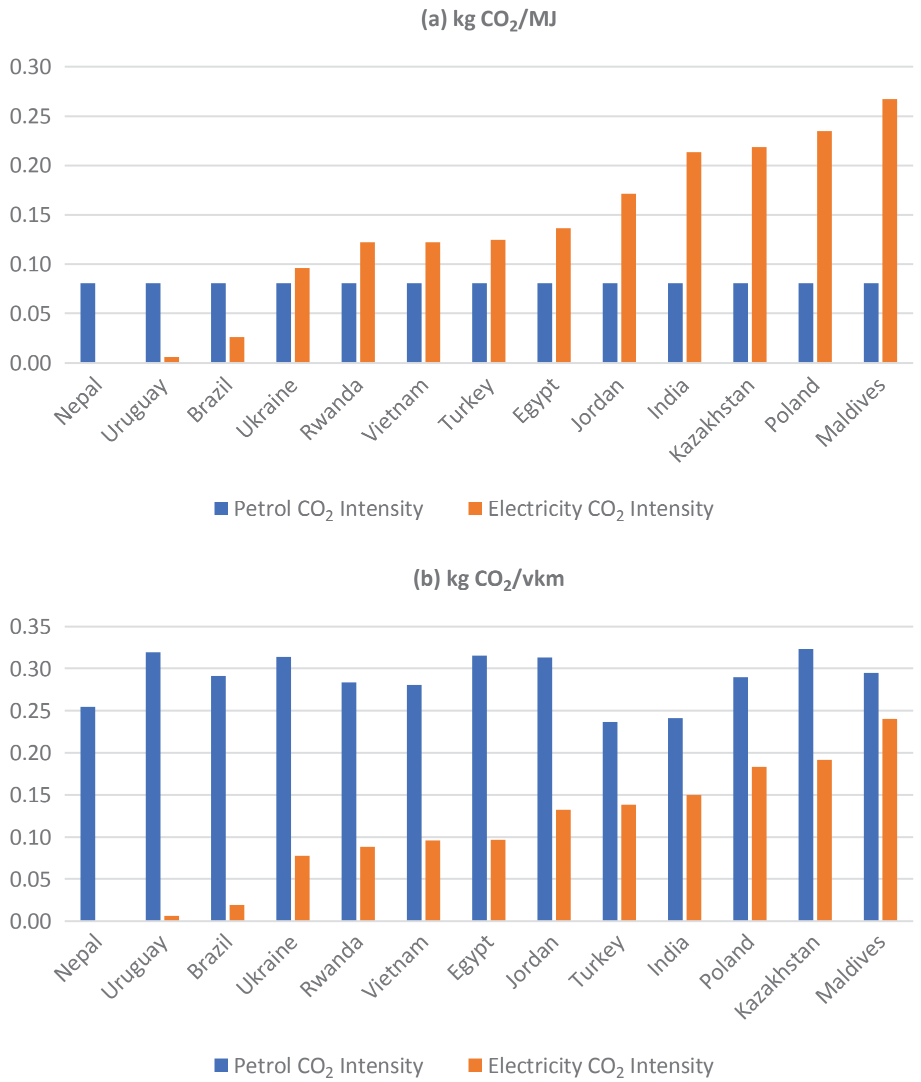
However, as noted (figure 2.9), BEVs are several times more energy efficient than ICEVs. When this additional energy efficiency is taken into account by normalizing carbon emissions against vehicle-kilometers of transport services provided (figure 2.12, panel b), electricity turns out to be a less carbon intensive fuel than petrol for

FIGURE 2.11. Comparative PM10 Intensity of Vehicle Fuels



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

FIGURE 2.12. Carbon Intensity of Vehicle Fuels in Alternative Units



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

every country in the sample, *including those that continue to rely heavily on fossil fuels for power generation* (such as Kazakhstan, Maldives, and Poland). Moreover, this carbon footprint will fall over time as the electricity sector further decarbonizes.

The energy efficiency effect overwhelms the carbon intensity effect in the countries studied so that even in the 30×30 scenario *increasing electrification of the vehicle fleet brings both local and global environmental benefits irrespective of how carbon intensive is a country's current power generation mix* (table 2.7). In most countries, the value of externality costs saved as a result of the transmission to electric mobility is of the order of US$5,000 per million passenger-kilometers. However, in a few cases, they can be much higher. However, countries such as Egypt and Turkey report higher externality cost savings, to the order of between US$10,000 and US$20,000, due to relatively high damage coefficients for pollutants and/or high bus mileage. In both countries, savings in local pollutant emissions are particularly high and account for the bulk of the externality benefits. Breaking down the externalities by vehicle type (table 2.8) illustrates how large the externality advantages associated with electric buses are for countries such as Egypt, Kazakhstan, and Maldives.

For many countries, the reduced externalities associated with local pollutants are significant, and in a handful—Egypt, Kazakhstan, Maldives, Poland, and Turkey—they overwhelm the benefits from the reduced externalities associated with carbon emissions (figure 2.13). They do so because in countries with severe urban air quality problems and high damage factors electrifying the vehicle fleet brings substantial benefits in terms of local air pollution, resulting primarily from reductions in PM10.

Aggregating Across Cost Categories

The discussion has examined the relative costs of the 30×30 scenario for electric vehicle adoption component by component. The results indicate that the 30×30 scenario entails a significant premium in vehicle capital costs and charging infrastructure, but that maintenance costs, energy costs, and environmental externalities are invariably lower. The remaining question is whether the substantial operating advantages of electric vehicles outweigh the significant capital cost premium.

Table 2.9 considers this question at the national scale, allowing the economic cost differentials to accumulate step by step. When only capital cost differentials are considered, the 30×30 scenario is generally unattractive. Comparing the relative magnitude of the cost differentials for charging infrastructure and vehicle purchase suggests that the latter typically accounts for about 80 percent of the additional investment entailed by the electric mobility scenario. However, as soon as the lifetime advantage in operating costs is added to the capital costs (see the subtotal column), the balance shifts to being at least slightly advantageous to EVs in seven of the 20 countries considered—Cambodia, Ethiopia, Ghana, India, Nigeria, Tajikistan, and Vietnam. In terms of

TABLE 2.7. Environmental Advantage of Electric Vehicles at year 2030

	in US$/Mpaxvkm			% of BAU values	in '000 tons of CO_2 equivalent		
	a	b	c = a + b		a	b	c = a + b
	Local externalities (NO_x, SO_x, PM10)	Global externalities (CO_2)	Cost advantage (economic analysis)	Cost advantage (economic analysis)	Local externalities (NO_x, SO_x, PM10)	Global externalities (CO_2)	Total externalities savings
Brazil	*1,143*	*3,553*	*4,697*	*24*	*72*	*20,179*	*20,251*
Cambodia	*189*	*2,415*	*2,604*	*18*	*0*	*27*	*28*
Egypt	*16,640*	*2,378*	*19,019*	*24*	*48*	*4,516*	*4,565*
Ethiopia	*7*	*1,323*	*1,330*	*7*	*0*	*134*	*135*
Ghana	*398*	*2,096*	*2,494*	*13*	*1*	*226*	*227*
India	*1,666*	*1,549*	*3,215*	*23*	*3*	*7,588*	*7,591*
Jamaica	*444*	*2,339*	*2,782*	*16*	*2*	*470*	*472*
Jordan	*1,193*	*813*	*2,006*	*9*	*2*	*97*	*100*
Kazakhstan	*6,459*	*1,017*	*7,476*	*12*	*1*	*398*	*399*
Maldives	*4,702*	*928*	*5,630*	*18*	*0*	*2*	*2*
Nepal	*456*	*4,253*	*4,709*	*31*	*0*	*158*	*158*
Nigeria	*240*	*1,695*	*1,935*	*12*	*5*	*972*	*977*
Poland	*2,408*	*652*	*3,060*	*8*	*0*	*1,233*	*1,233*
Rwanda	*225*	*1,535*	*1,760*	*9*	*0*	*15*	*15*
Tajikistan	*192*	*1,542*	*1,733*	*10*	*0*	*81*	*82*
Turkey	*9,551*	*754*	*10,304*	*16*	*2*	*381*	*383*
Ukraine	*2,862*	*2,119*	*4,981*	*13*	*4*	*1,322*	*1,326*
Uruguay	*687*	*4,300*	*4,987*	*30*	*2*	*699*	*702*
Vanuatu	*210*	*2,036*	*2,247*	*11*	*0*	*1*	*1*
Vietnam	*4,195*	*3,916*	*8,110*	*34*	*4*	*1,037*	*1,041*
Typologies							
Car dominant	3,163	2,429	5,591	17	3,163	2,429	5,591
Mixed fleet	2,854	1,843	4,696	23	2,854	1,843	4,696
Net oil exporter	1,247	3,107	4,354	21	1,247	3,107	4,354
Net oil importer	3,180	1,769	4,949	22	3,180	1,769	4,949
High-cost vehicles	2,836	2,935	5,771	22	2,836	2,935	5,771
Low-cost vehicles	2,940	1,599	4,539	22	2,940	1,599	4,539

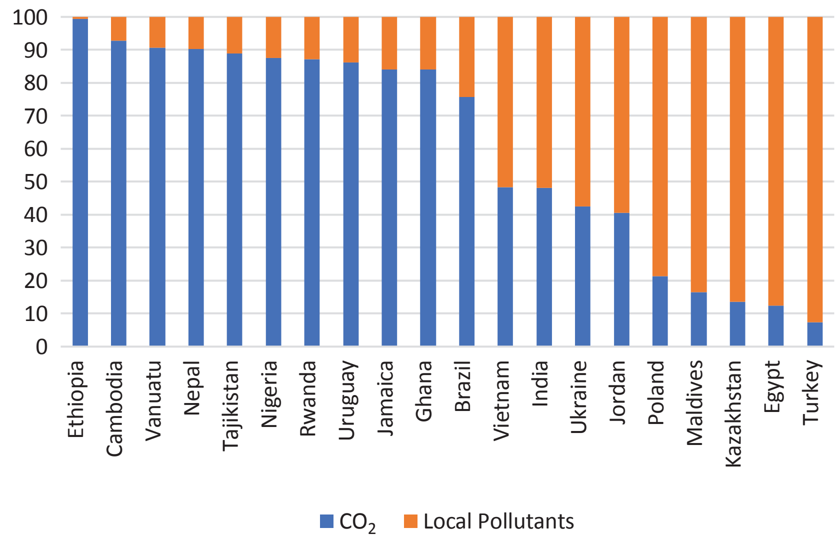
Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
Note: BAU Scenario minus 30×30 Scenario (average over fleet additions).

TABLE 2.8. Cost Advantage of Electric Vehicles at year 2030

	US$/vehicle								
	Electric buses			2W			4W		
	a	b	c = a + b	a	b	c = a + b	a	b	c = a + b
	Local externalities (NO_x, SO_x, PM10)	Global externalities (CO_2)	Total externalities	Local externalities (NO_x, SO_x, PM10)	Global externalities (CO_2)	Total externalities	Local externalities (NO_x, SO_x, PM10)	Global externalities (CO_2)	Total externalities
Brazil	2,966	7,827	10,792	49	85	134	46	203	249
Cambodia	309	2,597	2,907	3	42	44	4	74	78
Egypt	33,680	4,470	38,150	170	33	203	1,255	161	1,416
Ethiopia	8	1,320	1,327	0	23	23	0	64	64
Ghana	568	2,681	3,249	7	49	56	8	72	80
India	3,094	1,310	4,405	54	53	108	17	33	50
Jamaica	998	3,526	4,524	25	66	91	29	163	192
Jordan	1,836	1,177	3,013	41	39	80	55	33	89
Kazakhstan	14,662	1,458	16,120	152	46	198	230	55	284
Maldives	27,502	909	28,411	102	24	127	54	29	83
Nepal	637	3,848	4,486	3	59	61	1	170	171
Nigeria	126	764	890	5	42	47	20	178	198
Poland	5,156	500	5,656	34	9	43	63	20	84
Rwanda	259	1,531	1,790	3	30	33	4	55	59
Tajikistan	2,206	1,987	4,193	N/A	N/A	N/A	3	92	95
Turkey	10,536	1,090	11,625	132	26	158	360	11	370
Ukraine	8,363	2,882	11,245	25	56	80	11	100	111
Uruguay	859	5,096	5,954	30	88	118	6	214	220
Vanuatu	228	2,084	2,312	6	48	53	0	63	64
Vietnam	5,257	4,457	9,714	80	76	156	110	93	204
Results by Typology									
Car dominant	7,661	3,429	11,090	87	48	136	104	108	213
Mixed fleet	4,562	1,784	6,347	47	47	94	142	54	196
Net oil exporter	1,717	3,228	4,945	26	56	82	55	189	244
Net oil importer	6,159	1,825	7,985	63	45	108	146	45	191
High-cost vehicles	3,167	2,521	5,688	43	44	88	115	147	263
Low-cost vehicles	6,927	1,793	8,720	65	50	115	131	45	175

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
Note: BAU scenario minus 30×30 scenario by type of vehicle (average over fleet additions).

FIGURE 2.13. Environmental Benefits of Switching to Electric Mobility (% on total gains)



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

the country typology, the balance becomes favorable for countries with mixed vehicle fleets, net oil importing status, or relatively low vehicle costs.

The balance only swings further in the direction of electric mobility when externality costs are further considered (see the total in the second green column), with 10 of the 20 countries now better off after adopting electric mobility. Thus *the inclusion of externality costs changes the direction of the overall policy conclusion on electric mobility* in several cases—notably, Egypt, Kazakhstan, and Vanuatu.

Although the central focus of this report is on economic results, financial results, which portray the extent to which the switch to electric mobility is in the monetary interest of those concerned, are also important. As noted, two factors drive the difference between the economic and financial results. The first is the exclusion of the externalities, which invariably makes electric mobility less desirable than when externalities are accounted for. The second is the reincorporation of taxes and subsidies, which more often than not makes electric mobility more attractive than in the economic analysis due to distortions in the fiscal regime in many countries that work in its favor.

In an ideal world, the fiscal policy toward transportation and energy should be aligned with the externality costs of transport and energy decisions. In such a world, the magnitude of the fiscal wedge should be broadly consistent

TABLE 2.9. National Aggregate Cost Advantage of Electric Vehicles at Year 2030

	in US$/Mpaxvkm								as a % of BAU values	
	a	b	c	d = a + b + c	e	f = d + e	g	h = d + g		
	Charging infrastructure	Vehicle capital cost	Vehicle operating cost	Subtotal	Externality	Cost advantage (economic analysis)	Net taxes and subsidies (fiscal wedge)	Cost advantage including fiscal wedge (financial analysis)	Cost advantage (economic analysis)	Cost advantage including Fiscal wedge (financial analysis)
Brazil	*(6,111)*	*(21,880)*	*10,855*	*(17,137)*	*4,697*	(12,441)	*35,543*	18,406	(2.8)	2.9
Cambodia	*(2,709)*	*(12,724)*	*19,254*	*3,822*	*2,604*	6,426	*16,708*	20,530	2.5	6.2
Egypt	*(4,107)*	*(13,010)*	*15,300*	*(1,817)*	*19,019*	17,201	*10,165*	8,347	4.8	2.6
Ethiopia	*(1,512)*	*(4,692)*	*6,920*	*715*	*1,330*	2,045	*11,359*	12,074	0.8	4.6
Ghana	*(3,017)*	*(6,241)*	*10,846*	*1,587*	*2,494*	4,081	*9,346*	10,933	1.5	3.4
India	*(3,024)*	*(12,207)*	*23,217*	*7,986*	*3,215*	11,201	*43,109*	51,095	5.0	17.4
Jamaica	*(7,188)*	*(27,919)*	*10,378*	*(24,729)*	*2,782*	(21,947)	*16,993*	(7,736)	(4.2)	(1.0)
Jordan	*(6,158)*	*(41,124)*	*12,543*	*(34,739)*	*2,006*	(32,733)	*59,233*	24,494	(6.6)	3.3
Kazakhstan	*(7,192)*	*(8,347)*	*8,283*	*(7,257)*	*7,476*	219	*12,773*	5,516	0.1	1.5
Maldives	*(463)*	*(9,370)*	*(11,290)*	*(21,123)*	*5,630*	(15,492)	*27,540*	6,417	(9.8)	3.9
Nepal	*(4,252)*	*(39,111)*	*32,720*	*(10,644)*	*4,709*	(5,935)	*(13,928)*	(24,572)	(2.5)	(6.0)
Nigeria	*(4,330)*	*(6,511)*	*10,850*	*9*	*1,935*	1,944	*(1,112)*	(1,103)	0.7	(0.4)
Poland	*(13,772)*	*(26,712)*	*14,838*	*(25,646)*	*3,060*	(22,586)	*80,405*	54,759	(2.8)	5.3
Rwanda	*(2,762)*	*(5,112)*	*6,356*	*(1,518)*	*1,760*	243	*25,110*	23,592	0.1	6.5
Tajikistan	*(3,530)*	*1,351*	*8,437*	*6,258*	*1,733*	7,991	*11,174*	17,431	2.8	5.5
Turkey	*(9,198)*	*(31,494)*	*16,523*	*(24,169)*	*10,304*	(13,865)	*23,127*	(1,042)	(2.6)	(0.1)
Ukraine	*(5,737)*	*(11,376)*	*10,636*	*(6,478)*	*4,981*	(1,497)	*39,734*	33,256	(0.3)	6.5
Uruguay	*(6,341)*	*(37,121)*	*29,216*	*(14,247)*	*4,987*	(9,260)	*74,957*	60,710	(1.8)	7.4
Vanuatu	*(6,629)*	*(3,915)*	*7,221*	*(3,322)*	*2,247*	(1,076)	*(40,029)*	(43,352)	(0.2)	(8.6)
Vietnam	*(1,754)*	*(22,595)*	*31,078*	*6,728*	*8,110*	14,839	*26,451*	33,179	6.1	10.7
				Typologies					Typologies	
Car dominant	(7,641)	(23,287)	12,297	(18,632)	5,591	(13,040)	38,198	19,566	(2.6)	2.9
Mixed fleet	(3,007)	(13,055)	22,494	6,433	4,696	11,129	36,705	43,138	4.6	14.4
Net oil exporter	(5,750)	(18,329)	10,726	(13,352)	4,354	(8,998)	28,242	14,891	(2.2)	2.7
Net oil importer	(3,589)	(14,465)	22,137	4,083	4,949	9,032	38,397	42,480	3.3	12.4
High-cost vehicles	(4,852)	(21,642)	17,145	(9,348)	5,771	(3,577)	26,252	16,904	(1.0)	3.4
Low-cost vehicles	(3,540)	(12,597)	21,789	5,652	4,539	10,191	40,875	46,527	3.9	14.3

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
Note: BAU scenario minus 30×30 scenario (average over fleet additions).

with the externality cost differential, obliging economic actors to pay financially for the environmental impacts of their actions. Overall, 17 of the 20 countries studied have fiscal wedges that favor the adoption of electric mobility, whether through favorable tax or subsidy differentials on vehicle purchase and/or energy purchase. In 16 of these cases, the fiscal advantage is larger than what is warranted by the externality costs, resulting in excessive incentives for adoption. This is illustrated by the countries above the 45-degree line shown in figure 2.14.

The overall effect is that the number of countries for which the 30×30 scenario is financially advantageous as opposed to economically advantageous rises from 10 of 20 to 15 of 20. Relative to the results of the economic analysis, the fiscal wedge reverts the negative economic conclusion to a positive financial one in six countries—Brazil, Jordan, Maldives, Poland, Ukraine, and Uruguay. All have relatively large net subsidies in favor of adoption. However, in one country—Nigeria, where EVs are fiscally penalized—the fiscal wedge reverses a positive economic conclusion into a negative financial one.

Table 2.10 presents the same detailed set of results but disaggregated to display only the results for electric buses—a vehicle category of particular public policy interest. The results indicate that charging infrastructure investments for electric buses are around US$5,000 per vehicle. The incremental capital costs associated with their purchase are somewhat higher than the cost of charging infrastructure and much more variable, typically between US$6,000 and US$18,000. Only in Uruguay and Vanuatu is there a modest capital cost advantage from purchasing an electric bus. This is explained by the exceptionally high cost of diesel buses in Vanuatu.

FIGURE 2.14. Relative Value of the Fiscal Wedge and Externality Cost Advantage of 30×30 Scenario

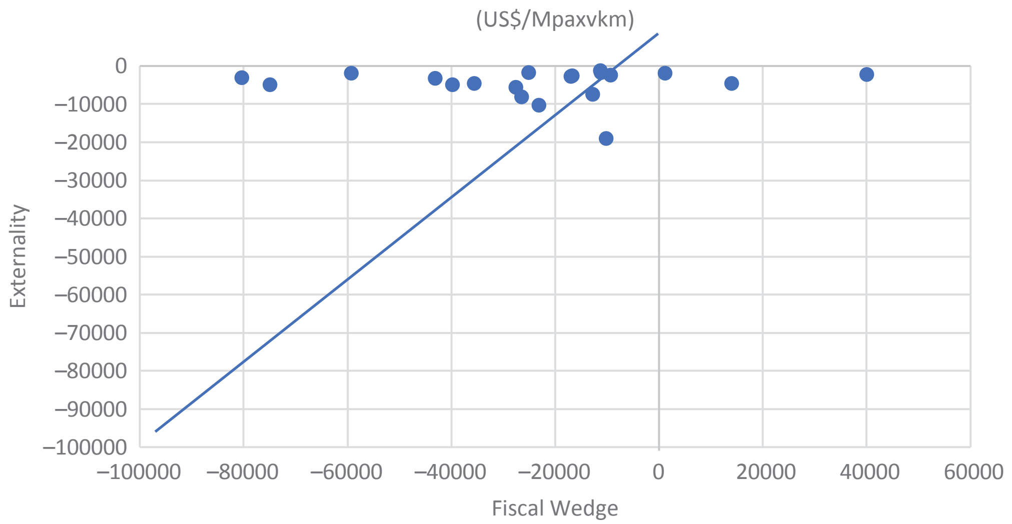


TABLE 2.10. Aggregate Cost Advantage at Year 2030 for Electric Buses

	in US$/vehicle								% of BAU values	
	a	b	c	d = a + b + c	e	f = d + e	g	h = d + g		
	Charging infrastructure	Vehicle capital cost	Vehicle operating cost	Subtotal	Externality	Cost advantage (economic analysis)	Net taxes and subsidies (fiscal wedge)	Cost advantage including fiscal wedge (financial analysis)	Cost advantage (economic analysis)	Cost advantage including fiscal wedge (financial analysis)
Brazil	*(6,102)*	*(6,136)*	*15,207*	*2,969*	*10,792*	13,762	*28,373*	31,342	3.5	6.1
Cambodia	*(5,180)*	*(9,621)*	*20,299*	*5,497*	*2,907*	8,404	*13,770*	19,267	2.6	5.0
Egypt	*(6,036)*	*(12,107)*	*27,579*	*9,437*	*38,150*	47,587	*8,806*	18,243	10.0	5.5
Ethiopia	*(1,545)*	*(3,375)*	*6,809*	*1,890*	*1,327*	3,217	*10,787*	12,676	1.3	5.0
Ghana	*(3,675)*	*(7,738)*	*13,212*	*1,800*	*3,249*	5,048	*11,965*	13,765	1.8	4.1
India	*(6,104)*	*(14,027)*	*27,370*	*7,239*	*4,405*	11,644	*29,988*	37,227	3.6	9.7
Jamaica	*(5,759)*	*(5,219)*	*15,966*	*4,989*	*4,524*	9,513	*21,756*	26,745	2.8	6.0
Jordan	*(3,653)*	*(9,111)*	*14,088*	*1,324*	*3,013*	4,336	*9,086*	10,409	1.5	3.2
Kazakhstan	*(3,516)*	*(11,639)*	*6,043*	*(9,112)*	*16,120*	7,008	*8,952*	(160)	2.2	(0.1)
Maldives	*(2,871)*	*(5,501)*	*(29,435)*	*(37,807)*	*28,411*	(9,397)	*39,411*	1,604	(1.8)	0.5
Nepal	*(6,102)*	*(18,705)*	*29,789*	*4,981*	*4,486*	9,467	*681*	5,663	3.6	1.4
Nigeria	*(2,668)*	*(6,418)*	*5,222*	*(3,863)*	*890*	(2,973)	*(938)*	(4,801)	(2.2)	(3.5)
Poland	*(5,911)*	*(12,412)*	*11,529*	*(6,794)*	*5,656*	(1,138)	*15,011*	8,217	(0.5)	3.3
Rwanda	*(3,054)*	*(7,116)*	*5,825*	*(4,346)*	*1,790*	(2,556)	*24,523*	20,178	(1.0)	5.5
Tajikistan	*(2,098)*	*(6,226)*	*10,114*	*1,790*	*4,193*	5,983	*11,437*	13,227	2.2	5.1
Turkey	*(6,088)*	*(12,982)*	*17,814*	*(1,256)*	*11,625*	10,370	*13,684*	12,428	3.9	4.1
Ukraine	*(4,525)*	*(10,558)*	*14,748*	*(334)*	*11,245*	10,911	*37,988*	37,653	3.1	10.4
Uruguay	*(6,013)*	*249*	*27,870*	*22,106*	*5,954*	28,060	*11,764*	33,869	7.7	6.8
Vanuatu	*(6,082)*	*996*	*7,367*	*2,281*	*2,312*	4,594	*(46,122)*	(43,840)	1.2	(10.4)
Vietnam	*(6,102)*	*(14,234)*	*34,576*	*14,239*	*9,714*	23,953	*13,784*	28,023	5.7	6.2
	Typologies								Typologies	
Car dominant	(5,759)	(10,383)	15,675	(467)	11,090	10,623	20,949	20,482	3.4	5.6
Mixed fleet	(4,876)	(11,162)	21,224	5,186	6,347	11,533	18,822	24,008	3.8	7.3
Net oil exporter	(3,898)	(6,736)	9,378	(1,256)	4,945	3,688	10,240	8,983	1.5	3.2
Net oil importer	(5,377)	(12,164)	22,990	5,449	7,985	13,434	21,728	27,178	4.2	7.7
High-cost vehicles	(4,121)	(8,325)	13,776	1,329	5,688	7,017	10,936	12,266	2.7	4.1
Low-cost vehicles	(5,852)	(13,255)	25,380	6,273	8,720	14,992	26,288	32,561	4.4	8.9

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
BAU scenario minus 30×30 scenario (average over fleet additions).

Nevertheless, the associated operating cost savings are substantial given their relatively long mileage, amounting to almost US$10,000 on average per bus over its entire life cycle. Operating cost savings are particularly high in some countries—such as Nepal and Uruguay—where they exceed US$20,000 per vehicle and is attributable to relatively large operating cost savings driven by low-cost electricity.

Considering the overall balance of these economic costs and benefits before taking externalities into account reveals that electric buses are already economically desirable in 13 of the 20 countries studied: Brazil, Cambodia, Egypt, Ethiopia, Ghana, India, Jamaica, Jordan, Nepal, Tajikistan, Uruguay, Vanuatu, and Vietnam. However, their externality benefits are large given their high mileage and major contribution to local air pollution, amounting to over US$10,000 over their life cycle. Once this is fully accounted for, the number of countries where electric buses are economically desirable rises from 13 to 16 of the 20 studied. Specifically, the inclusion of externalities tips the balance in their favor in Kazakhstan, Turkey, and Ukraine. Nevertheless, the cost advantage is no more than 10 percent of the BAU.

Finally, as noted, many countries operate a fiscal regime that further favors electric mobility in financial terms. When it comes to electric buses, switching from an economic to a financial lens, Maldives, Poland, and Rwanda also become favorable. However, the composition of the country list has changed somewhat. In the case of Kazakhstan and Vanuatu, the fiscal regime is stacked against electric buses, flipping a positive economic evaluation to a negative financial one. Overall, the financial results for electric buses tend to be more favorable in countries with lower dominance of private cars, which import oil and have access to relatively low-cost vehicles.

Table 2.11 repeats these detailed results for two-wheel EVs only. The economic conclusions are particularly favorable for this vehicle category. Even without considering externalities, two-wheel EVs are economically attractive in 14 of the 19 countries for which data is available. Considering externalities, increases the number of countries with favorable results to 15 out of 19. Moreover, once the fiscal wedge is included, electric two-wheelers turn out to be financially advantageous in 18 of the 19 countries studied. Moreover, the percentage of cost advantages for electric two-wheelers are especially large. In economic terms, electric two-wheelers have a 10 to 15 percent cost advantage over their conventional counterparts; in financial terms, this advantage further rises to 20 to 30 percent.

Finally, table 2.12 presents detailed results for electric four-wheelers only, the most challenging economic case for electric mobility. Excluding externalities, only three countries (Nigeria, Rwanda, and Tajikistan) have operating cost savings that outweigh the higher capital costs. When externalities are considered, an additional country—Egypt—achieves a favorable economic balance. However, clearly fiscal advantages of owning an electric four-wheeler are large enough in many countries to tip the financial balance in their favor in as many as 14 of the 20 countries. Countries where fiscal incentives make all the difference include Brazil, Ethiopia,

TABLE 2.11. Aggregate Cost Advantage at Year 2030 for Two-Wheelers

	in US$/vehicle								% of BAU values	
	a	b	c	d = a + b + c	e	f = d + e	g	h = d + g		
	Charging infrastructure	Vehicle capital cost	Vehicle operating cost	Subtotal	Externality	Cost advantage (economic analysis)	Net taxes and subsidies (fiscal wedge)	Cost advantage including fiscal wedge (financial analysis)	Cost advantage (economic analysis)	Cost advantage including fiscal wedge (financial analysis)
Brazil	0	(125)	361	236	134	370	700	936	13.9	25.6
Cambodia	0	(154)	334	180	44	224	291	471	10.5	17.3
Egypt	0	(202)	265	63	203	266	93	156	12.9	8.9
Ethiopia	0	(172)	129	(43)	23	(20)	223	180	(1.2)	9.2
Ghana	0	(71)	290	219	56	275	220	439	13.9	18.7
India	0	(199)	680	481	108	589	1,252	1,733	21.4	43.8
Jamaica	0	(305)	458	153	91	243	458	611	9.2	16.6
Jordan	0	(451)	434	(17)	80	63	1,233	1,216	2.6	28.3
Kazakhstan	0	(107)	413	306	198	504	311	618	22.6	29.6
Maldives	0	(231)	(234)	(465)	127	(338)	627	162	(14.5)	7.3
Nepal	0	(694)	449	(245)	61	(183)	(344)	(589)	(10.3)	(19.3)
Nigeria	0	(12)	254	243	47	290	(27)	216	15.0	12.3
Poland	0	(29)	82	53	43	96	263	316	3.7	11.8
Rwanda	0	(32)	148	115	33	149	425	540	8.5	20.4
Tajikistan										
Turkey	0	(368)	376	8	158	166	461	469	7.2	16.6
Ukraine	0	(128)	301	173	80	253	789	961	11.9	33.1
Uruguay	0	(404)	751	347	118	466	1,156	1,503	16.7	30.7
Vanuatu	0	(351)	283	(68)	53	(15)	469	401	(0.5)	8.3
Vietnam	0	(348)	605	258	156	413	506	764	13.3	19.7
	Typologies								Typologies	
Car dominant	0	(161)	344	183	110	293	642	825	11.3	23.9
Mixed fleet	0	(225)	634	409	117	526	1,040	1,449	19.2	38.4
Net oil exporter	0	(114)	350	236	132	368	623	859	14.2	24.9
Net oil importer	0	(227)	631	404	108	513	1,038	1,442	18.8	38.2
High-cost vehicles	0	(314)	524	209	134	343	492	702	12.0	19.1
Low-cost vehicles	0	(198)	644	446	104	550	1,156	1,602	20.4	42.4

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
Note: BAU scenario minus 30×30 scenario (average over fleet additions).

TABLE 2.12. *Aggregate Cost Advantage at Year 2030 for Four-Wheelers*

	(in US$/vehicle)								Aggregate cost % of BAU values	
	a	b	c	d = a + b + c	e	f = d + e	g	h = d + g		
	Charging infrastructure	Vehicle capital cost	Vehicle operating cost	Subtotal	Externality	Cost advantage (economic analysis)	Net taxes and subsidies (fiscal wedge)	Cost advantage including fiscal wedge (financial analysis)	Cost advantage (economic analysis)	Cost advantage including fiscal wedge (financial analysis)
Brazil	*(529)*	*(1,983)*	*650*	*(1,862)*	*249*	(1,612)	*2,688*	827	(4.3)	1.5
Cambodia	*(363)*	*(1,397)*	*613*	*(1,147)*	*78*	(1,069)	*852*	(295)	(4.1)	(0.8)
Egypt	*(567)*	*(1,100)*	*880*	*(787)*	*1,416*	629	*1,256*	469	1.5	1.1
Ethiopia	*(142)*	*(1,173)*	*376*	*(939)*	*64*	(875)	*1,093*	154	(4.3)	0.6
Ghana	*(232)*	*(290)*	*413*	*(110)*	*80*	(30)	*332*	222	(0.1)	0.8
India	*(568)*	*(1,412)*	*983*	*(997)*	*50*	(947)	*2,731*	1,733	(3.2)	4.5
Jamaica	*(527)*	*(2,010)*	*700*	*(1,837)*	*192*	(1,645)	*1,184*	(652)	(4.3)	(1.2)
Jordan	*(441)*	*(2,895)*	*633*	*(2,703)*	*89*	(2,615)	*3,946*	1,243	(7.6)	2.4
Kazakhstan	*(540)*	*(459)*	*572*	*(427)*	*284*	(142)	*895*	468	(0.5)	1.7
Maldives	*(211)*	*(2,011)*	*(948)*	*(3,170)*	*83*	(3,087)	*3,496*	326	(10.4)	0.7
Nepal	*(504)*	*(5,593)*	*1,276*	*(4,820)*	*171*	(4,649)	*(3,063)*	(7,884)	(18.5)	(13.8)
Nigeria	*(342)*	*308*	*1,043*	*1,009*	*198*	1,206	*29*	1,038	3.9	3.2
Poland	*(460)*	*(886)*	*470*	*(876)*	*84*	(793)	*2,725*	1,848	(2.9)	5.3
Rwanda	*(249)*	*18*	*246*	*15*	*59*	74	*1,268*	1,283	0.3	4.3
Tajikistan	*(221)*	*115*	*505*	*399*	*95*	494	*677*	1,077	2.8	5.5
Turkey	*(574)*	*(2,172)*	*583*	*(2,163)*	*370*	(1,792)	*1,338*	(825)	(4.9)	(1.7)
Ukraine	*(393)*	*(712)*	*491*	*(615)*	*111*	(503)	*2,396*	1,781	(1.7)	4.9
Uruguay	*(555)*	*(2,866)*	*1,250*	*(2,171)*	*220*	(1,951)	*5,085*	2,914	(4.7)	4.4
Vanuatu	*(550)*	*(2,473)*	*227*	*(2,796)*	*64*	(2,733)	*1,094*	(1,702)	(6.1)	(2.8)
Vietnam	*(569)*	*(3,004)*	*942*	*(2,631)*	*204*	(2,427)	*1,872*	(759)	(6.7)	(1.4)
Typologies									**Typologies**	
Car dominant	(507)	(1,591)	578	(1,520)	213	(1,308)	2,397	877	(3.9)	1.9
Mixed fleet	(556)	(1,426)	964	(1,017)	196	(821)	2,466	1,448	(2.6)	3.7
Net oil exporter	(512)	(1,731)	657	(1,587)	244	(1,342)	2,384	797	(3.7)	1.6
Net oil importer	(541)	(1,430)	835	(1,136)	191	(944)	2,451	1,315	(3.0)	3.3
High-cost vehicles	(528)	(2,056)	680	(1,904)	263	(1,642)	2,238	333	(4.5)	0.6
Low-cost vehicles	(537)	(1,232)	849	(920)	175	(745)	2,530	1,610	(2.5)	4.3

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
Note: BAU scenario minus 30×30 scenario (average over fleet additions).

Ghana, India, Jordan, Kazakhstan, Maldives, Poland, Ukraine, and Uruguay. Nevertheless, even in financial terms, the advantage of owning a four-wheeler is typically no more than 2 to 3 percent of life-cycle costs.

Exploring Sensitivity of Results

Although the results of the cost-benefit analysis presented provide an illustrative reference scenario for the acceleration of electric mobility, they are based on numerous assumptions that may not materialize. It is therefore important to undertake sensitivity analysis to examine the robustness of the results and to explore plausible alternative scenarios. This section presents sensitivity analysis against five important dimensions: the greening of the power grid, the evolving price of batteries, the management of bus fleets, targeted adoption for taxi fleets, and pursuit of greater fuel efficiency in conventional internal combustion engine vehicles. In what follows, the results of the corresponding green grid scenario, the scarce minerals scenario, the efficient bus scenario, the taxi fleet scenario, and the fuel efficiency scenario are compared in turn against the 30×30 scenario.

Green Grid Scenario

The 30×30 scenario explores the accelerated adoption of electric mobility while holding constant a country's power generation mix. In many countries, power generation remains carbon intensive, holding longer-range plans to decarbonize the system only gradually. The greener a country's power generation mix, the larger the externality benefits associated with electric mobility. This sensitivity analysis compares the 30×30 scenario results with those of a green grid scenario, in which countries achieve by 2030 certain region-specific targets for acceleration of renewable energy, based on authoritative simulations by the International Renewable Energy Agency (IRENA). Specifically, IRENA sets target renewable energy shares by 2030 of 60 percent for East Asia, 55 percent for European Union, 85 percent for Latin America and the Caribbean, 27 percent for the Middle East and North Africa, 66 percent for Oceania, 52 percent for the rest of Asia, 42 percent for the rest of Europe, 53 percent for Southeast Asia, and 67 percent for Sub-Saharan Africa.

As anticipated, the results show that the savings in externality costs are noticeably larger under the green grid scenario than under the 30×30 scenario (table 2.13). This is true both for local and global externalities. What is most striking, however, is that the incorporation of the larger externality benefits does not fundamentally alter the overall conclusion regarding the desirability of electric mobility adoption at the country level. In general, the increase of externality benefits either reduces the magnitude of the net costs of electric mobility or increases the magnitude of the net benefits without changing the sign from net costs to net benefits. This illustrates that many of the externality benefits of vehicle electrification were already captured by the energy efficiency savings in the 30×30 scenario, such that a relatively modest increase in renewables penetration contemplated in the green grid scenario was not enough to change the conclusions of the analysis.

TABLE 2.13. Comparison, Green Grid and 30 × 30 Scenarios

Cost advantage at 2030 BAU scenario minus analyzed scenario								
	Local externalities		Global externalities		Externalities		Aggregate results	
US$/mn.pax-vkm	30×30	Green Grid	30×30	Green Grid	30×30	Green Grid	30×30	Green Grid
Brazil	1,143	1,302	3,553	3,601	4,697	4,903	(12,441)	(12,234)
Cambodia	189	189	2,415	2,415	2,604	2,604	6,426	6,426
Egypt	16,640	23,228	2,378	2,593	19,019	25,821	17,201	24,004
Ethiopia	7	7	1,323	1,323	1,330	1,330	2,045	2,045
Ghana	398	445	2,096	2,302	2,494	2,746	4,081	4,334
India	1,666	2,141	1,549	2,356	3,215	4,497	11,201	12,483
Jamaica	444	605	2,339	2,801	2,782	3,406	(21,947)	(21,323)
Jordan	1,193	2,148	813	1,133	2,006	3,281	(32,733)	(31,458)
Kazakhstan	6,459	11,620	1,017	1,568	7,476	13,189	219	5,932
Maldives	4,702	5,722	928	1,253	5,630	6,975	(15,492)	(14,148)
Nepal	456	456	4,253	4,253	4,709	4,709	(5,935)	(5,935)
Nigeria	240	261	1,695	1,874	1,935	2,136	1,944	2,145
Poland	2,408	5,832	652	1,024	3,060	6,856	(22,586)	(18,790)
Rwanda	225	411	1,535	1,886	1,760	2,297	243	779
Tajikistan	192	192	1,542	1,542	1,733	1,733	7,991	7,991
Turkey	9,551	14,662	754	1,041	10,304	15,704	(13,865)	(8,465)
Ukraine	2,862	3,033	2,119	2,318	4,981	5,351	(1,497)	(1,127)
Uruguay	687	687	4,300	4,300	4,987	4,987	(9,260)	(9,260)
Vanuatu	210	236	2,036	3,274	2,247	3,510	(1,076)	187
Vietnam	4,195	5,602	3,916	4,604	8,110	10,206	14,839	16,935

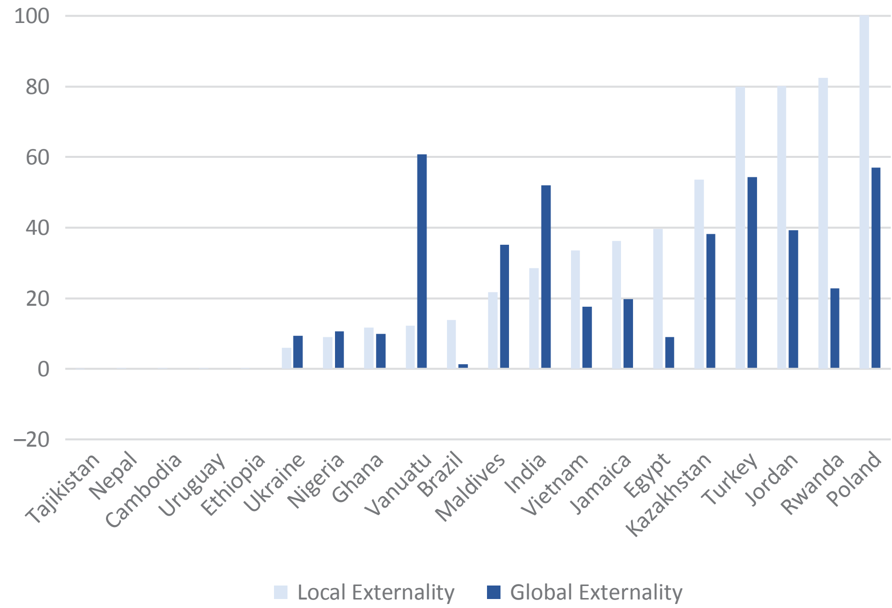
Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

It is interesting to examine how the percentage reduction in externality costs under the green grid scenario varies across countries and types of externalities (figure 2.15). Evidently, those countries whose grids are already almost entirely renewable—notably hydro-dependent Cambodia, Ethiopia, Nepal, Tajikistan, and Uruguay—offer no scope for further greening of the grid and the value of externalities is thus unchanged. Among countries with more carbon-intensive grids, the percentage reduction in externalities can be quite large, averaging around 30 percent overall. In the vast majority of cases, the percentage reduction in local externality costs as a result of greening the grid is substantially higher than for global externalities. Indeed, the reduction in local externalities is around two to five times as large as that for global externalities in Jordan, Maldives, and Poland, and around eight to 10 times as large for Egypt, Turkey, and Kazakhstan.

Scarce Minerals Scenario

An important assumption driving the results of the 30×30 scenario is the projected reduction in the cost of batteries for electric vehicles. As a result of technological change, these costs have been falling sharply in recent years. Extrapolating on historical trends, the model predicts a comparable further reduction by 2030. About half of the cost of an EV is accounted for by the battery, the remainder by the vehicle body. Whereas

FIGURE 2.15. Change inExternality Cost Advantage under Green Grid Scenario (%)



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

the cost of vehicle bodies has remained relatively stable, the cost of batteries has been falling in response to rapid technological change. In the scenarios presented, a log-linear function was fitted to the historic cost of batteries and used to extrapolate battery cost over time. The resulting decline of approximately 7 percent annually was found to be consistent with estimates elsewhere in the literature.

However, according to Bloomberg New Energy Finance's *Battery Price Survey* 2021, it may not be possible to sustain historical cost reduction trends going forward. The reason is not related so much to the pace of technological change as to the limited availability and steeply rising prices of minerals (such as lithium and cobalt) that are the critical ingredients of battery manufacture. In view of this, the scarce mineral scenario explores how the results of the analysis might change were battery costs to fall at only half the historically observed rate through 2030.

Evidently, slowing the pace of reduction of battery costs leads to substantially higher capital cost differentials for EVs (table 2.14). Overall, the percentage increase in vehicle capital costs associated with the more pessimistic assumptions regarding the evolution of battery costs is typically around 40 percent (figure 2.16). In Vanuatu, however, the differential becomes more than 100 percent.

Because vehicle capital costs are an important component of the overall case for electric vehicles, the overall results deteriorate under the scarce minerals scenario (table 2.14). Nevertheless, in the vast majority of cases, the higher capital costs either make an existing total cost premium larger, or reduce an existing cost advantage, without reversing the overall balance of costs and benefits. Only in Kazakhstan, Nigeria, and Rwanda is the additional battery cost effect large enough to convert a positive evaluation of EVs into a negative one.

Efficient Bus Scenario

The economic analysis of electric buses is highly sensitive to good management practices in the procurement of vehicles and their subsequent operation. The 30×30 scenario draws on historic procurement data to establish the baseline capital cost of vehicles and uses historic mileage data to estimate the operating cost savings associated with electric buses. Nevertheless, some pioneering countries, notably China and India, are showing that the economics of electric buses can be significantly improved by adopting more efficient practices.

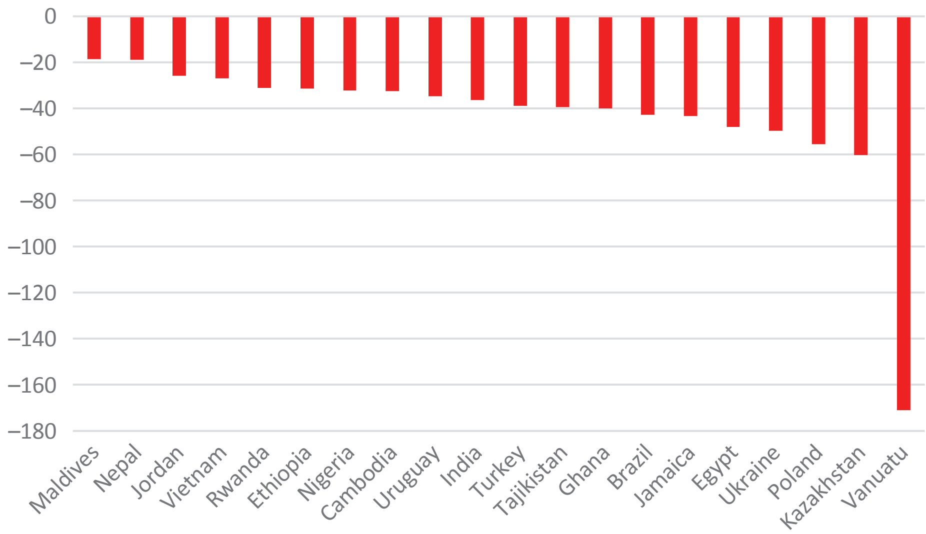
In the efficient bus scenario, municipalities collaborate at a national or regional scale to permit much larger procurement packages, realizing capital cost reductions of 35 percent in the procurement of buses, such as those recently observed in India. Further, municipalities optimize the design and operation of bus routes to allow EVs to extend their lifetime mileage to 75,000 kilometers for countries with large conurbations, 60,000 kilometers for those with midsized conurbations, and 35,000 for those with relatively small ones. Given that EVs present

TABLE 2.14. Comparison, Scarce Minerals and 30 × 30 Scenarios

Cost Advantage at 2030 BAU scenario minus analyzed scenario				
	Vehicle capital cost		Aggregate results	
US$/mn.pax-vkm	30 × 30	Scarce Minerals	30 × 30	Scarce minerals
Brazil	(21,880)	(31,234)	(12,441)	(22,047)
Cambodia	(12,724)	(16,860)	6,426	1,696
Egypt	(13,010)	(19,252)	17,201	10,536
Ethiopia	(4,692)	(6,170)	2,045	70
Ghana	(6,241)	(8,741)	4,081	528
India	(12,207)	(16,662)	11,201	6,483
Jamaica	(27,919)	(39,989)	(21,947)	(34,021)
Jordan	(41,124)	(51,711)	(32,733)	(43,562)
Kazakhstan	(8,347)	(13,378)	219	(5,278)
Maldives	(9,370)	(11,104)	(15,492)	(17,325)
Nepal	(39,111)	(46,449)	(5,935)	(14,560)
Nigeria	(6,511)	(8,612)	1,944	(2,139)
Poland	(26,712)	(41,506)	(22,586)	(37,589)
Rwanda	(5,112)	(6,701)	243	(2,522)
Tajikistan	1,351	818	7,991	7,366
Turkey	(31,494)	(43,733)	(13,865)	(27,171)
Ukraine	(11,376)	(17,040)	(1,497)	(7,796)
Uruguay	(37,121)	(50,012)	(9,260)	(22,356)
Vanuatu	(3,915)	(10,604)	(1,076)	(9,792)
Vietnam	(22,595)	(28,694)	14,839	8,484

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

FIGURE 2.16. Change in Vehicle Capital Costs, Scarce Minerals Scenario (%)



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

higher capital costs than ICEVs yet provide operational savings that accumulate with use, the case for electric mobility is clearly stronger the more passenger-kilometers a vehicle undertakes throughout its life. This is particularly true of buses, which due to their public service nature and near continuous operation, can achieve higher mileage than private vehicles.

The combined effect of these measures is to reduce both the capital cost and operating cost associated with electric buses (table 2.15). The magnitude of the overall savings obtained ranges from around US$4,000 over the life cycle of a vehicle in the Maldives to almost US$30,000 in Nepal, but more typically amount to around US$15,000 per vehicle (figure 2.17). The value of the capital cost savings (green bar) is largest in countries where buses are currently more expensive, such as Turkey or Ukraine, whereas the value of operating cost savings (yellow bar) is largest in countries where buses currently run relatively low mileage, such as Nepal or Poland.

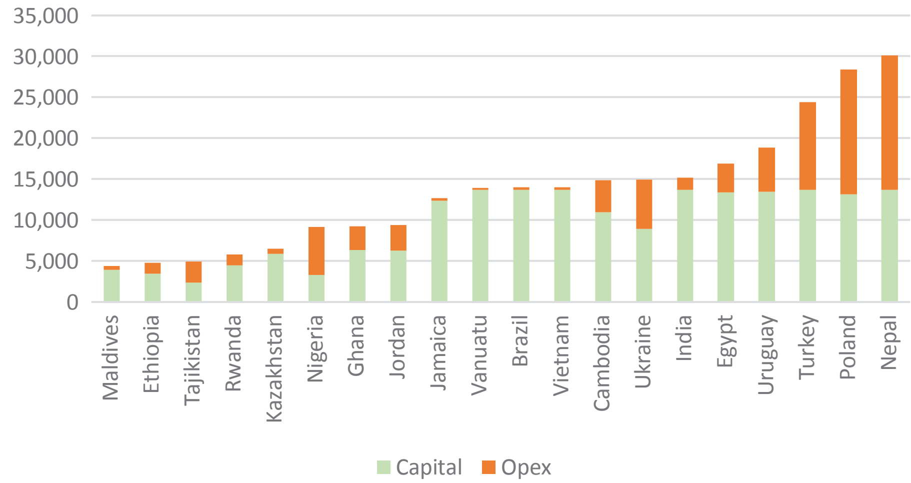
What is most striking is that such cost savings, achievable through better management of costs along the life cycle of buses, are large enough to revert the economic balance in favor of electric buses in many countries (table 2.15). Specifically, for Nigeria, Poland, and Rwanda, they become economically viable under the efficient bus scenario. In other countries, where they were already viable, even before the adoption of such efficient practices, the economic case only becomes stronger. In fact, under the efficient bus scenario, in only one country—Maldives—are electric buses still not economical.

TABLE 2.15. Comparison, Efficient Bus and 30 × 30 Scenarios, Electric Buses

Cost advantage at 2030 BAU scenario less analyzed scenario						
US$/vehicle	Vehicle capital costs		Operating costs		Aggregate results	
	30 × 30	Efficient buses	30 × 30	Efficient buses	30 × 30	Efficient buses
Brazil	(6,136)	7,599	15,207	15,506	13,762	27,796
Cambodia	(9,621)	1,316	20,299	24,250	8,404	24,025
Egypt	(12,107)	1,318	27,579	31,042	47,587	70,395
Ethiopia	(3,375)	101	6,809	8,120	3,217	8,337
Ghana	(7,738)	(1,367)	13,212	16,076	5,048	15,093
India	(14,027)	(288)	27,370	28,817	11,644	27,071
Jamaica	(5,219)	7,124	15,966	16,293	9,513	22,182
Jordan	(9,111)	(2,806)	14,088	17,178	4,336	14,486
Kazakhstan	(11,639)	(5,749)	6,043	6,655	7,008	14,615
Maldives	(5,501)	(1,570)	(29,435)	(29,006)	(9,397)	(5,035)
Nepal	(18,705)	(4,970)	29,789	46,179	9,467	42,835
Nigeria	(6,418)	(3,102)	5,222	11,091	(2,973)	7,558
Poland	(12,412)	742	11,529	26,750	(1,138)	45,854
Rwanda	(7,116)	(2,628)	5,825	7,134	(2,556)	3,688
Tajikistan	(6,226)	(3,860)	10,114	12,707	5,983	11,980
Turkey	(12,982)	710	17,814	28,499	10,370	46,394
Ukraine	(10,558)	(1,606)	14,748	20,770	10,911	32,198
Uruguay	249	13,729	27,870	33,285	28,060	48,444
Vanuatu	996	14,670	7,367	7,668	4,594	18,568
Vietnam	(14,234)	(499)	34,576	34,876	23,953	37,988

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

FIGURE 2.17. Overall Cost Saving in Efficient Bus Scenario for Buses only (at 2030 in US$/vehicle)



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

Taxi Fleet Scenario

Although the economics of electric mobility for four-wheel vehicles were not especially favorable in many countries, the efficient bus scenario illustrates that the case improves for more intensively used vehicles. In that sense, it is possible that electrifying intensively used four-wheel vehicle fleets—such as taxis, shared ride vehicles, or corporate cars—may yield a more attractive balance of economic costs and benefits than electrification of lightly used private family cars.

To investigate this issue, the taxi fleet scenario examines the case of intensively used commercial vehicles, notionally taxis, and compares them with normally used four-wheel EVs. To represent the scenario, two important changes in assumptions are in order. The first is the vehicle mileage, which increases four times in each country to reflect greater usage and leading to a larger saving in operating costs. The second is to increase the investment in public charging infrastructure by doubling the fast charger density for cars in recognition that it would be necessary to support a larger electric taxi fleet. On maintenance, the maintenance cost for cars is doubled; and assumed two battery replacements during lifetime for EVs, at years 5 and 10 respectively. Because these changes affect the results in opposite directions, the outcome cannot be readily predicted.

The results in table 2.16 indicate that the increase in operating cost savings largely exceeds the higher investment needed in charging infrastructure. Nevertheless, the positive impact is seldom large enough to reverse the prior

TABLE 2.16. Comparison, Taxi Fleet and 30 × 30 Scenarios, Four-Wheelers

Cost advantage at 2030 for four wheelers only BAU scenario minus analyzed scenario						
US$/vehicle	**Charging infra costs**		**Operating costs**		**Aggregate results**	
	30×30	**Taxi fleet**	**30×30**	**Taxi fleet**	**30×30**	**Taxi fleet**
Brazil	(529)	(583)	650	348	(1,612)	(1,182)
Cambodia	(363)	(401)	613	883	(1,069)	(591)
Egypt	(567)	(626)	880	1,077	629	5,573
Ethiopia	(142)	(157)	376	884	(875)	(182)
Ghana	(232)	(256)	413	643	(30)	427
India	(568)	(627)	983	1,438	(947)	(349)
Jamaica	(527)	(582)	700	722	(1,645)	(1,078)
Jordan	(441)	(486)	633	587	(2,615)	(2,377)
Kazakhstan	(540)	(595)	572	(68)	(142)	212
Maldives	(211)	(233)	(948)	(4,602)	(3,087)	(6,494)
Nepal	(504)	(557)	1,276	2,932	(4,649)	(2,509)
Nigeria	(342)	(378)	1,043	2,718	1,206	3,439
Poland	(460)	(508)	470	(116)	(793)	(1,059)
Rwanda	(249)	(276)	246	(59)	74	(79)
Tajikistan	(221)	(244)	505	1,108	494	1,358
Turkey	(574)	(633)	583	(174)	(1,792)	(1,033)
Ukraine	(393)	(435)	491	285	(503)	(395)
Uruguay	(555)	(612)	1,250	2,599	(1,951)	30
Vanuatu	(550)	(608)	227	(1,552)	(2,733)	(4,351)
Vietnam	(569)	(628)	942	1,029	(2,427)	(1,681)

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

conclusions regarding the economic case for electrifying four-wheelers. In fact, in only three countries do the conclusions switch from unfavorable to favorable for electric mobility: Ghana, Kazakhstan, and Uruguay.

Fuel Efficiency Scenario

As noted, internal combustion engine vehicles in developing countries are characterized by low fuel efficiency (figure 2.9), which makes energy efficient EVs look particularly attractive in operating cost terms. However, this raises the question of whether increasing the fuel efficiency of conventional vehicles might not be a more cost-effective decarbonization strategy. The fuel efficiency scenario explores this possibility by doubling the annual rate of improvement of fuel efficiency assumed for the internal combustion engine fleet from 15 to 30 percent.

This has the effect of reducing the operating cost advantage of electric vehicles by 20 to 40 percent in most cases. However, it does not generally affect the overall case for electric mobility. In fact, only three countries—Ethiopia, Kazakhstan, and Rwanda—actually experience a reversal with the overall balance of economic benefits tilting away from electric mobility (table 2.17).

Considering Financial Implications

As noted, the transition to electric mobility has major financial implications. The associated aggregate investment requirements are substantial and dispersed across sectors and actors. For private individuals, issues of affordability and the potential need for financing arise. When it comes to the public sector, the transition to electric mobility may reduce fiscal revenues, given the nature of existing distortions in energy pricing. This situation makes it much less likely that the shift could be partially self-financing through government revenue flows. A final possibility is that of tapping carbon finance, which depends on the implicit carbon price associated with EV adoption, as well as the share of investment potentially coverable through carbon credits. Each of these aspects is explored in the following section by repurposing data and drawing on calculations undertaken for the cost-benefit analysis.

Assessing Investment Needs

Behind the economic results are a significant volume of investments that different actors need to make. To begin with, both private and public vehicle owners will face incremental capital costs associated with vehicle purchase. In addition, significant expansions of public infrastructure are needed to support the expanded electric vehicle fleet, notably charging stations. Although there are also implications for investments in the power sector, given that the 30×30 scenario simulated entails only a tiny growth in electricity demand of well

TABLE 2.17. Comparison, Fuel Efficiency and 30 × 30 Scenarios

Cost Advantage at 2030 BAU scenario minus analyzed scenario				
US$/mn.pax-vkm	Operating costs		Aggregate results	
	30×30	Fuel efficiency	30×30	Fuel efficiency
Brazil	10,855	6,163	(12,441)	(18,037)
Cambodia	19,254	16,156	6,426	2,959
Egypt	15,300	11,082	17,201	9,479
Ethiopia	6,920	5,077	2,045	(6)
Ghana	10,846	8,415	4,081	1,344
India	23,217	20,101	11,201	7,634
Jamaica	10,378	4,856	(21,947)	(28,194)
Jordan	12,543	8,896	(32,733)	(37,041)
Kazakhstan	8,283	4,956	219	(4,504)
Maldives	(11,290)	(11,826)	(15,492)	(16,134)
Nepal	32,720	28,186	(5,935)	(10,987)
Nigeria	10,850	9,619	1,944	558
Poland	14,838	11,015	(22,586)	(27,415)
Rwanda	6,356	4,813	243	(1,484)
Tajikistan	8,437	7,768	7,991	7,240
Turkey	16,523	11,850	(13,865)	(20,860)
Ukraine	10,636	6,741	(1,497)	(5,887)
Uruguay	29,216	23,088	(9,260)	(16,112)
Vanuatu	7,221	(582)	(1,076)	(9,758)
Vietnam	31,078	27,062	14,839	9,914

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

under one percentage point, these are not considered here, and would in any case be fully funded through the payment of the electricity tariff.

The additional total investments associated with the 30×30 scenario are expressed in terms of the absolute value of the additional capital expenditure needed in 2030, which functions as a representative year (table 2.18). The investment needs are broken down between additional capital costs of vehicles and construction of charging infrastructure facilities. The relative importance of these different types of investments varies hugely across countries (figure 2.18).

In relatively developed countries—such as Brazil, Jamaica, Poland, Turkey, Ukraine, and Uruguay—that rely heavily on cars, the bulk of the investment needs are associated with the higher capital cost of electric four-wheelers incurred by private actors. In lower middle-income Asian countries, a large share comes from private actors purchasing more expensive electric two-wheelers—such as in Cambodia, Maldives, Nepal, and Vietnam. In African countries, the additional cost of electric buses accounts for the largest share of investment—such as in Ethiopia, Ghana, Nigeria, and Rwanda. In another group of countries—Kazakhstan, Tajikistan, and Vanuatu—the largest share of investment is associated with public charging infrastructure, both for private cars and municipal buses.

These investment components fall to different economic actors. Private households and enterprises will face higher vehicle costs as well as the need to install in-house vehicle charging infrastructure. Public authorities will incur the additional cost of electric buses and once again the associated charging infrastructure. In figure 2.18, countries are ranked from those with the highest share of investment needs falling on the private sector to the right side of the graphic. Examples include Jordan, Maldives, and Uruguay, where 80 to 90 percent of investment needs can be expected to fall on the private sector. At the other end of the spectrum, in countries such as Ghana, Nigeria, and Rwanda, more than 80 percent of investment needs fall on the public sector.

Because the absolute investment needs vary hugely with the size of the country, it is helpful to normalize them for the purposes of comparison (figure 2.19). Total investment needs can usefully be expressed as a percentage of gross domestic product (GDP), which ranges between less than 0.1 percent in Cambodia, Kazakhstan, Maldives, Nigeria, and Tajikistan, to more than 1.0 percent in Jamaica and Nepal. Another useful normalization is to look at the public component of the investment needs against the tax revenues of the country. Where possible, this normalization ranges from 0.4 percent of tax revenues in Jordan to 4 percent in Nepal.

These findings illustrate the diverse financing challenges that countries face in embarking on the transition to electric mobility and underscores the importance of bringing together a range of financing mechanisms to support electric mobility, specifically tailored to the needs of various actors. Given the significance of household

TABLE 2.18. Additional Investment Needs at 2030 of Pursuing the 30×30 Scenario

	Vehicle capital investment					Charging infrastructure				Total		
US$, millions	4W	2W	3W	Bus	Total	4W private	3/4W public	Bus public	Total	Private	Public	Aggregate
Brazil	5,088	213	3	174	5,479	342	1,014	174	1,530	5,646	1,362	7,009
Cambodia	13	15	-	8	36	1	3	4	8	29	15	44
Egypt	799	548	143	320	1,810	105	307	160	571	1,594	787	2,381
Ethiopia	64	21	6	160	252	2	6	73	81	93	240	333
Ghana	24	4	10	92	129	5	14	43	62	42	149	192
India	8,410	6,375	722	2,449	17,956	857	2,525	1,065	4,447	16,364	6,039	22,403
Jamaica	150	3	—	0	153	10	29	0	39	163	30	193
Jordan	219	16	—	7	242	8	25	3	36	243	35	278
Kazakhstan	87	0	—	48	135	26	76	15	116	113	139	251
Maldives	3	6	1	0	10	0	0	0	0	9	1	10
Nepal	134	338	9	185	666	3	9	60	72	485	254	739
Nigeria	(43)	2	—	305	263	13	36	127	175	(29)	467	438
Poland	1,399	5	—	65	1,469	184	543	31	757	1,587	639	2,226
Rwanda	(0)	1	0	12	13	0	1	5	7	1	19	20
Tajikistan	(3)	—	—	1	(2)	1	4	0	5	(1)	5	3
Turkey	1,981	130	—	522	2,633	131	393	245	769	2,242	1,160	3,402
Ukraine	243	7	—	107	357	35	100	46	180	285	252	537
Uruguay	242	59	—	(0)	301	12	35	5	51	313	39	352
Vanuatu	1	0	—	(0)	1	0	0	1	2	1	1	2
Vietnam	863	2,047	374	258	3,542	41	123	111	275	3,325	491	3,817

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

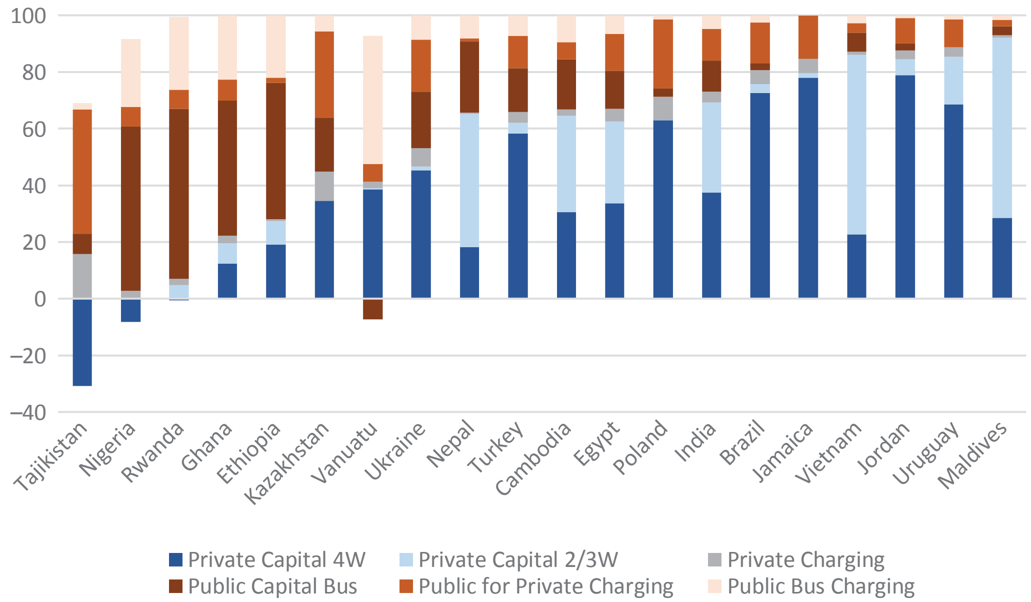
investment, consumer finance clearly has a place to support the up-front investments involved in transitioning to electric mobility. In regard to charging infrastructure, the world offers a variety of business models. It is clearly possible for such infrastructure to be fully financed by the private sector, as long as a policy commitment to stimulate demand for electric mobility is sufficiently clear. Nevertheless, the segment of the investment that would fall to the public budget is significant, notably all that associated with electrification of buses.

Assessing Fiscal Implications

Given the significant demands that electric mobility can make on public investment, it is relevant to consider the fiscal implications of adoption. One question is whether increased penetration of electric mobility will lead to better or worse public finances, and whether this will help or hinder financing the associated costs.

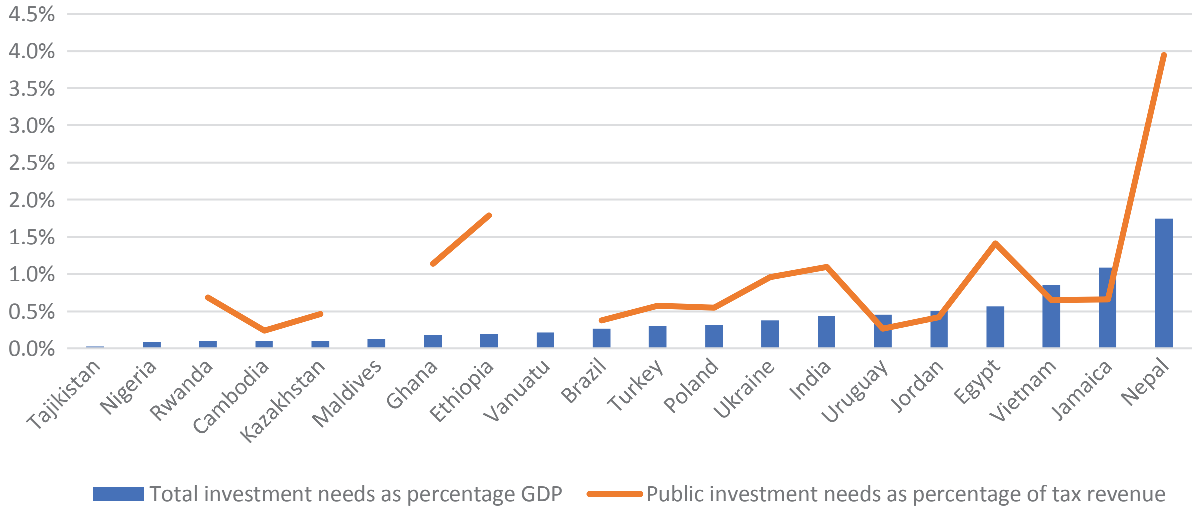
In view of the extensive web of taxes and subsidies covering liquid transportation fuels and electricity, the acceleration of electric mobility will likely have fiscal implications. Specifically, this study finds that overall countries are more

FIGURE 2.18. Additional Investment Needs by Public and Private Shares (% on total needs)



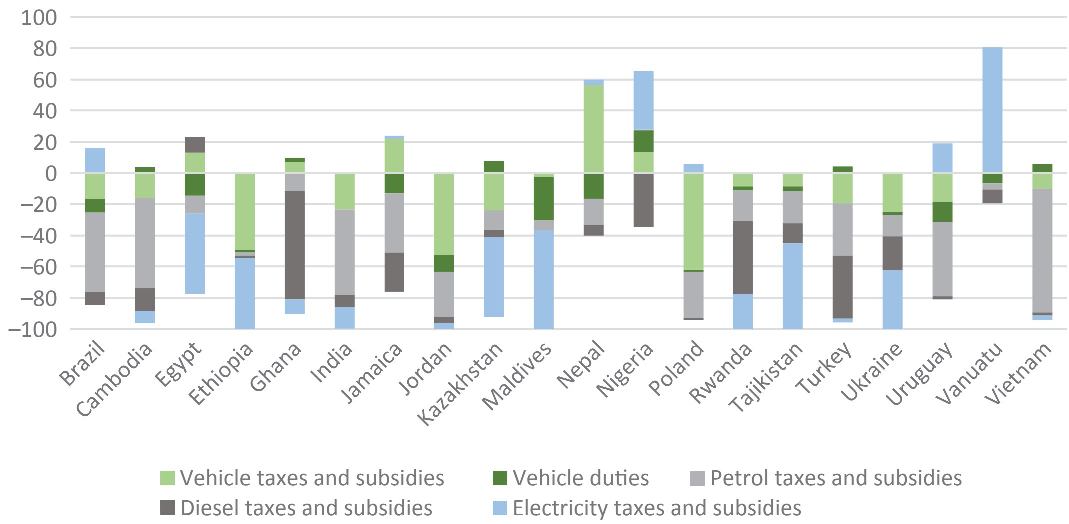
Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

FIGURE 2.19. Normalized Additional Investment Needs at 2030, 30×30 Scenario



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

FIGURE 2.20. Relative Fiscal Impact of Electric Mobility by Tax Stream (% of total impact)



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

likely to tax petroleum and diesel and subsidize electricity. Wherever this is the case, a shift toward electric mobility could have adverse effects on the government's net fiscal position by reducing tax revenues from liquid transportation fuels while drawing additional subsidies into the power sector. Further, the extent that the vehicle taxation regime favors EVs will lead to reduced fiscal revenues as the uptake of electric vehicles accelerates.

The simulations indicate that, in the vast majority of countries, the 30×30 scenario leads to a deterioration in government finances. The fiscal impact is measured as the net present value of the change in the cumulative stream of net tax revenues received over time from the electric vehicles purchased in 2030 under the 30×30 scenario relative to BAU. The absolute value of the fiscal impact is reported in table 2.19, broken down both by revenue stream and by vehicle category. The impact on fiscal revenues is overwhelmingly negative in most countries.

For comparison and interpretation, normalizing the fiscal impact is helpful to understanding the sign and key drivers of changes on the government's projected tax revenue stream for 2030. Across countries, by far the largest negative effect on the public finances is a significant reduction in revenues collected from petrol and diesel taxes. In addition, several countries public finances are adversely affected by a significant increase in subsidies to the electricity sector—in particular Egypt, Ethiopia, Kazakhstan, Maldives, Tajikistan, and Ukraine.

TABLE 2.19. Net Fiscal Impact at 2030 **30 X 30** Scenario Minus BAU Scenario

US$, millions	By Fiscal Revenue Stream						By Vehicle Category				
	Vehicle taxes & subsidies	Vehicle duties	Petrol taxes & subsidies	Diesel taxes & subsidies	Electricity taxes & subsidies	Total	4W	2W	3W	Buses	Total
Brazil	(2,120)	(1,148)	(6,619)	(1,064)	2,051	(8,900)	(6,897)	(1,192)	(4)	(807)	(8,900)
Cambodia	(8)	2	(30)	(8)	(4)	(48)	(8)	(28)	0	(11)	(48)
Egypt	335	(370)	(296)	254	(1,336)	(1,414)	(912)	(252)	(17)	(233)	(1,414)
Ethiopia	(301)	(10)	(11)	(9)	(279)	(609)	(59)	(28)	(10)	(512)	(609)
Ghana	17	6	(28)	(166)	(23)	(193)	(27)	(11)	(14)	(142)	(193)
India	(14,881)	98	(34,687)	(5,178)	(8,761)	(63,410)	(16,258)	(40,137)	(1,780)	(5,235)	(63,410)
Jamaica	39	(23)	(68)	(45)	4	(93)	(89)	(4)	0	(0)	(93)
Jordan	(183)	(37)	(102)	(13)	(14)	(348)	(299)	(42)	0	(7)	(348)
Kazakhstan	(58)	18	(31)	(11)	(125)	(207)	(169)	(1)	0	(37)	(207)
Maldives	(1)	(8)	(2)	(0)	(18)	(28)	(5)	(16)	(5)	(2)	(28)
Nepal	666	(198)	(195)	(80)	44	237	74	168	3	(7)	237
Nigeria	20	20	1	(50)	55	45	(4)	5	0	45	45
Poland	(3,117)	(61)	(1,457)	(79)	292	(4,422)	(4,301)	(42)	0	(79)	(4,422)
Rwanda	(5)	(2)	(13)	(30)	(14)	(64)	(9)	(13)	(0)	(42)	(64)
Tajikistan	(1)	(0)	(3)	(2)	(9)	(17)	(16)	0	0	(1)	(17)
Turkey	(414)	85	(704)	(844)	(58)	(1,934)	(1,221)	(162)	0	(551)	(1,934)
Ukraine	(310)	(22)	(176)	(268)	(470)	(1,247)	(818)	(45)	0	(384)	(1,247)
Uruguay	(182)	(123)	(466)	(21)	185	(607)	(429)	(170)	0	(9)	(607)
Vanuatu	0	(1)	(1)	(1)	12	9	(0)	(0)	0	10	9
Vietnam	(463)	261	(3,716)	(89)	(138)	(4,146)	(537)	(2,981)	(378)	(250)	(4,146)

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

The impact via vehicle taxes, subsidies, and duties is more ambiguous, bringing a significant increase in fiscal revenues for some countries (Jamaica, Nepal, and Nigeria) and a significant reduction in others (Ethiopia, Jordan, Poland, Ukraine, and Uruguay).

The overall conclusion is that in the absence of significant fiscal reform in the energy sector the adoption of electric vehicles—far from generating the fiscal revenues needed to finance the associated public investments—is more likely to lead to a deterioration in public finances.

Assessing Affordability

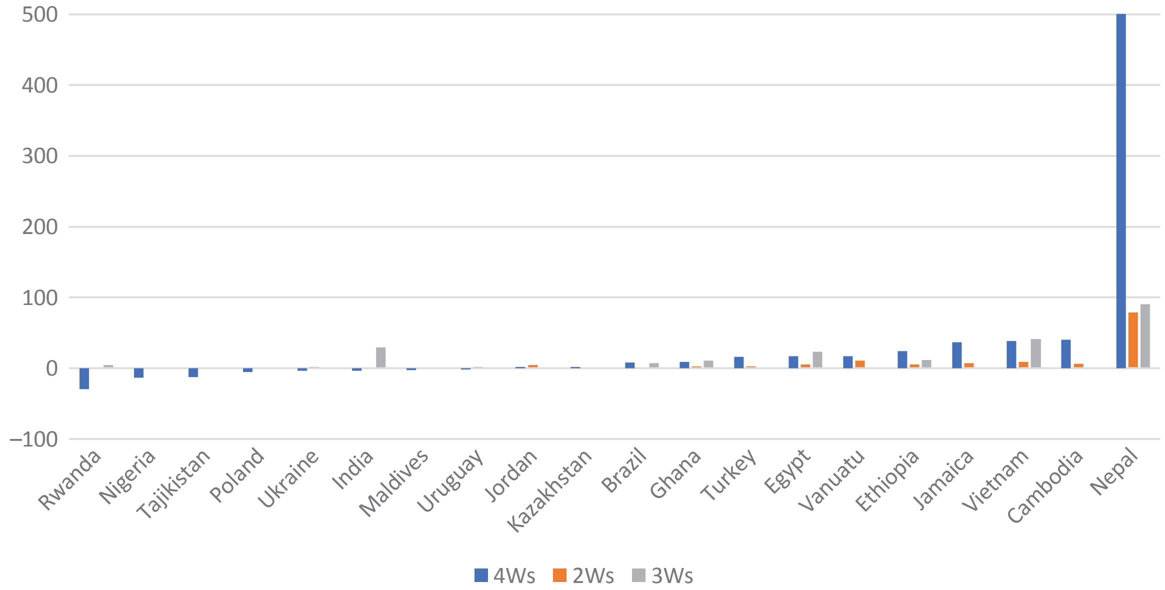
When it comes to incremental vehicle capital costs that private households assume, it becomes pertinent to ask whether these are likely to be affordable, given relatively modest budgets in low- and middle-income countries. Whereas four-wheelers are likely to be purchased primarily by the wealthiest households, two-wheelers tend to be in the purview of poorer families as well as small and midsize enterprises running transportation businesses.

To evaluate this issue, the incremental capital cost associated with both electric vehicles and associated household-based charging infrastructure, is expressed as a percentage of gross national income (GNI) per capita in the 20 countries studied (figure 2.21). The results indicate that two-wheel EVs are relatively affordable, carrying a capital cost increment typically no higher than 10 percent of GNI per capita, with the notable exception of Nepal, where the premium rises to a prohibitive 80 percent. When it comes to four-wheel EVs, the capital cost premium exceeds 20 percent of GNI per capita in a significant minority of countries (Cambodia, Ethiopia, Jamaica, and Vietnam)—and in excess of 100 percent in Nepal. Given that four-wheel EVs tend to be luxury goods, assessing the extent to which these cost differentials may be binding is more difficult.

Assessing Prospects for Carbon Finance

Given the significant investments associated with electric mobility, as well as the associated reduction in carbon emissions, it is interesting to explore whether part of these capital costs could be met through carbon

FIGURE 2.21. Incremental Capital Cost of an EV (as a percentage of GNI per capita)



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

finance. To evaluate this possibility, it is necessary to calculate the implicit carbon price associated with electric mobility to see how it aligns with market rates, and to explore what percentage of the associated investments could potentially be covered by carbon credits.

The implicit carbon price is calculated as the economic cost differential between the 30×30 scenario and BAU in 2030 divided by the lifetime carbon savings of the additional electric vehicles entering the fleet during that year (table 2.20). It is important to note that the economic cost differential incorporates the local externality benefits of electric mobility adoption, although excluding them does not make much difference to the results in most cases. As already noted above, in 8 out of the 20 countries, electric mobility adoption is already advantageous economically, resulting in negative implicit carbon prices, meaning that the carbon abatement essentially comes

TABLE 2.20. Implicit Carbon Price at 2030 30 × 30 Scenario Minus BAU Scenario

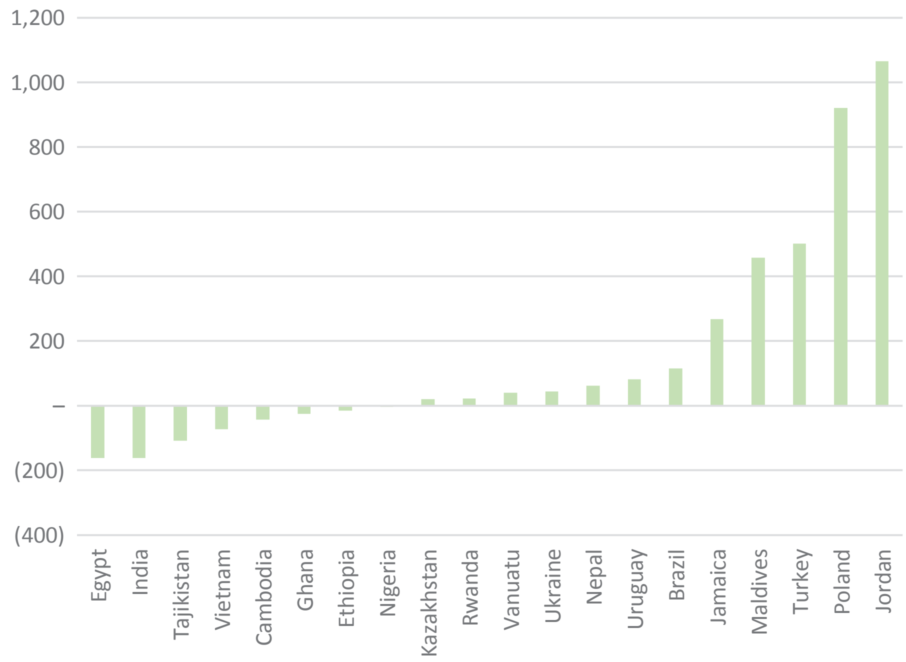
	Implicit carbon price					Potential carbon financing as share of investment				
US$/ton	**4W**	**2W**	**3W**	**Buses**	**Total**	**4W**	**2W**	**3W**	**Buses**	**Charging***
Brazil	230.9	(86.9)	0.2	(19.6)	116.4	8%	68%	25%	64%	51%
Cambodia	401.1	(112.9)		(57.8)	(43.0)	4%	27%		18%	27%
Egypt	(75.2)	(180.9)	221.9	(249.5)	(161.2)	10%	16%	4%	25%	38%
Ethiopia	380.1	48.6	(65.4)	(37.2)	(14.1)	5%	13%	31%	27%	60%
Ghana	36.7	(119.3)	(77.5)	(22.8)	(24.5)	14%	69%	32%	23%	42%
India	769.2	(258.9)	(197.8)	(203.9)	(161.1)	2%	27%	19%	7%	8%
Jamaica	287.6	(69.4)		(43.9)	268.5	6%	22%		32%	41%
Jordan	2057.9	(15.4)		(69.4)	1066.5	1%	9%		9%	10%
Kazakhstan	93.4	(258.7)		(98.4)	20.3	5%	43%		10%	14%
Maldives	2773.8	386.8	273.8	293.3	457.6	1%	11%	45%	11%	19%
Nepal	733.6	106.7	(59.9)	(37.8)	61.9	3%	8%	19%	16%	45%
Nigeria	(149.6)	(152.6)		126.5	(3.8)	516%	364%		8%	70%
Poland	1040.7	(262.8)		84.7	921.2	2%	30%		3%	6%
Rwanda	(8.8)	(103.8)	(90.6)	69.0	21.8	24%	92%	73%	15%	30%
Tajikistan	(113.4)			(52.0)	(108.2)	87%			24%	56%
Turkey	4318.8	(136.5)		(220.3)	501.5	0%	7%		6%	3%
Ukraine	155.8	(92.0)		(72.1)	44.1	9%	43%		19%	34%
Uruguay	261.2	(111.1)		(116.5)	81.5	6%	22%		88%	51%
Vanuatu	1141.9	33.7		(31.1)	39.5	2%	14%		41%	16%
Vietnam	697.8	(114.7)	(42.4)	(113.1)	(72.1)	3%	21%	16%	22%	22%

Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.
Note: *This calculation is based on the assumption that all the carbon savings associated with 4Ws are allocated to the associated public charging infrastructure and that the government accesses carbon financing to develop this.

“for free” (as in Cambodia, Egypt, Ethiopia, Ghana, India, Nigeria, Tajikistan, and Vietnam. Among countries with an overall positive implicit carbon price, three—Kazakhstan, Rwanda, and Vanuatu—have relatively low implicit carbon prices, ranging between US$20 and US$40, suggesting that acceleration of electric mobility is a relatively cost-effective way of carbon abatement (figure 2.22). The implicit carbon price for the remaining countries—Brazil, Jamaica, Jordan, Maldives, Nepal, Poland, Turkey, Ukraine, and Uruguay—is much higher, between US$45 and US$1,000, suggesting that acceleration of electric mobility is a relatively costly carbon abatement strategy.

While the overall country level implicit carbon prices are informative, in many ways it is more relevant to examine implicit carbon prices by vehicle category (table 2.20). In particular, in as many as about three quarters of the studied countries, the implicit carbon price associated with the adoption of electric two-wheelers and buses is negative, suggesting that carbon abatement is a by-product of other economically attractive benefits. Even in countries with relatively high implicit carbon prices at the national level, two-wheelers and/or buses remain attractive forms of decarbonization. This is true for Maldives, Nigeria, Poland, and Rwanda. In fact, because small islands face extreme energy prices, only in Maldives is electric mobility still unattractive as a form of carbon abatement, even

FIGURE 2.22. Implicit Carbon Prices Associated with 30×30 Scenario (US$/tonne)

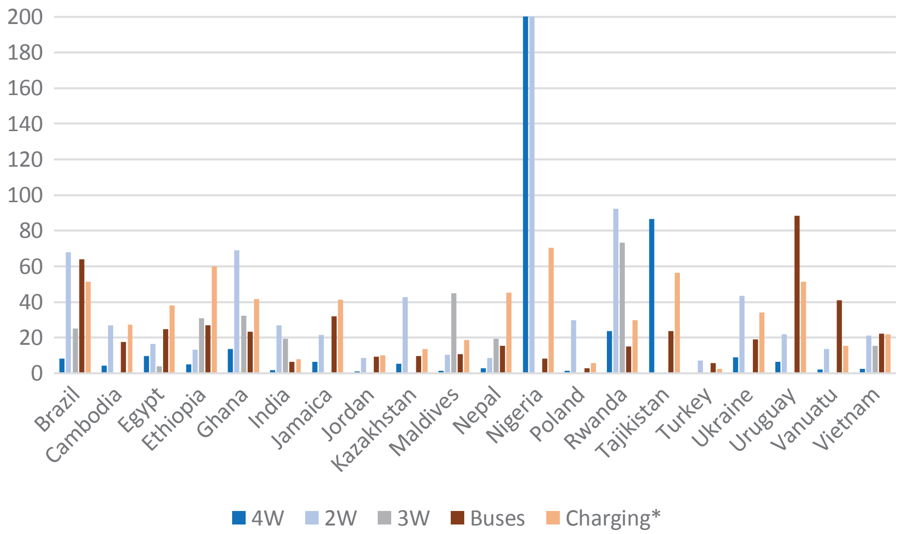


Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

disaggregating by vehicle category. Clearly, four-wheel EVs are the most expensive form of carbon abatement, with implicit carbon prices in the range US$200 to US$700 in the vast majority of countries. Only in a handful of cases does four-wheel electric transportation provide negative implicit carbon prices: Egypt, Nigeria, Rwanda, and Tajikistan.

The projects best suited to carbon finance are those that can cover a significant percentage of their incremental capital costs with the carbon credits created. To evaluate this issue, the carbon savings associated with the 30×30 scenario are valued at the World Bank's reference price of carbon for 2030, at US$50 per ton, and this value is divided by the total incremental investment associated with the transition (figure 2.23). The results are encouraging. In the case of electric buses, carbon financing could potentially cover 25 to 75 percent of the incremental capital costs in the majority of cases. Similarly, when it comes to two-wheel electric vehicles, carbon finance could cover around 50 percent of the incremental capital costs. The situation is not as promising for four-wheel EVs, where carbon finance is unlikely to cover more than 20 percent in all but a handful of cases. Nevertheless, if the carbon savings associated with four-wheelers are allocated entirely to the associated public charging infrastructure, it would be enough to cover more than half of the investments associated with public charging infrastructure in most countries.

FIGURE 2.23. Value of Carbon Savings from 30×30 Scenario as Share of Incremental Capital Costs (%)



Source: World Bank, *Economics of Electric Mobility Scoping Tool*, 2022.

These estimates of the potential contribution of carbon finance to cover incremental costs associated with electric mobility are purely illustrative simulations. For this source of finance to be realized, suitable contractual and institutional mechanisms would need to be identified to secure the related carbon transactions.

Generalizing the Typology

Throughout this chapter, results are presented in a typology that distinguishes between countries with and without car-dominated vehicle fleets, countries that import rather than export oil, and countries that face high rather than low vehicle purchase costs. These three factors systematically affect results in the sample, the most favorable conditions for electric mobility appearing in countries that have relatively few four-wheel vehicles, import oil, and can purchase vehicles at relatively low cost (and vice versa).

Given that this study was able to examine the economics of electric mobility for a diverse cross-section of only 20 low- and middle-income countries, the typology provides an approximative way of gauging how promising electric mobility might be in countries outside the sample.

Implications and Conclusions

In summary, the main findings of this analysis are that, first, electric vehicles across all vehicle categories present significant capital cost differentials. Although these cost differentials are falling over time, they nonetheless present a significant affordability challenge and may prompt some consideration of consumer financing policies. The differentials are still quite prohibitive for cars, less so for two-wheelers.

Second, in about one-third of the countries studied, the lower operating costs of EVs over the lifetime of the vehicles more than justify the additional capital costs, in economic terms. EVs are not only cheaper to maintain but also consume a fraction of the energy of ICEVs, thanks to greater energy efficiency. This energy efficiency effect overwhelms the fact that electricity is a significantly more expensive a source of energy in economic terms on a normalized per unit of energy basis.

Third, due to highly distortionary taxes and subsidies, the financial case for electric vehicles is stronger than the economic case, making two-wheelers and electric buses attractive across the majority of countries studied—although to a far lesser extent for four-wheelers. With some notable exceptions, the tax treatment of electric and conventional vehicles is not all that different. However, across countries, the tendency is to tax petrol and subsidize electricity. This further accentuates the energy cost advantage of electric mobility beyond what is economically justifiable.

Fourth, the reduced local (PM) and global (CO_2) environmental externalities associated with electric vehicles further amplify the case for their adoption. Even in countries with carbon-intensive electricity generation, electric mobility is found to bring environmental benefits, given that (once again) the energy efficiency benefit of EVs overwhelms any disadvantage they might have in terms of carbon intensity. However, the analysis did not find any cases in which the electrification of transport was justified solely on externality benefits. Instead, externality benefits strengthened the case in countries where a pecuniary advantage already existed. In countries with poor urban air quality, the local externality benefits were found in some cases to be even larger than the global ones.

Fifth, national scale adoption of electric mobility is economically advantageous in half of the countries studied but becomes financially advantageous in three-quarters of them. Specifically, the case for electric two-wheelers is strong across the majority of countries studied, but the same cannot be said for four-wheelers. The economic case for electric buses is both economically and financially favorable in three-quarters of the countries studied.

Sixth, sensitivity analysis demonstrates that the case for electric mobility improves under the green grid scenario (where the expansion of renewable electricity is accelerated) and deteriorates under the scarce minerals scenario (where the decline in battery costs slows down to half the former level). The fuel efficiency scenario (which made internal combustion engine vehicles increasingly efficient) slightly weakened the case for electric mobility but typically did not reverse it. Nevertheless, the former results remain robust because these sensitivities rarely change the overall direction of the conclusion either for or against electric mobility.

Eighth, the economic case for electric buses can be greatly strengthened through the efficient bus scenario, where capital costs are lowered in large-scale performance efforts, and lifetime savings are optimized by greater bus mileage. Such efficient practices could make electric buses economically advantageous in all but the most challenging environments. However, the same cannot be said for four-wheel EV fleets: despite more intensive use, they do not materially improve the economic case for the adoption of electric mobility.

Ninth, the investment needs associated with the electric mobility transition are substantial (up to 1 percent of GDP) and fall differentially on public and private actors across countries. Public financing of electric mobility is not helped by the fact that distortions in energy taxation mean that electric mobility has an adverse fiscal impact. However, carbon finance offers some potential for covering public investments, given implicit carbon prices that are relatively favorable in many cases.

Last, although the results reported in this chapter are based on a sample of only 20 countries, some degree of further generalization is possible based on the presentation of different country typologies. Overall, the case for the electrification of transport is expected to be stronger in countries that have vehicle fleets not dominated by cars, net oil importing status, and relatively low-cost vehicles.

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CHAPTER 3

Transport Policies to Promote the Adoption of Electric Passenger Vehicles

Transport Policies to Promote the Adoption of Electric Passenger Vehicles

With rising adoption in major markets, electric vehicle (EV) prices have been falling and their quality has been improving, but not always to a point where market forces alone can bring about the transition to electric mobility. As highlighted in chapter 2, governments may often find themselves in a situation where electric mobility is both economically and financially attractive on a life-cycle basis, but the significant need for additional up-front investments in charging infrastructure and more expensive vehicles continue to present an important barrier to adoption, particularly in view of the limited sources of finance. Public policies are therefore necessary to overcome such barriers. Persistent market failures justify active policies, most of all the environmental externalities from the burning of fossil fuels, leading to significant local and global externalities that are not priced and therefore provide an unfair advantage to conventional vehicles. Likely underinvestment in environmental technologies (including EVs), incomplete information among producers and consumers, and the interdependence of EV adoption and charging infrastructure strengthen the case for proactive support to the electric mobility transition.

Low-and middle-income countries (LMICs) can learn from mounting experience among earlier adopters in China, Europe, and North America. Governments have used a range of policy instruments, including supply-side incentives such as research support or zero emissions vehicle (ZEV) mandates; demand incentives such as purchase subsidies or high occupancy vehicle (HOV) privileges; investments in public charging infrastructure; and switching public vehicle fleets to electric to provide demonstration effects. LMICs can also learn from one another, as a variety of innovative policies have been set in place to unlock EV adoption across vehicle categories, making EVs more affordable, inclusive, and favorable to local economies.

Experience from wealthier countries and early LMIC adopters is useful as a starting point, but policy priorities and instruments need to be both adapted to local circumstances and constraints, and also scaled up and replicated across countries more systematically. Approaches with low and predictable cost as well as those that yield benefits beyond EV adoption are preferable. Those approaches include the development of financial structures and business models that reduce the financing risk and burden of up-front capital costs and improve the bankability of charging infrastructure and EV rollout projects. Governments can also prioritize public transit and fleet operations, as well as electric two- and three-wheelers that are within reach of less affluent residents. Scaling up successful demand aggregation exercises – using cross-country mechanisms— if necessary — can increase the bargaining power of purchasers in small markets. Most important, despite the understandable current excitement about electric mobility, policymakers should not lose sight of the broader goal of achieving a sustainable transportation system—regardless of the technologies that power it.

The Case for EV Policies

The case for initial public policy support to promote the electric mobility transition is strong. Ideally, adoption of EVs would occur spontaneously, driven by rapidly changing consumer preferences and market forces. Given the large investments by automobile companies in EV production, one might assume that markets are indeed driving the transition to electric mobility. In just about all countries, however, policies have induced and sustained this process through mandates and incentives. Without them, car companies would have had little incentive to switch from vehicles fueled by gasoline or diesel. Policymakers are justified in using such policies because the persistence of internal combustion engine vehicles (ICEVs) is attributable to several market failures (Rapson and Muehlegger 2021). The most important is their contribution to climate change, but there are also market failures that hinder the electric mobility transition more directly. Such problems are common in the adoption of new technologies, including those that reduce environmental harm, such as EVs (Jaffe, Newell, and Stavins 2005). Reviewing some of the market failures related to transport technology provides a context for the policies discussed in this chapter.

The electric mobility rapid adoption cannot rely on market forces alone for at least six reasons. First, conventional ICEVs produce local and climate pollution. This creates costs that are borne by everyone and that ICEV drivers are not paying for—a classic case of an environmental externality. ICEV drivers therefore have little incentive to purchase more expensive EVs that would reduce or eliminate pollution. Taxing vehicle emissions, increasing gas taxes, or imposing strict fuel efficiency and emission standards are all ways to address the problem. Implementation of such measures, though, has been limited in many countries because the measures are politically unpopular.

Innovation market failures are a second factor affecting countries with the potential to manufacture EVs (Bryan and Williams 2021). Companies are reluctant to invest in environmental technology while uncertainty about the returns to a high fixed investment in research and development is high. For many technologies, the expected benefits for society are also larger than the private returns for inventors. For these reasons, development of environmental technology tends to be lower than it might be. These problems justify public support for research and development (R&D) at initial stages of technology development until product and process innovation become self-sustaining. Renewable energy technologies are examples of publicly funded research and initial support for deployment leading to rapidly falling prices to the point that they are now market competitive with conventional alternatives.

Information failures are a third barrier to fast adoption of EVs. Producers, distributors, and service providers are uncertain about the size of required investments and future profitability. Consumers are uncertain about the long-term cost and performance of a new technology. Both supply and demand of EVs are therefore lower than they would be if everyone had full information. Governments signaling a strong commitment to the electric mobility transition help overcome these information problems.

The need for a new EV fueling infrastructure is a fourth barrier to widespread adoption. This is a classic chicken-and-egg problem: for EVs to become attractive to consumers requires a dense and convenient charging infrastructure; yet to make major investments in charging networks, investors need to be sure of a sufficiently large market. This means that EV purchases or charging networks may require initial support until a critical mass has been achieved. More generally, EV buyers will be better off the more others adopt EVs, creating a process of dynamic increasing returns similar to network effects in many digital services.

A fifth failure comes from the mismatch between the tenor of available financing instruments in local markets and the EV vehicle technology payback period. In a life-cycle analysis, EV adoption is becoming economic and financially advantageous in a significant number of countries (chapter 2). Yet the high capital cost remains a barrier because the operating and maintenance benefits occur over a longer period that exceeds most available commercial market tenors, in the case of private EVs, and concession contract duration, in the case of buses and charging infrastructure. In this case, it might be necessary to establish a financial bridge to make it through the initial period from capital investment in the electric technology until benefits turn positive over time in the form of public-sector undertaking such as subsidies and/or guarantees. Special considerations for a financial bridge will not be necessary once capital cost parity is reached between electric and internal combustion engine vehicles.

The fragmentation of demand into small markets is a sixth failure that reduces the bargaining power of buyers and hampers economies of scale of emerging EV producers. In many LMICs, projects and procurement batches are small in size, making municipalities and even country price takers with huge premiums. At worst, the projects are not attractive enough for commercial financiers to step in. Through a combination of economies of scale in procurement, consolidation of demand, and contractual improvements, governments can reduce the unit cost of vehicles and mobilize commercial financiers (Acharya, Gadepalli, and Ollivier 2022; World Bank 2022a).

Government failures also hold back EV adoption. Many policies favor harmful incumbent technologies. In many oil-exporting countries, fossil fuel subsidies make ICEVs cheaper than they would be if drivers had to pay full market prices including the full cost of environmental damages if emissions are priced. Instead, fuel prices are more often determined by a country's politics, revenue needs and resource endowments—in mid-2020 a liter of gasoline cost US$0.02 in Venezuela and US$2.24 in Hong Kong (Mahdavi, Martinez-Alvarez, and Ross 2020). Likewise, governments must be careful not to introduce new distortions when addressing perceived market failures (box 3.1) or to be overly generous with subsidies which may reward consumer choices that would have been made in any case. An interesting observation from chapter 2 is that such government failures can also run in favor of EV adoption, as in countries where petrol is taxed while electricity is subsidized. Such a fiscal differential can be an appropriate way of reflecting the externality benefits of electricity. However, in some countries, the financial incentive may even go beyond what would be warranted by the externality.

Assessing EV Policies

The objective of policies that promote electric mobility is to make EVs better, more affordable, and more convenient than conventional vehicles. *Better*, in that the technology should provide superior performance such as range, speed, noise, and environmental footprint. Support for R&D is one type of policy that can help improve EV technology. *More affordable*, so that EVs are more accessible to own than ICEV vehicles. Until

BOX. 3.1 Government Support to EVs Can Be Motivated by Industrial Policy

Electric mobility promotion is motivated by environmental goals, but EVs also disrupt an important industrial sector and are a massive market opportunity. Thus, in few cases the government support to EVs is an industrial rather than just a climate policy. Strong economic interests seek to influence where EVs and associated technologies, such as batteries, will be produced. Many governments justify EV policies by citing job creation, international competitiveness, or technology leadership, in addition to global warming and air quality. Policies in the EU and United States have been motivated by climate change, but also seek to protect jobs and ensure the competitiveness of their domestic vehicles industry (Steen et al. 2015). Similarly, Japan and Korea seek to support their vehicle sectors, which emerged from industrial policies in the last century (Åhman 2006; Lee and Mah 2020; Lane et al. 2013). China and India, whose urban areas are severely affected by air pollution, also intend to take advantage of the shift to EVs to build globally competitive vehicle sectors (Liu et al. 2020). In Africa, governments are increasingly encouraging domestic production or assembly of electric vehicles by granting favorable tax regimes and affordable leases on state-owned land.

technology drives down the up-front cost below parity, as is widely expected to happen in due course, targeted incentives or special financing structures can reduce the burden to the consumer and help attract commercial finance. *More* convenient, so that no more effort is required to operate an EV, especially in terms of fueling. Ensuring a dense and easy-to-use charging infrastructure is critical.

This section reviews policy instruments aimed at promoting EVs that are grouped into the broad categories listed in table 3.1. Most of the policy experience has been in high and upper-middle income countries where the transition to EVs has started earlier. The following section discusses the relevance of these policy instruments for countries with fewer resources, where the electric mobility transition is still at an early stage, and some degree of adaptation would be needed.

Supply Incentives

Policies targeting the supply of EVs in a market aim to reduce the risk to producers and importers unsure whether the market in a relatively new and locally unproven technology will be profitable. They may put less effort into developing, producing, and marketing EVs if they think consumers will find ICEVs to be preferable. R&D support through tax incentives or direct public investments reduce innovation-related risks. Almost all Organisation for Economic Co-operation and Development (OECD) countries provide R&D tax breaks or subsidies, ranging—across all sectors of the economy—from about 0.01 percent of gross domestic product in Latvia or Mexico to about 0.4 percent in France (Bryan and Williams 2021). Information on how much of this goes to EV-related firms is not available. Although most EV R&D will be funded by industry, direct public support is needed for fundamental research of uncertain profitability or neglected areas such as development of lower-cost technologies that most benefit lower-income countries.

Another strategy to increase the supply of EVs to national markets is to impose increasingly stringent vehicle emission regulations such as the US CAFE (corporate average fuel economy) standard or China's CAFC rules that cover fuel consumption evaluation methods and targets for passenger cars. This makes ICEVs cleaner but also more expensive, and it strengthens the role of EVs especially where automobile firms face fleet-wide emission standards. The International Energy Agency (IEA) estimates that more than 85 percent of global car sales now face CO_2 or other tailpipe emission standards (IEA 2021). Going a step further, California and China, for instance, mandate sales targets that force producers and importers to sell a certain share of EVs. Most often, these mandates require a new zero emission vehicle market share of about 15 percent by 2025, some jurisdictions recently announcing longer-term mandates of up to 100 percent (Axsen, Plötz, and Wolinetz 2020). Early mandates—California's date to the early 1990s—have sent a strong transformative signal to the car industry, triggering R&D investments that have helped bring EV prices down significantly.

TABLE 3.1. Policies That Promote the Electric Mobility Transition

Policy type or area	Main barrier or market failure	Objective
Supply incentives	innovation market failure; need to jump-start supply	promote technology development; encourage manufacturers to bring more EVs to market
Direct demand incentives	unpriced environmental externalities; need to jump-start demand	reduce cost of EVs to consumers to make EVs price competitive with ICEVs
	consumers and municipalities credit-constrained and possibly unable to access necessary finance	provide credit lines or leasing mechanisms to facilitate purchase of EVs; unlock access to carbon finance for charging infrastructure
Indirect demand incentives	information market failures	provide nonmonetary inducements such as informing potential EV owners or making EV operation more convenient
Charging and power infrastructure	network dependencies (chicken-egg-problem)	reduce EV owners' anxiety about reliable operation of vehicles
Public, shared, and fleet operations	unpriced environmental externalities	jump-start demand; encourage bus operators, taxis, or ride-sharing firms to shift to EVs as an efficient way to mainstream the technology
Procurement and consolidation mechanisms	small and fragmented demand	increase bargaining power of consumers and attract commercial financing through demand aggregation vehicles
Vehicle disposal regulations	environmental externalities	ensure that the full environmental cost of EVs is reflected in prices, even after their useful lifespan
Energy pricing	fiscal distortions in taxes and subsidies affecting electricity and liquid transportation fuels	provide accurate price signals on the relative costs of different types of energy for transportation, capturing externality effects

Where such policies are linked to an emission trading system, companies that produce a large share of EVs benefit by selling emission allowances (or regulatory credits) to laggards that still rely on ICEV sales. For such policies to be effective, a clear commitment to such regulations is needed. Uncertainty over the stringency of CO_2 emissions standards in the next decade caused many legacy automakers to rely on non-EV related compliance options to meet the standard in recent years (Mathieu and Poliscanova 2020). Such uncertainty could hold back the supply of electric cars throughout the 2020s even as the technology matures and consumer demand rises in the EU (Mock 2021). The strictest regulation finally is to phase out ICEVs completely. An increasing number of cities, regions, and countries have announced target dates for prohibiting the sale or operation of ICEVs (Wappelhorst 2020). In 2022, California, the largest auto market in United States, introduced a ban on the sale of new gasoline cars by 2035. The most aggressive goal is in Norway, however, where all new passenger vehicles and light vans need to be electric by 2025.

Many types of incentives used by governments aim to achieve not only environmental goals but also economic objectives. Targeted aid to domestic EV-related industries is expected to boost labor markets and help firms stay competitive in the face of a massive technology shift. Some countries see it as an opportunity to create a new industry or leapfrog to a globally leading position. EV support then becomes an element of green industrial policies. EVs are technologically simpler than ICEVs and have more standardized components.

Significant barriers remain, however, to creating competitive firms in a fiercely contested global market, or even just to become a location for component production or vehicle assembly. Factors that make success more likely include a large domestic or easily accessible regional market, comparative advantages like a skilled labor force and access to low cost and clean energy, and a sound investment and business climate. Where these conditions are absent, attempts at creating local champions or attracting investors have low chances of success.

Whether policies promoting EVs and other green technologies are motivated by environmental concerns or industrial policy objectives does not matter greatly as long as they are well designed and implemented. In fact, because climate change policies not only tend to incur local costs but also bring global gains, they are often a hard sell. Highlighting the domestic economic benefits makes approval more likely. But it is still important to be aware of potential pitfalls given the mixed track record of industrial policy (Oqubay et al. 2020). The main concern is that governments tend to have limited information about which firms or industries to help and how to best provide support—they should let markets allocate resources rather than try to “pick winners.” Examples of poor targeting resulting in wasted money and white elephants are in fact numerous. Also, the risk of rent seeking and collusion where support goes to the well-connected rather than the best prepared is real.

A guiding principle for green industrial policy should be to consider whether support is likely to be economically efficient. Industrial policy is what economists call a second-best policy to combat climate change. It will be less efficient than a simple price instrument such as a carbon or energy tax that enables markets to allocate resources and provide incentives. Instruments used in industrial policies, however, also differ in terms of efficiency, largely depending on how narrowly they target.

- Most restrictive are **tariffs**, a form of protectionism that will make green technology more expensive for local consumers and hurt domestic industries that depend on imports. US tariffs on solar panels introduced in 2018 raised prices, reduced investment, and cost many jobs (SEIA 2019). By sheltering local firms, tariffs will inhibit domestic innovation.

- **Support for specific domestic firms** is a pure form of picking winners and is perhaps most subject to rent-seeking and collusion. Nevertheless, it can sometimes be successful. In 2009, the US government bailed out Tesla with a US$465 million loan guarantee. The firm's later success created useful competitive pressure that accelerated the shift to EVs.

- **Support for domestic sectors** often involves rules restricting beneficiaries of subsidies. Especially in public procurement, governments tend to limit subsidies to domestic suppliers. If multiple domestic firms compete, incentives to offer lower prices and better products will remain. India's recent round of electric-bus procurement, for instance, saw five domestic firms or consortia compete to supply 5,450 urban buses (World Bank 2021). The terms of the winning bids were considerably lower than for previous purchases. Local content requirements are another approach that also aims to promote technology transfer. Korean EV producers had to set up battery production in China so that their cars sold in the country would qualify for subsidies (Lutsey et al. 2018).

- The least restrictive approach is **technology-specific support** without rules of origin. Green incentives for EVs or solar panels in the EU or United States tend to be open to foreign-made products. In fact, subsidies for solar panels in several EU countries and US states helped pay for panels made by firms in East Asia, mostly China. Incidentally, those firms also received significant initial support such as cheap land and finance in their home countries. In the interest of industrial policy objectives, the Chinese government, in effect, subsidized consumers in California and Spain.

Although green industrial policies may often be justified, governments still need to minimize the risks inherent in interventionist approaches. Dani Rodrik (2014) proposes three simple rules. First, industrial policy should not be seen as a fixed set of instruments but as a process of learning and adapting. Governments do not have full information and will not get everything right. The failure of individual projects or measures matters less when the overall portfolio of support succeeds over time. Responding quickly to problems will depend on close interaction between bureaucrats administering policies and beneficiaries, which requires safeguards to prevent capture.

Second, governments need to be clear about their objectives. Policies will not always efficiently serve multiple objectives. Not all climate change mitigation measures also create jobs, but they may still be necessary. Clarity also helps determine measures of success that facilitate program evaluation. For environmental objectives, the cost reductions of green technology such as EVs will often be the best measure.

Finally, accountability is essential and clear. Governments need to explain to the public what they are doing and why they are doing it. Transparent disclosure of budgets, beneficiaries, and outcomes will reduce the risk of rent seeking and capture. Appointing a high-level official as the public face of green industrial policies can make communication more effective.

EV supply chain bottlenecks, above all in the production and availability of batteries, call for government interventions. The skyrocketing production of EVs reveals that the battery-manufacturing industry will soon be challenged. First, China concentrates 80 percent of global battery production, which increases the risks of global EV manufactures regarding supply chain disruptions. Second, despite ambitious plans by leading battery makers (BYD, CATL, LG, Samsung, and SK) and many newcomers to develop a total global capacity of close to 6,000 gigawatt-hours, the lead time for establishing a battery-manufacturing plant is between three and five years. Finally, uncertainty in the availability of the key rare earth minerals needed for battery production is already affecting the price of nickel, cobalt, and more prominently lithium that has raised for the first time in 2022 (*The Economist* 2022; Bloomberg 2021). Despite possibly ample mineral reserves, developing mines takes time and in few cases involves tapping into artisanal and informal mining under questionable labor conditions. This situation is making the battery industry innovate by looking for new battery chemistries that reduce the dependance on these minerals. More important, governments are fostering battery recycling more systematically and the adoption of smaller EV and smaller batteries (IEA 2021).

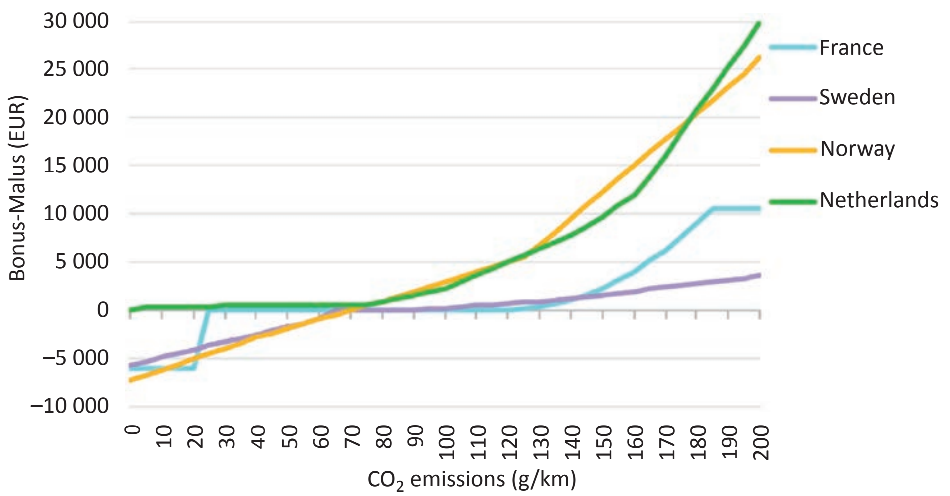
In incipient EV markets, pilot projects structured as a cooperation between private-sector, government, and international organizations can provide a good jump start. East Africa exemplifies an active arena for piloting projects. In Rwanda, electrification of mototaxis (collaboration of Ampersand and Fonerma), installation of charging points accessible via app for taxi services (Siemens, Volkswagen, Radisson Blue), e-motorbikes (Safi Ride and Rwanda Electric Mobility), and e-bike sharing services (Gura Ride) are just a few examples of pilots with private and public collaboration. Similar examples can be found in Kenya, where there are several start-ups for deployment of electric and solar powered vehicles (Solar-e-Cycles), and innovative manufacturing schemes to lower EV capital costs by replacing the internal combustion engine of trucks and buses with electric power trains and producing low-cost e-mopeds (Bloomberg 2022). Similar projects, with the support of the UN

Environmental Program, Global Environmental Facilities have been launched in Burundi, Sierra Leone, Togo, and Uganda (Arroyo Arroyo et al. 2021; World Bank 2022a).

Direct Demand Incentives

Direct incentives to encourage consumers to purchase EVs are the most visible types of policies. As noted in chapter 2, the additional capital costs associated with EVs are one of the single most important barrier to adoption. Rebates are essentially subsidies where a portion of the purchase price is covered by the government. Tax reductions or credits similarly shift some of the cost to the public. *Feebates* are a combination of a reward (bonus) for buyers of vehicles that are, for example, cleaner than some benchmark, and a penalty (malus) on vehicles that are more polluting. If well designed, they can be revenue neutral. Countries have used varying bonus-malus schedules (figure 3.1). Scrappage programs have been popular during financial crises as a way to increase demand for new cars. By offering a seller of an ICEV a higher price than could be realized in

FIGURE 3.1. Passenger Car Taxation Based on Tailpipe CO_2 Emissions, 2018



Notes: glkm = grammes per kilometre. Sweden applies its malus (tax) for a three-year period of ownership. The figure shows the total malus the owner of a new gasoline vehicle would have to pay over the first three-years of ownership; owners of diesel vehicles would pay an extra fee. For the Netherlands, taxation rates for vehicles with emissions above 61 grammes of carbon dioxide per kilometre (g CO_2/km) are based on gasoline vehicles. An extra fee per g CO_2 (not shown in the figure) applies to diesel vehicles with emissions above 61 g CO_2,km.
Sources: IEA elaboration based on ACEA (2018).

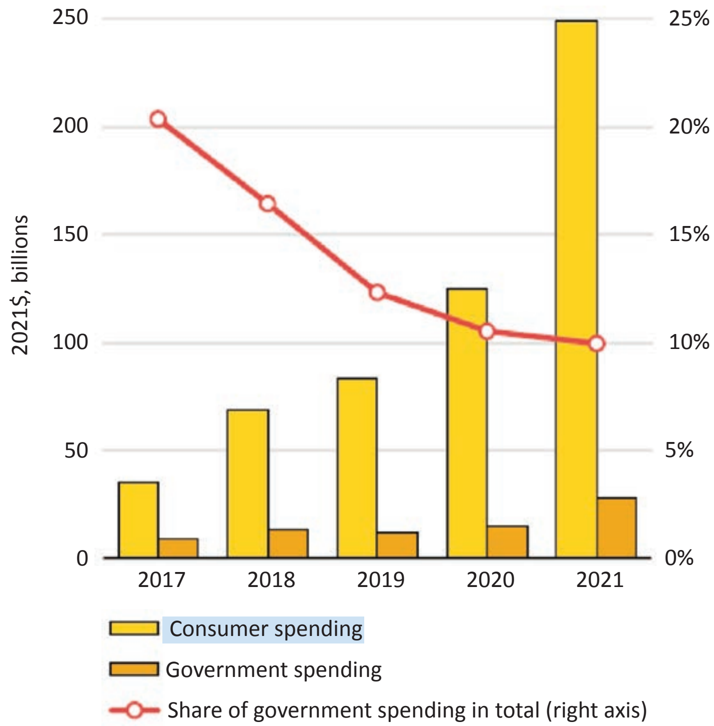
A number of countries apply vehicle purchase taxes that differentiate on the basis of tailpipe GHG emissions and offer incentives for vehicles with the best performance supported by taxes on vehicles with poor performance

Source: IEA 2021.

the market, they reduce the cost of a new EV similar to a rebate or subsidy. Finally, a more coercive approach is to restrict the import of polluting cars outright in markets that have no domestic car industry.

Subsidies are an effective policy tool that may be initially necessary to create EV demand and bring down prices. But subsidies are expensive. A study of global EV adoption between 2013 and 2020 estimated that it took about US$10,000 in consumer purchase subsidies to induce one additional EV adoption (Li et al. 2021). In contrast, it took only a US$1600 investment in charging infrastructure. In leading markets there are indications that—as EV technology is becoming cheaper—direct subsidies are becoming relatively less important compared to consumers' own spending. In 2020, governments across the world spent US$14 billion on direct purchase incentives and tax deductions for electric cars, a 25 percent rise year-on-year. In 2021, government subsidies doubled to nearly US$30 billion, even as consumer spending doubled to nearly US$250 billion (igure 3.1). Notwithstanding, the share of government incentives in total spending on EVs, in contrast, has been declining from roughly 20 percent in 2017 to 10 percent in 2021 (igure 3.2) (IEA 2021b).

FIGURE 3.2. Consumer Spending on Electric Cars Relative to Government Spending



Source: IEA 2022, IEA 2021

As the cost of EV ownership falls further, governments will be able to reduce or phase out direct purchase incentives. China had intended to phase out related subsidies and tax break policies in 2020, but extended them to 2022 in response to the economic impact of COVID-19. Subsidies are also becoming unnecessary where EVs are already cost competitive, for instance, for some types of intensely used commercial or smaller vehicles.
The total cost of ownership (TCO) of ride-hailing cars in European cities is already estimated to be lower for electric vehicles (Le Petit 2020). The same goes for the overall cost of electric light-duty commercial vehicles in urban duty cycles, which was lower in 2020 in Germany than for equivalent diesel vehicles (McKerracher et al. 2021).
For short-distance travel, the TCO of low-speed electric scooters is lower than of conventional gasoline scooters in Delhi (Rokadiya and Bandivadekar 2016). In some regions with high taxation on ICEVs, the tipping point for cost parity has been reached for electric cars; in Norway, for example, the market share of EVs was 54 percent by 2021 (Reuters 2021). In many LMICs, electric vehicles and their components are exempt from import duties and excise duties (Poland, Rwanda, Ukraine, Uruguay, and Vanuatu); in some favorable fiscal regimes, subsides are given for EVs (Maldives and Poland).

Although subsidies may be helpul at least initially and in places that have adequate fiscal resources, policies need to be designed carefully. Generous direct incentives can have unintended consequences, one of which is *border leakage*. At first, Sweden's subsidy for EV buyers was a straightforward incentive but eventually converted to a feebate system. While the feebate system appeared more efficient, many Swedes were selling their new EVs to Norwegians who were claiming an EV rebate on the other side of the border. This led to over subsidization, most of the EVs subsidized in Sweden ending up in another country within a year where they received additional incentives (Riedl 2020). Germany has faced a similar problem. EV buyers received up to Euro 9,000 and could then, after six months, sell these cars in countries that do not offer comparable subsidies (Seyerlein 2022). An estimated 30,000 recently purchased EVs disappeared from the German market between January and September 2021.
One way to reduce this subsidy leakage is to require a longer minimum ownership period. Another problem has been encountered where subsidies did not distinguish by type of EV. In the Netherlands and some other countries, plug-in hybrid electric vehicles (PHEV) received the same subsidies as pure battery electric vehicles. But many PHEV owners rarely drove in electric mode and recent research suggests that PHEVs are more polluting in non-electric mode than previously thought (Poliscanova 2020).

The capital cost premium associated with EVs remains a barrier to adoption, but this need not necessarily give rise to purchase subsidies, which tend to be costly and likely regressive in distributional impact, given that EVs remain something of a luxury good. Another potential policy approach is to focus on spreading the cost of EV purchase rather than reducing it, particularly when lifetime costs may already be advantageous, as is the case for two-wheelers. This points to the potential use o financial structures and (possibly subsidized) consumer credit lines for EV purchase and risk mitigation financing structures, particularly in the market or two and three-wheelers as well as electric buses.

In terms of financial instruments that would bring in commercial financiers, some countries have considered interest-free loans. Others have introduced for sophisticated schemes based on market-incentives to bring in the private sector. For example, India's 2021 Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) initially increased subsidies and benefits to two-wheelers, aiming to reach price parity with their internal combustion engine counterparts. However, a key barrier for the uptake turned out to be the limited financing flows from commercial lenders. Even when credit lines are available, interest rates may be prohibitively high given technological risks, risk of default in a market characterized by high informality, the absence of credit scores, and restricted access to finance.

To reduce the cost of funds to users, the government of India introduced the Electric Vehicles Risk Sharing Program as part of FAME II to offer a first-loss partial credit guarantee to financial institutions. The partial guarantee is intended to reduce the risk premium for electric vehicles, unlock commercial financing availability at concessional rates for EV financing, and bring down the cost of finance for the purchase of electric two and three-wheelers. The scheme targets the two and three-wheeler markets, with two-wheelers being the largest segment in the Indian automobile industry with domestic sales of 15.1 million units in fiscal year 2021 and contributing to around 81 percent of total automobile sales volume, making the support to EV adoption a progressive scheme within an inclusive and development mobility agenda (World Bank 2021). The World Bank will finance the capital base of the partial credit guarantee.

Alternatively, leasing models, which allow consumers to pay the capital cost of the vehicle gradually over time, are already widespread in OECD countries and could be particularly suitable for EVs in LMICs. Leasing EVs can be effective in mitigating the ownership risks of EV by consumers and transferring them to leasing companies that may be better equipped to deal with the key risks. For example, the concept of Battery as a Service (BaaS) introduces a business model in which the cost of the battery is decoupled from the vehicle and allows for leasing as well as mitigation of technology (obsolescence) risks. For the Li-Ion battery of EVs, the major degradation occurs early on in the lifecycle, easily leading to a cumulative depreciation rate of 90 percent of value in the first two years of use (World Bank 2021). Moreover, the cost of batteries is the primary reason electric vehicles cost more to buy than internal combustion engine (ICE) equivalents. To address this issue, the deployment of e-motorbikes in Rwanda has been combined with a battery-swapping business model and leasing schemes significantly lowering the cost per passenger-kilometer (World Bank 2022b). Similarly, leasing schemes have been introduced to make the adoption of electric buses more palatable.

In Chile, the business model used for the implementation of electric buses in Santiago consists of a public-private partnership between the state (Ministry of Transport and Telecommunications) and private companies (energy companies Enel and Engie, which are bus operators and investors) the financing coming from traditional sources and bringing in—with adequate policies—incentivizing companies (such as utilities) to invest and bear the technology risk, minimizing the fiscal burden. For Santiago's electric buses, fleet provision and depot ownership are separated from the operation of buses in the street, introducing two types of contracts: one for operations and another for the enabling infrastructure and assets. Financing of charging infrastructure and electric buses was developed as part of a scheme in the core business of the utilities Enel and Engie, which developed leasing contracts with private bus operator companies to include monthly payments to cover fleet provision, charging infrastructure, and energy supply (World Bank 2020).

Rwanda is also introducing a model for electric buses in Kigali, separating the sourcing of finance and procurement of assets while retaining asset ownership under a publicly owned company and leasing the buses to operators. By ultimately bearing the credit risk, the public sector lowers user costs and offsets the risk of a technology whose financial benefits extend beyond the concession tenor (IFC 2021). In a similar vein, increased reliance on shared mobility and mobility-as-a-service models is a way of shifting the burden of higher capital costs to firms with potentially easier access to credit and having consumers pay gradually per trip or via monthly subscriptions.

Indirect Demand Incentives

Consumers can be nudged more indirectly to switch to EVs in many ways (Li, Zhu, et al. 2020). Many EV drivers not only wish to reduce their pollution and carbon footprint; but want to be seen doing so. Special license plates, for instance, allow drivers to make a statement and appear to be an effective (and inexpensive) instrument to promote EVs. Adding to the attraction of a new and somewhat futuristic new technology, this kind of virtue signaling benefits the driver and helps advertise that EVs are becoming mainstream. Other types of regulations make EVs relatively more convenient by allowing them privileged use of HOV or toll lanes, parking spots or restricted traffic zones (Hardman 2019). In Norway, EV uptake was highest on the Finnøy archipelago, where EV drivers were exempt from high toll charges to use an undersea tunnel (Cazzola et al. 2018). In Oslo, early benefits for EV drivers such as cordon toll exemptions, free parking, free charging, and access to bus lanes also led to high adoption rates. Enforcing such privileges is made easier by special license plates that make it easy to identify eligible vehicles.

Charging and Power Infrastructure

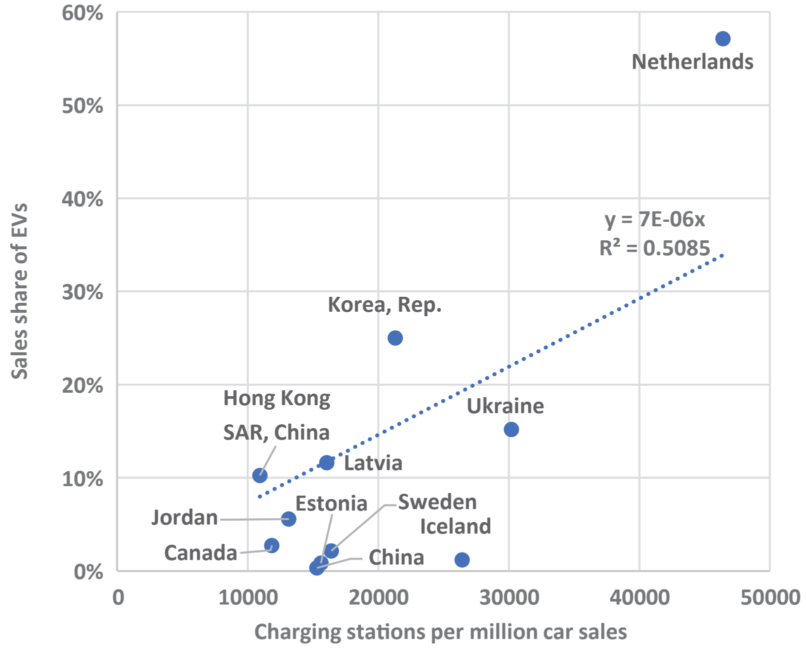
Limited access to convenient chargers is one of the biggest barriers to EV adoption because many consumers do not have the option of home charging and range anxiety persists for longer trips (Lee and Clark 2018; Colle et al. 2021). For urban charging, the challenge is greater in countries with dense settlement patterns, such as China, the Netherlands, or South Korea. The Nordic countries, the United States, and Canada have lower population densities and more single-family housing facilitating access to home charging (Hardman 2019; Hall and Lutsey 2017). Governments have a range of options for facilitating a dense charging infrastructure.

They can directly invest in charging facilities or adapt regulations to make it easier for private providers to build and operate chargers. Another important role for the public sector is to ensure the availability of an affordable and clean electricity supply for charging.

Public support helps create a critical mass of charging stations that encourages initial EV adoption, which will then motivate private providers to invest. Generally, charging infrastructure appears to rise in line with EV adoption (figure 3.3). Subsidies can support chargers at the workplace, in public locations, and at home. A variety of charging options not only increases convenience but can also distribute the load on the energy system, for instance, by encouraging charging at work during the day when solar power is most abundant. As noted earlier, subsidies for expanding charging infrastructure are about six times more cost effective than purchase subsidies (Li, Wang, et al. 2021).

Private investments in chargers need to be recouped by selling electricity. In some cases, governments have subsidized electricity rates for charging, but this involves an uncertain financial commitment and can lead to overconsumption. Furthermore, as chapter 2 shows, many countries already subsidize electricity for all uses,

FIGURE 3.3. Ratio of Public Chargers per EV Stock, 2020



Source: Alam and Lee 2021.

often to the tune of 20 to 40 percent. Electricity should instead be priced to reflect its social marginal cost for all uses, addressing affordability concerns with targeted measures (Rapson and Muehlegger 2021; Laderchi, Olivier, and Trimble 2013). More important is to use regulatory approaches to ensure an open and competitive charging ecosystem that keeps rates affordable. Ideally, charging facilities should be developed as easily as gas stations. However, in practice, hurdles are numerous. These range from charging stations being restricted to service certain vehicle brands or payment systems, to lack of standardization of charging adapters. Governments can also facilitate the development of a charging infrastructure by ensuring that building codes and land use regulations allow or even mandate charger construction. Creative solutions for public charge points include equipping lamp posts with chargers. By switching streetlights to LED, some places have freed up line capacity to allow vehicle charging. Chapter 4 discusses policies related to power systems in more detail. In Sahelian countries, electric mobility is challenged by the scarcity of electricity, but its piloting adoption can start when underpinning social and economic initiatives in selected niches (box 3.2).

BOX 3.2. Electric Mobility Uptake and Broader Initiatives in the Sahel

Estimates are that, under the existing meager supply conditions, changing 5 percent of current two- and three-wheelers to electric models would consume 1.3 percent (in Bamako) and 6.9 percent (in Ouagadougou) of the respective country's electricity production. Changing 70 percent of current two- and three-wheelers to electric models would consume 19.5 percent (in Bamako) and 82 percent (in Ouagadougou) of the country's electricity production. This calls for conscious sequencing vis-à-vis the power sector development and a phased and targeted deployment of EV via piloting exercises. More important, it calls for investment and interventions that would help with the adoption of electric mobility while targeting key development objectives such as creating jobs and mobility enhancing investment propositions. Sahelian countries have identified several—soon to be implemented—pilot exercises that could provide win-win alternatives to EV entry points:

- *Electric mototaxis in Bamako* would be introduced in close collaboration with one or more official mototaxi companies already operational in Bamako, allowing to pilot a battery-swapping system. This investment concept should be carried out according to the same franchise formula currently in place for ICE mototaxis. To ensure that the periodic amount paid by the riders to the mototaxi company is not higher than at present, it will be important to select low-cost electric motorcycles that have already (or close to) achieve price parity with the petrol-powered ones.

(*continues*)

BOX 3.2. Electric Mobility Uptake and Broader Initiatives in the Sahel (Continued)

- *Electric bicycles for students and employees in Ouagadougou* would be a pilot project targeting students in higher education (secondary and/or university level), public-sector employees and university administrative staff. Because schools are expected to have a more reliable electricity supply than private homes, charging bicycle batteries would be done during school hours. Participants in the pilot should be identified on a voluntary basis and receive the vehicle free of charge from the sponsoring institutions. In universities, electric bicycles could be made in shared hailing schemes.

- *Electric scooters for mail or newspaper delivery services in Bamako and Ouagadougou* would introduce, in the short term, a few electric scooters to be used for mail or newspaper delivery services. This concept will necessarily have to be realized in close cooperation with the company (public or private) in charge of the delivery. During the pilot phase, the deployment could be limited to 20 electric scooters assigned to a single postman for a fixed period of time (such as 6 months) in order to collect enough information on driving habits and driving patterns, testing the use of light electric vehicles on targeted and fixed routes with battery recharging during nonworking hours. Recharging would take place at the headquarters of the companies involved, which are assumed to have a reliable electricity supply. Operational costs (charging, maintenance, and so on) should be fully covered by the delivery company.

- *Electric scooters for public-sector employees in Bamako and Ouagadougou* for their daily home-to-work commute targets a part of the trips already made by ICE vehicles. Given the limited accessibility to electricity at home and unstable electricity supply, recharging would need to take place in the offices.

Source: Arroyo Arroyo et al. 2021; World Bank 2022a.

The lack of charging infrastructure has been a key concern among consumers. In LMICs, the absence of formal charging stations has been circumvented by the development of simpler lower cost approaches, such as battery-swapping arrangements. Some manufacturers have already set up battery-swapping stations on a pilot basis, where delivery personnel of e-commerce companies using EVs can replace their batteries (World Bank 2022a, 2022b). The main constraints preventing a more rapid scale-up of this promising approach are product standardization and proprietary issues around battery technology that can impede ready swapping of batteries among different brands of EVs. Partnership across manufacturers seems to be a prerequisite for these swapping schemes to succeed. Nonetheless, battery swapping has been seen in China, India, and Thailand and increasingly in Africa. BaaS might be a key enabler for electrification of micromobility and truck fleets (Maadalin 2022).

Public, Shared, and Fleet Operations

Transitioning public and shared transport to electric vehicles poses similar challenges as promoting the adoption of private EVs. This sector includes city buses, minibuses, taxis, ride-shares and—in many lower-income countries—the use of two-wheelers for specific niches and public service provisions as entry points for electric vehicle deployment given their social and economic implications. First, the role of two and three-wheelers in the provision of the last mile as a complement to public transportation in rural and remote areas increases the interest in the rollout of e-mototaxis and e-bikes. The use of online payment, booking, and information applications is an opportunity for enhanced services. Thus, shifting two and three-wheelers to electric can be a good opportunity to tap into the formalization and training of informal mobility providers (Arroyo et al. 2021). Second, the supply chain for parts is currently concentrated in China and Asia, while the opportunity to develop greater manufacturing capacity and associated skilled jobs in Africa, as is being pursued by countries such as Rwanda.

Chinese cities are furthest along in electrifying public transport and provide useful policy experience. In Shenzhen, a city of about 12 million in southern China, all city buses and taxis are now electric (Berlin, Zhang, and Chen 2020). Effective 2020, ride-sharing vehicles must also be electric. The city started in the early 2010s with initial pilots and by 2018 had replaced its entire bus fleet. It limited purchases to only a few bus models to reach favorable procurement terms and created a financial leasing arrangement to spread out the total costs. The city still had to rely on national and local subsidies to manufacturers, the bus operating agency, and the provider of charging infrastructure (which it outsourced). Without the subsidy, the total cost of ownership of electric buses in 2020 would have been about 20 percent higher than for diesel buses. As electric bus production becomes more efficient, the authorities are beginning to reduce subsidies, aiming to phase them out completely in time.

Shenzhen's electric buses have sufficient range to run all day, especially given that most bus routes are now shorter feeder lines serving metro stations. This means that all buses can be charged nightly at central charging depots. Electric buses have cut public transport CO_2 emissions per 100 kilometers travel to about half (vehicle and electricity production still cause emissions). Electricity and battery production remain large emitters because of the heavy reliance on fossil fuels in the power sector. Most local air pollution from public transit has been eliminated, which had been the main policy motivation for switching to EVs. The success of Shenzhen's transformation of the public and shared transit sector shows the importance of detailed planning, clear objectives, and a comprehensive road map that reflects transport, environmental, and industrial policy priorities. Implementation benefited from close partnership among bus operators, bus manufacturers, financial organizations, and charging companies that has reduced technology uncertainty and costs.

The bus system in Santiago, Chile, is another example of electrification of public transport in a country that does not have local electric bus manufacturing (World Bank 2020). The system is organized as a public-private partnership under which the government acts as the regulator that collects and distributes revenues; six private operators run the bus lines with a shared electronic payment system; and the main energy companies financed the initial purchases of Chinese-made electric buses, set up the charging system, and provided electricity.
The initial pilots demonstrated the suitability of electric buses in the transport system, showing improvements in quality and convenience for passengers, including noise reductions, will reduce emissions of carbon and other pollutants, and paved the way for further conversion of the public vehicle fleet.

As noted in chapter 2, the capital cost premium associated with electric buses can be substantial, particularly given that the number of manufacturers globally is currently quite limited. This makes the overall economic and financial case for such vehicles particularly sensitive to the anticipated vehicle mileage. This suggests that targeting public transport systems and routes with particularly high vehicle mileage may be helpful during the transition. Furthermore, packaging bus procurements at the national or even regional level to achieve larger scale could help achieve significant capital cost savings.

India's Phase II of the Faster Adoption and Manufacturing of Electric (and hybrid) vehicles in India (FAME II) has been running since 2013 and prioritizes the electrification of public transport. The approach includes earmarked funds for targeted subsidies and a heavy-handed procurement in support of electric buses provision across cities in various provinces. FAME II simultaneously strengthens the bargaining power of states to reduce prices for electric buses and supports the Indian auto-making sector. This procurement process that discovered prices under the Gross Cost Contracting (GCC) model is also known as the Grand Challenge (GC) process and has represented an inflection point in India's efforts to scale up electric buses.

Procurement Practices and Demand Consolidation Mechanisms

Governments are trying to overcome the combination of two key obstacles that are keeping the price of electric vehicle relatively high. On the supply side, it is well known that production of electric vehicles is highly concentrated, while the demand side is characterized by small and fragmented markets with little bargaining power and limited access to financing schemes. To overcome these challenges, in phase 2 of FAME II, India adopted an aggregated procurement approach with concentrated large-scale deployment and standardized procurement specifications to achieve economies of scale. Demand was aggregated across nine major cities having a population of over four million (Mumbai, Delhi, Bangalore, Hyderabad, Ahmedabad, Chennai, Kolkata, Surat, and Pune), buying a total of 5,450 buses with tendered prices on average 37 percent (but up to 52 percent in the Kolkata electric bus batch) lower than previous procurement under phase 1, which had the same subsidy (Acharya, Gadepalli, and Ollivier 2022).

The same economic rationale of aggregating demand to increase economies of scale and mitigate risks can be applied at a multicountry scale. Multilateral organizations such as the World Bank Group can play a role in setting in place regional, multicountry facilities that would consolidate and aggregate demand across countries with small markets to attract major commercial financiers. Such facilities could offer blended financing putting together commercial finance and concessional resources, provide technical assistance, and bring the experience and creditworthiness of multilateral development banks to compensate for the lack of a track record of many of governments to mobilize long-term financing to support and accelerate development in a low carbon transport sector. **A regional financing facility to support clean mobility** could **bring scale to compensate for the low competition on the supply side of EV production, diversify risks of still new technologies, reduce transaction costs (many of which are linked to information asymmetries), and address financing needs more flexibly at the country or asset level**.

Vehicle Disposal Regulations

Although recycling and reuse of most parts of an EV is no different from standard cars, the expected volume of used batteries will pose new challenges for reuse and recycling. These batteries contain raw materials such as lithium and cobalt that are expensive to mine but can be recovered and reused for manufacturing new batteries. The EU expects annual lithium recycling volumes to eventually reach 33,000 tons (NOW 2020). China expects that by 2029, 3 million used EV battery packs will be available annually, equivalent to about 108 GWh storage capacity. The EU battery directive regulates requirements for collection, recycling, and disposal techniques. In China, all batteries since 2018 are registered on a platform that tracks each battery through the supply chain. A government directive mandates the establishment of collection plants that will manage batteries' second life (recycling).

Recycling is made complicated by the varying battery chemistry and often complex installation that make standardized recycling difficult. So far, demand is low for used batteries for a second life in stationary applications, although new business models are likely to emerge as EVs age and used battery volumes grow. Governments need to use the time until the first cohorts of EVs are retired to put the regulations and infrastructure in place for sustainable reuse and recycling. This problem also has an international dimension. For smaller countries, volumes may be too small for a domestic battery recycling facility. Establishing cross-country networks can create the economies of scale necessary. Given experience from past exports of electronic waste to less affluent countries with inadequate disposal capacity, international regulations should be established to manage the export of EV-related waste, see box 3.3.

Although many countries have invested in developing battery recycling methods and adopted policies pertaining to handling of hazardous materials impact battery recycling, few countries have introduced policies for mandating or incentivizing reuse or recovery of lithium-ion batteries with combined economic and environmental focus. A notable exception is Asia, particularly China and Japan. Europe is only recently considering the inception of a comprehensive regulatory framework for storage management, with the United States and India lagging well behind.

So far, the most promising approach to promote battery recycling lies in extended producer responsibility regulation to make battery recycling effective and economical "assigning responsibility for recycling while allowing flexibility in its execution would facilitate adaptation to technological developments while ensuring the throughput necessary for recycling facilities." (Bird et al. 2022) Where implemented, this approach is starting to induce joint ventures among manufacturers, notable example: Korea's SK and Kia Motors initiatives in battery recycling.

Energy Pricing

The decision to purchase an electric vehicle is driven not only by the relative capital costs but also by the relative costs of operating the vehicle. The most significant difference in operating costs between ICEV and EV is the switch from liquid fuels, such as petrol and diesel, to electricity. As shown in chapter 2, and discussed in further detail in chapter 4, most countries maintain significant taxes and subsidies affecting the absolute and relative prices of electricity and liquid fuels. Other incentives assign favorable electric tariffs to charging stations and to recharge during off-peak hours

Although in many cases, petrol and diesel are quite heavily taxed and electricity is subsidized, the opposite can also be true. Moreover, the taxes and subsidies levied on energy products do not necessarily capture the associated environmental externalities. As a result, the choice between ICEV and EV can be significantly distorted, and the true relative cost advantages even reversed. In that sense, the reform of energy taxes and subsidies is a critical part of creating the enabling policy environment for EVs—one that neither penalizes EV adoption nor favors it beyond what is warranted economically. Energy subsidies are addressed in further detail in chapter 4.

BOX 3.3. EV Battery Recycling: A Quick Snapshot

Lifespan

The lifespan of EV batteries is generally labeled as eight years or 100,000 miles, which is consistent with battery warranties provided by various EV manufacturers (Kelleher Environmental 2020). Battery failure (manufacturing defects, overheat, faulty charging, and so on) or vehicle collisions could result in an end-of-life sooner than eight years. The lifespan of an EV bus can vary more dramatically. BYD, a publicly listed Chinese manufacturing company, claimed that their lithium iron phosphate batteries can last up to 7,200 charge-discharge cycles. If assuming one charging cycle per day, the EV bus lifespan is at the range of 20 years (California Air Resources Board 2016).

Recycling Rate

Battery recycling is one method to reclaim the expensive minerals from the batteries. Reported recycling rate varies dramatically across processes and mineral, but the lithium-ion battery collection recycling rate is at around 15 to 25 percent (Larouche et al. 2020). This number could increase to 90 percent by 2030 (Slowik, Lutsey, and Hsu 2020). Motivated by economic policy objectives, China and European countries are the most advanced in recycling capacity, representing about 50 and 33 percent of global capacity respectively (Steward, Mayyas, and Mann 2019). In 2016, the global battery recycling capacity was 94,000 kt/year. By 2022, it increased to around 200 kt/year, China accounting for about half (IEA 2021).

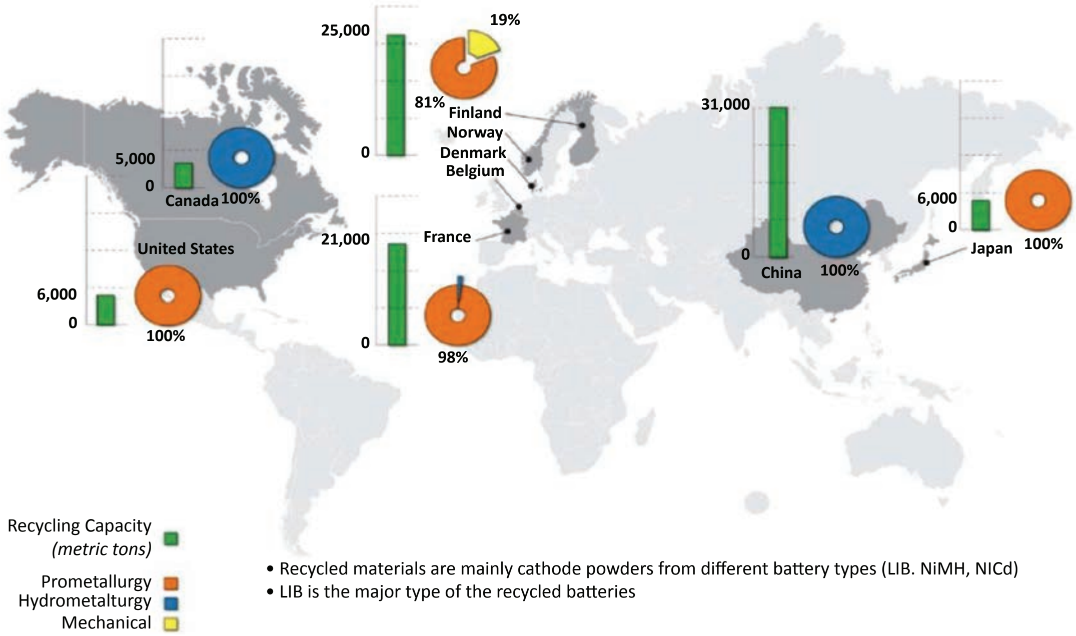
Cost of Recycling

The U.S. Department of Energy National Renewable Energy Laboratory (NREL) developed a tool in 2016 for calculating the cost of repurposing EV batteries (NREL 2016). "PHEV batteries can be repurposed for as little as US$20/kwh or US$500 per battery." Adding other aspects of reusing a battery into the equation, the total battery recycling costs would be in the US$50 per 100/kwh range. "The dynamics of the EV battery recycling market would change when the cost of new EV batteries fell to US$100/kWh" (Kelleher Environmental 2020).

(*continues*)

BOX 3.3. EV Battery Recycling: A Quick Snapshot (Continued)

FIGURE B3.1. Recycling Capacities of Spent Batteries in Metric Tons



Source: Steward, Mayyas, and Mann 2019.

Policy Priorities for Low- and Middle-Income Countries

EV policy experience around the world provides useful insights for countries still in the early stages of the electric mobility transition. These countries can build not only on policies in industrialized countries, but also on the rich experience of LMICs. One reason is that the opportunity cost of using scarce resources to fund costly incentives is higher. Most countries face more urgent needs in the transport sector and beyond. Lower-income countries also have different travel patterns and vehicle fleets. Public transit and smaller vehicles remain more important than in places where car ownership is near saturation levels. Countries should therefore rely less on expensive subsidies and other incentives and instead focus on investments in transport and energy infrastructure that are needed independently of electric mobility. Additionally, rather than supporting electric car purchases by individuals who are most often better off, they should focus on electrifying public transit where feasible and promote electrification of lower-cost two- and three-wheelers, which will benefit lower-income groups.

Most important, countries should concentrate less on specific technologies and instead pursue the broader policy goal of sustainable and affordable transport. All this suggests five simple principles for electric mobility in low- and middle-income countries.

Avoid Vehicle Subsidization Policies with High Fiscal Costs

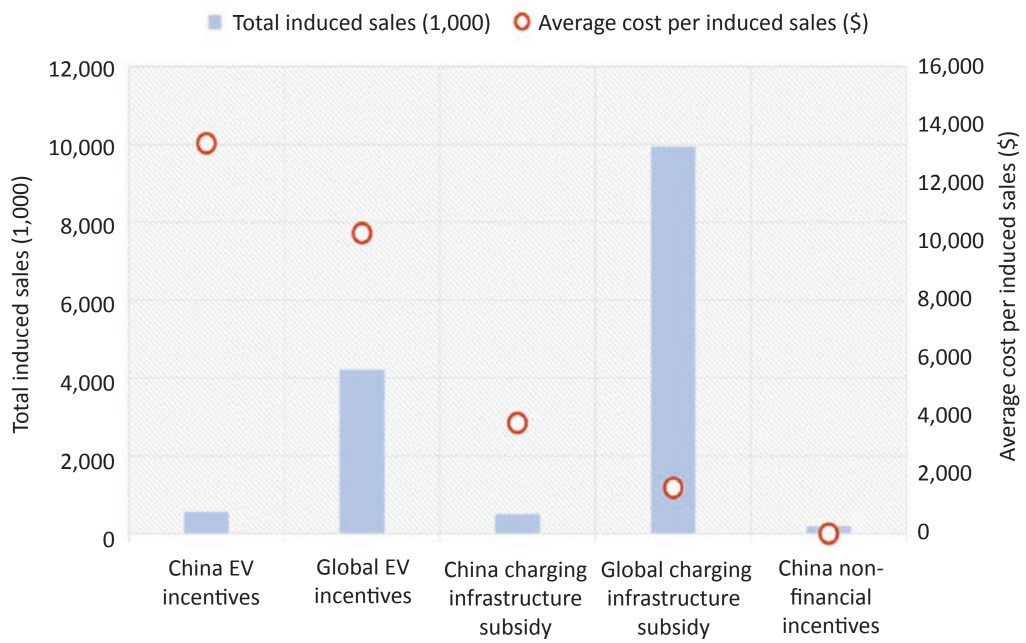
EV policies can be costly. EV purchase incentives in leading markets have been effective because they are generous. One study estimated that 13 surveyed countries spent about US$43 billion on demand side incentives between 2013 and 2020 (Li, Wang, et al. 2021). Few low- or middle-income countries can afford to subsidize each EV purchase with US$7,500 as in the United States or Euro 9,000 as in Germany in 2021 (ACEA 2021). Other forms of incentives can also have high fiscal costs. Colombia eliminated the 19 percent sales tax and 35 percent import tariff for fully electric vehicles and reduced both to 5 percent for hybrids (Callejas, Linn, and Steinbuks 2021). These purchase incentives had an average fiscal cost of between US$350 and US$515 per ton of CO_2 avoided. Although reasons might be good to reduce distortionary sales taxes or import tariffs, the revenue loss needs to be made up elsewhere. Moreover, given that EVs are already economically or financially attractive on a lifecycle basis in many countries (chapter 2), further weakens the case for subsidizing ownership.

Should low and middle-income countries emulate direct purchase incentive programs? For most, the fiscal cost would be too high and the feasible volume of subsidies too small to achieve significant domestic EV adoption. In fact, analysis shows that subsidies to the purchase of electric vehicles are not a very cost-effective way of promoting uptake (figure 3.4). Furthermore, EV buyers receiving these subsidies would likely be better-off residents, so this policy would be regressive as the cost is borne by all taxpayers. For most lower income countries, a better strategy will be to let richer economies drive down EV costs and benefit from lower prices and better performance as later adopters—similar to past experience with solar panels or mobile phones.

Target Industrial Policy Measures Towards Low-Cost Vehicles

Industrial policy is a different motivation for generous subsidies. Industrial policy is a different motivation for generous subsidies. Many countries want to support their legacy automakers as they transition to manufacturing a rising share of EVs, or alternatively they may aim to attract new entrants in the market for manufacture of EVs and components such as batteries. China’s central government started an EV subsidy program in 2009 with some local governments providing additional incentives (Li et al. 2020), eventually helping China to become a large manufacturer of electric cars and electric buses.

FIGURE 3.4. Cost-Effectiveness of Alternative Policies



Source: Li et al. 2021.

In middle-income countries with significant vehicle manufacturing, direct incentives may sometimes be justified to promote a local industry. Subsidies could be targeted to support domestic production of smaller, more affordable electric cars or electric two- or three-wheelers that are closer to cost parity with ICEVs and are within reach of a broader segment of the population.

Use Public and Shared Transport as an Entry Point

Public and shared transit is more important in lower-income countries, where a larger share of the population cannot afford a car or motorbike. This segment of the transport sector includes buses, minibuses like the matatus of Kenya, as well as taxis and ride-sharing vehicles. Many of these services are informally organized and are essential for providing mobility to the poor. Electrifying some of these fleets would have a useful demonstration effect and address specific transport problems. Several factors also make public and shared transport easier to electrify. Charging buses or fleets could be centralized in depots reducing investment costs. Battery swapping is therefore also easier, though not yet widespread. Vehicles run up high mileage quickly, so higher capital costs amortize faster. Also, lower maintenance needs of electric vehicles keep them on the road more dependably.

The main barrier to broader adoption of electric public and shared transit is, as with private adoption, the higher purchase cost (BNEF 2018; Alves et al. 2019). The purchase cost of electric buses remains somewhat higher than that of diesel buses, in part because the number of manufacturers has so far been limited. However, as shown in chapter 2, given lower maintenance and fuel operating costs, life-cycle costs are already lower in a significant number of cases, particularly where bus mileage is relatively high, and when externality costs are fully accounted for. The Efficient Bus Scenario discussed in chapter 2 illustrates how smart procurement and intensive usage of electric buses can significantly improve the economic case.

For public transit, procurement is by governments, so administratively complex subsidy schemes or regulations are not needed. The extra spending also benefits the broader public rather than individual, often well-off drivers. Also, where diesel vehicles and fuel are expensive, the cost difference shrinks. Countries could explore green financing vehicles to cover the remaining incremental costs. Finally, the benefits of locally pollution free transport could be high in areas of a city characterized by severe air pollution. Prioritizing electric buses in such locations, can bring targeted relief. Even if electric buses are still expensive, countries should explore opportunities for building local electric bus manufacturing capacity. Electric buses will eventually displace diesel buses and more producers will help bring costs down more quickly.

Promote Two- and Three-Wheeler Transport

Whether privately owned or used commercially, two- and three-wheelers provide mobility for lower-income groups in urban and rural areas of many countries. In India, two-and three-wheelers together account for 83 percent of all vehicles (Das, Chandana, and Ray 2020). Globally, as many as 900 million two- and three-wheelers may be on the road today (BNEF 2020). In contrast to electric cars, electric two- and three-wheelers already offer lower lifecycle costs in the vast majority of countries (see chapter 2). Their potential to reduce emissions and noise pollution is considerable, especially in rapidly growing cities in developing countries. For example, Rwanda has announced ambitious plans to phase out non-electric two-wheelers (Peters 2020). Currently 20,000 to 30,000 motorcycle taxis operate in Kigali and a local company has begun producing electric two-wheelers whose batteries can be easily swapped. Or again, India’s main program for electrifying vehicles set aside 23 percent of its funds to support two-wheeler rickshaw electrification and 29 percent for three-wheelers (Das, Chandana, and Ray 2020). Initial pilots have begun to replace some of the 51,000 mototaxis in Bangkok with electric two-wheelers (Praiwan 2021).

Yet two- and three-wheelers are often excluded from discussions about electrifying transport. Instead, they should be seen as an effective and affordable step in the electric mobility transition that complements rather than competes with public and nonmotorized transport (Berlin, Goetsch, and Alam 2022). Relative to electric cars, electric two- and three-wheelers are more amenable to being manufactured in many low- and middle-income countries, are easier to maintain, take up less road space, are easier to charge, and are more affordable to a larger share of the population. In addition to electric motorbikes, e-bikes (bicycles) and e-scooters can fill niches in local transport systems given how short most urban trips are. In cities, local governments can provide the legal basis for such vehicles such as treating them like regular bicycles that do not require licensing or insurance, set and enforce standards such as speed limits or helmet requirements, and create safe infrastructure such as protected bike lanes (ITDP 2020). Even where smaller electric vehicles are cost competitive, additional public support is arguably more justified than for electric cars, because they tend to promote access to jobs and opportunity for poorer population groups, advancing both equity and environmental objectives.

Focus on Sustainable Mobility Rather Than Specific Technologies

Much of the current attention in the transport sector is on electric vehicles. They are an important tool for reducing the sector's climate change impacts, but far from the only one. It is important to distinguish between outcomes and ultimate impacts. The proximate outcome of EV policies is increased adoption of such vehicles. But the impact that countries are really after is a reduction in air pollution and greenhouse gases. That means that EV policies "compete" with other policies that achieve the same goals and that may be cheaper, more effective, or better at also addressing other transport sector objectives such as equitable and affordable access. Examples are policies that reduce the need for travel, make nonmotorized transport safer, or that make public transit use cheaper and more convenient. EV policies should therefore be embedded in broader sustainable transport strategies such as the avoid-shift-improve paradigm discussed in chapter 1.

EV policies then become one element in an integrated policy mix that addresses all factors contributing to the transport sector's environmental impacts: the carbon or pollution intensity of vehicle fuels, the vehicles' efficiency in using those fuels, and the amount of vehicle travel (table 3.2). All these factors need to be considered in designing a comprehensive sustainable transport roadmap, because they often interact. For instance, fuel efficiency improvements reduce vehicle operating costs, which could induce more travel and thus a potentially offsetting increase in energy consumption and pollution—the well-documented rebound effect, or Jevon's paradox. Easier remote work could encourage sprawl and increased nonwork travel as people move out of dense cities. Measures that address individualized motorized travel demand, such as active (nonmotorized) travel, public transportation, land use changes, or reducing the need for travel through remote work all contribute to pollution mitigation in transport. Available evidence, though, shows that their individual impact is often modest or can be realized only in the long term. Countries with continued high population

TABLE 3.2. Pathways to Greater Road Transport Sustainability

	Environmental impact =				
	Pollution intensity (per unit of energy)	×	**Energy consumption (per km)**	×	**Travel demand (km)**
Regulations	• low carbon fuel standards • vehicle emission standards • EV mandates and privileges (HOV, parking)		• fuel efficiency standards • speed limits		
Prices (taxes, fees, tariffs)	• carbon taxes • pollution-based import tariffs		• fuel taxes		• road or mobility charges
Investments (incentives)	• R&D subsidies • information provision • EV purchase subsidies or tax and tariff reductions		• R&D subsidies • information provision • support for nonmotorized (active) travel • convenient and affordable public transit • transit-oriented development		• information provision • compact development • support remote work (such as digital connectivity)

Source: Axsen, Plötz, and Wolinetz 2020.

growth and urbanization still have options for avoiding lock-in to unsustainable land-use and transportation systems. The evidence over recent decades has not been encouraging, however. More policy experimentation will be necessary in developing countries to determine the optimal policy mix of regulations favoring low and zero emission vehicles, pricing instruments, and measures to reduce travel demand.

Prioritize Policies with General Purpose Benefits

Avoiding expensive subsidy programs does not mean that lower-income countries should ignore the global shift to EVs. Rather than spend on direct demand incentives, they could prepare for the electric mobility transition in ways that have little downside risk. Such no-regrets policies have general purpose benefits or they involve incentives with low fiscal costs:

- Put institutions and regulations in place that govern imports, sales, maintenance, recycling, and disposal of EVs and components such as batteries.
- Remove existing distortions in the domestic vehicle market caused by protective regulations or high import tariffs (Barwick, Cao, and Li 2021). Such distortions can change the welfare effects of environmental policies including those promoting EVs.
- Consider fuel-neutral regulatory instruments that encourage the switch to cleaner transport independently of vehicle type or drive train such as tighter emission standards, limits on imports of polluting used cars, or general carbon taxes. In Colombia, a carbon tax would have been more effective at reducing vehicle carbon dioxide emissions than the government's costly reduction of EV sales taxes and import tariffs because it encourages substitution within and across fuel types to lower emitting vehicles (Callejas, Linn, and Steinbuks 2021)
- Prepare for a quick rollout of charging infrastructure once EV adoption becomes widespread. This includes putting aside space for future charging points or adapting building regulations to require charging facilities.
- Develop EV-oriented training programs that will benefit future EV production and maintenance but that also teach portable skills as economies are increasingly electrified.
- Use inexpensive incentives to encourage early EV adopters such as information programs, special license plates, and incentives that make it more convenient to use EVs like parking or HOV preferences.

- Improve the power infrastructure, as discussed in chapter 4, including any measures to strengthen national power infrastructure and accelerate its decarbonization will greatly enhance a country's readiness to adopt electric mobility.

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CHAPTER 4

Energy Policies to Support the Transition to Electric Mobility

Energy Policies to Support the Transition to Electric Mobility

As electric vehicles (EVs) gradually replace gas- and diesel-fueled vehicles, the absolute increase in power demand will likely be less of a concern to governments and utilities than the distribution of this new demand over time and space (Engel et al. 2018). Managing the necessary upgrades to transmission and distribution infrastructure will be challenging for any power system, but particularly so in low- and middle-income countries, where utilities struggle to provide basic services. An equally important challenge will be to adapt the energy pricing and fiscal regime to ensure that consumers have the incentive to behave efficiently in regard to vehicle charging, and that the financial equilibrium of power utilities is not further stressed. Without early and comprehensive preparation, countries risk further degrading power supply systems that are essential to growth and welfare.

A review of early evidence and academic studies suggests three policy priorities. First, countries should conduct detailed power system planning based on modeling and simulations to assess the impact of electric mobility on their power system, including not only generation but also and crucially the transmission and distribution grid. Such analyses will inform concrete investment plans and regulatory reforms that get the power system in shape for widespread EV adoption. Second, a critical element of EV-oriented power sector strategies is demand management that shaves off peak loads and ultimately makes EVs an integral part of the power system by tight grid integration. An important element of demand management will be correcting numerous distortions in electricity and fuel pricing. Third, to secure the greatest possible climate and pollution reduction benefits from EVs, policymakers and utilities need to continue to advance with improvements in energy efficiency along the electricity supply chain, as well as in the greening of power generation, in all policy decisions.

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The International Energy Agency (IEA) expects EV demand for electricity globally to rise from 55 terawatt-hours (TWh) in 2020 to 1,150 TWh by 2030 if stated policies are implemented. That is roughly equivalent to twice today's total electricity use in Brazil (IEA 2022)[1] For most countries, IEA expects that the EV share of power consumption will not exceed 6 percent by 2030 and 10 percent by 2040, relative to about 1 percent today. Moreover, it needs to be considered in the context of wider electrification of many other uses of energy (such as heating and cooling), shifting patterns of sectoral demand due to economic restructuring, and the general trend toward greater energy efficiency. A greater concern is that this demand will likely be concentrated when many EV owners charge at once or where adoption is high. Uncoordinated charging—which carries the attendant risk that vehicle recharging could be highly concentrated in certain locations or at certain times of day—may overwhelm existing distribution networks or require expensive upgrades to match short duration peak demand. Such concerns could either be addressed by further investment in grid upgrades, or more cost-effectively resolved by demand management measures, which redistribute charging activity across locations and time periods. Options range from relatively simple information and incentive programs to more complex technical solutions. Time-of-use electricity pricing creates incentives for EV users to charge when overall demand is lowest. Closer integration of electric vehicles with the grid through smart charging allows system operators to guide charging schedules and may in the future make EV batteries an integral part of the grid. However, such integration may require additional investments in smart charging infrastructure. The payoff is a more stable power system and savings from avoided grid reinforcements.

EVs will be just one new use of electricity that will strain power supply systems, already struggling to keep pace with the demands of economic development while on a decarbonization trajectory. Upgrading generation and transmission requires considerable investment but is relatively concentrated in a few "lumpy" projects. Much more challenging will be to upgrade local distribution and feeder systems, which can number in the hundreds of thousands and may be overstretched in areas of rapid urbanization. As noted in chapter 2, making the required investments will be harder if persistent price distortions in many countries' energy sectors are not removed. Ensuring security of supply requires integrated power planning to assess the impact of EV adoption scenarios, both at the systems level and for local distribution systems. Planning and analysis will identify the most efficient technical options, gauge the required level of investment, and suggest regulatory and market reforms that help pay for the investments and ensure security of supply.

As discussed in chapter 2, because EVs are considerably more efficient in their energy use, they already contribute to the global goal of avoiding dangerous climate change even in countries where fossil fuels

1 Projections according to the Announced Pledge Scenario. By 2030, electricity demand for EVs accounts for at least 2% of global final electricity consumption in both scenarios. The 2021 value of 80 TWh presented in the Global EV Outlook 2021 was revised by the IEA on light of updated data and assumptions that show a reduced number of two/three-wheelers in China

dominate electricity generation. Nevertheless, carbon benefits can be further enhanced as power systems decarbonize. Throughout the process of preparing for electric mobility, policymakers and utilities need to search for opportunities to improve the efficiency of the power system and to shift to zero carbon energy sources. Wind and solar are already cost competitive, but reliable power supply also requires large-scale electricity storage, the cost of which is expected to fall over the coming years.

Electric Mobility Poses Challenges for Power Systems

EV adoption poses a range of challenges for power systems. Perhaps the most obvious one of these, the boost to electricity demand, turns out to be the least problematic to handle. Of greater concern is the significant redistribution of load and resulting potential for localized grid overload. Less often discussed, but equally important, electric mobility throws into relief numerous inadequacies in the pricing framework and fiscal regime for the electricity sector.

EV Adoption Will Boost Demand for Electricity

Switching a rising share of the vehicle fleet to electric motors will reduce the demand for oil and increase demand for electricity. In many developing countries, new EV demand could worsen existing shortcomings in the power supply sector, among them aging and inefficient generation units, underinvestment, and poor market design. EV demand will coincide with new demand from other uses, such as space cooling, as well as growing demand from population and income growth. Large and growing countries such as Brazil, Nigeria, and Pakistan expect large increases in electricity consumption and consequently a vast need for additional generation capacity. In such contexts, EV demand will be just one among many factors driving investment needs.

IEA's stated policies scenario predicts an increase of the global stock of EVs (excluding two- and three-wheelers) from 18 million in 2020 to almost 100 million, or 10 percent of the road vehicle fleet, by 2030 (IEA 2022). In 2020, EVs used about 55 TWh of electricity globally, of which 5 TWh were consumed by electric two- and three-wheelers in China and equates roughly to current total electricity demand in the Czech Republic. Under the IEA stated policies scenario, electricity demand from EVs reaches 780 TWh by 2030 (IEA 2021b). In the Announced Pledge Scenario that includes all recent major national announcements of 2030 targets and longer-term net zero and other pledges, demand would increase to 1,100 TWh by the end of the decade with the largest demand in China (330 TWh), Europe (187 TWh), and the United States (153 TWh).

Even in optimistic scenarios, additional power demand from EVs is significant but not overwhelming, with very few salient exceptions. Case in point Sahelian countries (see chapter 3). Electricity generation will need to rise in any case. Decarbonization will shift additional energy uses such as industrial processes or heating

TABLE 4.1. EV Load Power System Impacts in the Context of Developing Countries

Category	Impacts	Developing country context
Impact on power demand	• Increase in total energy consumption • Reshaping daily load curve • Changing the magnitude, duration, and potentially timing of the peak load • Changing the variability of the load profile and increasing the uncertainty of load	• Geographical location, extreme weather, demography, and driving patterns also impact uptake, EV power consumption, and charging behavior • E2Ws and E3Ws might be a dominant mode in many economies • Economic, regulatory, and geographical barriers in establishing public charging infrastructure
Impact on distribution system	• Overloading of feeders and transformers • Additional power losses • Voltage deviations • Power quality issues (harmonic distortion)	• Inadequately designed and weak distribution systems • High level of distribution system losses • High rate of transformer failures • Lack of appropriate management, standards, and regulations • Already high reinforcement requirements due to growing demand
Impact on transmission system	• Risk of congestion because of insufficient transmission capacity • Increased need for flexible reactive power	• Low level of interconnectivity and cross-border capacity • Lack of appropriate regulations holds back investments • High investment requirements to provide adequate level of interconnections with growing demand

(*continues*)

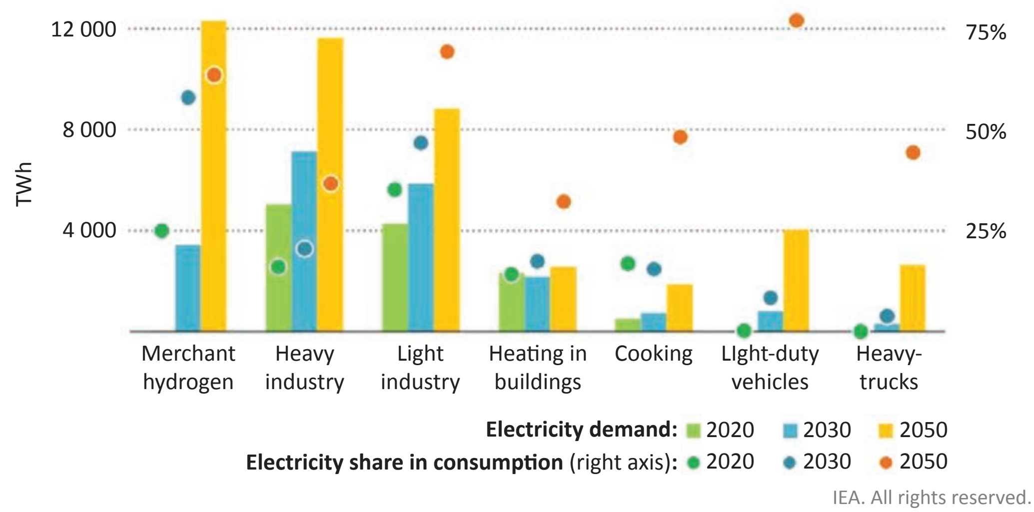
TABLE 4.1. EV Load Power System Impacts in the Context of Developing Countries (Continued)

Category	Impacts	Developing country context
Impact on generation	• Need for new generation capacity investments • Increased power system emissions • High ramping requirements due to sharp increase in power demand • Increased need for ancillary services • Increased need for storage	• Insufficient capacity and reliability to satisfy even current needs • High generation investments requirements due to rapidly growing demand • Carbon-intensive generation fleet, often based on poor quality fossil fuel powered units • Poor electricity market regulation and difficulties in providing reserves
Impact on utilities	• Electricity tariff structures not designed with EV charging in mind • Where electricity is subsidized, financial position of utilities may be weakened by EV adoption	• Increasing block tariffs (IBTs) commonplace and may penalize EV charging • Time of use (TOU) charging and associated smart meters relatively rare • Electricity prices tend to embody significant subsidies and cross-subsidies

from fossil fuels to electricity (figure 4.1). Rising temperatures and growing wealth will increase electricity use for air conditioning. In lower-income countries, expanding electricity access to underserved and growing populations remains an urgent task. Improved energy efficiency and economic shifts to less energy-intensive sectors may dampen some expected demand growth. Against this backdrop, EV demand will not dramatically change the power sector outlook in most countries, especially because it will unfold gradually, with relatively slow uptake expected in lower-income countries. In most scenarios, the EV share of power consumption does not exceed 6 percent by 2030 and 10 percent by 2040 (Taljegard et al. 2019; IEA 2022), and much less in emerging markets at the initial stages of the electric mobility transition (Kapustin and Grushevenko 2020).

More detailed studies have looked at the impacts in specific places. A scenario for Colombia estimates that a 10 percent share of electric or hybrid cars by 2030 would trigger an annual electricity demand of 2.9 TWh, which corresponds to about 3 percent of total national consumption (Unidad de Planeación Minero-Energética 2020).

FIGURE 4.1. Global Electricity Demand and Consumption in Net Zero Emissions Scenario



Global electricity demand more than doubles in the period to 2050, with the largest rises to produce hydrogen and in industry

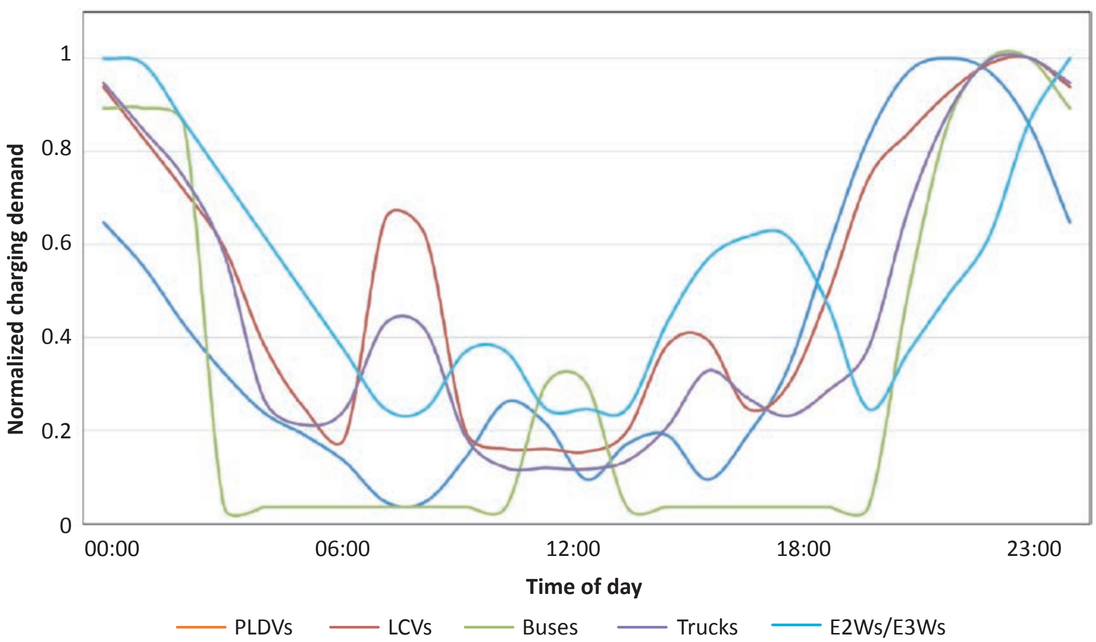
Source: IEA 201a.
Note: Merchant hydrogen, produced by one company to sell to others; light-duty vehicles = passenger cars and vans; heavy trucks = medium- and heavy-freight trucks.

If all passenger car sales in India were electric by 2030, the additional demand would reach 82 TWh per year, some 3.3 percent of total demand (Abhyankar et al. 2017). In Turkey, 2.5 million EVs in 2030 (10 percent of the stock and 55 percent of sales) translate into an additional 4.1 TWh annually and a 12.5 percent increase in peak demand (Saygin et al. 2019). In Vietnam, a 20 percent EV penetration for cars and motorcycles would raise power demand to 9 TWh per year, some 3.3 percent of total demand (IES and MKE 2016). Another interesting scenario undertaken for Chile assumes a level of 150,000 electric cars, 28,000 taxis and 360 buses (Manríquez et al. 2020). The study estimates this will lead to an increase in generation investments of about 3 percent (US$18 million) and increased operational costs of 1 percent (US$18 million). A study for Chongqing, China, assumes two million electric cars and unmanaged charging (Li et al. 2020). It finds that evening peaks would increase by about seven percent, requiring an increase in operating costs of almost 8 percent (US$6.5 billion). For India, finally, a national-level study assumes a stock of electric two-wheelers of 367 million in addition to 89 million electric cars by 2030 (Abhyankar et al. 2017). The findings suggest that the peak charging load will exceed 30 gigawatts (GW), which will be 6 percent of the total peak load by 2030, and that this additional demand can be fully met with planned capacity expansion.

Electric **Vehicles** Will Significantly Redistribute Power Load

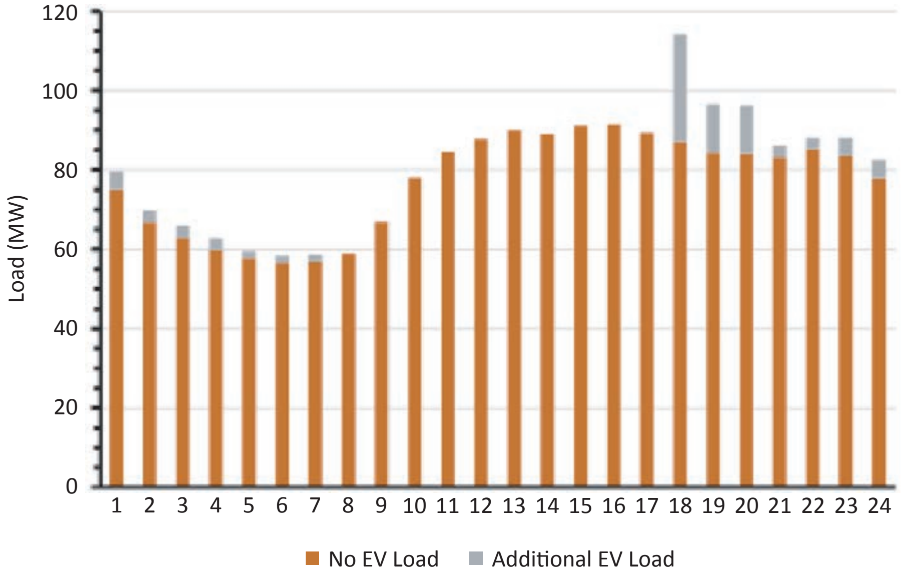
The specific profile of electricity demand from EVs could pose a greater challenge to national and local power grids than the overall associated increase in electricity usage. Before EVs, most power systems experience an evening peak for residential use and a morning or evening peak from commercial use. EV charging will not be distributed uniformly over time and space, so peaking demand could stress power systems even if capacity is adequate overall. The pattern of EV charging will depend on a number of variables that shape the so-called load curve. One factor is the vehicle mode, because different types of EVs will be charged at different times of the day (figure 4.2). Charging demand tends to peak in the evening after private car owners return from work and public buses return to the depot for overnight charging. These times coincide with existing high domestic demand periods, such as in the predicted load patterns for Male in the Maldives in figure 4.3. Electric two- and three-wheelers have small batteries and their charging is more likely distributed over the course of the day (Weiss, Cloos, and Helmers 2020). Light commercial vehicles such as delivery vans and shared transport such as taxis are also more likely to require additional charging during the day. Overall, a concentration of charging demand during the evening across a range of EV types seems to be likely.

FIGURE 4.2. Normalized Charging Profiles



Sourc: IEA 2020a.
Note: PLDVs = passenger light duty vehicles; E2Ws/E3Ws = electric two- and three-wheelers; LCVs = light commercial vehicles.

FIGURE 4.3. Load in Malé on a Typical Working Day for 2030, Baseline (No EV) and EV load



Source: ESMAP 2021.

Although the broad demand patterns are similar, the vehicle mix in a given location shapes the aggregate charging pattern. In higher income countries, personal cars will likely make up the largest share of the EV fleet. As shown in chapter 2, in many developing countries, buses, two- and three-wheelers, or taxis dominate the vehicle fleet and thus the emerging EV market. Differences between workdays or weekends, or increased demand at certain times of the year such as the beginning or end of major public holidays, further complicate demand patterns. For example, during the month of the Spring Festival holiday 2018 in China, demand at highway charge points doubled over the prior month (Hove and Sandalow 2019).

Geographic concentration of EVs, particularly those with large charging demand, could cause spikes in the load curve even if overall EV penetration remains small. For instance, a larger number of electric cars in a high-income neighborhood could stress the local distribution system if charging is uncoordinated. Sudden loads from buses at fast charging stations can locally cause high variability and load spikes (Rogge, Wollny, and Sauer 2015). Geography also influences absolute demand. Congestion, very high or very low temperatures, and hilly terrain all cause efficiency losses in EVs and increase demand for electricity (Florio, Absi, and Feillet 2021). Use of heating and air conditioning, for instance, can reduce an EV's range by up to 50 percent in hot and humid conditions and steep hills by more than 20 percent (IEA 2019; Liu, Yamamoto, and Morikawa 2017).

Other factors affecting the magnitude and timing of local demand include the type of EV: plug-in hybrids have smaller batteries and might be initially more appropriate in developing countries with fewer charging points and geographic characteristics that reduce the range of pure EVs. Demography can also play a role (Zhang et al. 2020). For instance, rural residents tend to drive longer distances than urban ones. Or again, younger and wealthier drivers tend to cause later charging peaks. Understanding these patterns and trends helps utilities and policymakers anticipate where and when transport demand for electricity will be concentrated, supporting proactive rather than reactive power system planning.

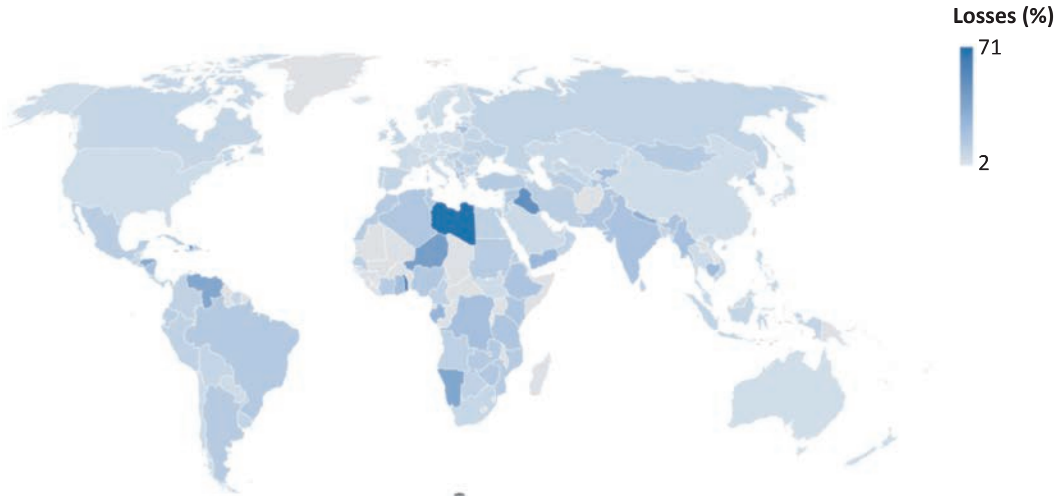
Discussions about the electric mobility transition often overlook the importance of local distribution systems. This part of the electric power system will need perhaps the largest improvements. EV charging will require some new access points, often along highway corridors and at higher voltages for fast charging. However, much of the requisite vehicle charging will be conducted at traditional end-use locations such as homes or businesses, placing additional strain on systems not designed to sustain such loads. In many developing countries, the distribution system is the weakest link in the power supply system. Without sufficient upgrades, extensive EV charging could cause overloading of feeders and transformers, voltage deviations, power losses, and power quality problems (Crozier, Morstyn, and Mcculloch 2020). Given the inadequacies of existing distribution infrastructure, such upgrades will likely be required in any case, and electrification of transport will help increase the economic benefit and financial return associated with these necessary investments.

Even at moderate EV penetration, vehicle charging could stress local power systems, creating hotspots in higher-income neighborhoods with higher EV adoption or at higher-use charging locations such as parking lots. Although most EVs are likely to be recharged slowly using conventional power connections at homes and offices, to the extent that fast-charging systems are adopted the load requirements may be multiple times higher (Hensley, Knupfer, and Pinner 2018). In many places, buses and fleet vehicles like taxis are likely the first to be electrified at larger scale. Those types of vehicles rely on centralized charging facilities, which will greatly increase power demand at specific locations. For instance, almost 300,000 taxi minibuses in South Africa that could be electrified provide three-quarters of all work and school trips (ESMAP 2022). A depot for seventy-five buses in Chile needed 6 MW of power, requiring upgrades of local distribution infrastructure. And in India, a bus depot charger may require US$150,000 in distribution system upgrades (Acharya, Gadepalli, and Ollivier 2022).

The biggest concern in distribution grids is overloading transformers and feeders. One study estimates that 312,000 low-voltage feeders in the UK—one-third of all such feeders in the country—will need to be upgraded by 2050 to manage EV charging that is often clustered locally (EA Technology 2016). A large share of the distribution system is aging even in higher-income countries, and overloading will reduce their lifetime further. The costs will add up (Sahoo, Mistry, and Baker 2019). In a Danish region with 127 EVs, the local distribution grid would require a €52,000 investment to upgrade transformers and cables (see references in ESMAP 2022). Electrification of 500 vehicles in 25 postal hubs in Madrid would require more than €120,000 upgrades in the distribution network to enable fast charging. In New Zealand, a 10 percent EV penetration would require US$22 million in upgrades, rising to US$154 million with a 40 percent adoption rate.

Higher levels of EV charging can also cause voltage instability, power quality problems, and power losses. System voltage should normally remain within 10 percent of optimal levels for safe operations, which can be exceeded during charging peaks. When EV chargers draw a great deal of power, they cause highly variable loads, which can lead to so-called harmonic distortions, which are the main cause of power quality issues. A large proportion of solar photovoltaic (PV) in the local power supply could worsen these problems, requiring adequate design of distribution system upgrades (Angelim and Affonso 2019). Low power quality and power losses during transmission and distribution are already a major problem in many developing regions (figure 4.4). India has been losing 26 percent of power annually and up to 60 percent in some regions, Latin America and the Caribbean and Africa have losses of about 17 percent (see ESMAP 2022). Poor planning and regulation, limited resources often related to large electricity subsidies, and hasty

FIGURE 4.4. Electric Power Transmission and Distribution Losses



Source: World Bank Group; IEA 2021a.

deployment have made power systems prone to failures, especially in rural areas, where feeders need to cover large distances. In many contexts, meshed distribution networks rather than the more common radial or tree architecture could be better suited for many developing country contexts including small island developing states (SIDS) (IRENA 2019a).

Large-scale EV deployment will also affect transmission lines. Estimates of how much upgrading will be necessary vary widely. One study for the Nordic countries expects a 60 percent capacity increase with full EV penetration and uncoordinated charging by 2050 (see references in ESMAP 2022). In contrast, another study for Chile found no major upgrades were required even at high levels of EV adoption. For the US market, a 15 percent EV penetration requires a US$420 transmission investment per EV through 2030. Even without major EV adoption, large investments will be required in lower-income regions because of investment backlog and rising demand. Africa will need to spend between US$3.2 billion and US$4.3 billion annually between 2015 and 2040 (African Development Bank 2019). India expects that US$24 billion will be needed by 2025 (*Economic Times* 2020; Zhang 2019). More broadly, IEA estimates that universal access to electricity by 2030 will require additional investments of US$391 billion, of which US$115 billion will be for distribution and transmission upgrades (IEA 2019).

Electric Mobility May Also Exacerbate Financial Stress on Power Utilities

In addition to any physical stresses that EV adoption may place on power systems is the potential for significant financial stresses. These arise from the electricity sector's price distortions. Two issues are of particular relevance—the level of prices and the structure of tariffs.

Subsidization of electricity supply is widespread in low- and middle-income countries (Parry, Black, and Vernon 2021). Even if individual consumers and firms benefit from lower prices, electricity subsidies typically represent a net cost to society. They cause fiscal deficits and weaken power utility finances, starving them of necessary funds for preventive maintenance and new investment, and gradually leading to a deterioration in service quality. Subsidies also encourage waste from overuse of electricity, potentially leading to shortages and excessive environmental impacts. In the context of electric mobility, subsidization of electricity supply poses two distinct risks.

First, subsidization of electricity may lead to over-adoption of electric vehicles. As noted in chapter 2, a key advantage of electric vehicles from a consumer standpoint is lower energy bills. Although electricity has a natural cost advantage over liquid fuels in transportation, given the higher energy efficiency of electric motors, this advantage will be exaggerated if electricity is subsidized or at least taxed less heavily than petrol and diesel. Some fiscal differentiation may be warranted by the fact that electricity typically has lower associated externality costs than liquid fuels. However, for most countries studied, the fiscal advantage of electricity over liquid fuels significantly exceeds the associated difference in externality costs. The result may be to accelerate the transition to electric mobility beyond what would be warranted on economic grounds. This underscores the importance of looking at electricity pricing policy not only in isolation, but also in relation to substitute sources of energy for the transportation sector. The relative price of electricity needs to be considered alongside its absolute price.

Second, electricity subsidization may exacerbate the precarious finances of many power utilities across the developing world. When subsidy policies lead power utilities to charge tariffs below cost recovery levels, they lose money on every unit of electricity sold. Thus an important new source of power demand—electric mobility—will only widen the power sector's financial deficit. In the short term, this will create many operational and financial challenges for the utility, likely to result in under-maintenance of the system, and an accumulation of debts on the balance sheet. Further, the rationale for subsidizing electricity for household use may not necessarily carry over to subsidizing electricity for transportation, particularly if private electric vehicles are regarded as something of a luxury good. Electricity subsidies are already widely known for being regressive in distributional impact (Komives et al. 2005), which the adoption of electric mobility could aggravate.

Another important issue is that electricity tariff structures are often designed in ways not especially compatible with EV adoption. Across low- and middle-income countries, rising block tariff structures remain widespread (Foster and Witte 2020), the implication being that home charging of electric vehicles is likely to take households into more highly priced consumption blocks. To some extent, this might be viewed as a counterweight to concerns about distributional incidence. However, depending on the specificities of the tariff structure design, it could mean that vehicle charging attracts punitive rates that dissuade adoption. Additionally, time-of-day pricing, which is essential to managing demand for charging electric vehicles and directing it toward off-peak periods, is comparatively rare in low- and middle-income countries, in part because of the prerequisite investment in smart meters to make this technically possible.

Power System Impacts of Electric Mobility Need to be Carefully Managed

The physical and financial stresses that chaotic adoption of electric mobility may place on the power system can be managed in a variety of ways. The classical response of investing in infrastructure upgrades to accommodate new system demands may be inevitable in some instances. However, the extent of necessary investment can be significantly curtailed through proactive adoption of a range of demand management measures, encompassing both technical fixes as well as financial incentives, as illustrated by a recent evaluation of EV adoption undertaken in New Delhi (box 4.1).

BOX 4.1. Detailed Analysis of Distribution Systems Aids Large-Scale EV Integration

India will likely become one of the largest electric vehicle (EV) markets in the world, but its power distribution system already struggles to keep up with rising demand. Identifying its shortcomings is a crucial first step in supporting large-scale EV adoption. An example is a study of ten distribution feeders in New Delhi that collected load and voltage profiles, information on distribution transformers, consumer mixes and energy consumption (GIZ 2019). This allowed careful modeling of the impact of charging stations on load flow, load volumes, voltage, and harmonics. For three of these feeders, the study then conducted detailed simulations in five areas: travel patterns, energy consumption, power consumption, EV penetration levels, and EV charging strategies. The simulations investigated various scenarios that varied EV penetration levels, installation of public chargers, the addition of electricity storage facilities, or solar photovoltaic integration.

This study found that with the appropriate balance of network improvements and time-of-use tariffs, the distribution systems operator (DSO) can manage a high level of EV deployment provided the DSO as well as commercial charging operators follow grid connection standards and practices to avoid equipment failures. The study showed that comprehensive network analysis provides full quantification of the potential impact of EV integration, enables assessment of various scenarios and system designs, and yields valuable information about required network upgrades and charging locations.

Some Degree of Power System Reinforcement May Be Needed

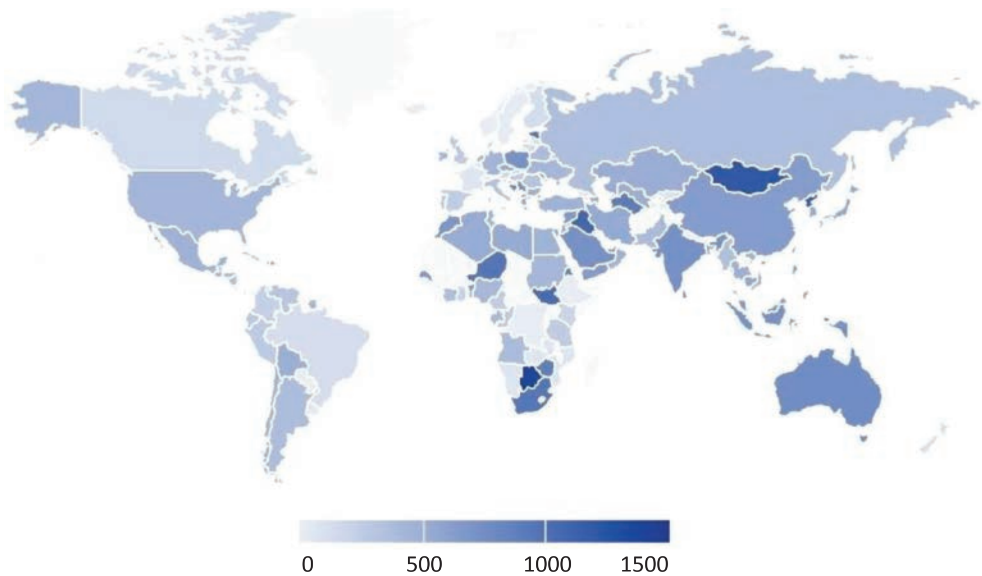
Satisfying increased peak demand requires flexible and more expensive generation units that can be ramped up quickly, such as gas turbines. Pumped or battery storage can also fulfill this role but is not yet always a feasible or cost-effective option. Maintaining capacity will therefore be a challenge. Already, supply-demand balances are tight in many places, as indicated by frequent load shedding in countries such as Kenya, Nepal, and South Africa. Also, smaller island nations or countries with complex topography, such as Indonesia, have limited options for balancing out demand and supply across wider geographic areas or international borders.

Adding to these challenges is the need to decarbonize electricity generation. Although EVs do not emit greenhouse gases during operation, they still have a carbon footprint if the electricity stored in their batteries and used in their manufacturing is generated using fossil fuels. Overall, the emission intensity depends on the generation mix and how different types of generation units are deployed. Baseload is often provided by coal, hydro, or nuclear power along with varying levels of wind and solar depending on conditions, whereas management of peak loads or periods of low wind and solar generation relies on gas, diesel generators, or stored energy. The impact of additional EV demand on the emission intensity of electricity supply is therefore highly country specific (figure 4.5), and such national averages hide considerable within-country as well as seasonal and even daily variability in the generation mix. As illustrated by the widely varying estimations of investment needs in chapter 2, each country faces a unique set of conditions in terms of the status and reliability of the existing grid, fuel sources, the vehicle fleet, the likely EV adoption path, and so on.

That is, even though no simple prescriptions for readying the power sector for the electric mobility transition are possible, several useful general observations are.

First, given the long lead time for energy sector investments, preparing for the EV transition needs to start early. Integrated power sector models help assess the implications of a rising share of electric vehicles on the electricity supply infrastructure, along the electricity supply chain from generation to transmission and distribution. They provide a basis for scenario analysis and comprehensive planning, especially when used in conjunction with EV specific analyses such as those facilitated by the scoping tool presented in this report.

FIGURE 4.5. Average Power System Emission Intensity [gCO_2/kWh]



Source: Pavarini and Mattion 2019.

An example for a comprehensive analysis of the impact of EV adoption on the power sector is a study undertaken for the Maldives by ESMAP (2021). The study began with forecasts of electricity demand for each type of EV over the period between 2021 and 2030. Defining the likely charging profile under different charging strategies yields EV load curves for typical days. This information fed into the World Bank's Electricity Planning Model (EPM) to suggest least-cost generation and expansion plans accounting for detailed technological, economic, and environmental parameters of the country's electricity system. Outputs included parameters such as dispatch schedules of the generation units, power system emissions, and operational costs. Comparing results with and without EVs, and under different assumptions of charging behavior, generated policy relevant information such as the incremental investments in additional generation or emission intensities under different scenarios. In addition to aggregating capacity expansion requirements, detailed modeling also helped identify transmission and distribution bottlenecks. Accompanying these system wide analyses, separate simulation studies for distribution networks subsequently identified the impacts of EV charging on local feeder networks (recall box 4.1).

Second, greening the power sector must be a key consideration in any power sector planning exercise. Mobility cannot be fully green as long as vehicle manufacturing and electricity generation rely on fossil fuels. As illustrated by the Green Grid Scenario discussed in chapter 2, the net benefits of electric mobility are significantly amplified as countries progress further with the decarbonization of their power generation mix.

Returning to the Maldives example, emissions could actually increase in the scenario with coordinated charging because more charging would happen off-peak, when generation uses diesel-based units. Replacing those generators with renewable energy from the country's ample solar resources would require battery storage that chargers can draw on during nighttime. So far, large capacity batteries are expensive but so are diesel imports, and electricity storage technology will likely benefit from massive current investments to drive costs down.

Third, universal access remains an important consideration and an unfinished agenda. Globally, 733 million people still live without electricity at home (IEA et al. 2022). Many low- and middle-income countries continue to work toward universal electrification. As more and more activities—and notably transportation—become electrified during the decarbonization process, it becomes increasingly important to ensure that all citizens can use this cleaner form of energy.

Managing Charging Behavior Will Reduce Investment Needs

Another important insight is that demand management is often the most effective way to mitigate the potential negative impacts of EV adoption on the grid given the bunching of charging load at certain times in certain places. The ability to manage EV charging demand is an additional source of flexibility for the power system as a whole—comparable to dispatchable resources such as gas turbines. Such demand management measures should be prioritized given that they are likely to cost far less than investing in additional peak demand capacity that will be used only infrequently.

Returning to the Maldives example, that study assumed a 30 percent share of EVs by 2030 including the country's large number of two-wheelers. The scenario with uncoordinated charging predicted a relatively modest increase in energy demand of 3.1 percent. But because much of that demand was predicted to occur at peak times, it would require a 26.1 percent increase in generation capacity entailing 16 percent more investment than in the base case without EVs. Introducing demand management, in the form of an optimized charging regime, reduces generation capacity additions to just 1.8 percent and would also reduce stress on distribution systems.

Although demand management is complex, managing loads can be substantially more cost effective than capacity additions and grid enforcement, especially in systems that already require very large improvements because of investment backlog and rising demand from all sources. Moreover, a wide array of technical fixes for demand management are available—from the simple to the sophisticated.

The most straightforward approach to demand management is to use information programs to encourage EV owners to charge during off-peak periods either in general or through real-time push notifications. Such programs have been successful in reducing energy consumption for heating (Gillingham, Keyes, and Palmer 2018), though they may be most effective when combined with time-differentiated charging.

Another strategy for managing demand is to increase the density of public charging infrastructure. If charging points are more widely available and spread out geographically, EV owners will also be more likely to spread out vehicle charging over time, allowing for smaller but more frequent "top-ups"—at work, at store parking lots, or along city streets—as opposed to concentrating charging at home during the evening peak.

Electricity storage is another approach to better adapt electric power demand to supply. This involves equipping charging stations with battery storage systems that can balance supply from the grid. If charged, for example, by locally produced solar PV, this also yields additional revenue for station owners (Feng et al. 2020). Adding storage can also be attractive to fleet operators. In a case of adding storage to a fast-charging station for electric buses, costs were 23 percent lower than without storage (Ding, Hu, and Song 2015).

Rather than using intermediate storage in regular charging systems, some operators replace discharged vehicle batteries with fully charged ones. For electric cars, battery swapping is not yet widely used. A lack of standard design limits interoperability so swapping only works in specific cases such as taxi fleets. Battery swapping is more suitable for smaller EVs, especially two- or three-wheelers. Several battery swapping services have emerged in India, including subscription services for station networks where electric two- and three-wheelers can swap in fully charged battery packs (Das and Tyagi 2020). Moreover, India expects the market for battery swapping to grow by more than 30 percent annually during this decade (Kumar, Bhat, and Srivastava 2021). China and Indonesia, among other countries, also promote battery swapping mostly for electric two-wheelers.

Beyond these relatively simple solutions, smart charging provides the ultimate technical fix for managing power demand for electric vehicle charging, allowing the power system operator some control over the timing and duration of vehicle charging. Such smart charging infrastructure allows electric utilities to manage the process, whether in one direction (V1G sending power to the vehicle), or both directions (V2G additionally taking power from the vehicle).

In unidirectional vehicle-to-grid integration (V1G), the operator can manage EV charging to reduce grid congestion, regulate frequency, and avoid peak period overloading. In various studies and pilot applications, V1G provided considerable savings. One modeling study in an urban setting estimated a reduction of 34 percent of the local marginal cost (Heinisch et al. 2021). In a study of a low-voltage Danish distribution network with a 50 percent EV share, charging costs decreased by 17 percent in addition to other benefits, such as more balanced voltage (García-Villalobos et al. 2016).

Bidirectional controlled vehicle-to-grid integration (V2G) allows EVs to become electricity storage systems, returning power to the grid, for instance, when demand from other uses is strong and tariffs are high. In more local versions, a vehicle could similarly be integrated just with a single home or building (V2H, V2B). The potential benefits are large in that V2G could, in principle, provide almost 600 GW of flexible capacity across China, India, the EU, and the United States by 2030, saving 470 TWh and avoiding 330 million tons of CO_2 emissions (IEA 2020a). Importantly, V2G can make grid integration of renewables easier by providing flexible power at times when wind or solar production is low (Richardson 2013). Several studies have estimated the prospective financial benefits of V2G, mostly in high-income countries. Although estimates vary widely, all studies find significant cost savings for systems operators in addition to reductions in carbon emissions (see, for example, Park, Yoon, and Hwang 2016; Oldfield et al. 2021).

A study in Chile found that smart charging enables a larger proportion of solar electricity in the system which reduces operational and environmental costs and offsets investment costs (Manríquez et al. 2020). V2G technology connecting 2,500 EVs in Mexico could improve the power supply's technical performance leading to a 69 percent decline in power losses (Khan and Castillo 2017). A particularly interesting example of an electric mobility program built around advocacy and smart charging is South Africa's uYilo program, which is one of the few field applications of V1G and V2G in the developing world (box 4.2).

BOX 4.2. uYilo Electric Mobility Program

South Africa's national electric mobility program, known as uYilo (Xhosa for "to create"), developed successful pilot projects in smart charging and electric mobility advocacy. Addressing more than just EVs, uYilo focuses on developing the entire ecosystem for successful electric mobility implementation—from sustainable energy generation through skills development to circular economy. In 2013, uYilo established the Smart Grid EcoSystem facility to analyze EV-grid interoperability and to determine the future challenges regarding the control of the entire electric mobility system. The facility includes integrated PV panels, storage through second-life EV batteries, vehicle-to-grid services, energy management systems, and various types of chargers. With that infrastructure in place, uYilo tests energy optimization techniques to provide reliable and undisturbed service to the connected loads under various available grid capacities (including blackouts or brownouts) or availability of renewable energy and level of integrated energy storage. The system's primary goal is resilience, shifting to alternative and available sources of energy when needed and making sure that the EV is always charged. The facility is also used to test smart grid remote communications standards between various players in the system and the grid operator. uYilo uses the outcomes of the ongoing field experiments to campaign for electric mobility benefits in the region. Furthermore, the experience and insights gained inform conversations with decision-makers, regulators, and utilities to promote smart charging strategies implementation alongside transport electrification.

Source: Hiten Parmar, director of uYilo Programme, interview, 2021.

Yet even in high-income countries, implementation of EV power demand management has been slow. In part, this may be because of a lack of urgency while EV penetration is low. In part, also, it is also because such approaches are complex to implement. They require additional software, communication, and control equipment in electrical systems and cars, as well as regulatory frameworks that guide the technology and economics. Applications in developing countries have mostly been pilot projects and proof-of-concept studies.

Scaling up requires a gradual build-out of smart charging infrastructure and regulatory reforms in electricity markets that signal to EV buyers, manufacturers, and charging companies that investments will yield adequate returns. The benefits of a smoothly operating charging ecosystem in lower-income countries could be large: lower charging costs, reduced power generation investments, more stable electricity supply, and lower operations and maintenancecosts for power operators. This underscores the strategic importance of establishing such systems at an early stage to avoid the burgeoning power system costs that might otherwise ensue.

Pricing Reform Is a Critical Aspect of Demand Management

Given the prevalence of distortions in energy pricing, and the importance of harnessing demand management approaches, electricity tariff reform will need to play an important role in the transition to electric mobility. Getting electricity prices right is not only helpful in its own right, but also a valuable complement to some of the technical solutions presented earlier, which can further incentivize their uptake and amplify their respective impacts. The two critical aspects of electricity pricing reform are ensuring that prices attain cost recovery levels and redesigning electricity tariff structures to align with and influence electric mobility demand patterns (IRENA 2019b).

Making the transition to electric mobility sustainable will require comprehensive electricity (as well as fossil fuel) subsidy reform where prices do not currently reflect the full cost of production—let alone their full social cost. Such reforms have proved difficult. Often introduced as well-intentioned efforts to stabilize prices or reduce price volatility, subsidies become entrenched and widely popular. Yet many countries have successfully carried out electricity subsidy reform, among them Armenia, Brazil, China, Egypt, Kenya, Morocco, Philippines, Turkey, Uganda, and the United Arab Emirates (Sovacool 2017).

A main lesson from successful cases is that subsidy reform is largely a political economy problem rather than a purely fiscal issue (Inchauste and Victor 2017; Flochel and Gooptu 2017). It will require strong administrative capacity to design and implement an effective reform strategy consisting of best practice subsidy measurement, subsidy impact analysis, a reform schedule, and a plan for distributional concerns. Reform is generally easier when beneficiaries are concentrated—such as when most support goes to a few large firms—rather than diffused. Reform efforts are also easier to defend politically when robust social protection systems are in place that buffer the effect of price reforms on poor households and small firms.

Besides freeing up scarce fiscal resources that can be recycled into service expansion and improvement, reform also pays immediate environmental dividends. Energy subsidy reform in Indonesia led to lower demand and a change in energy mix that will reduce greenhouse gas emissions by between 5 and 9 percent by 2030 (Sovacool 2017).

When it comes to the reform of energy tariff structures, a first step is to move away from increasing block tariff (IBT) structures toward linear pricing, to ensure that vehicle charging demand is not unduly penalized. Beyond this, the key issue is to influence the timing of vehicle charging in such a way as to avoid accentuating demand peaks. To this end, time of use (TOU) tariff schedules that charge higher prices during peak hours, are the most suitable pricing instrument—once the necessary smart meter infrastructure is in place to permit their implementation. Under TOU pricing schemes, electricity tariffs could be pre-determined based on historical load patterns (static pricing), or they could adjust continuously based on prevailing wholesale market signals (dynamic pricing). In both cases, users save money from lower rates and utilities from avoided investments. For example, the Jamaican utility JPS designed a TOU tariff scheme that will be implemented alongside infrastructure investments (Office for Utilities Regulation 2019).

Experience has shown that TOU schemes work quite well. A significant proportion of EV owners adjust charging time in response to price signals, in one case reducing spikes in power demand by 64 percent (Gao et al. 2012). In another case, among 8,000 urban EVs in China, peak-valley differences dropped by 16 percent and charging costs by 4 percent (Chen et al. 2018). Reducing the variability of electricity demand also benefits the grid infrastructure by reducing power losses, voltage deviations, and overloading, thus extending the lifespan of transformers and other equipment (Klettke and Mose 2018). Implementation of TOU pricing schemes requires careful design to avoid unintended side effects, such as peak shifting (or creating new demand peaks in formerly off-peak hours). The regulatory tariff setting process can be complex and requires lengthy preparation (European Commission 2015).

Conclusion

As long as electric mobility scales up gradually, the impact on overall electricity demand will be relatively modest, except perhaps in the most fragile power systems. What is more relevant is how the timing of uncoordinated electric vehicle charging may further accentuate system peaks and how potential geographical concentration of charging could create overload on local distribution networks. Despite a small aggregate impact, such concentrated impacts could be much larger and more significant. Moreover, they could be exacerbated by the subsidization of electricity, which in turn could incentivize overuse, as well as the prevalence of antiquated electricity tariff structures, which are not necessarily helpful in shaping demand.

The key implication is that the transition to electric mobility needs to be anticipated and proactively managed by power systems. An important starting point is to integrate transportation demand into generation, transmission and distribution master plans. A certain amount of additional investment may be inevitable to reinforce the weakest links in the grid, but a great deal of investment can be avoided by proactive demand management measures, aimed particularly at shifting vehicle charging outside peak periods. This can already be done through relatively straightforward measures, such as information campaigns and battery swapping arrangements. Ultimately, full grid integration of EV batteries would allow more sophisticated centralized management of charging and even allow EVs to become grid storage assets. In any case, pricing reform will be a critical component of any demand management effort, and—in particular—a shift toward TOU pricing promises to be an effective approach to influencing behavior.

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Country at a Glance – Passenger Electric Mobility in Brazil

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
CAR DOMINANT	EXPORTER	HIGH

Country Background

The dominant vehicle type in Brazil is cars (84.3 percent), followed by two-wheelers (14.5 percent), buses (1.0 percent) and three-wheelers (0.2 percent).[1] In 2021, electricity was generated primarily from renewable sources (85 percent) – notably, hydro (65.2 percent), wind (8.8 percent), solar (0.6 percent), and biomass and waste (9.1 percent). Gas (8.3 percent) is the largest fossil source for electricity generation, followed by oil (2.1 percent) and coal (2.7 percent).[2] Brazil is one of the largest vehicle manufacturers in the world with its own large domestic market. The expansion of electric vehicles in the country has been slow,[3] partly due to the country's prioritization of ethanol to mitigate CO2 emissions from the transport sector. In 2019, more than 92 percent[4] of the Brazilian cars sold were powered by flex-fuel[5]. More recently, e-mobility implementation in Brazil has been ramping up, both on the policy side and infrastructure supply. Electric buses are tax-exempt in seven Brazilian states, with a reduced tax rate in three further states. From 2022, national electric bus manufacturers are full tax exempt for bus chassis assembly machines and lithium-ion batteries but import duties to electric vehicles remain in place. These incentives are sponsored by the National Development Bank (BNDES).[6] However, the Brazilian manufacturing industry produces diesel buses at very low costs which makes for a tough competitive market despite the said incentives.

Overall Messages

Brazil faces many conditions that are less favorable towards electric mobility, including a car-dominated fleet, relatively high-cost vehicles, and energy exporting status (Figure 1a). While electrification of transport does not yet look economically favorable as a national strategy (Table 2), this is largely driven by the fact that the electrification of 4W vehicles is not attractive under current conditions, given large capital cost differentials (Table 1). By contrast, there is a strong case for adoption of 2W electric motorbikes (Figure 1b), which present a lifecycle cost advantage of almost 15 percent (almost 25 percent in financial terms). In addition, the 8 percent capital cost differential associated with electric 2Ws looks relatively affordable, representing no more than 1 percent of GNI per capita. Furthermore, electric buses are beginning to offer modest economic advantages of the order of 3.5 percent of lifecycle cost.

The externality benefits of electric mobility in Brazil are relatively small (Figure 1c), perhaps due to the existing prevalence of biofuel. An important exception is provided by 2W electric vehicles, which present much lower externalities than their conventional counterparts (Figure 1d). Otherwise, fuel cost savings are the main advantage associated with electric mobility in Brazil. Given a fiscal regime that taxes petrol and diesel two to three times as heavily as electricity, these fuel cost savings are further accentuated in financial terms; which is why the overall case for electric mobility in Brazil looks better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$7 billion per year by 2030 (or 0.27 percent of Brazilian GDP). About three quarters of the required outlay is associated with the incremental capital of electric vehicles (Figure 2a). In terms of public investment, the most significant item is the provision of public charging infrastructure for private vehicles (Figure 2a). Given that implicit carbon prices associated with electric 2Ws and buses in Brazil are negative (Table 3), there is significant scope to cover 50-70 percent of public investment costs through carbon financing arrangements. However, for 4W electric vehicles, the implicit carbon price exceeds US$200 per ton.

The overall economic case for electric mobility in Brazil certainly does not improve under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), nor is there much scope for further decarbonization of the power sector (Green Grid Scenario). On a positive note, the emerging advantage associated with electrification of buses can be as much as doubled through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, there is no real case for electrification of 4Ws even when it comes to taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). If the appropriate road safety measures are in place, the 2W segment of the fleet is an enormous opportunity and should be prioritized for Brazil given the many strong advantages.

[1] Source: ANFAVEA (2019) Brazilian Automotive Industry Yearbook 2020.
[2] Source: Generation mix comes from National Energy Balance (BEN) 2021 (base year 2020) and US EIA international database and WB data.
[3] Source: Green Transportation, The Outlook for Electric Vehicles in Latin America, Energy Working Paper, 2015.
[4] Source: https://socialsciences.nature.com/posts/the-future-of-electric-vehicles-in-brazil
[5] Flex-fuel means that the cars run on ethanol and gasoline at the same time.
[6] Source: MOVILIDAD ELÉCTRICA, OPORTUNIDADES PARA LATINOAMÉRICA, PNUMA, Union Europea, 2016.

Table 1. Cost Advantage at year 2030 of Accelerated EV Adoption BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(125)*	*361*	236	*49*	*85*	370	*700*	936	13.9	25.6
4W	*(529)*	*(1,983)*	*650*	(1,862)	*46*	*203*	(1,612)	*2,688*	827	(4.3)	1.5
Buses	*(6,102)*	*(6,136)*	*15,207*	2,969	*2,966*	*7,827*	13,762	*28,373*	31,342	3.5	6.1

Note: results normalized by new vehicles entering the market in 2030.

Figure 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

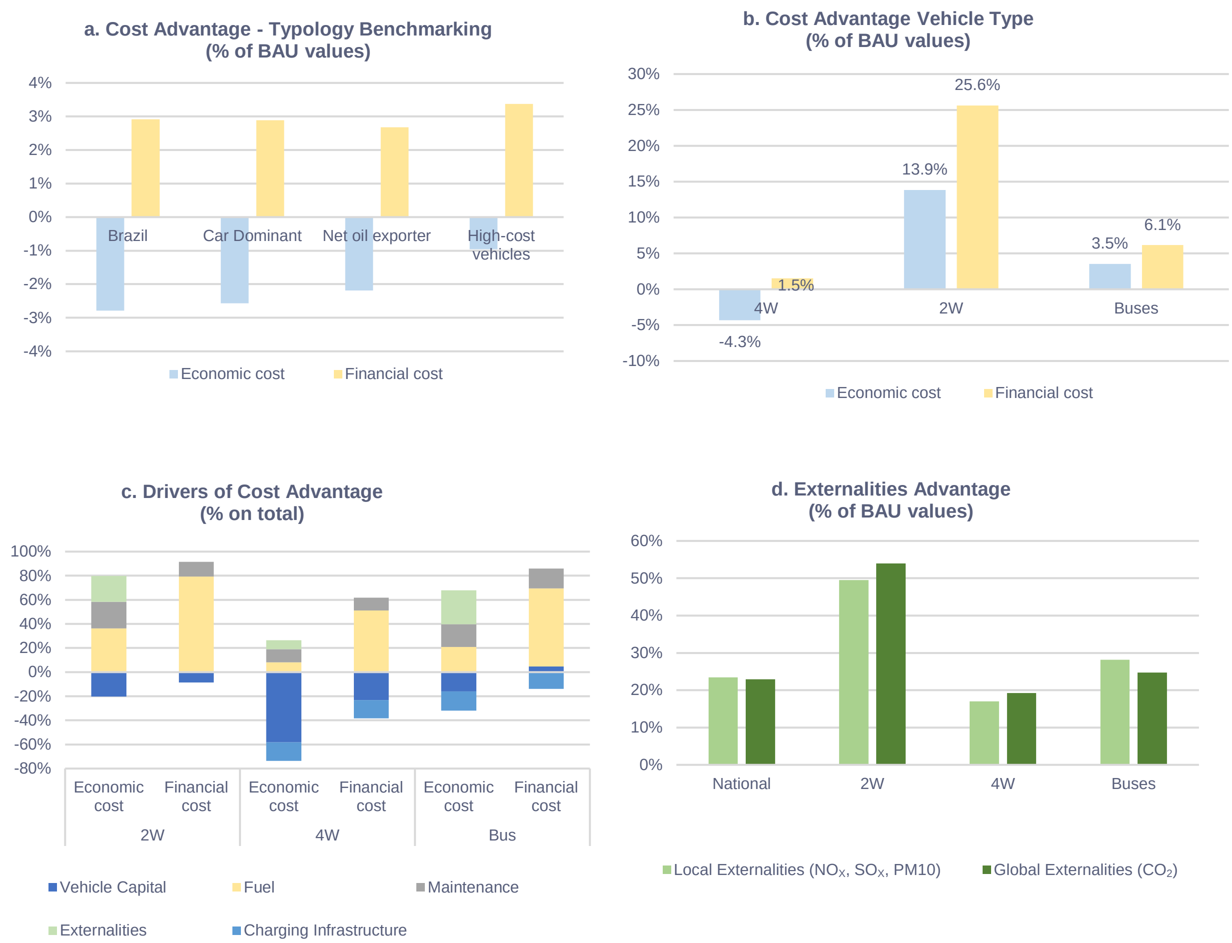
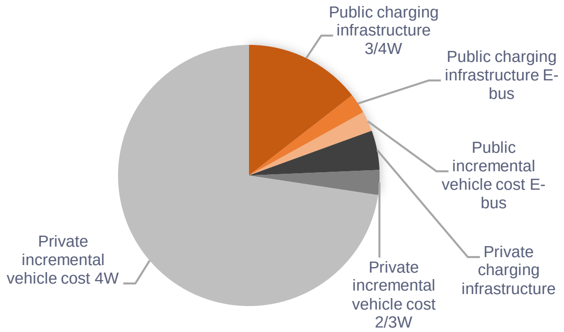


Figure 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

a. Breakdown of investment needs US$ 7,009m or 0.27% of GDP (% of total)



b. Investment needs potentially covered by carbon financing (% of total needs)

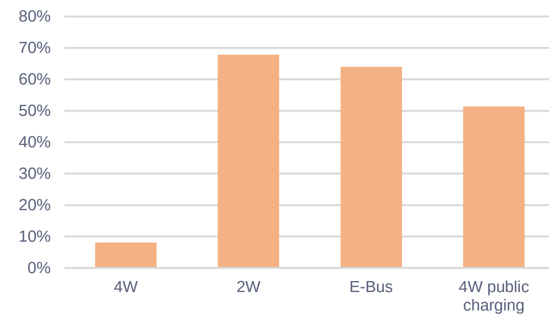


Table 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(21,880)	(21,880)	(31,234)	(21,880)	(6,136)	7,599	(1,983)	(1,983)
Vehicle maintenance cost	5,567	5,567	5,315	5,567	7,199	7,499	373	(760)
Vehicle fuel cost	5,287	5,287	5,287	596	8,007	8,007	277	1,107
Private charging infrastructure	(1,367)	(1,367)	(1,367)	(1,367)	-	-	(133)	(133)
Public charging infrastructure	(4,744)	(4,744)	(4,744)	(4,744)	(6,102)	(6,102)	(395)	(450)
Sub-total	**(17,137)**	**(17,137)**	**(26,743)**	**(21,829)**	**2,969**	**17,003**	**(1,862)**	**(2,219)**
Local externalities	1,143	1,302	1,143	996	2,966	2,966	46	196
Global externalities	3,553	3,601	3,553	2,796	7,827	7,827	203	842
Economic cost advantage	**(12,441)**	**(12,234)**	**(22,047)**	**(18,037)**	**13,762**	**27,796**	**(1,612)**	**(1,182)**
Fiscal wedge	35,543	35,543	34,055	29,829	28,373	28,373	2,688	7,260
Financial cost advantage	**18,406**	**18,406**	**7,312**	**8,001**	**31,342**	**45,376**	**827**	**5,041**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(1,612)	(1,598)	(2,413)	(2,016)				
2W	370	372	284	327				
E-bus	13,762	14,131	6,528	3,464				

Table 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	31,534	4W mileage (kms)	17,459	Overall investment needs (US$m)	7,009
Price of 4W EV (US$/vehicle)	35,267	2W mileage (kms)	7,627	-of which 4W purchase	5,088
Price of 2W ICE (US$/vehicle)	1,101	Bus mileage (kms)	78,699	-of which 2W purchase	213
Price of 2W EV (US$/vehicle)	1,278	4W lifetime (years)	22	-of which e-bus purchase	174
Price of bus ICE (US$/vehicle)	136,359	2W lifetime (years)	17	Fiscal impact (US$m)	(8,900)
Price of bus EV (US$/vehicle)	135,324	Bus lifetime (years)	20	-of which vehicle duties	(2,120)
Net tax difference on 4W EV (%)	15%	4W second hand (%)	0.2%	-of which vehicle taxes/subsidies	(1,148)
Net tax difference on 2W EV (%)	0%	2W second hand (%)	0.2%	-of which petrol taxes/subsidies	(6,619)
Net tax difference on E-bus (%)	17%	Bus second hand (%)	0.05%	-of which diesel taxes/subsidies	(1,064)
Price of petrol (US$/liter)	0.46	Efficiency 4W ICE (MJ/km)	2.18	-of which electricity taxes/subsidies	2,051
Net petrol tax (US$/liter)	0.62	Efficiency 4W EV (MJ/km)	0.68	Implicit carbon price ($/tonne)	116
Price of diesel (US$/liter)	0.50	Efficiency 2W ICE (MJ/km)	0.85	-of which for 4W	231
Net diesel tax (US$/liter)	0.36	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	(87)
Price of electricity (US$/kWh)	0.13	Efficiency bus ICE (MJ/km)	15.61	-of which for buses	(20)
Net electricity tax (US$/kWh)	0.05	Efficiency bus EV (MJ/km)	5.17	Pollution reduction (tons)	35
Electricity carbon intensity (g/kWh)	93	4W share (% pax-kms)	72%	- of which local (SO_X, NO_X, PM10)	0.19
Discount rate (%)	6.6%	2W share (% pax-kms)	10%	- of which global (CO_2)	34.40
		Bus share (% pax-kms)	18%	Affordability of 2W EV (Δ cost % GNI pc)	0.9%
				Affordability of 4W EV (Δ cost % GNI pc)	8.0%

Country at a Glance – Passenger Electric Mobility in Cambodia

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	IMPORTER	HIGH

Country Background

The dominant vehicle type in Cambodia is two-wheelers (78 percent), followed by cars (15 percent) and buses (6 percent)[1]. In 2018, electricity was primarily generated from renewable sources (60 percent) and less from fossil fuels (40 percent). Coal (36 percent) is the largest fossil fuel source for electricity generation, followed by oil (4 percent). Hydro (59 percent), solar and biomass (together barely 1 percent) form part of the renewable sources of the electricity generation, with most of the balance coming from coal (36 percent)[2]. The Cambodian government has stepped up to explore the increase in the adoption of low-carbon vehicles in the transport eco-system. In 2019, the Global Green Growth Institute (GGGI) became a delivery partner of the National Council for Sustainable Development (NCSD) to deliver its Green Climate Fund (GCF) for promoting green mobility through electric vehicles. There have been several pilot schemes launched in the country. One of them is the electric motorbike-sharing system called Go2, making electric vehicles more accessible to consumers[3]. The country has introduced electric buses fitted with solar panels. The supporting charging infrastructure placed along the bus routes are also solar powered[4]. In 2021, the National Council for Sustainable Development prepared a strategy for promoting electric two-wheelers in the country[5]. In addition, the national energy policy sets important objectives for increasing renewable energy with greater reliance on private investment.

Overall Messages

Despite facing relatively expensive vehicle costs, the case for electric mobility in Cambodia benefits from the dominance of 2W vehicles in the fleet, as well as the country's status as an oil importer (Figure 1a). As a result, the overall case for electric mobility in the country is good (Table 2). There is a strong case for adoption of 2W electric motorbikes (Figure 1b), which present a lifecycle cost advantage of over 10 percent (almost 20 percent in financial terms). Nevertheless, the capital cost premium for electric 2W vehicles in Cambodia is particularly high at around 29 percent and represents as much as 6 percent of GNI per capita, suggesting that provision of credit lines may be important to support adoption. At the same time, electric buses are beginning to offer modest economic advantages of the order of 3 percent of lifecycle cost. By contrast, the economics of electric 4W vehicles is quite marginal, and the associated capital cost premium prohibitive at 40 percent of GNI per capita.

The externality benefits of electric mobility in Cambodia are relatively small (Figure 1c), perhaps due to the existing prevalence of hydro energy and limited urban air quality issues. An important exception is provided by 2W electric vehicles, which present much lower externalities than their conventional counterparts (Figure 1d). Otherwise, fuel cost savings are the main advantage associated with electric mobility in Cambodia. The fiscal regime neither incentivizes nor disincentivizes the purchase of electric vehicles. However, fiscal policies do accentuate the fuel cost advantage of owning them; given that petrol and diesel are taxed at 20-50 percent, while electricity is slightly subsidized. Consequently, the overall case for electric mobility in Cambodia looks better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$44 million per year by 2030 (or 0.1 percent of Cambodian GDP). About two thirds of the required outlay is associated with the incremental capital cost of electric vehicles (Figure 2a). In terms of public investment, the most significant item is the provision of public charging infrastructure for private vehicles and buses (Figure 2a). Given that implicit carbon prices associated with electric 2Ws and buses in Cambodia are negative (Table 3), there is significant scope to cover 17-27 percent of public investment costs through carbon financing arrangements. However, for 4W electric vehicles, the implicit carbon price exceeds US$400 per ton.

The overall economic case for electric mobility in Cambodia is robust to more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), neither is there much scope for further decarbonization of the power sector (Green Grid Scenario). On a positive note, the emerging advantage associated with electrification of buses can be as much as tripled through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, the case for electrification of 4Ws is only marginally improved for the case of taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). It is clear that electric mobility in Cambodia needs to prioritize the 2W segment of the fleet, which offers so many strong advantages.

[1] Source: Global Green Growth Institute (2021): Promoting Green Mobility Through Electric Motorbikes in Cambodia.
[2] Source: Generation mix comes from a combination of US EIA international database and WB data.
[3] Source: https://cambodianess.com/article/a-campaign-to-promote-the-use-of-electric-vehicles-is-held-this-month-in-phnom-penh
[4] Source: http://www.phnompenhpost.com/post-weekend/solar-buses-temples-angkor
[5] Source: Promoting Green Mobility through Electric Motorcycles, GGGI, 2021.

Table 1. Cost Advantage at year 2030 of Accelerated EV Adoption BAU Scenario minus 30x30 Scenario (average over fleet additions)

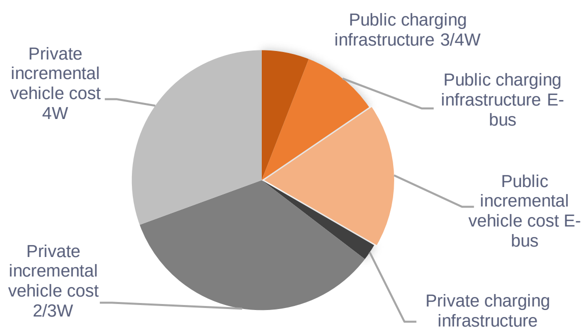
	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(154)*	*334*	180	*3*	*42*	224	*291*	471	10.5	17.3
4W	*(363)*	*(1,397)*	*613*	(1,147)	*4*	*74*	(1,069)	*852*	(295)	(4.1)	(0.8)
Buses	*(5,180)*	*(9,621)*	*20,299*	5,497	*309*	*2,597*	8,404	*13,770*	19,267	2.6	5.0

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

Figure 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

a. Breakdown of investment needs US$ 44m or 0.1% of GDP (% of total)



b. Investment needs potentially covered by carbon financing (% of total needs)

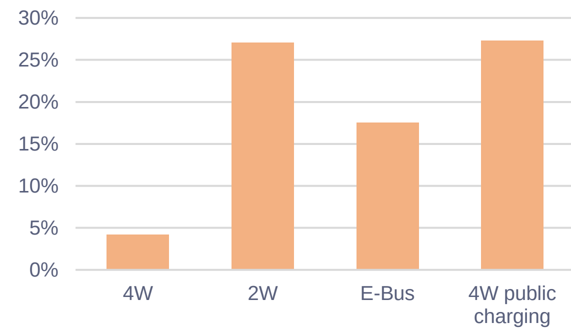


Table 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(12,724)	(12,724)	(16,860)	(12,724)	(9,621)	1,316	(1,397)	(1,397)
Vehicle maintenance cost	5,178	5,178	4,584	5,178	5,700	6,036	258	(537)
Vehicle fuel cost	14,077	14,077	14,077	10,979	14,599	18,214	355	1,420
Private charging infrastructure	(316)	(316)	(316)	(316)	-	-	(94)	(94)
Public charging infrastructure	(2,392)	(2,392)	(2,392)	(2,392)	(5,180)	(5,180)	(270)	(308)
Sub-total	**3,822**	**3,822**	**(908)**	**724**	**5,497**	**20,386**	**(1,147)**	**(915)**
Local externalities	189	189	189	178	309	386	4	17
Global externalities	2,415	2,415	2,415	2,057	2,597	3,253	74	307
Economic cost advantage	**6,426**	**6,426**	**1,696**	**2,959**	**8,404**	**24,025**	**(1,069)**	**(591)**
Fiscal wedge	16,708	16,708	15,423	15,772	13,770	19,869	852	2,319
Financial cost advantage	**20,530**	**20,530**	**14,515**	**16,496**	**19,267**	**40,255**	**(295)**	**1,404**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(1,069)	(1,069)	(1,532)	(1,268)				
2W	224	224	182	200				
E-bus	8,404	8,404	2,334	1,557				

Table 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	32,349	4W mileage (kms)	15,224	Overall investment needs (US$m)	44
Price of 4W EV (US$/vehicle)	41,899	2W mileage (kms)	7,627	-of which 4W purchase	13.4
Price of 2W ICE (US$/vehicle)	1,193	Bus mileage (kms)	48,092	-of which 2W purchase	15
Price of 2W EV (US$/vehicle)	1,683	4W lifetime (years)	22	-of which e-bus purchase	7.8
Price of bus ICE (US$/vehicle)	151,773	2W lifetime (years)	17	Fiscal impact (US$m)	(48)
Price of bus EV (US$/vehicle)	162,388	Bus lifetime (years)	20	-of which vehicle duties	(8.2)
Net tax difference on 4W EV (%)	28%	4W second hand (%)	73.3%	-of which vehicle taxes/subsidies	2.0
Net tax difference on 2W EV (%)	10%	2W second hand (%)	73.3%	-of which petrol taxes/subsidies	(30)
Net tax difference on E-bus (%)	30%	Bus second hand (%)	31.5%	-of which diesel taxes/subsidies	(7.5)
Price of petrol (US$/liter)	0.60	Efficiency 4W ICE (MJ/km)	2.31	-of which electricity taxes/subsidies	(4.1)
Net petrol tax (US$/liter)	0.32	Efficiency 4W EV (MJ/km)	4.34	Implicit carbon price ($/tonne)	(43)
Price of diesel (US$/liter)	0.74	Efficiency 2W ICE (MJ/km)	0.87	-of which for 4W	401
Net diesel tax (US$/liter)	0.14	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	(113)
Price of electricity (US$/kWh)	0.14	Efficiency bus ICE (MJ/km)	16.58	-of which for buses	(58)
Net electricity tax (US$/kWh)	(0.01)	Efficiency bus EV (MJ/km)	5.69	Pollution reduction (tons)	0.3
Electricity carbon intensity (g/kWh)	398	4W share (% pax-kms)	21%	- of which local (SOx, NOx, PM10)	0.003
Discount rate (%)	6.6%	2W share (% pax-kms)	52%	- of which global (CO_2)	0.27
		Bus share (% pax-kms)	28%	Affordability of 2W EV (Δ cost % GNI pc)	6.2%
				Affordability of 4W EV (Δ cost % GNI pc)	39.9%

Country at a Glance – Passenger Electric Mobility in Egypt

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	IMPORTER	LOW

Country Background

The dominant vehicle type in Egypt is car (57.5 percent)[1] and electricity is primarily generated from fossil fuels (90.8 percent).[2] EV adoption has been slow but the Government is redoubling efforts to mainstreaming electric vehicles,[3] by considering the inception of:
(i) an integrated framework for sustainable transport and green urban development that would include EV adoption as one of its pillars;
(ii) policies to prioritize electrification of shared services and public transportation; (iii) motorization management practices to address vehicles registration and licensing, scrapping and fleet renewal; and (iv) policies to improve fuel standards and use of cleaner non-electricity fuels to address air quality while in transition. In the power sector, the current energy plans and policies aim at increasing the country's renewable share to 25 percent by 2030[4], that will have a compound effect in the benefits of EV adoption. Further, investments have been set in place to install 300 electric vehicle charging points by 2023, of which 150 charging points at 40 stations across have already been built.[5] Finally, Egypt is pursuing a joint-venture between a state-owned automotive industry and a Chinese company for setting in place a domestic EV assembly line deployment of EV charging facilities[6].

Overall Messages

Electric mobility in Egypt looks to be a promising strategy (Table 1). Egypt shares many characteristics with other countries that are favorable towards the economics of electric mobility, including relatively low cost of vehicles, a diversified mixed fleet, and being an oil importer (Figure 1a). The economic case for electric 2W and buses is particularly strong, providing a lifetime cost advantage of the order of 10-15 percent (Figure 1b). When it comes to 4W vehicles, however, the case for electric mobility is much more marginal (Figure 1b).

From an affordability standpoint, 2W electric motorbikes also look to be more within reach. Although the associated capital cost premium exceeds 25 percent, this is under 5 percent of GNI per capita, suggesting that the extra cost might potentially be affordable with some kind of consumer finance (Table 3). By contrast, the 3 percent capital cost premium associated with 4W electric vehicles exceeds 17 percent of GNI per capita and therefore requires some financial support to be affordable (Table 3).

One of the main factors driving the case for electric mobility in Egypt is the very high externality costs associated with internal combustion engine vehicles (Figure 1c). Poor urban air quality, and resulting health impacts, is a very serious issue for the country – particularly in the Greater Cairo area – leading to local externality benefits of electric mobility that are even larger than global externality savings associated with reduced carbon emissions.

Egypt has a fiscal regime neutral to the actual purchase of electric vehicles, but petrol is taxed at over 20 percent and electricity subsidized by over 50 percent which substantially reduces the operating cost of electric vehicles and leads to fuel savings when expressed in financial terms (Figure 1c). Nevertheless, the sizable fiscal wedge in favor of electric mobility does not come close to matching the social costs associated with internal combustion engines. As a result, electric mobility in Egypt is more attractive in economic terms than in financial terms, even though it remains financially advantageous (Table 1).

The overall investment needs associated with the 30x30 Scenario amount to US$2.3 billion per year by 2030 (or 0.56 percent of Egyptian GDP). About two thirds of the required outlays fall on the private sector due to the incremental capital cost associated with electric vehicles and private charging infrastructure (Figure 2a). Nevertheless, the public sector would need to find finance for about one third of this total to cover the higher cost of electric buses and the provision of public charging infrastructure for the overall fleet. The good news is that given negative implicit carbon prices associated (Table 3), there is significant scope to cover 25-35 percent of public investment costs of electric mobility through carbon financing arrangements.

The economic case for electric mobility remains robust (Table 2), even under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), while benefits are significantly amplified as Egypt further decarbonizes its electricity sector (Green Grid Scenario). Furthermore, the advantage associated with electrification of buses can be further increased through more efficient procurement and operation of the vehicles (Efficient Bus Scenario), while the electrification of 4Ws also becomes more advantageous when confined to taxi fleets and other intensively used vehicles (Taxi Fleet Scenario).

[1] Source: OICA (2020) Passenger cars sales statistics Statista (2019) Number of licensed motorcycles and buses in Egypt.
[2] Source: Generation mix comes from a combination of US EIA international database and WB data.
[3] Source: Mainstreaming Electric Mobility in Egypt, The Ministry of Environment, 2020.
[4] Source: Renewable Energy Outlook, Egypt, IRENA, 2018.
[5] Source: https://enterprise.press/hardhats/egypt-ready-electric-vehicles/
[6] Source: https://enterprise.press/stories/2021/01/19/one-step-forward-for-our-ev-future-29775/

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle										% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g			
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*		*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(202)*	*265*	63	*170*	*33*	266	*93*	156		12.9	8.9
4W	*(567)*	*(1,100)*	*880*	(787)	*1,255*	*161*	629	*1,256*	469		1.5	1.1
Buses	*(6,036)*	*(12,107)*	*27,579*	9,437	*33,680*	*4,470*	47,587	*8,806*	18,243		10.0	5.5

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

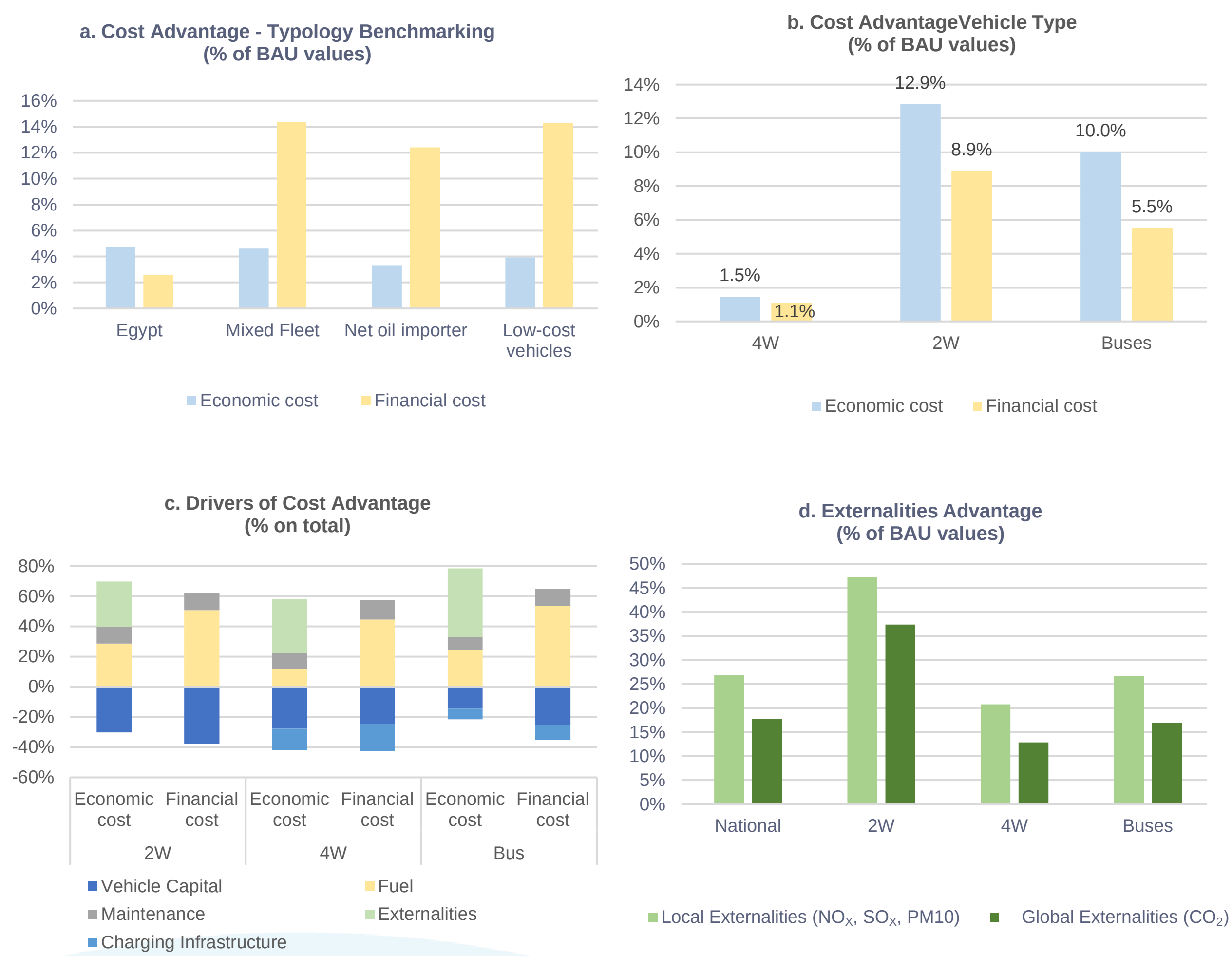


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

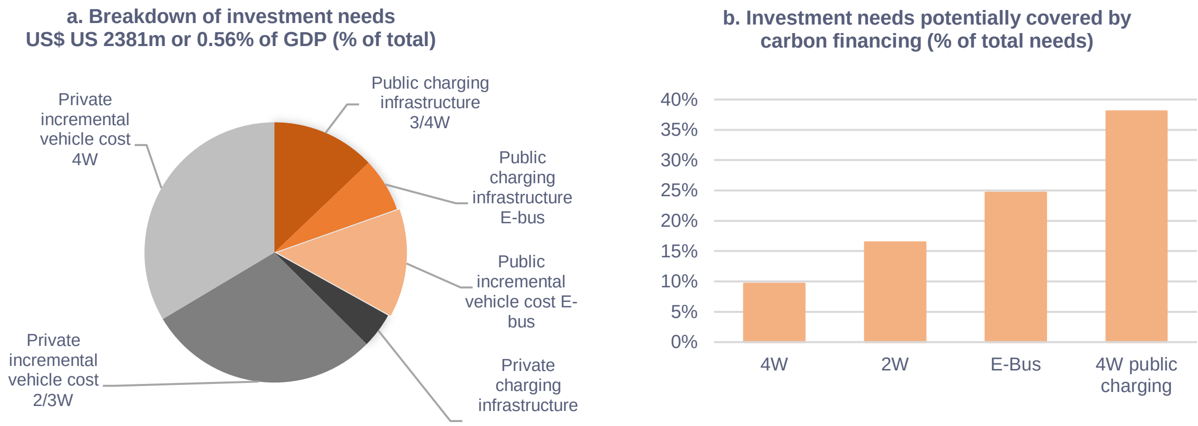


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(13,010)	(13,010)	(19,252)	(13,010)	(12,107)	1,318	(1,100)	(1,100)
Vehicle maintenance cost	5,053	5,053	4,630	5,053	7,065	7,371	406	(818)
Vehicle fuel cost	10,247	10,247	10,247	6,029	20,514	23,670	474	1,895
Private charging infrastructure	(752)	(752)	(752)	(752)	-	-	(144)	(144)
Public charging infrastructure	(3,355)	(3,355)	(3,355)	(3,355)	(6,036)	(6,036)	(423)	(481)
Sub-total	**(1,817)**	**(1,817)**	**(8,483)**	**(6,035)**	**9,437**	**26,324**	**(787)**	**(649)**
Local externalities	16,640	23,228	16,640	13,733	33,680	38,905	1,255	5,550
Global externalities	2,378	2,593	2,378	1,781	4,470	5,167	161	672
Economic cost advantage	**17,201**	**24,004**	**10,536**	**9,479**	**47,587**	**70,395**	**629**	**5,573**
Fiscal wedge	10,165	10,165	8,885	10,178	8,806	14,152	1,256	4,072
Financial cost advantage	**8,347**	**8,347**	**402**	**4,143**	**18,243**	**40,476**	**469**	**3,422**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	629	629	(96)	(168)				
2W	266	266	195	230				
E-bus	47,587	47,587	40,459	32,698				

TABLE 3: Supporting Information on Parameters and Results

Parameters	**Value**	**Parameters**	**Value**	**Other results for 30x30 Scenario**	**Value**
Price of 4W ICE (US$/vehicle)	25,777	4W mileage (kms)	20,000	Overall investment needs (US$m)	2,381
Price of 4W EV (US$/vehicle)	29,790	2W mileage (kms)	7,000	-of which 4W purchase	799
Price of 2W ICE (US$/vehicle)	913	Bus mileage (kms)	65,000	-of which 2W purchase	548
Price of 2W EV (US$/vehicle)	1,249	4W lifetime (years)	20	-of which e-bus purchase	320
Price of bus ICE (US$/vehicle)	114,338	2W lifetime (years)	7	Fiscal impact (US$m)	(1,414)
Price of bus EV (US$/vehicle)	160,359	Bus lifetime (years)	20	-of which vehicle duties	335
Net tax difference on 4W EV (%)	0%	4W second hand (%)	5.6%	-of which vehicle taxes/subsidies	(370)
Net tax difference on 2W EV (%)	0%	2W second hand (%)	5.6%	-of which petrol taxes/subsidies	(296)
Net tax difference on E-bus (%)	0%	Bus second hand (%)	30.8%	-of which diesel taxes/subsidies	254
Price of petrol (US$/liter)	0.48	Efficiency 4W ICE (MJ/km)	2.36	-of which electricity taxes/subsidies	(1,336)
Net petrol tax (US$/liter)	0.09	Efficiency 4W EV (MJ/km)	0.93	Implicit carbon price ($/tonne)	(161)
Price of diesel (US$/liter)	0.61	Efficiency 2W ICE (MJ/km)	0.85	-of which for 4W	(75)
Net diesel tax (US$/liter)	(0.07)	Efficiency 2W EV (MJ/km)	0.11	-of which for 2W	(181)
Price of electricity (US$/kWh)	0.15	Efficiency bus ICE (MJ/km)	15.58	-of which for buses	(249)
Net electricity tax (US$/kWh)	(0.08)	Efficiency bus EV (MJ/km)	3.78	Pollution reduction (tons)	13
Electricity carbon intensity (g/kWh)	464	4W share (% pax-kms)	42%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	27%	- of which global (CO_2)	13
		Bus share (% pax-kms)	25%	Affordability of 2W EV (Δ cost % GNI pc)	5%
				Affordability of 4W EV (Δ cost % GNI pc)	17%

Country at a Glance – Passenger Electric Mobility in Ethiopia

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	IMPORTER	HIGH

Country Background

The vehicle fleet in Ethiopia is quite diverse, about half of the fleet is buses (49.7 percent), followed by cars (22.8 percent), three-wheelers (16.5 percent) and two-wheelers (11.0 percent)[1]. Close to 100 percent of the electricity comes from renewable sources hydro (95.64 percent) and wind (3.96 percent).[2] Adoption of electric mobility has been very limited in Ethiopia and is particularly difficult due to the country's high reliance on imported second-hand vehicles, almost all of them more than 11 years old[3]. Other challenges include[4] the lack of electric vehicle charging facilities and skill shortages in the local labor market for production and maintenance of electric vehicles. The Ethiopian government developed a Climate Resilient Green Economy strategy, which promotes a shift towards more sustainable urban transport including investment in the light-rail transit and bus rapid transit systems, and also emphasizes the use of hybrid and plug-in electric vehicles[5]. Moreover, the Ethiopian Federal Environmental Protection Authority (EPA), together with a private organization, launched a UNDP supported Electric Vehicles pilot project in Ethiopia in 2013, while a private Ethiopian transit and cargo company has announced their plan to establish an electric bicycle assembly plant in Ethiopia[6].

Overall Messages

Despite facing relatively expensive vehicle costs, the case for electric mobility in Ethiopia benefits from the dominance of buses in the vehicle fleet, as well as the country's status as an oil importer (Figure 1a). While the overall case for electric mobility in the country is good (Table 2), this is entirely attributable to the favorable balance of economic benefits for the electrification of buses, which leads to a modest lifecycle cost advantage of a few percentage points. In contrast to many other countries, the case for 2W electric vehicles in Ethiopia is very marginal, given a capital cost premium of more than 25 percent which represents a share of around 5 percent of GNI per capita (Table 3). The capital cost premium for 4W electric vehicles also exceeds 3 percent and is equivalent to over 23 percent of GNI per capita (Table 3).

The externality benefits of electric mobility in Ethiopia are relatively small (Figure 1c), perhaps due to the existing prevalence of hydro energy and limited urban air quality issues. Across all vehicle types, it is 2W electric vehicles that present the greatest advantage on externalities relative to their conventional counterparts (Figure 1d). Otherwise, fuel cost savings are the main advantage associated with electric mobility in Ethiopia, particularly for 2Ws and buses. The fiscal regime neither incentivizes nor disincentivizes the purchase of electric vehicles. However, fiscal policies do accentuate the fuel cost advantage of owning them; given that petrol is taxed at around 25 percent, while electricity is heavily subsidized. Consequently, the overall case for electric mobility in Ethiopia looks better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$333 million per year by 2030 (or 0.2 percent of Ethiopian GDP). About half of the required outlay is associated with the incremental capital cost of private electric vehicles and the remaining half is mainly public investment associated with charging infrastructure for electric buses (Figure 2a). Given that implicit carbon prices associated with electric buses in Ethiopia are negative (Table 3), there is significant scope to cover 25-60 percent of associated public investment costs through carbon financing arrangements. However, for 4W electric vehicles, the implicit carbon price exceeds US$300 per ton.

The overall economic case for electric mobility in Ethiopia is robust to more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), neither is there much scope for further decarbonization of the power sector (Green Grid Scenario). On a positive note, the emerging advantage associated with electrification of buses can be as much as doubled through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, the case for electrification of 4Ws remains negative even for taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). It is clear that electric mobility in Ethiopia needs to focus primarily on public transportation.

[1] Source: Ethiopia Information Communication Technology Directorate.
[2] Source: Generation mix comes from a combination of US EIA international database and WB data.
[3] Source: https://energymonitor.ai/sector/transport/africas-bumpy-road-to-an-electric-vehicle-future
[4] Source: https://ethiopianmonitor.com/2020/10/01/ministry-pins-hope-on-electric-vehicles-to-cut-pollution/
[5] Source: Ethiopia's Climate Resilient Green Economy, Green Economy Strategy, 2011.
[6] Source: https://www.meetup.com/Electric-Bicycles/messages/boards/thread/35923732?_cookie-check=LJZ-i4y3hgS88ueT

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption
BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle										% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g			
	Charging Infrastructure	***Vehicle Capital Cost***	***Vehicle Operating Cost***	***Sub-Total***	***Local Externality***	***Global Externality***	***Cost Advantage (Economic Analysis)***	***Net Taxes and Subsidies (Fiscal Wedge)***	***Cost Advantage including Fiscal Wedge (Financial Advantage)***		***Cost Advantage (Economic Analysis)***	***Cost Advantage including Fiscal Wedge (Financial Advantage)***
2W	*0*	*(172)*	*129*	(43)	*0*	*23*	(20)	*223*	180		(1.2)	9.2
4W	*(142)*	*(1,173)*	*376*	(939)	*0*	*64*	(875)	*1,093*	154		(4.3)	0.6
Buses	*(1,545)*	*(3,375)*	*6,809*	1,890	*8*	*1,320*	3,217	*10,787*	12,676		1.3	5.0

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

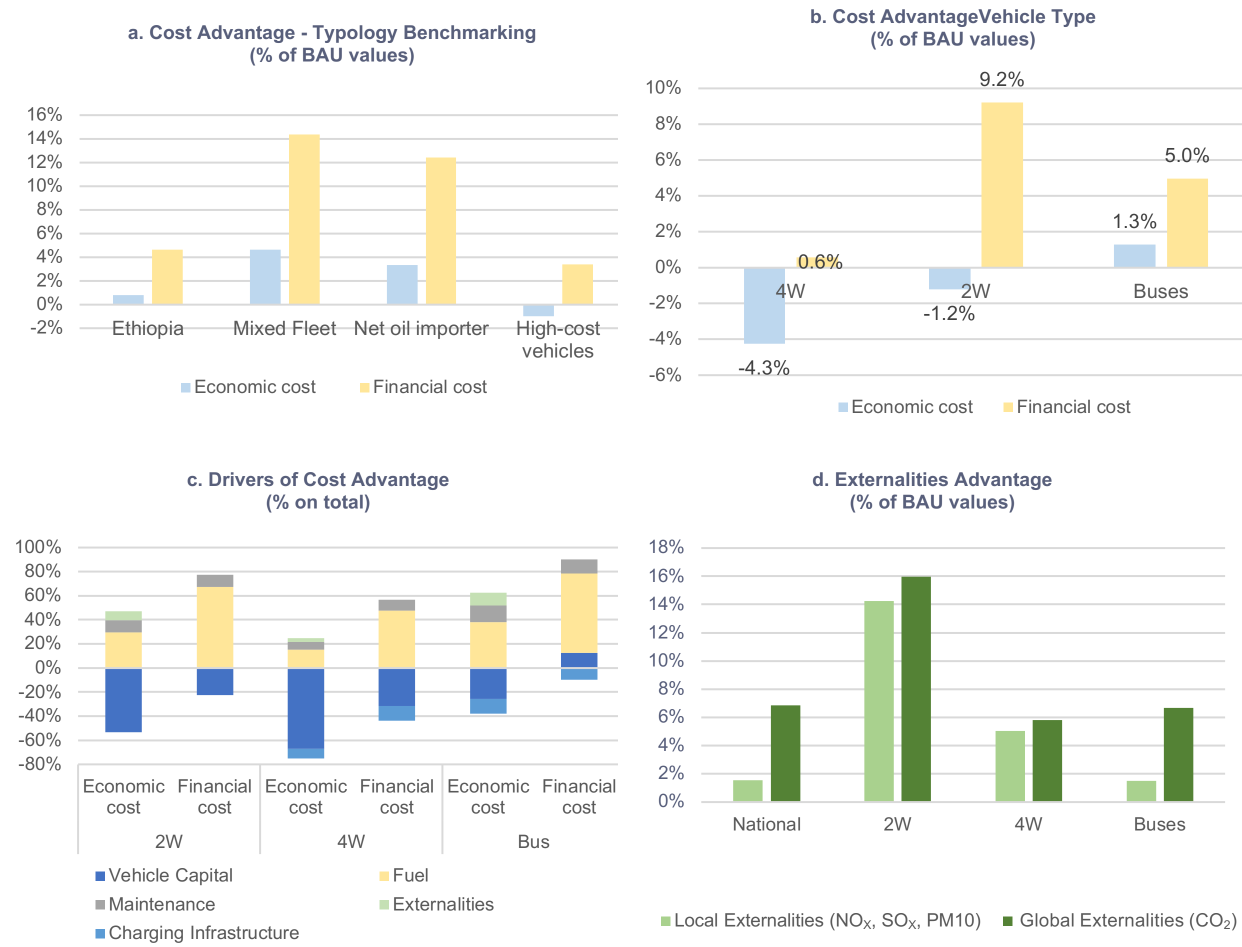


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

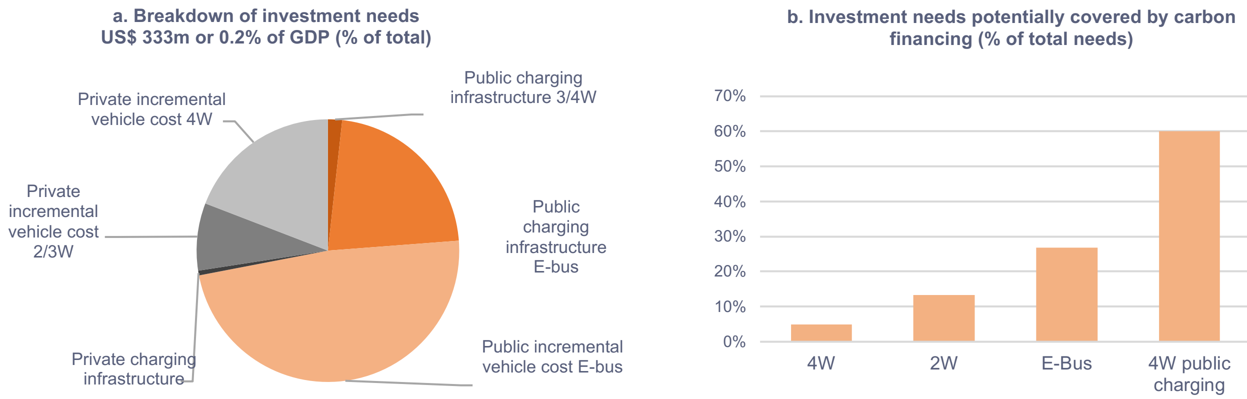


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(4,692)	(4,692)	(6,170)	(4,692)	(3,375)	101	(1,173)	(1,173)
Vehicle maintenance cost	1,838	1,838	1,341	1,838	1,822	1,898	105	(198)
Vehicle fuel cost	5,082	5,082	5,082	3,239	4,987	6,222	271	1,082
Private charging infrastructure	(36)	(36)	(36)	(36)	-	-	(36)	(36)
Public charging infrastructure	(1,476)	(1,476)	(1,476)	(1,476)	(1,545)	(1,545)	(106)	(121)
Sub-total	**715**	**715**	**(1,260)**	**(1,128)**	**1,890**	**6,677**	**(939)**	**(445)**
Local externalities	7	7	7	7	8	10	0	0
Global externalities	1,323	1,323	1,323	1,114	1,320	1,651	64	263
Economic cost advantage	**2,045**	**2,045**	**70**	**(6)**	**3,217**	**8,337**	**(875)**	**(182)**
Fiscal wedge	11,359	11,359	11,295	11,311	10,787	12,289	1,093	1,956
Financial cost advantage	**12,074**	**12,074**	**10,036**	**10,183**	**12,676**	**18,966**	**154**	**1,511**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(875)	(875)	(1,147)	(1,001)				
2W	(20)	(20)	(47)	(33)				
E-bus	3,217	3,217	1,386	1,092				

TABLE 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	33,232	4W mileage (kms)	15,224	Overall investment needs (US$m)	333
Price of 4W EV (US$/vehicle)	37,988	2W mileage (kms)	7,627	-of which 4W purchase	64
Price of 2W ICE (US$/vehicle)	1,129	Bus mileage (kms)	48,092	-of which 2W purchase	21
Price of 2W EV (US$/vehicle)	1,593	4W lifetime (years)	22	-of which e-bus purchase	160
Price of bus ICE (US$/vehicle)	164,688	2W lifetime (years)	17	Fiscal impact (US$m)	(609)
Price of bus EV (US$/vehicle)	135,324	Bus lifetime (years)	20	-of which vehicle duties	(301)
Net tax difference on 4W EV (%)	80%	4W second hand (%)	91.8%	-of which vehicle taxes/subsidies	(10)
Net tax difference on 2W EV (%)	80%	2W second hand (%)	91.8%	-of which petrol taxes/subsidies	(11)
Net tax difference on E-bus (%)	80%	Bus second hand (%)	91.1%	-of which diesel taxes/subsidies	(9)
Price of petrol (US$/liter)	0.58	Efficiency 4W ICE (MJ/km)	2.43	-of which electricity taxes/subsidies	(279)
Net petrol tax (US$/liter)	0.16	Efficiency 4W EV (MJ/km)	5.34	Implicit carbon price ($/tonne)	(14)
Price of diesel (US$/liter)	0.73	Efficiency 2W ICE (MJ/km)	0.86	-of which for 4W	380
Net diesel tax (US$/liter)	0.01	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	49
Price of electricity (US$/kWh)	0.13	Efficiency bus ICE (MJ/km)	16.66	-of which for buses	(37)
Net electricity tax (US$/kWh)	(0.10)	Efficiency bus EV (MJ/km)	5.60	Pollution reduction (tons)	3
Electricity carbon intensity (g/kWh)	0.4	4W share (% pax-kms)	6%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	4%	- of which global (CO_2)	3
		Bus share (% pax-kms)	85%	Affordability of 2W EV (Δ cost % GNI pc)	4.9%
				Affordability of 4W EV (Δ cost % GNI pc)	23.9%

World Bank (2022), Scoping Tool

Country at a Glance – Passenger Electric Mobility in Ghana

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	EXPORTER	LOW

Country Background

The vehicle fleet in Ghana is diverse. Less than half of the fleet is cars (47.3 percent), followed by buses (37.6 percent), three-wheelers (9.8 percent) and two-wheelers (5.3 percent)[1]. Electricity was generated from both renewable sources (50.7 percent) and from fossil fuels (49.3 percent) in 2018. Hydro (50.3 percent) is the largest renewable source for electricity generation and gas (49.3 percent) is the main fossil fuel source[2]. Ghana does not have any policies that explicitly promote electric vehicles. The country's National Transport Policy mainly focuses on mass transportation[3]. However, the Government of Ghana, with the assistance of the Climate Technology Centre and Network (CTCN), started drafting an electric mobility policy in 2020[4], and adopted several promotional initiatives.[5] Ghana's Energy Commission launched the Drive Electric Initiative in 2019 to promote EV uptake. POBAD International partnered with the national power utility company, the Electricity Company of Ghana (ECG), to install EV charging stations across Ghana. In the first phase of the project, POBAD is expected to install a total of 200 chargers across southern Ghana. At the same time, SolarTaxi Ghana has started offering EV leasing services, and has already established three solar charging stations across the country with more planned.

Overall Messages

Despite being an oil exporter, Ghana presents some other conditions that are quite favorable to electric mobility, including access to relatively low-cost vehicles and a diversified vehicle fleet (Figure 1a). As a result, the overall economics of electric mobility in the country is good (Table 2). There is a particularly strong case for adoption of 2W electric motorbikes (Figure 1b), which present a lifecycle cost advantage of almost 15 percent (almost 20 percent in financial terms); compared with more marginal lifecycle cost advantages of 1-2 percent for electric 2Ws and buses. The capital cost premiums associated with electric vehicles in Ghana are relatively modest, standing at 20-25 percent for 2Ws and buses, and as low as 3 percent for 4Ws (Table 3). All things considered, the additional cost of an electric 2W represents no more than 1-2 percent of GNI per capita and may be affordable with some provision of credit, while for 4Ws the extra vehicle cost represents almost 9 percent of GNI per capita.

The externality benefits of electric mobility are relatively small (Figure 1c), perhaps due to the prevalence of hydro energy and limited urban air quality issues. An important exception is provided by 2W electric vehicles, which present much lower externalities than their conventional counterparts (Figure 1d). Otherwise, fuel cost savings are the main advantage associated with electric mobility. The fiscal regime is neutral to the purchase of electric vehicles. However, fiscal policies do accentuate the fuel cost advantage of owning them; given that petrol and diesel are taxed at around 40 percent, while electricity is slightly subsidized. Consequently, the overall case for electric mobility in Ghana looks better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$192 million per year by 2030 (or 0.18 percent of Ghanaian GDP). Over three quarters of this investment is associated with the incremental capital cost of electric buses and their charging infrastructure, hence falling on the public sector (Figure 2a). Given that implicit carbon prices associated with electric 2Ws in Ghana are strongly negative (Table 3), there is potential to cover a significant part (70 percent for 2W) of the incremental capital cost of such vehicles through carbon financing arrangements (Figure 2b).

The overall economic case for electric mobility in Ghana is robust to more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario) and only improves as the country's power grid shifts further towards renewable energy (Green Grid Scenario). On a positive note, the emerging advantage associated with electrification of buses can be as much as tripled through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). This is largely due to the relatively low existing mileage of buses at under 50,000 kilometers per year (Table 3). Moreover, the case for electrification of 4Ws, which does not offer cost advantage for private vehicles, becomes economically attractive for taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). In sum, the electrification of 2Ws in Ghana clearly makes a lot of economic sense, albeit they comprise a relatively small share of the fleet. At the same time, the electrification of buses and commercial 4W vehicles also shows promise, as long as it is targeted towards the most intensively used vehicle segments.

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[1] Source: Ghana Revenue Authority.
[2] Source: Generation mix comes from a combination of US EIA international database and WB data.
[3] Source: Ghana Project Scoping, E-Mobility Options, Wuppertal Institute, UN Habitat, UN environment, Urban Pathways, 2018.
[4] Source: https://www.ctc-n.org/news/ctcn-ghana-developing-national-policy-e-mobility
[5] Source: https://cleantechnica.com/2020/12/08/the-electricity-company-of-ghana-pobad-international-partner-to-install-ev-charging-stations-in-ghana/

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption
BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle										% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g			
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*		*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(71)*	*290*	219	*7*	*49*	275	*220*	439		13.9	18.7
4W	*(232)*	*(290)*	*413*	(110)	*8*	*72*	(30)	*332*	222		(0.1)	0.8
Buses	*(3,675)*	*(7,738)*	*13,212*	1,800	*568*	*2,681*	5,048	*11,965*	13,765		1.8	4.1

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

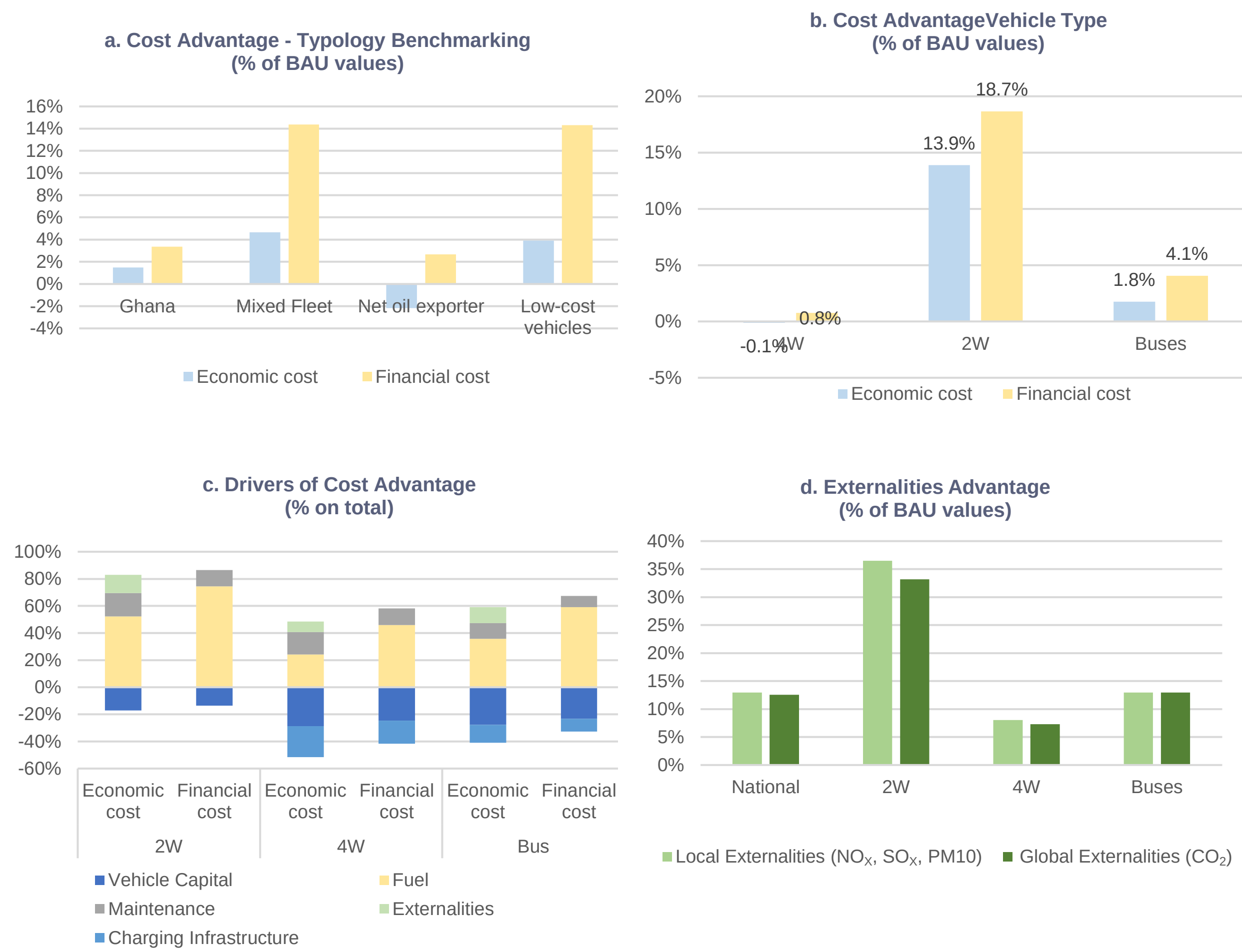

FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

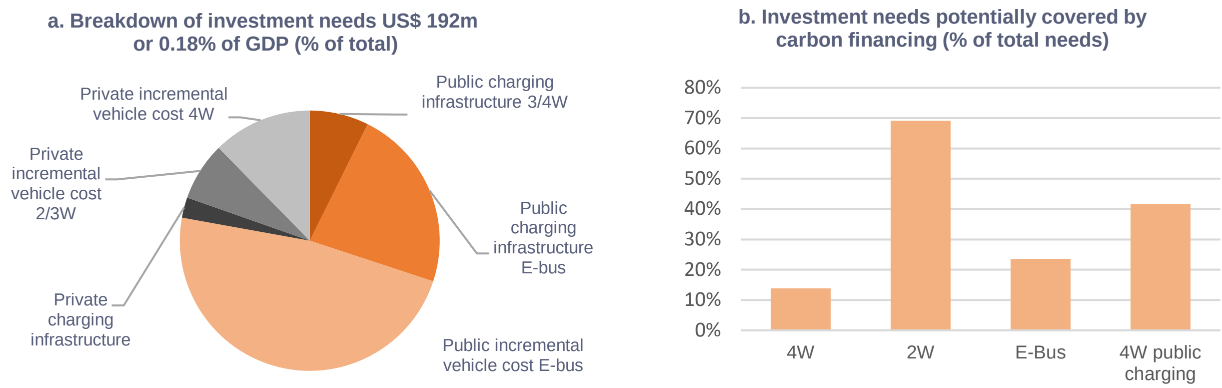

TABLE 2. Sensitivity Analysis Results – Cost Advantages

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(6,241)	(6,241)	(8,741)	(6,241)	(7,738)	(1,367)	(290)	(290)
Vehicle maintenance cost	2,826	2,826	1,772	2,826	3,251	3,649	167	(338)
Vehicle fuel cost	8,020	8,020	8,020	5,589	9,961	12,427	245	981
Private charging infrastructure	(234)	(234)	(234)	(234)	-	-	(59)	(59)
Public charging infrastructure	(2,783)	(2,783)	(2,783)	(2,783)	(3,675)	(3,675)	(172)	(197)
Sub-total	**1,587**	**1,587**	**(1,966)**	**(843)**	**1,800**	**11,034**	**(110)**	**97**
Local externalities	398	445	398	368	568	708	8	33
Global externalities	2,096	2,302	2,096	1,819	2,681	3,350	72	296
Economic cost advantage	**4,081**	**4,334**	**528**	**1,344**	**5,048**	**15,093**	**(30)**	**427**
Fiscal wedge	9,346	9,346	8,944	8,390	11,965	16,341	332	1,447
Financial cost advantage	**10,933**	**10,933**	**6,978**	**7,547**	**13,765**	**27,375**	**222**	**1,544**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(30)	(20)	(292)	(183)				
2W	275	278	249	254				
E-bus	5,048	5,365	879	1,476				

TABLE 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	26,183	4W mileage (kms)	15,400	Overall investment needs (US$m)	192
Price of 4W EV (US$/vehicle)	29,071	2W mileage (kms)	7,627	-of which 4W purchase	24
Price of 2W ICE (US$/vehicle)	904	Bus mileage (kms)	48,092	-of which 2W purchase	4
Price of 2W EV (US$/vehicle)	1,219	4W lifetime (years)	22	-of which e-bus purchase	92
Price of bus ICE (US$/vehicle)	118,214	2W lifetime (years)	17	Fiscal impact (US$m)	(193)
Price of bus EV (US$/vehicle)	153,085	Bus lifetime (years)	20	-of which vehicle duties	17
Net tax difference on 4W EV (%)	0%	4W second hand (%)	93.4%	-of which vehicle taxes/subsidies	6
Net tax difference on 2W EV (%)	0%	2W second hand (%)	93.4%	-of which petrol taxes/subsidies	(28)
Net tax difference on E-bus (%)	0%	Bus second hand (%)	94.7%	-of which diesel taxes/subsidies	(166)
Price of petrol (US$/liter)	0.58	Efficiency 4W ICE (MJ/km)	2.41	-of which electricity taxes/subsidies	(23)
Net petrol tax (US$/liter)	0.26	Efficiency 4W EV (MJ/km)	5.68	Implicit carbon price ($/tonne)	(24)
Price of diesel (US$/liter)	0.73	Efficiency 2W ICE (MJ/km)	0.88	-of which for 4W	37
Net diesel tax (US$/liter)	0.28	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	(119)
Price of electricity (US$/kWh)	0.14	Efficiency bus ICE (MJ/km)	17.31	-of which for buses	(23)
Net electricity tax (US$/kWh)	(0.01)	Efficiency bus EV (MJ/km)	5.91	Pollution reduction (tons)	2
Electricity carbon intensity (g/kWh)	203	4W share (% pax-kms)	24%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	4%	- of which global (CO2)	2
		Bus share (% pax-kms)	55%	Affordability of 2W EV (Δ cost % GNI pc)	2.2%
				Affordability of 4W EV (Δ cost % GNI pc)	9.0%

Country at a Glance – Passenger Electric Mobility in India

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	IMPORTER	LOW

Country Background

The dominant vehicle type in India is two-wheelers[1] (73.0 percent), followed by cars (15.3 percent), three-wheelers (8.5 percent) and buses (3.2 percent)[2]. Electricity is primarily generated from fossil fuels (79.5 percent), with the balance of renewable energy coming mostly from hydro (8.6 percent).[3]The electric vehicle industry is growing rapidly, supported by public incentives and financial and industrial policy schemes launched by both central and state governments. The most emblematic program is the FAME (in phase II) that includes explicit policies in support of automakers, innovative practices of procurement and demand aggregation and the inception of risk mitigation instruments to attract commercial financing. The National Electric Mobility Mission Plan 2020, developed in 2013, addresses the issues of national energy security, vehicular pollution, growth of domestic manufacturing capabilities[4], and emphasize the use of hybrid and electric vehicles[5]. The Government has plans to make a significant shift to electric vehicles by 2030[6], prompting the Ministry of Power to issue guidelines and standards for charging infrastructure for electric vehicles in 2018 [7]. Moreover, the National Energy Policy (NEP) aims to increase the share of non-fossil fuel-based capacity in the electricity mix to more than 40% by 2030[8].

Overall Messages

India presents many of the country characteristics most favorable to the adoption of electric mobility, including relatively low vehicle costs, a highly diversified fleet, and oil importing status (Figure 1a). In addition, the vast scale of the Indian market helps to drive down costs and makes possible domestic production. As a result, the overall case for electric mobility is good (Table 2). There is a particularly strong case for adoption of 2W electric motorbikes (Figure 1b), which present a lifecycle cost advantage of over 20 percent (over 40 percent in financial terms). The case for electrification of buses is also moderately supported, while electric 4Ws are not yet economically attractive (Figure 1b). Nevertheless, the capital cost premium for electric 2W vehicles in India is around 5 percent and represents as much as 1.2 percent of GNI per capita, suggesting that provision of credit lines may be important to support adoption.

The externality benefits of electric mobility in India are relatively small (Figure 1c), despite the existing prevalence of coal-fired power and serious urban air quality issues. Nevertheless, both electric 2Ws and buses are able to reduce externalities by around 20 percent, and buses have a particularly large effect on local externalities (Figure 1d). Otherwise, fuel cost savings are the main advantage associated with electric mobility in India. Not only does the fiscal regime incentivize the purchase of electric vehicles with a tax differential of minus 32 percent, but it also accentuates the fuel cost savings of electric vehicles, given that petrol and diesel are heavily taxed between 40-100 percent even as electricity is subsidized by about 40 percent (Table 3). Consequently, the overall case for electric mobility in India looks better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$22.4 billion per year by 2030 (or 0.44 percent of Indian GDP). Over two thirds of the required outlay is associated with the incremental capital cost of 2W and 4W electric vehicles borne by the private sector (Figure 2a). In terms of public investment, the most significant item is the provision of charging infrastructure for both buses and private vehicles (Figure 2a). Given that implicit carbon prices associated with electric 2Ws in India is negative (Table 3), there is significant scope to cover 26 percent of the incremental capital costs through carbon financing arrangements (Figure 2b). Although implicit carbon prices for buses are similarly negative, the potential for carbon finance is quite small relative to incremental capital costs. By contrast, for 4W electric vehicles, implicit carbon price is approaching an exorbitant US$700 per ton.

The overall economic case for electric mobility in India is robust to more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario) and improves somewhat under further decarbonization of the power sector (Green Grid Scenario) (Table 2). On a positive note, the emerging advantage associated with electrification of buses can be as much as doubled through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, the case for electrification of 4Ws remains unfavorable even for taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). It is clear that electric mobility in India needs to prioritize the massive 2W segment of the fleet, which offers so many strong advantages, while working towards further improving the case for electrification of buses.

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[1] Two wheelers cover all motorized two-wheeler vehicles registered.
[2] Source: MOPSI (2018) India Statistical Yearbook India Ministry of Road Transport & Highways (2020) Vahan 4.0 Dashboard.
[3] Source: Generation mix comes from a combination of US EIA international database and the World Bank data.
[4] Source: India Prime Minister today unveiled the National Electric Mobility Mission Plan (NEMMP) 2020. Press Information Bureau, Government of India. Retrieved 15 August 2015.
[5] Source: https://www.drishtiias.com/daily-updates/daily-news-analysis/national-electric-mobility-mission-2020
[6] Source: https://web.archive.org/web/20160916145621/http://www.horizons.gc.ca/eng/content/india-planning-reach-100-electric-vehicles-2030
[7] Source: Charging Infrastructure for Electric Vehicles Revised Guideline Standards, Ministry of Power, Government of India, 2019.
[8] Source: Draft National Energy Policy, NITI Aayog, Government of India, 2017.

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption
BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(199)*	*680*	481	*54*	*53*	589	*1,252*	1,733	21.4	43.8
4W	*(568)*	*(1,412)*	*983*	(997)	*17*	*33*	(947)	*2,731*	1,733	(3.2)	4.5
Buses	*(6,104)*	*(14,027)*	*27,370*	7,239	*3,094*	*1,310*	11,644	*29,988*	37,227	3.6	9.7

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

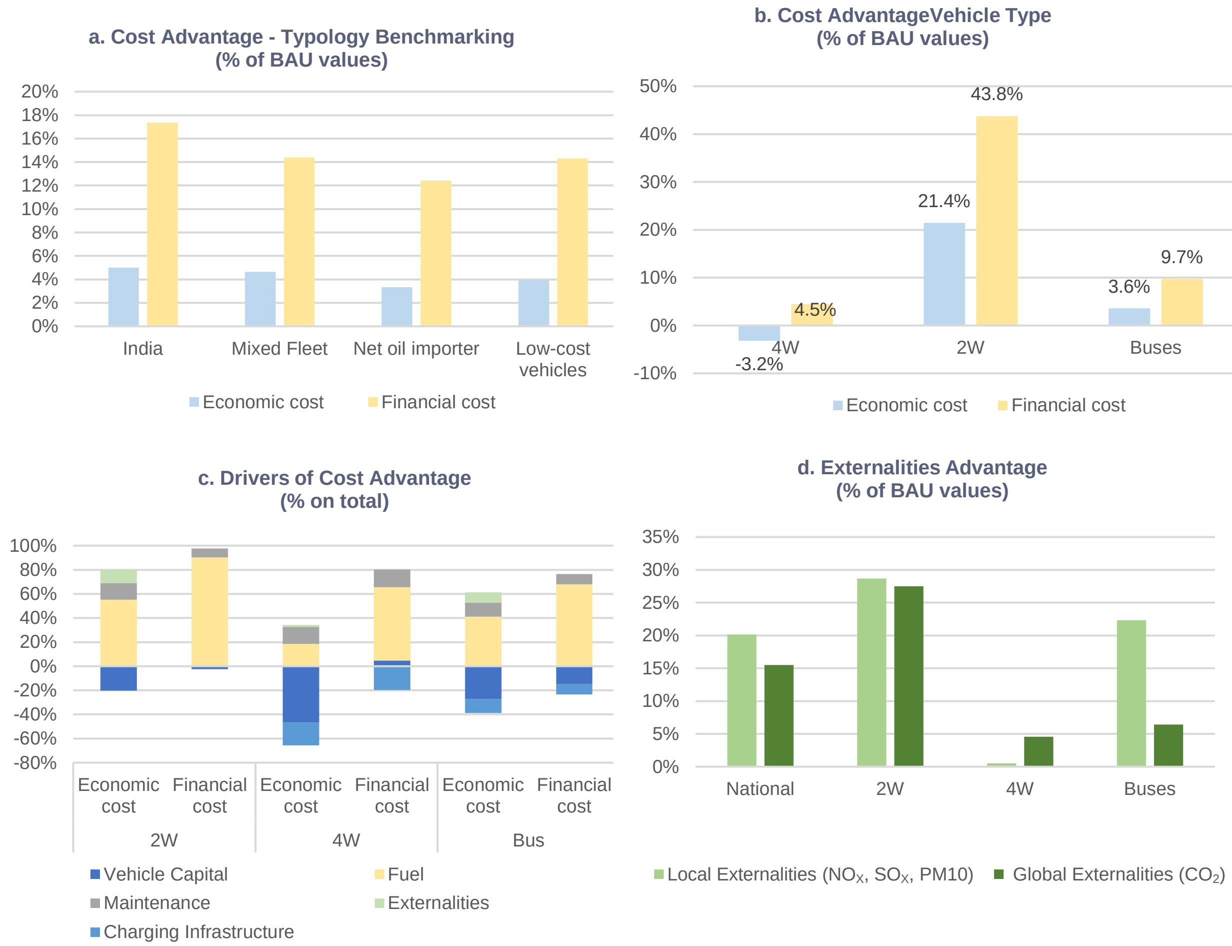

FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

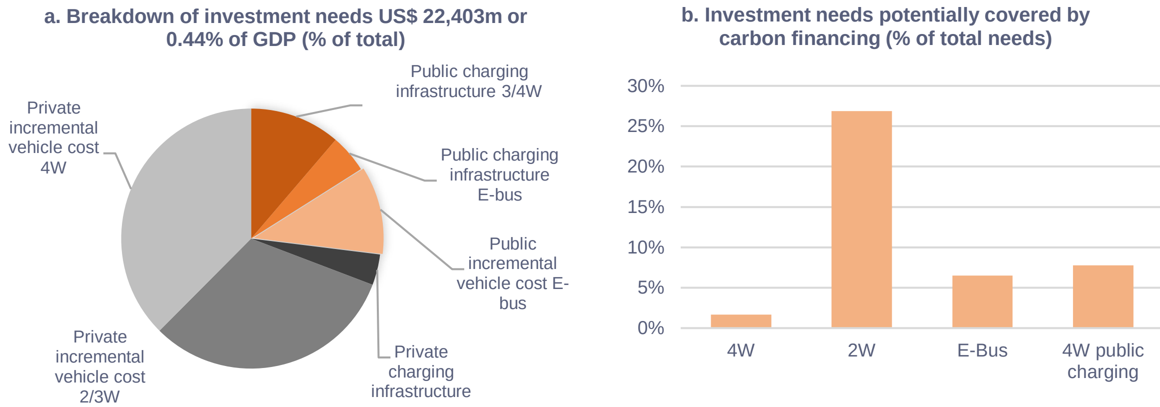

TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(12,207)	(12,207)	(16,662)	(12,207)	(14,027)	(288)	(1,412)	(1,412)
Vehicle maintenance cost	5,465	5,465	5,201	5,465	6,017	6,317	424	(798)
Vehicle fuel cost	17,752	17,752	17,752	14,637	21,353	22,500	559	2,236
Private charging infrastructure	(582)	(582)	(582)	(582)	-	-	(144)	(144)
Public charging infrastructure	(2,441)	(2,441)	(2,441)	(2,441)	(6,104)	(6,104)	(424)	(483)
Sub-total	**7,986**	**7,986**	**3,268**	**4,871**	**7,239**	**22,426**	**(997)**	**(601)**
Local externalities	1,666	2,141	1,666	1,596	3,094	3,261	17	92
Global externalities	1,549	2,356	1,549	1,168	1,310	1,384	33	161
Economic cost advantage	**11,201**	**12,483**	**6,483**	**7,634**	**11,644**	**27,071**	**(947)**	**(349)**
Fiscal wedge	43,109	43,109	42,622	40,804	29,988	32,513	2,731	6,284
Financial cost advantage	**51,095**	**51,095**	**45,890**	**45,675**	**37,227**	**54,939**	**1,733**	**5,683**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(947)	(867)	(1,561)	(1,239)				
2W	589	618	528	524				
E-bus	11,644	13,807	4,408	4,029				

TABLE 3: Supporting Information on Parameters and Results

Parameters	**Value**	**Parameters**	**Value**	**Other results for 30x30 Scenario**	**Value**
Price of 4W ICE (US$/vehicle)	22,275	4W mileage (kms)	12,200	Overall investment needs (US$m)	22,403
Price of 4W EV (US$/vehicle)	20,451	2W mileage (kms)	12,800	-of which 4W purchase	8,410
Price of 2W ICE (US$/vehicle)	783	Bus mileage (kms)	71,175	-of which 2W purchase	6,375
Price of 2W EV (US$/vehicle)	843	4W lifetime (years)	22	-of which e-bus purchase	2,449
Price of bus ICE (US$/vehicle)	100,420	2W lifetime (years)	17	Fiscal impact (US$m)	(63,410)
Price of bus EV (US$/vehicle)	142,090	Bus lifetime (years)	20	-of which vehicle duties	(14,881)
Net tax difference on 4W EV (%)	32%	4W second hand (%)	0%	-of which vehicle taxes/subsidies	98
Net tax difference on 2W EV (%)	33%	2W second hand (%)	0%	-of which petrol taxes/subsidies	(34,687)
Net tax difference on E-bus (%)	23%	Bus second hand (%)	0%	-of which diesel taxes/subsidies	(5,178)
Price of petrol (US$/liter)	0.57	Efficiency 4W ICE (MJ/km)	1.86	-of which electricity taxes/subsidies	(8,761)
Net petrol tax (US$/liter)	0.55	Efficiency 4W EV (MJ/km)	0.65	Implicit carbon price ($/tonne)	(161)
Price of diesel (US$/liter)	0.73	Efficiency 2W ICE (MJ/km)	0.65	-of which for 4W	769
Net diesel tax (US$/liter)	0.29	Efficiency 2W EV (MJ/km)	0.15	-of which for 2W	(259)
Price of electricity (US$/kWh)	0.11	Efficiency bus ICE (MJ/km)	10.82	-of which for buses	(204)
Net electricity tax (US$/kWh)	(0.04)	Efficiency bus EV (MJ/km)	3.66	Pollution reduction (tons)	89
Electricity carbon intensity (g/kWh)	648	4W share (% pax-kms)	20%	- of which local (SOx, NOx, PM10)	1
Discount rate (%)	6.6%	2W share (% pax-kms)	56%	- of which global (CO2)	88
		Bus share (% pax-kms)	17%	Affordability of 2W EV (Δ cost % GNI pc)	1.2%
				Affordability of 4W EV (Δ cost % GNI pc)	-3.6%

Country at a Glance – Passenger Electric Mobility in Jamaica

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
CAR DOMINANT	IMPORTER	HIGH

Country Background

The dominant vehicle type in Jamaica is cars (95.8 percent)[1]. As of 2018, electricity was primarily generated from fossil fuels (87.0 percent), essentially oil, with the balance coming from renewable sources (13.0 percent), notably wind (7.2 percent) and hydro (4.2 percent).[2]. Jamaica is at an early stage of electric mobility adoption and gradually gaining traction, with the government currently drafting supportive legislation and several promotional initiatives are underway.[3] For instance, with assistance from the Inter-American Development Bank, the country is due to introduce 200 electric vehicles and provide training to 400 individuals on maintenance and safety practices. Furthermore, the Jamaica Public Service Company installed a public electric charging station at Drax Hall, St Ann, with plans for five additional ones by the end of 2021 in the island's two cities, Kingston and Montego Bay, as well as in other urban centers.

Overall Messages

Due to relatively high-cost vehicles and a fleet dominated by cars, Jamaica does not present very favorable conditions for the adoption of electric mobility (Figure 1a). Nevertheless, the case for electric mobility is quite strong in the much smaller niches of 2Ws and buses (Table 1). There is a particularly strong case for adoption of 2W electric motorbikes (Figure 1b), which present a lifecycle cost advantage of 10 percent (16 percent in financial terms). Nevertheless, the capital cost premium for electric 2W vehicles in Jamaica is particularly high at almost 40 percent and represents as much as 7 percent of GNI per capita, suggesting that provision of credit lines would be essential to support adoption. At the same time, electric buses are beginning to offer modest economic advantages of the order of 3 percent of lifecycle cost. By contrast, the economics of electric 4W vehicles is consistently negative, given the large capital cost premium of such vehicles approaching 6 percent, which is prohibitive representing almost 37 percent of GNI per capita. This represents a major hurdle to the electrification of transport in Jamaica, given that 4W vehicles represent almost the totality of the fleet.

The externality benefits of electric mobility in Jamaica are relatively small (Figure 1c), despite the prevalence of oil-fired power generation, but perhaps reflecting limited urban air quality issues. An important exception is provided by 2W electric vehicles, which present much lower externalities than their conventional counterparts (Figure 1d). Otherwise, fuel cost savings are the main advantage associated with electric mobility in Jamaica. The fiscal regime neither incentivizes nor disincentivizes the purchase of electric vehicles. However, fiscal policies do accentuate the fuel cost advantage of owning them; given that petrol and diesel are taxed at 60-80 percent, while electricity is not taxed at all. Consequently, the overall case for electric mobility in Jamaica looks better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$193 million per year by 2030 (or 1.08 percent of Jamaican GDP). About four fifths of the required outlay is associated with private investment in the incremental capital cost of 4W electric vehicles (Figure 2a). In terms of public investment, the most significant item is the provision of public charging infrastructure for private vehicles (Figure 2a). Given that implicit carbon prices associated with electric buses in Jamaica are negative (Table 3), there is significant scope to cover around 30 percent of incremental public investment costs through carbon financing arrangements. However, for 4W electric vehicles, the implicit carbon price is as high as US$288 per ton.

The overall economic case for electric mobility in Jamaica remains negative under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), and even when some further decarbonization of the power sector is undertaken (Green Grid Scenario) (Table 2). On a positive note, the emerging advantage associated with electrification of buses can be as much as doubled through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, the case for electrification of 4Ws remains unsupportive even for more intensively used commercial 4W vehicles, such as taxis (Taxi Fleet Scenario). It is clear that electric mobility in Jamaica needs to focus initially on the relatively small 2W and bus segments of the fleet, which already offer considerable advantages, while awaiting more favorable cost conditions for the electrification of the bulk of the 4W vehicles.

[1] Source: Government of Jamaica, Ministry of Economic Growth and Job Creation (2015) - Biennial update report of Jamaica Global Fuel Economy Initiative (2018) Jamaica Project Overview ITF (2020) World Road Statistics
[2] Source: Generation mix comes from a combination of US EIA international database and WB data.
[3] Source: https://www.smart-energy.com/industry-sectors/electric-vehicles/jamaicas-electric-vehicle-market-set-to-take-off/

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption
BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(305)*	*458*	153	*25*	*66*	243	*458*	611	9.2	16.6
4W	*(527)*	*(2,010)*	*700*	(1,837)	*29*	*163*	(1,645)	*1,184*	(652)	(4.3)	(1.2)
Buses	*(5,759)*	*(5,219)*	*15,966*	4,989	*998*	*3,526*	9,513	*21,756*	26,745	2.8	6.0

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

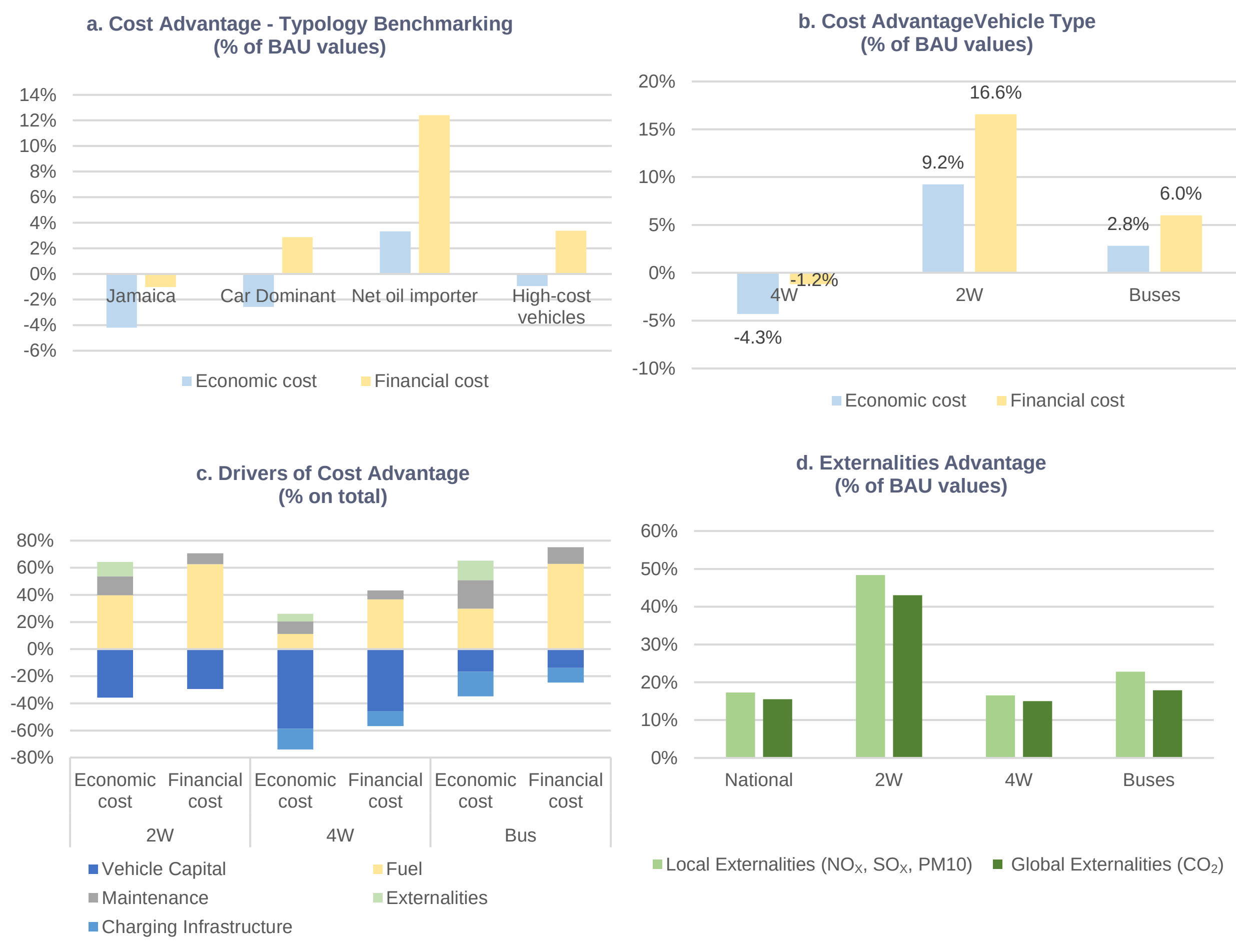

FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

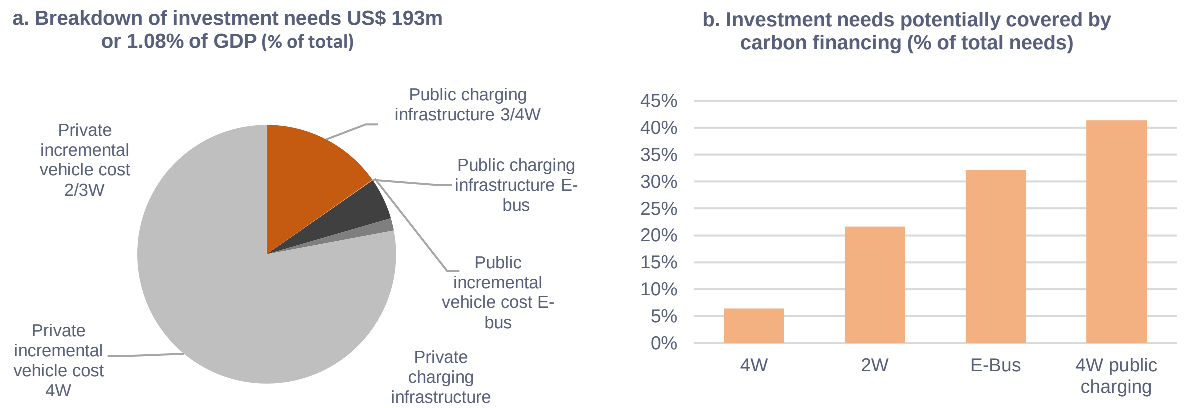

TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(27,919)	(27,919)	(39,989)	(27,919)	(5,219)	7,124	(2,010)	(2,010)
Vehicle maintenance cost	4,483	4,483	4,478	4,483	6,550	6,877	313	(826)
Vehicle fuel cost	5,895	5,895	5,895	373	9,416	9,416	387	1,548
Private charging infrastructure	(1,826)	(1,826)	(1,826)	(1,826)	-	-	(134)	(134)
Public charging infrastructure	(5,362)	(5,362)	(5,362)	(5,362)	(5,759)	(5,759)	(393)	(448)
Sub-total	**(24,729)**	**(24,729)**	**(36,804)**	**(30,251)**	**4,989**	**17,658**	**(1,837)**	**(1,869)**
Local externalities	444	605	444	361	998	998	29	119
Global externalities	2,339	2,801	2,339	1,695	3,526	3,526	163	672
Economic cost advantage	**(21,947)**	**(21,323)**	**(34,021)**	**(28,194)**	**9,513**	**22,182**	**(1,645)**	**(1,078)**
Fiscal wedge	16,993	16,993	11,898	13,158	21,756	26,866	1,184	5,317
Financial cost advantage	**(7,736)**	**(7,736)**	**(24,906)**	**(17,093)**	**26,745**	**44,524**	**(652)**	**3,447**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(1,645)	(1,601)	(2,520)	(2,097)				
2W	243	253	163	197				
E-bus	9,513	10,325	2,779	2,327				

TABLE 3: Supporting Information on Parameters and Results

Parameters	**Value**	**Parameters**	**Value**	**Other results for 30x30 Scenario**	**Value**
Price of 4W ICE (US$/vehicle)	34,758	4W mileage (kms)	17,823	Overall investment needs (US$m)	193
Price of 4W EV (US$/vehicle)	47,069	2W mileage (kms)	7,627	-of which 4W purchase	150
Price of 2W ICE (US$/vehicle)	1,280	Bus mileage (kms)	46,374	-of which 2W purchase	3
Price of 2W EV (US$/vehicle)	1,994	4W lifetime (years)	15	-of which e-bus purchase	0
Price of bus ICE (US$/vehicle)	163,704	2W lifetime (years)	17	Fiscal impact (US$m)	(93)
Price of bus EV (US$/vehicle)	175,921	Bus lifetime (years)	20	-of which vehicle duties	39
Net tax difference on 4W EV (%)	1%	4W second hand (%)	25.2%	-of which vehicle taxes/subsidies	(23)
Net tax difference on 2W EV (%)	0%	2W second hand (%)	25.2%	-of which petrol taxes/subsidies	(68)
Net tax difference on E-bus (%)	0%	Bus second hand (%)	19.7%	-of which diesel taxes/subsidies	(45)
Price of petrol (US$/liter)	0.64	Efficiency 4W ICE (MJ/km)	2.78	-of which electricity taxes/subsidies	4
Net petrol tax (US$/liter)	0.50	Efficiency 4W EV (MJ/km)	2.84	Implicit carbon price ($/tonne)	269
Price of diesel (US$/liter)	0.70	Efficiency 2W ICE (MJ/km)	0.86	-of which for 4W	288
Net diesel tax (US$/liter)	0.41	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	(69)
Price of electricity (US$/kWh)	0.16	Efficiency bus ICE (MJ/km)	16.12	-of which for buses	(44)
Net electricity tax (US$/kWh)	0.00	Efficiency bus EV (MJ/km)	5.46	Pollution reduction (tons)	0
Electricity carbon intensity (g/kWh)	261	4W share (% pax-kms)	97%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	3%	- of which global (CO_2)	0
		Bus share (% pax-kms)	0.2%	Affordability of 2W EV (Δ cost % GNI pc)	7.3%
				Affordability of 4W EV (Δ cost % GNI pc)	36.9%

Country at a Glance – Passenger Electric Mobility in Jordan

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
CAR DOMINANT	IMPORTER	HIGH

Country Background

The dominant vehicle type in Jordan is cars (84.5 percent), followed by two-wheelers[1] (13.7 percent), and buses (1.8 percent)[2]. Electricity is primarily generated from fossil fuels (88.9 percent), with very limited availability of renewable sources, mainly in the form of solar (7.4 percent) and wind (3.7 percent)[3]. The current National Green Growth Plan for Jordan identified fostering electric vehicles as a step towards achieving sustainability. The Intended Nationally Determined Contribution (INDC) makes sustainability of the sector a main pillar in the Ministry of Transport's National Transport Strategy and includes several targets to green the transport sector[4] such as: reducing fuel consumption and emissions (i.e., CO2, PM and NOx); introducing Zero-Emission Electric Vehicles (ZEV); and ensuring inclusion of energy efficiency considerations when purchasing all types of vehicle. In the public sector, the government replaced hundreds of gasoline-powered cars in its fleet with electric ones. The purchase of 151 low emission buses, including 15 battery-electric buses (BEV), is part of the rapid transit project in Amman[5]. The central region[6] has a specific advantage for higher uptake due to the availability of charging stations and maintenance centers[7].

Overall Messages

Jordan's relatively high-cost vehicles, combined with its car-dominated fleet, present a difficult set of conditions for the adoption of electric mobility (Figure 1a). As a result, the overall case for electric mobility in the country is not favorable (Table 2). Nevertheless, there is a case for adoption of 2W electric motorbikes (Figure 1b), which present a lifecycle cost advantage of close to 3 percent (approaching 30 percent in financial terms). Nevertheless, the capital cost premium for electric 2W vehicles in Jordan is around 20 percent and represents as much as 4 percent of GNI per capita, suggesting that provision of credit lines may be important to support adoption. At the same time, electric buses are beginning to offer modest economic advantages of the order of 1-2 percent of lifecycle cost. By contrast, the economics of electric 4W vehicles is not supportive, although the associated capital cost premium is only 1.5 percent of GNI per capita.

The externality benefits of electric mobility in Jordan are relatively small (Figure 1c), perhaps due to the energy mix and limited urban air quality issues. An important exception is provided by 2W electric vehicles, which present much lower externalities than their conventional counterparts, particularly in terms of local air pollution (Figure 1d). Otherwise, fuel cost savings are the main advantage associated with electric mobility in Jordan. The fiscal regime significantly incentivizes the purchase of electric vehicles, with a tax differential approaching -60 percent. Moreover, fiscal policies further accentuate the fuel cost advantage of owning them, given that petrol is heavily taxed at over 100 percent, while electricity is slightly subsidized. Consequently, the overall case for electric mobility in Jordan looks marginally favorable in financial terms even though it is negative in economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$278 million per year by 2030 (or 0.51 percent of Jordanian GDP). About four fifths of the required outlay is associated with the incremental capital cost of 4W electric vehicles accruing to private individuals (Figure 2a). In terms of public investment, the most significant item is the provision of public charging infrastructure for private vehicles (Figure 2a). The potential for carbon finance of such investments is minimal (Figure 2b). Indeed, the implicit carbon price for 4W electric vehicles is more than US$2,000 per ton.

The overall economic case for electric mobility in Jordan is negative and this result is robust to more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), as well as more optimistic assumptions regarding the further decarbonization of the power sector (Green Grid Scenario) (Table 2). On a positive note, the emerging advantage associated with electrification of buses can be as much as tripled through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, the case for electrification of 4Ws does not improve even when attention focuses exclusively on more intensively used commercial vehicles (Taxi Fleet Scenario). The electric mobility strategy in Jordan needs to prioritize the modest 2W segment of the fleet, which offers considerable advantages, while also beginning to progress with electric buses. However, when it comes to the dominant 4W segment of the fleet, more time (or an improved vehicle procurement strategy) may be needed to allow the prohibitive vehicle costs to come down.

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[1] Two wheelers cover all motorized two-wheeler vehicles registered.
[2] Source: OICA (2020) Passenger cars sales statistics CEIC (2020) Number of Vehicles.
[3] Source: Generation mix comes from a combination of US EIA international database and the World Bank data.
[4] Source: Hashemite Kingdom of Jordan, Intended Nationally Determined Contribution (INDC) report.
[5] Source: Electric Vehicles in Jordan: Challenges and limitations, Laith Shalalfeh , Ashraf AlShalalfeh, Khaled Alkaradsheh , Mahmoud Alhamarneh, and Ahmad Bashaireh, 2021.
[6] Central region consists of Balqa, Amman, Zarqa and Madaba.
[7] Source: https://www.businesswire.com/news/home/20190906005441/en/Jordan-Electric-Vehicle-Market-Analysis-Outlook-2019-2025

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption
BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(451)*	*434*	(17)	*41*	*39*	63	*1,233*	1,216	2.6	28.3
4W	*(441)*	*(2,895)*	*633*	(2,703)	*55*	*33*	(2,615)	*3,946*	1,243	(7.6)	2.4
Buses	*(3,653)*	*(9,111)*	*14,088*	1,324	*1,836*	*1,177*	4,336	*9,086*	10,409	1.5	3.2

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

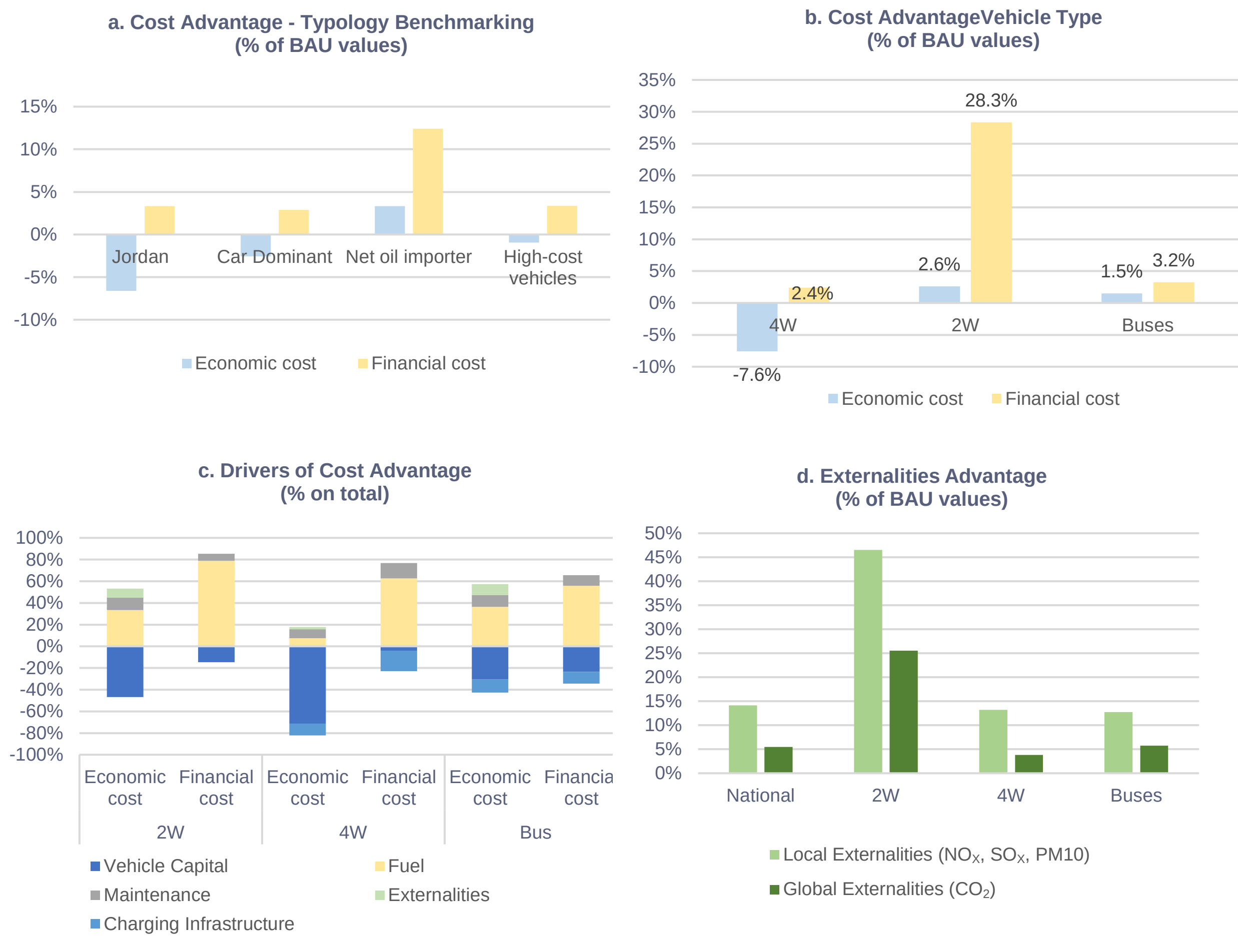


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

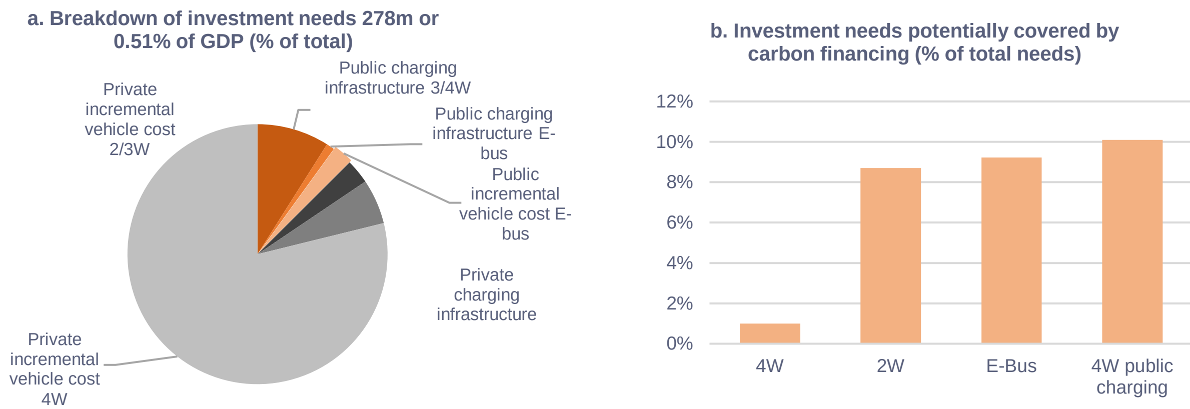


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(41,124)	(41,124)	(51,711)	(41,124)	(9,111)	(2,806)	(2,895)	(2,895)
Vehicle maintenance cost	5,356	5,356	5,114	5,356	3,216	3,614	332	(615)
Vehicle fuel cost	7,187	7,187	7,187	3,540	10,872	13,564	300	1,201
Private charging infrastructure	(1,436)	(1,436)	(1,436)	(1,436)	-	-	(111)	(111)
Public charging infrastructure	(4,722)	(4,722)	(4,722)	(4,722)	(3,653)	(3,653)	(329)	(375)
Sub-total	**(34,739)**	**(34,739)**	**(45,568)**	**(38,386)**	**1,324**	**10,719**	**(2,703)**	**(2,795)**
Local externalities	1,193	2,148	1,193	959	1,836	2,293	55	265
Global externalities	813	1,133	813	385	1,177	1,474	33	153
Economic cost advantage	**(32,733)**	**(31,458)**	**(43,562)**	**(37,041)**	**4,336**	**14,486**	**(2,615)**	**(2,377)**
Fiscal wedge	59,233	59,233	58,022	56,328	9,086	13,750	3,946	7,370
Financial cost advantage	**24,494**	**24,494**	**12,454**	**17,942**	**10,409**	**24,469**	**1,243**	**4,575**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(2,615)	(2,537)	(3,377)	(2,893)				
2W	63	77	(18)	19				
E-bus	4,336	5,813	194	718				

Table 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	39,329	4W mileage (kms)	15,224	Overall investment needs (US$m)	278
Price of 4W EV (US$/vehicle)	40,865	2W mileage (kms)	7,627	-of which 4W purchase	219
Price of 2W ICE (US$/vehicle)	1,225	Bus mileage (kms)	48,092	-of which 2W purchase	16
Price of 2W EV (US$/vehicle)	1,713	4W lifetime (years)	22	-of which e-bus purchase	7
Price of bus ICE (US$/vehicle)	157,274	2W lifetime (years)	17	Fiscal impact (US$m)	(348)
Price of bus EV (US$/vehicle)	148,856	Bus lifetime (years)	20	-of which vehicle duties	(183)
Net tax difference on 4W EV (%)	58%	4W second hand (%)	24.6%	-of which vehicle taxes/subsidies	(37)
Net tax difference on 2W EV (%)	58%	2W second hand (%)	24.6%	-of which petrol taxes/subsidies	(102)
Net tax difference on E-bus (%)	58%	Bus second hand (%)	66.9%	-of which diesel taxes/subsidies	(13)
Price of petrol (US$/liter)	0.60	Efficiency 4W ICE (MJ/km)	2.16	-of which electricity taxes/subsidies	(14)
Net petrol tax (US$/liter)	0.86	Efficiency 4W EV (MJ/km)	1.83	Implicit carbon price ($/tonne)	1,067
Price of diesel (US$/liter)	0.74	Efficiency 2W ICE (MJ/km)	0.86	-of which for 4W	2,058
Net diesel tax (US$/liter)	0.13	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	(15)
Price of electricity (US$/kWh)	0.14	Efficiency bus ICE (MJ/km)	17.03	-of which for buses	(69)
Net electricity tax (US$/kWh)	(0.02)	Efficiency bus EV (MJ/km)	5.69	Pollution reduction (tons)	0
Electricity carbon intensity (g/kWh)	598	4W share (% pax-kms)	78%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	9%	- of which global (CO2)	0
		Bus share (% pax-kms)	13%	Affordability of 2W EV (Δ cost % GNI pc)	4.3%
				Affordability of 4W EV (Δ cost % GNI pc)	1.5%

Country at a Glance – Passenger Electric Mobility in Kazakhstan

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
CAR DOMINANT	EXPORTER	LOW

Country Background

The dominant vehicle type in Kazakhstan is cars (92.1 percent), followed by buses (7.9 percent)[1]. Electricity is primarily generated from fossil fuels (89.1 percent) and hydropower (10.1 percent)[2] is the lead renewable energy source. One of the top priorities of the Kazakhstan 2050 Strategy is to make the country's public transport system more eco-friendly and to invest on charging infrastructure across the country. The City Almaty Sustainable Transport (CAST) project recommends the use of electricity produced from local gas to power electric vehicles[3]. In the absence of domestic manufacturing capability, Kazakhstan imports most of its vehicle fleet.[4] And while according to Kazakhstan's industry and infrastructure development ministry, approximately most of the 200 electric cars in operation in 2018 were imported, the target is to produce about 2,000 units of electric cars locally by the end of 2022.[5] The Government is already advancing an aggressive investment on charging infrastructure, having in place more than 50 charging stations in Nur-Sultan (2020)[6].

Overall Messages

Although vehicle costs are relatively low, Kazakhstan's car dominated fleet and oil exporting status create some countervailing challenges for the scale-up of electric mobility (Figure 1a). On balance, the overall case for electric mobility in the country is somewhat positive (Table 2). There is a particularly strong case for adoption of 2W electric motorbikes (Figure 1b), albeit there are very few in the fleet, because these present a lifecycle cost advantage of around 22 percent (almost 30 percent in financial terms). Moreover, the capital cost premium for electric 2W vehicles is moderate at around 17 percent, representing an affordable 0.6 percent of GNI per capita. The electrification of 4Ws does not offer lifecycle cost advantage but 4Ws are eminently affordable with a capital cost premium of less than two percent or the equivalent of little more than 2 percent of GNI per capita. On the other hand, the capital cost premium associated with electric buses is particularly high at around 51 percent, while a lifecycle cost analysis shows a modest advantage of around 2 percent.

The externality benefits of electric mobility in Kazakhstan are particularly significant in absolute value for the case of electric buses (Figure 1c); while 2W electric vehicles present much lower externalities than their conventional counterparts in percentage terms (Figure 1d). Otherwise, fuel cost savings are the main advantage associated with electric mobility. The fiscal regime neither incentivizes nor disincentivizes the purchase of electric vehicles. However, fiscal policies do accentuate the fuel cost advantage of owning them. Although fuel taxes are not particularly high – around 25 percent for petrol – electricity benefits from a 50 percent subsidy. Consequently, the overall case for electric mobility in Kazakhstan looks better in financial than economic terms (Figure 1c) for 2Ws and 4Ws.

The total investment needs associated with the 30x30 Scenario amount to US$251 million per year by 2030 (or 0.11 percent of Kazakhstan GDP). About 70 percent of the required outlay is associated with public investment in charging infrastructure (Figure 2a). Implicit carbon prices associated with electric vehicles in Kazakhstan are negative (Table 3) for 2Ws and buses. However, only in the case of electric 2Ws is there a potential for carbon finance to cover a substantial share of the incremental cost of vehicle purchase. The implicit carbon prices for 4Ws are around $93/ton.

The overall economic case for electric mobility in Kazakhstan is positive and improves substantially with further decarbonization of the power sector (Green Grid Scenario) (Table 2). However, this result is not robust to more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) nor the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), both of which tip the balance against electric mobility (Table 2). On a positive note, the emerging advantage associated with electrification of buses can be as much as doubled through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). Moreover, the case for electrification of 4Ws improved and offers cost advantage for the case of taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). Ironically, almost non-existent 2Ws are the most attractive segment for electrification in Kazakhstan. However, there is scope to advance with electrification of buses and 4Ws, as long as efforts are targeted towards more intensively used vehicles.

[1] Source: World Bank Group data
[2] Source: Generation mix comes from a combination of US EIA international database and WB data.
[3] Source: Policy review of the Development of the Public Transport Sector in Kazakhstan, UNDP/GEF, 2017.
[4] Source: https://caspiannews.com/news-detail/electric-cars-could-soon-be-mass-produced-in-kazakhstan-2019-7-11-9/
[5] Source: The Astana Times, Kazakhstan Plans to Launch Electric car production by 2021, October 2020.
[6] Source: The Astana Times, Kazakhstan Plans to Launch Electric car production by 2021, October 2020.

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption
BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle										% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g			
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*		*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(107)*	*413*	306	*152*	*46*	504	*311*	618		22.6	29.6
4W	*(540)*	*(459)*	*572*	(427)	*230*	*55*	(142)	*895*	468		(0.5)	1.7
Buses	*(3,516)*	*(11,639)*	*6,043*	(9,112)	*14,662*	*1,458*	7,008	*8,952*	(160)		2.2	(0.1)

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

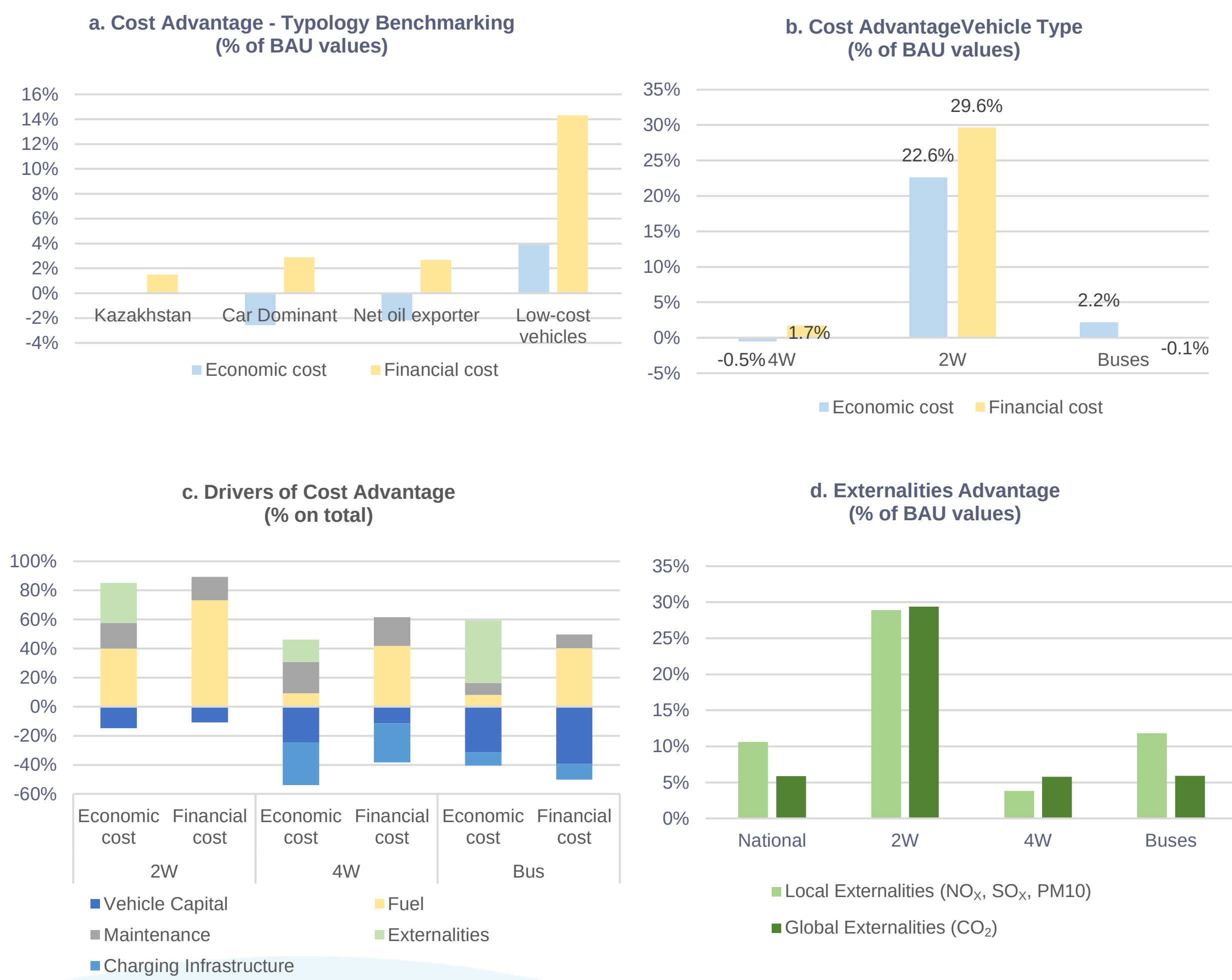


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

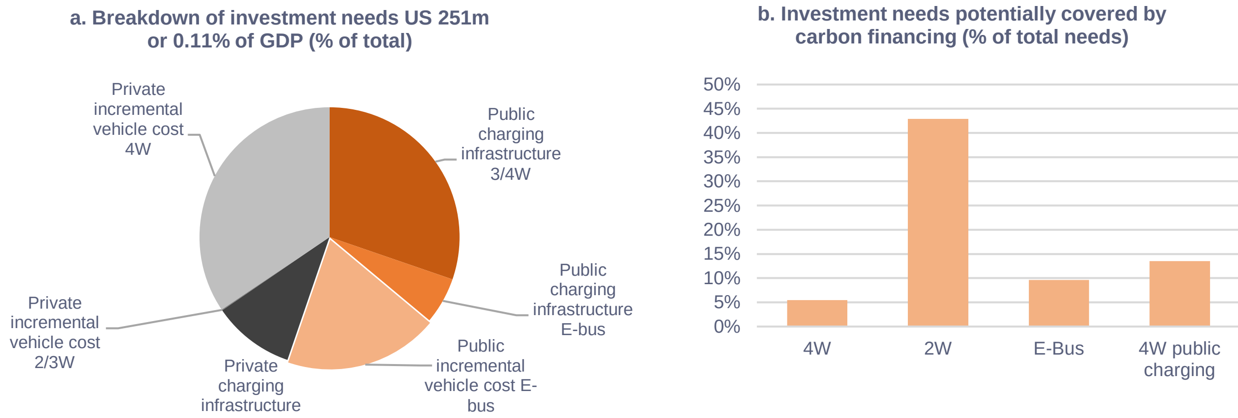


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(8,347)	(8,347)	(13,378)	(8,347)	(11,639)	(5,749)	(459)	(459)
Vehicle maintenance cost	5,448	5,448	4,982	5,448	2,993	3,397	400	(756)
Vehicle fuel cost	2,834	2,834	2,834	(492)	3,049	3,258	172	688
Private charging infrastructure	(1,587)	(1,587)	(1,587)	(1,587)	-	-	(136)	(136)
Public charging infrastructure	(5,605)	(5,605)	(5,605)	(5,605)	(3,516)	(3,516)	(404)	(459)
Sub-total	**(7,257)**	**(7,257)**	**(12,754)**	**(10,584)**	**(9,112)**	**(2,610)**	**(427)**	**(1,122)**
Local externalities	6,459	11,620	6,459	5,645	14,662	15,666	230	1,090
Global externalities	1,017	1,568	1,017	435	1,458	1,559	55	244
Economic cost advantage	**219**	**5,932**	**(5,278)**	**(4,504)**	**7,008**	**14,615**	**(142)**	**212**
Fiscal wedge	12,773	12,773	12,167	12,251	8,952	10,168	895	2,896
Financial cost advantage	**5,516**	**5,516**	**(586)**	**1,668**	**(160)**	**7,558**	**468**	**1,774**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(142)	188	(526)	(482)				
2W	504	547	466	458				
E-bus	7,008	14,272	3,038	4,075				

TABLE 3. Supporting Information on Parameters and Results

Parameters	**Value**	**Parameters**	**Value**	**Other results for 30x30 Scenario**	**Value**
Price of 4W ICE (US$/vehicle)	14,924	4W mileage (kms)	15,224	Overall investment needs (US$m)	251
Price of 4W EV (US$/vehicle)	14,525	2W mileage (kms)	7,627	-of which 4W purchase	87
Price of 2W ICE (US$/vehicle)	499	Bus mileage (kms)	56,162	-of which 2W purchase	0
Price of 2W EV (US$/vehicle)	609	4W lifetime (years)	22	-of which e-bus purchase	48
Price of bus ICE (US$/vehicle)	66,052	2W lifetime (years)	17	Fiscal impact (US$m)	(207)
Price of bus EV (US$/vehicle)	135,324	Bus lifetime (years)	20	-of which vehicle duties	(58)
Net tax difference on 4W EV (%)	12%	4W second hand (%)	11.4%	-of which vehicle taxes/subsidies	18
Net tax difference on 2W EV (%)	12%	2W second hand (%)	11.4%	-of which petrol taxes/subsidies	(31)
Net tax difference on E-bus (%)	12%	Bus second hand (%)	84.1%	-of which diesel taxes/subsidies	(11)
Price of petrol (US$/liter)	0.46	Efficiency 4W ICE (MJ/km)	2.21	-of which electricity taxes/subsidies	(125)
Net petrol tax (US$/liter)	0.12	Efficiency 4W EV (MJ/km)	1.44	Implicit carbon price ($/tonne)	20
Price of diesel (US$/liter)	0.43	Efficiency 2W ICE (MJ/km)	0.85	-of which for 4W	93
Net diesel tax (US$/liter)	0.02	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	(259)
Price of electricity (US$/kWh)	0.10	Efficiency bus ICE (MJ/km)	17.84	-of which for buses	(98)
Net electricity tax (US$/kWh)	(0.05)	Efficiency bus EV (MJ/km)	6.24	Pollution reduction (tons)	1
Electricity carbon intensity (g/kWh)	556	4W share (% pax-kms)	71%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	0.3%	- of which global (CO2)	1
		Bus share (% pax-kms)	29%	Affordability of 2W EV (Δ cost % GNI pc)	0.7%
				Affordability of 4W EV (Δ cost % GNI pc)	2.0%

Country at a Glance – Passenger Electric Mobility in Maldives

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	IMPORTER	HIGH

Country Background

The dominant vehicle type in the Maldives is two-wheelers[1] (78.4 percent), followed by cars (16.7 percent)[2]. Electricity is primarily generated from fossil fuels, essentially oil (99.6 percent), and very limited generation from renewable sources (0.4 percent), mainly wind[3]. The latest National Action Plan on Air Pollutants places emphasis on the adoption of electric vehicles in the islands and includes[4] formulating and adopting enforceable national requirements on emissions limits and standards; implementing effective programs for permitting and enforcement; developing a strategy to deploy electric vehicles, including financial mechanisms to support implementation and potential for using solar PV for charging facilities; and implementation of a demonstration project comprising 75 electric motorcycles and 200 electric bicycles. Several international entities are supporting the national Government to address air pollution issues. UNEP is providing technical assistance to the Government in adopting an integrated transport system that prioritizes non-motorized transport, as well as the introduction of electric vehicles powered by renewable energy. In addition, the Maldives is one of the countries under the Global Environment Facility (GEF) support program to shift towards electric vehicles, benefiting from a trust-funded Integrated and Low Emissions Transport project [5].

Overall Messages

The Maldives faces exceptionally high vehicle purchase costs that present a formidable barrier for the adoption of electric mobility, despite other favorable conditions, such as the country's diversified fleet and status as an oil importer (Figure 1a). As a result, there is no case for the adoption of electric mobility in the horizon to 2030 across any of the three vehicle types considered (Table 2). Although 2W electric vehicles are economically attractive in most countries, this is not true for the Maldives given that these vehicles cost over US$3,000, which represents a cost premium more than 76 percent over conventional counterparts before tax (although the cost gap shrinks since the Maldives relies heavily on second-hand vehicles and offers sizable tax advantages to EVs). Other vehicle categories are also exceptionally expensive.

The externality benefits of electric mobility in the Maldives are quite substantial for buses and 2W electric vehicles (Figure 1c), and are predominantly associated with reductions in local air pollution (Figure 1d). In economic terms, there is no fuel cost advantage for electric vehicles due to the exceptionally high cost of electricity on the islands (Figure 1c), approaching US$0.50 per kilowatt-hour (Table 3). However, since transportation fuel is (modestly) taxed and electricity is heavily subsidized at over 50 percent, the story changes completely in financial terms bringing a significant operating cost advantage – albeit not sufficient to offset the substantial capital cost premium (Figure 1c).

The total investment needs associated with the 30x30 Scenario amount to US$10 million per year by 2030 (or 0.13 percent of GDP). About four fifths of the required outlay is associated with the incremental capital cost of private electric vehicles (Figure 2a). Given that implicit carbon prices for electric mobility in the Maldives are over US$2,700 per ton for 4W electric vehicles and US$300-400 per ton for 2Ws and buses, the scope for carbon finance is relatively modest (Figure 2c), and the country may be better-off seeking more cost-effective means of decarbonizing the transport sector.

In sum, there is no overall economic case for electric mobility in the Maldives over the time horizon to 2030, even under a scenario of further decarbonization of the power sector (Green Grid Scenario) (Table 2). Moreover, the case deteriorates further under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario) (Table 2). Even achieving greater efficiency in the procurement and operation of electric buses fails to reverse the negative conclusion (Efficient Bus Scenario), and the outcome is similar for more intensive use of 4W vehicles (Taxi Fleet Scenario) (Table 2). The results strongly suggest that rapid adoption of electric mobility in the Maldives would be premature, across all vehicle types, and the country may be best advised to wait until capital cost premiums can be brought down further.

[1] Two wheelers cover all motorized two-wheeler vehicles registered.
[2] Source: Maldives National Bureau of statistics (2020) New Vehicle registrations 2018.
[3] Source: Generation mix comes from a combination of US EIA international database and the World Bank Group data.
[4] Source: National Action Plan on Air Pollutants, Ministry of Transport, Maldives, 2019.
[5] Source: Global Environment Facility, 2019.

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption
BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(231)*	*(234)*	(465)	*102*	*24*	(338)	*627*	162	(14.5)	7.3
4W	*(211)*	*(2,011)*	*(948)*	(3,170)	*54*	*29*	(3,087)	*3,496*	326	(10.4)	0.7
Buses	*(2,871)*	*(5,501)*	*(29,435)*	(37,807)	*27,502*	*909*	(9,397)	*39,411*	1,604	(1.8)	0.5

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

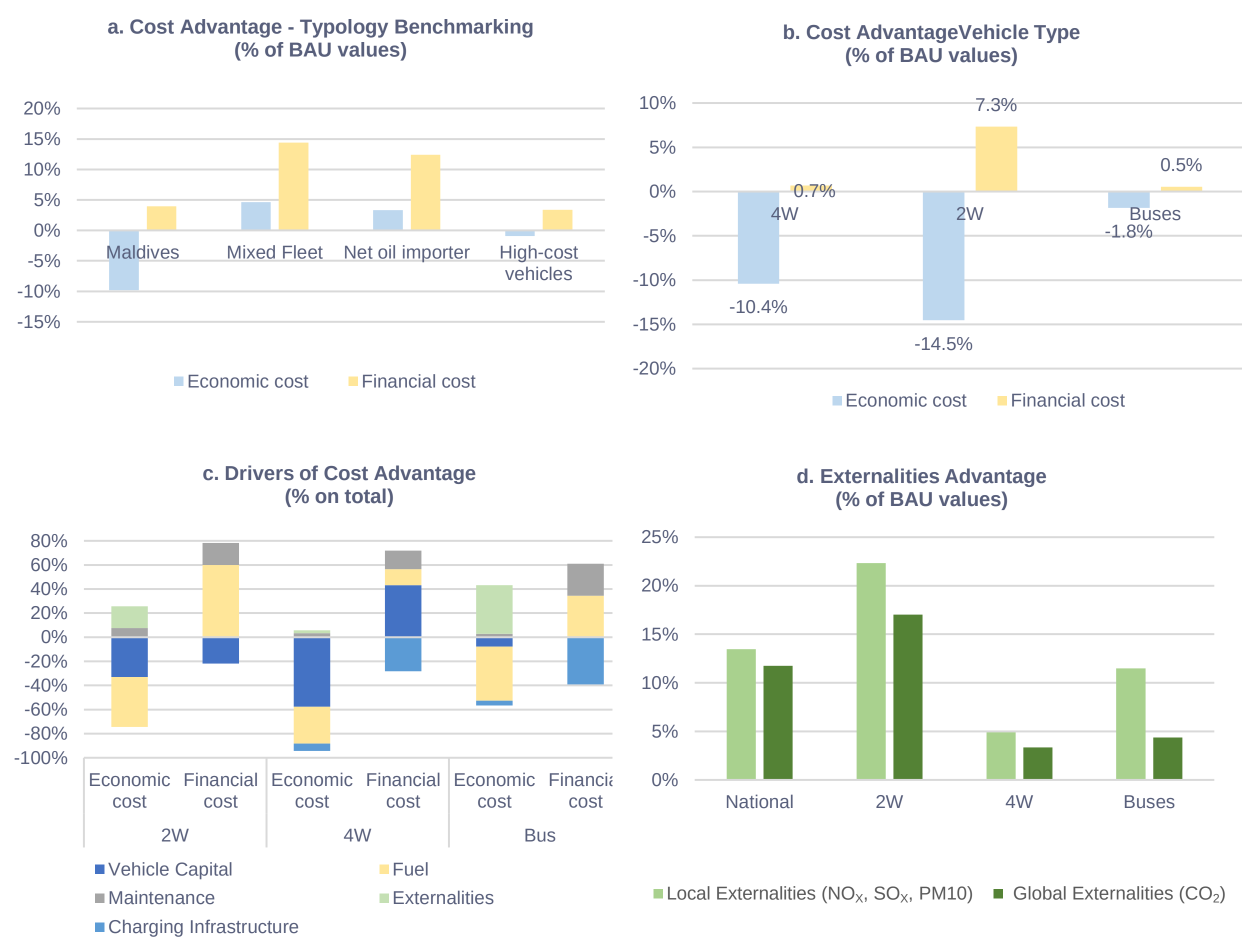
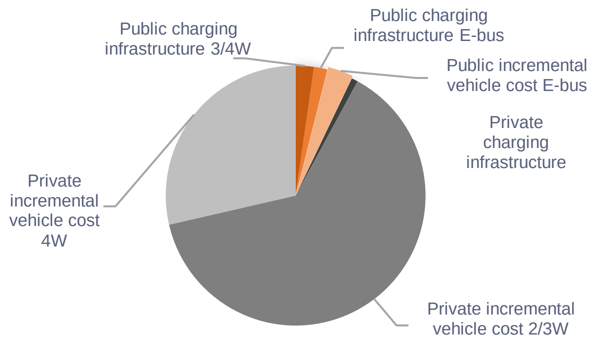


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

a. Breakdown of investment needs 10m or 0.13% of GDP (% of total)



b. Investment needs potentially covered by carbon financing (% of total needs)

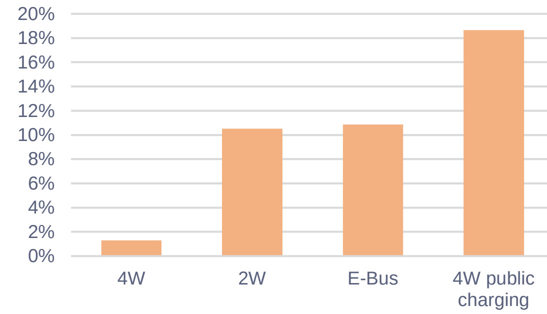


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(9,370)	(9,370)	(11,104)	(9,370)	(5,501)	(1,570)	(2,011)	(2,011)
Vehicle maintenance cost	1,784	1,784	1,686	1,784	1,943	2,373	114	(353)
Vehicle fuel cost	(13,074)	(13,074)	(13,074)	(13,610)	(31,379)	(31,379)	(1,062)	(4,249)
Private charging infrastructure	(77)	(77)	(77)	(77)	-	-	(55)	(55)
Public charging infrastructure	(386)	(386)	(386)	(386)	(2,871)	(2,871)	(156)	(178)
Sub-total	**(21,123)**	**(21,123)**	**(22,955)**	**(21,658)**	**(37,807)**	**(33,446)**	**(3,170)**	**(6,846)**
Local externalities	4,702	5,722	4,702	4,660	27,502	27,502	54	232
Global externalities	928	1,253	928	864	909	909	29	120
Economic cost advantage	**(15,492)**	**(14,148)**	**(17,325)**	**(16,134)**	**(9,397)**	**(5,035)**	**(3,087)**	**(6,494)**
Fiscal wedge	27,540	27,540	27,436	27,485	39,411	39,647	3,496	6,979
Financial cost advantage	**6,417**	**6,417**	**4,481**	**5,827**	**1,604**	**6,201**	**326**	**133**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(3,087)	(2,935)	(3,497)	(3,181)				
2W	(338)	(314)	(377)	(351)				
E-bus	(9,397)	(6,056)	(12,552)	(11,331)				

TABLE 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	35,187	4W mileage (kms)	15,224	Overall investment needs (US$m)	10.0
Price of 4W EV (US$/vehicle)	82,998	2W mileage (kms)	7,627	-of which 4W purchase	3
Price of 2W ICE (US$/vehicle)	1,584	Bus mileage (kms)	48,092	-of which 2W purchase	6
Price of 2W EV (US$/vehicle)	3,173	4W lifetime (years)	22	-of which e-bus purchase	0
Price of bus ICE (US$/vehicle)	162,258	2W lifetime (years)	17	Fiscal impact (US$m)	(28)
Price of bus EV (US$/vehicle)	143,443	Bus lifetime (years)	20	-of which vehicle duties	(1)
Net tax difference on 4W EV (%)	3%	4W second hand (%)	88.0%	-of which vehicle taxes/subsidies	(8)
Net tax difference on 2W EV (%)	12%	2W second hand (%)	88.0%	-of which petrol taxes/subsidies	(2)
Net tax difference on E-bus (%)	0%	Bus second hand (%)	93.6%	-of which diesel taxes/subsidies	(0.1)
Price of petrol (US$/liter)	0.60	Efficiency 4W ICE (MJ/km)	2.39	-of which electricity taxes/subsidies	(18)
Net petrol tax (US$/liter)	0.09	Efficiency 4W EV (MJ/km)	4.93	Implicit carbon price ($/tonne)	458
Price of diesel (US$/liter)	0.74	Efficiency 2W ICE (MJ/km)	0.88	-of which for 4W	2,774
Net diesel tax (US$/liter)	0.01	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	387
Price of electricity (US$/kWh)	0.47	Efficiency bus ICE (MJ/km)	17.81	-of which for buses	293
Net electricity tax (US$/kWh)	(0.28)	Efficiency bus EV (MJ/km)	6.10	Pollution reduction (tons)	0
Electricity carbon intensity (g/kWh)	609	4W share (% pax-kms)	9%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	38%	- of which global (CO2)	0
		Bus share (% pax-kms)	6%	Affordability of 2W EV (Δ cost % GNI pc)	0.5%
				Affordability of 4W EV (Δ cost % GNI pc)	-2.8%

Country at a Glance – Passenger Electric Mobility in Nepal

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	IMPORTER	HIGH

Country Background

The dominant vehicle type in Nepal is the two-wheelers[1] (61.4 percent), followed by three-wheelers (17.3 percent), cars (11.3 percent) and buses (10.0 percent)[2]. Moreover, 100 percent of the electricity produced in Nepal is from renewable sources, primarily hydro (98.1 percent)[3]. Nepal is quite advanced in creating a supportive policy framework for the adoption of electric mobility. The Government has developed its National Action Plan for electric mobility in 2018, which identified three priority actions[4]: (i) delivery of a National Program for Electric Mobility to facilitate electric vehicles purchase, investment in supporting infrastructure, and fast track operational progress and refine legislation; (ii) creation of a centralized regulatory and promotional unit, responsible for oversight of financial and program initiatives; and (iii) establishment of a "National Financing Vehicle" for effective management and disbursement of financial support to promote infrastructure, innovation, and entrepreneurship for electric mobility. These actions are reflected in the latest 2021 budget, which includes some key incentives to support the electric mobility adoption in the country[5]: a complete repeal of excise duties on electric vehicle imports; and reducing custom duties down to 10 percent. The current number of electric vehicles in Nepal is very limited, less than 100 electric cars are in the Kathmandu valley. There is a pilot project by Hulas Motor Company to produce small electric cars in the country. Otherwise, most of the electric vehicles are imported from India, China, and South Korea[6]. The Global Green Growth Institute (GGGI) conceptualized several investment projects for Nepal to upscale electric mobility in the country[7]: Deploying an electric trolley bus system in Kathmandu Valley; Upscaling electric vehicle battery leasing for three-wheelers; Upscaling and monetizing public access charging stations; Establishing battery recycling; and converting fossil fuel taxis to electric taxis.

Overall Messages

While Nepal faces several conditions that are less favorable towards electric mobility, notably its oil importing status and the predominance of two and three-wheelers in the vehicle fleet, these advantages are overwhelmed by the exceptionally high cost of vehicles in the country (Figure 1a). In fact, electric 2Ws and 4Ws remain at a substantial economic disadvantage relative to their conventional counterparts, and it is only in the bus segment that electrification brings modest advantages of the order of 3-4 percent of lifecycle costs (Figure 1b).

Underlying these findings is the fact that electric 2Ws and 4Ws have exceptionally high capital costs more than three times those of conventional alternatives (Table 3). Indeed, the incremental capital cost of a mere electric 2W is already enough to absorb almost 80 percent of GNI per capita, making such vehicles completely unaffordable for the population. While electric buses are also expensive by global standards, the cost differential against diesel buses is less than double (Figure 1c).

The externality benefits of electric mobility in Nepal are relatively small (Figure 1d), making fuel cost savings the main advantage associated with electric mobility. Given a fiscal regime that taxes petrol almost three times as heavily as electricity, these fuel cost savings are further accentuated in financial terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$739 million per year by 2030 (or 1.75 percent of Nepali GDP). About two thirds of the required outlay is associated with the incremental capital cost of electric vehicles, particularly two and three wheelers (Figure 2a). In terms of public investment, the most significant item is the additional capital cost associated with electric buses (Figure 2a). Implicit carbon prices associated with electric mobility in Nepal are negative for buses, but otherwise very high – above US$100 per ton for two-wheelers and US$700 per ton for four-wheelers (Table 3). The scope for carbon financing is therefore limited, except for the case of public provision of charging infrastructure for private vehicles (Figure 2b).

The overall economic case for electric mobility in Nepal is quite negative, with the notable exception of buses. The economics of electric two-wheelers and four-wheelers certainly does not improve, under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), nor is there any scope to further decarbonize a power sector that is already entirely renewable (Green Grid Scenario). On a positive note, the emerging advantage associated with electrification of buses can be hugely increased through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, there is no real case for electrification of 4Ws even when it comes to taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). It is clear that electric mobility in Nepal for the time being needs to prioritize the bus segment of the fleet, pending measures to reduce the capital costs of private vehicles.

[1] Two wheelers cover all motorized two-wheeler vehicles registered.
[2] Source: NADA - Automobiles association of Nepal (2020) Statistics of vehicle registrations in Nepal.
[3] Source: Generation mix comes from a combination of US EIA international database and WB data.
[4] Source: National Action Plan for Electric Mobility, Global Green Growth Institute, 2018.
[5] Source: https://www.nepalitimes.com/latest/new-nepal-budget-sparks-electric-comeback/
[6] Source: EV Readiness Assessment, Nepal Kathmandu, UEMI Solutions, 2018.
[7] Source: Investment Projects for E-mobility, GGGI, 2018.

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption
BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(694)*	*449*	(245)	*3*	*59*	(183)	*(344)*	(589)	(10.3)	(19.3)
4W	*(504)*	*(5,593)*	*1,276*	(4,820)	*1*	*170*	(4,649)	*(3,063)*	(7,884)	(18.5)	(13.8)
Buses	*(6,102)*	*(18,705)*	*29,789*	4,981	*637*	*3,848*	9,467	*681*	5,663	3.6	1.4

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

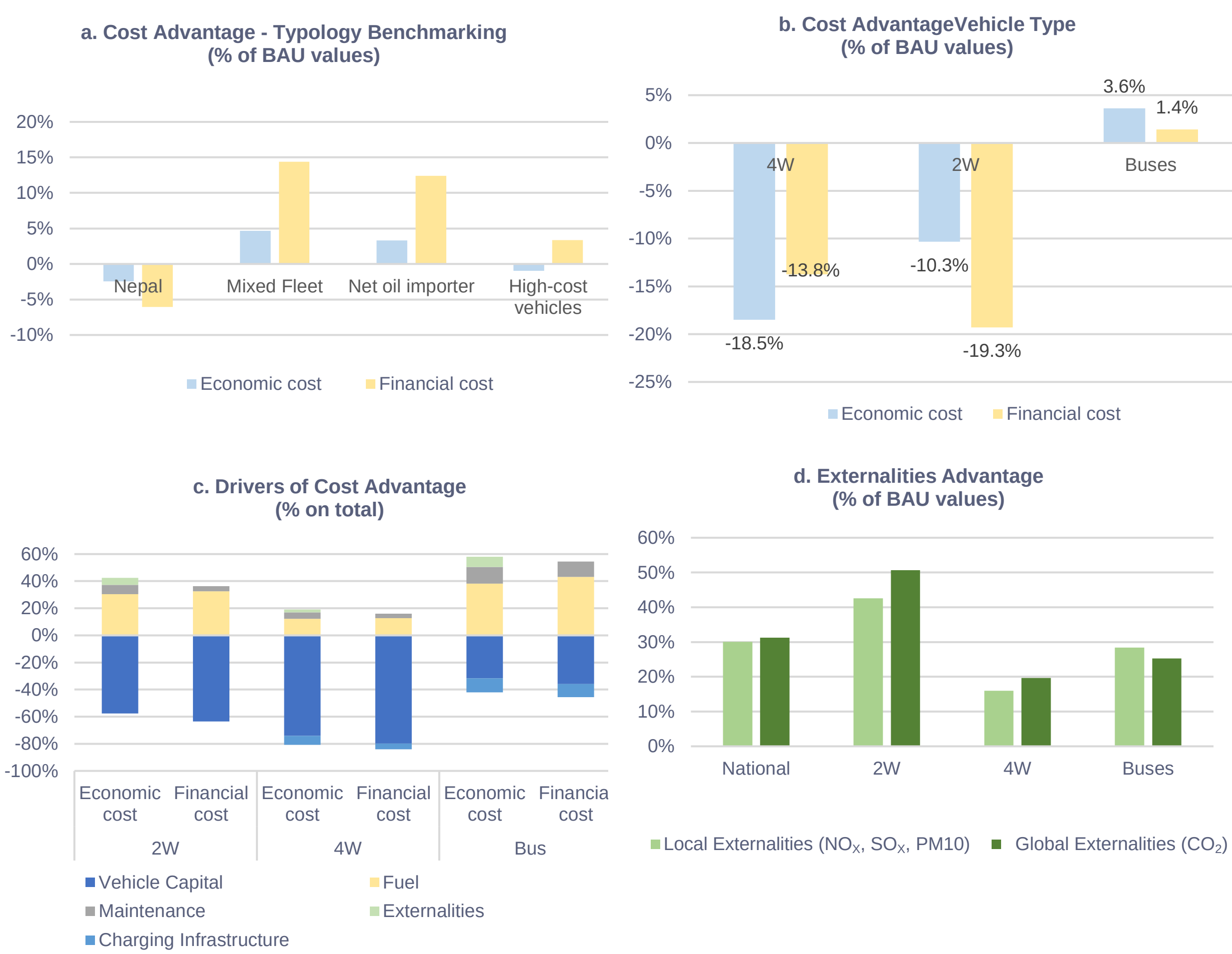
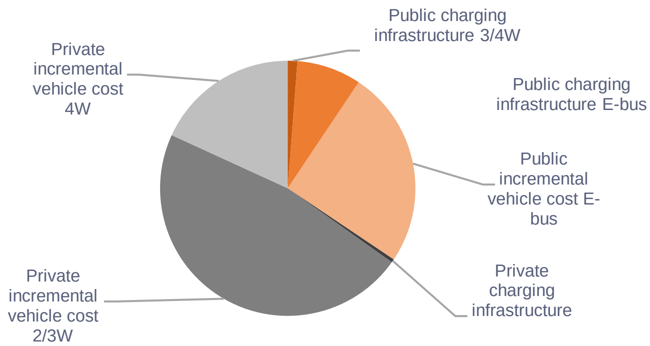


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

a. Breakdown of investment needs US 739m or 1.75% of GDP (% of total)



b. Investment needs potentially covered by carbon financing (% of total needs)

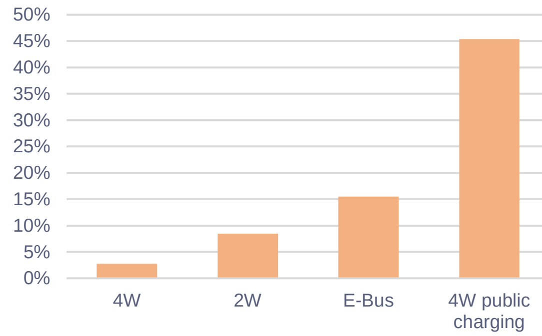


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(39,111)	(39,111)	(46,449)	(39,111)	(18,705)	(4,970)	(5,593)	(5,593)
Vehicle maintenance cost	7,174	7,174	5,887	7,174	7,200	7,500	358	(742)
Vehicle fuel cost	25,545	25,545	25,545	21,012	22,589	38,680	919	3,674
Private charging infrastructure	(182)	(182)	(182)	(182)	-	-	(130)	(130)
Public charging infrastructure	(4,070)	(4,070)	(4,070)	(4,070)	(6,102)	(6,102)	(374)	(427)
Sub-total	**(10,644)**	**(10,644)**	**(19,269)**	**(15,177)**	**4,981**	**35,107**	**(4,820)**	**(3,218)**
Local externalities	456	456	456	456	637	1,091	1	5
Global externalities	4,253	4,253	4,253	3,734	3,848	6,637	170	704
Economic cost advantage	**(5,935)**	**(5,935)**	**(14,560)**	**(10,987)**	**9,467**	**42,835**	**(4,649)**	**(2,509)**
Fiscal wedge	(13,928)	(13,928)	(22,303)	(15,420)	681	18,797	(3,063)	(1,367)
Financial cost advantage	**(24,572)**	**(24,572)**	**(41,571)**	**(30,597)**	**5,663**	**53,905**	**(7,884)**	**(4,585)**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(4,649)	(4,649)	(5,684)	(4,982)				
2W	(183)	(183)	(285)	(215)				
E-bus	9,467	9,467	2,233	3,209				

TABLE 3: Supporting Information on Parameters and Results

Parameters	**Value**	**Parameters**	**Value**	**Other results for 30x30 Scenario**	**Value**
Price of 4W ICE (US$/vehicle)	26,744	4W mileage (kms)	15,224	Overall investment needs (US$m)	739
Price of 4W EV (US$/vehicle)	84,356	2W mileage (kms)	7,627	-of which 4W purchase	134
Price of 2W ICE (US$/vehicle)	1,250	Bus mileage (kms)	35,040	-of which 2W purchase	338
Price of 2W EV (US$/vehicle)	3,537	4W lifetime (years)	20	-of which e-bus purchase	185
Price of bus ICE (US$/vehicle)	145,423	2W lifetime (years)	10	Fiscal impact (US$m)	237
Price of bus EV (US$/vehicle)	270,647	Bus lifetime (years)	20	-of which vehicle duties	666
Net tax difference on 4W EV (%)	0%	4W second hand (%)	16.4%	-of which vehicle taxes/subsidies	(198)
Net tax difference on 2W EV (%)	0%	2W second hand (%)	16.4%	-of which petrol taxes/subsidies	(195)
Net tax difference on E-bus (%)	0%	Bus second hand (%)	0.0%	-of which diesel taxes/subsidies	(80)
Price of petrol (US$/liter)	0.60	Efficiency 4W ICE (MJ/km)	2.12	-of which electricity taxes/subsidies	44
Net petrol tax (US$/liter)	0.43	Efficiency 4W EV (MJ/km)	1.45	Implicit carbon price ($/tonne)	62
Price of diesel (US$/liter)	0.74	Efficiency 2W ICE (MJ/km)	0.86	-of which for 4W	734
Net diesel tax (US$/liter)	0.16	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	107
Price of electricity (US$/kWh)	0.08	Efficiency bus ICE (MJ/km)	15.63	-of which for buses	(38)
Net electricity tax (US$/kWh)	0.02	Efficiency bus EV (MJ/km)	5.19	Pollution reduction (tons)	3
Electricity carbon intensity (g/kWh)	0	4W share (% pax-kms)	9%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	44%	- of which global (CO_2)	3
		Bus share (% pax-kms)	41%	Affordability of 2W EV (∆ cost % GNI pc)	78.7%
				Affordability of 4W EV (∆ cost % GNI pc)	527.6%

Country at a Glance – Passenger Electric Mobility in Nigeria

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	EXPORTER	HIGH

Country Background

The vehicle fleet in Nigeria is quite mixed though slightly over half is cars (51.8 percent), followed by buses (26.6 percent), and two-wheelers[1] (21.7 percent)[2]. Electricity is primarily generated from gas (81.3 percent), with most of the remainder being hydro (18.5 percent)[3]. There are no electric mobility policies and strategies developed for the country. PPIAF is supporting the country to develop an integrated electric mobility strategy and pilot models. The key components of that support include[4]: (i) development of an integrated e-mobility strategy, using renewable energy solutions; (ii) design of a pilot integrated e-mobility model for using clean powered electric public transport (along Bus Rapid Transport corridors) in the City of Lagos for subsequent replication in other parts of the country; (iii) development of an integrated e-mobility strategy and plan for rural areas of Nigeria; and (iv) assessment of market opportunities and investment barriers for private sector investment and operation of electric transport services and charging infrastructure. The Government is receiving support from the Climate Technology Centre and Network (UNEP) to assess the market readiness for electric vehicles, developing policy recommendations, creating a business case for EV deployment and capacity building & awareness program for stakeholders[5]. Nigeria's first locally assembled electric car, the Hyundai Kona, was officially unveiled by the Federal Government through the National Automotive Design and Development Council (NADDC) in 2021[6]. Additionally, NADDC installed a fully solar powered EV charging station in the country[7].

Overall Messages

Despite having a relatively diversified fleet, Nigeria faces many conditions that are less favorable towards electric mobility, including relatively high-cost vehicles, and energy exporting status (Figure 1a). While electrification of transport looks to be economically favorable as a national strategy (Table 2), this is driven entirely by private vehicles – and in particular 2Ws which present a lifecycle cost advantage of as much as 15 percent (Figure 1b). Underlying these results are relatively low capital cost differentials for private electric vehicles of around 10 percent for 4Ws and 30 percent for 2Ws. Not only are these capital cost differentials low in absolute terms, but they are also relatively affordable for the population. An important reason for this is the fact that, Nigeria relies heavily on imported second-hand vehicles. Hence, it is relevant to note that electric vehicles depreciate more rapidly than conventional ones, to a point where they may be cheaper to buy on a second-hand basis. Electric buses, on the other hand, remain marginally unattractive in economic terms, despite very low capital cost differentials of just five percent.

The externality benefits of electric mobility in Nigeria are relatively small (Figure 1c), with fuel cost savings representing the main advantage associated with electric mobility. However, given a fiscal regime that unusually taxes electricity more heavily than either petrol or diesel, these fuel cost savings are eroded; which is why the overall case for electric mobility in Nigeria looks better in economic than financial terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$438 million per year by 2030 (or 0.08 percent of Nigerian GDP). About four fifths of the required outlay is associated with the incremental public investment in electric buses and associated charging infrastructure (Figure 2a). Given that implicit carbon prices associated with electric 2Ws and 4Ws in Nigeria is strongly negative (Table 3), there is ample scope to cover incremental investment costs in private vehicles through carbon financing arrangements. However, in the case of electric buses, the implicit carbon price exceeds US$100 per ton.

The overall positive economic case for electric mobility in Nigeria, only improves when further action is taken to decarbonize the electricity sector (Green Grid Scenario); and can also withstand a scenario where internal combustion engine vehicles become more efficient (Fuel Efficiency Scenario) (Table 2). However, the case for electric mobility is reversed under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario). On a positive note, the negative balance for electric buses can be turned positive through the more efficient procurement and operation of vehicles (Efficient Bus Scenario); while the case for electric 4Ws only improves for the case of intensively used commercial vehicles (Taxi Fleet Scenario). Thus, electric mobility in Nigeria is likely to proceed with private vehicles, pending measures to make buses more efficient.

[1] Two wheelers cover all motorized two-wheeler vehicles registered.
[2] Source: OICA (2020) Passenger cars sales statistics Nigeria bureau of statistics (2020) Road transport data Q4 2018.
[3] Source: Generation mix comes from a combination of US EIA international database and WB data.
[4] Source: https://ppiaf.org/activity/nigeria-sustainable-green-e-mobility-solutions-0
[5] Source: https://www.ctc-n.org/technical-assistance/projects/developing-national-emobility-policy-and-framework-deploying-and
[6] Source: https://nairametrics.com/2021/02/05/naddc-moves-to-unveil-nigerias-first-electric-vehicle/
[7] Source: https://www.thecable.ng/nigeria-launches-first-solar-powered-charging-station-for-electric-vehicles

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle										% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g			
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*		*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(12)*	*254*	243	*5*	*42*	290	*(27)*	216		15.0	12.3
4W	*(342)*	*308*	*1,043*	1,009	*20*	*178*	1,206	*29*	1,038		3.9	3.2
Buses	*(2,668)*	*(6,418)*	*5,222*	(3,863)	*126*	*764*	(2,973)	*(938)*	(4,801)		(2.2)	(3.5)

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

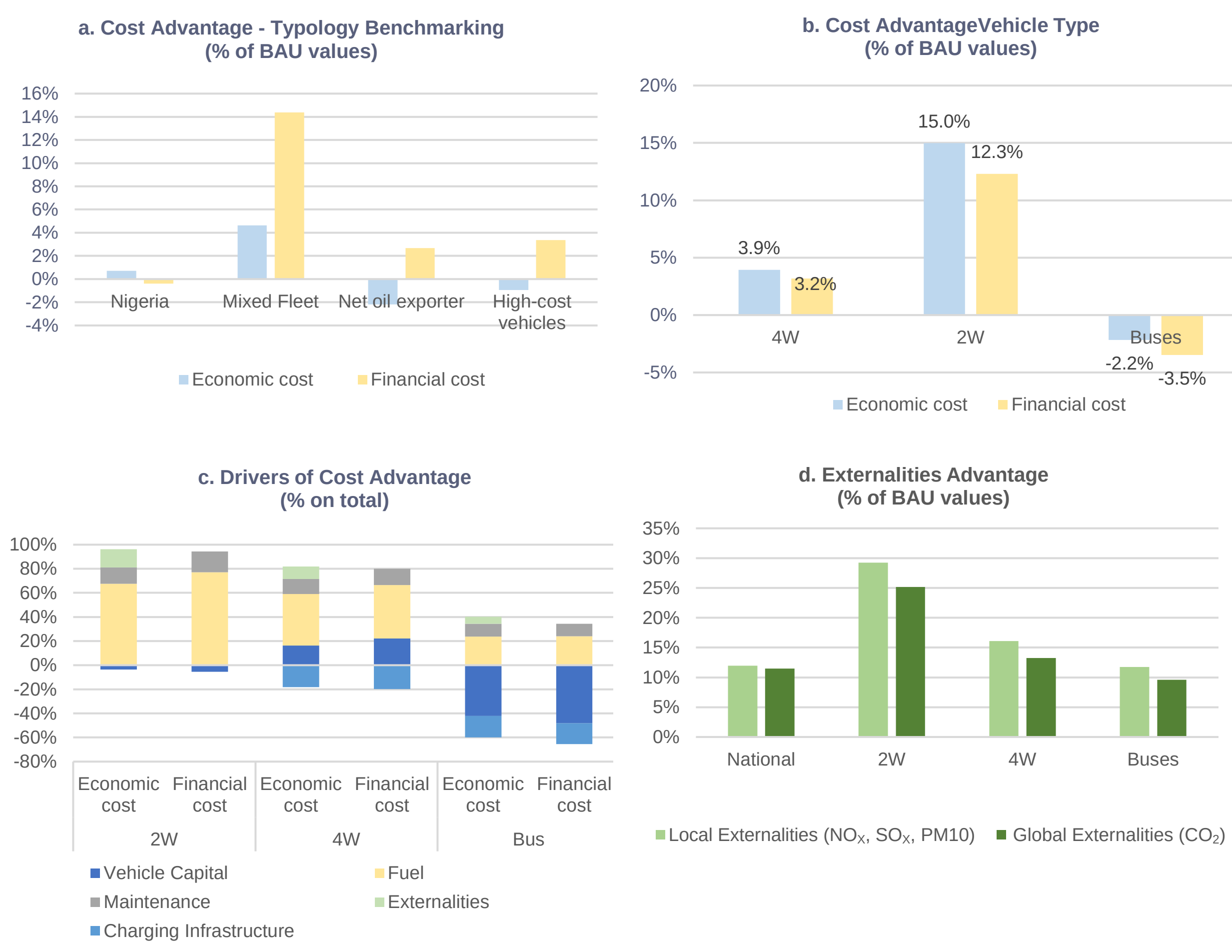


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

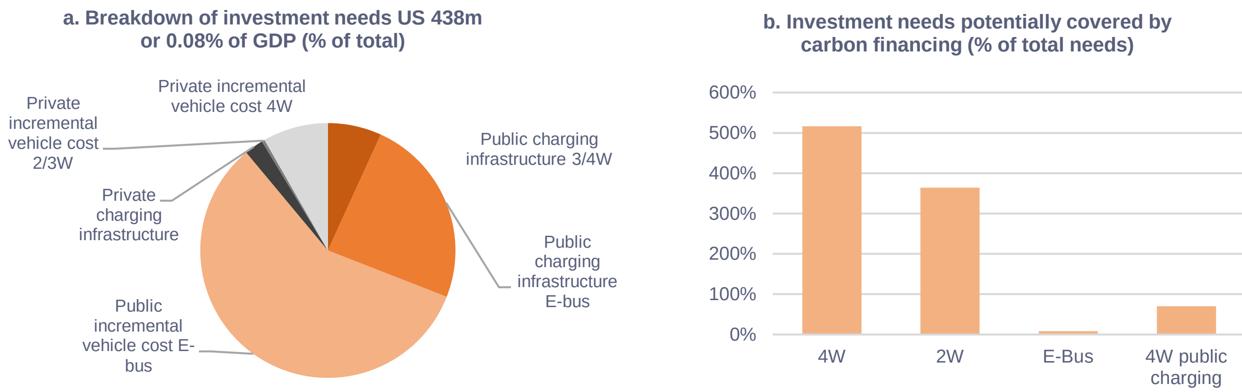


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
$/mnpaxvkm					$/vehicle			
Vehicle capital cost	(6,511)	(6,511)	(8,612)	(6,511)	(6,418)	(3,102)	308	308
Vehicle maintenance cost	2,888	2,888	905	2,888	1,613	2,051	233	(523)
Vehicle fuel cost	7,962	7,962	7,962	6,732	3,609	9,040	810	3,242
Private charging infrastructure	(311)	(311)	(311)	(311)	-	-	(89)	(89)
Public charging infrastructure	(4,018)	(4,018)	(4,018)	(4,018)	(2,668)	(2,668)	(253)	(289)
Sub-total	**9**	**9**	**(4,074)**	**(1,222)**	**(3,863)**	**5,322**	**1,009**	**2,647**
Local externalities	240	261	240	228	126	317	20	79
Global externalities	1,695	1,874	1,695	1,552	764	1,919	178	712
Total economic cost	**1,944**	**2,145**	**(2,139)**	**558**	**(2,973)**	**7,558**	**1,206**	**3,439**
Fiscal wedge	(1,112)	(1,112)	(1,484)	(1,187)	(938)	(248)	29	(112)
Total financial cost	**(1,103)**	**(1,103)**	**(5,559)**	**(2,409)**	**(4,801)**	**5,074**	**1,038**	**2,536**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	1,206	1,226	1,018	995				
2W	290	293	286	283				
E-bus	(2,973)	(2,874)	(5,872)	(3,496)				

TABLE 3: Supporting Information on Parameters and Results

Parameters	**Value**	**Parameters**	**Value**	**Other results for 30x30 Scenario**	**Value**
Price of 4W ICE (US$/vehicle)	29,885	4W mileage (kms)	17,000	Overall investment needs (US$m)	438
Price of 4W EV (US$/vehicle)	32,730	2W mileage (kms)	7,000	-of which 4W purchase	(43)
Price of 2W ICE (US$/vehicle)	1,038	Bus mileage (kms)	29,940	-of which 2W purchase	2
Price of 2W EV (US$/vehicle)	1,372	4W lifetime (years)	22	-of which e-bus purchase	305
Price of bus ICE (US$/vehicle)	137,037	2W lifetime (years)	17	Fiscal impact (US$m)	45
Price of bus EV (US$/vehicle)	145,473	Bus lifetime (years)	20	-of which vehicle duties	20
Net tax difference on 4W EV (%)	0%	4W second hand (%)	97.9%	-of which vehicle taxes/subsidies	20
Net tax difference on 2W EV (%)	0%	2W second hand (%)	97.9%	-of which petrol taxes/subsidies	1
Net tax difference on E-bus (%)	0%	Bus second hand (%)	95.7%	-of which diesel taxes/subsidies	(50)
Price of petrol (US$/liter)	0.58	Efficiency 4W ICE (MJ/km)	3.08	-of which electricity taxes/subsidies	55
Net petrol tax (US$/liter)	(0.00)	Efficiency 4W EV (MJ/km)	8.73	Implicit carbon price ($/tonne)	(4)
Price of diesel (US$/liter)	0.73	Efficiency 2W ICE (MJ/km)	1.13	-of which for 4W	(150)
Net diesel tax (US$/liter)	0.06	Efficiency 2W EV (MJ/km)	0.25	-of which for 2W	(153)
Price of electricity (US$/kWh)	0.12	Efficiency bus ICE (MJ/km)	10.86	-of which for buses	127
Net electricity tax (US$/kWh)	0.02	Efficiency bus EV (MJ/km)	3.70	Pollution reduction (tons)	3
Electricity carbon intensity (g/kWh)	215	4W share (% pax-kms)	24%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	6%	- of which global (CO_2)	3
		Bus share (% pax-kms)	70%	Affordability of 2W EV (Δ cost % GNI pc)	0.5%
				Affordability of 4W EV (Δ cost % GNI pc)	-13.8%

Country at a Glance – Passenger Electric Mobility in Poland

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
CAR DOMINANT	IMPORTER	LOW

Country Background

The dominant vehicle type in Poland is cars (91.5 percent), followed by two-wheelers[1] (7.5 percent), and buses (1.0 percent)[2]. Electricity is primarily generated from fossil fuels (86.5 percent), notably coal (81.3 percent). When it comes to renewable energy, the main sources are wind (7.8 percent), as well as biomass and waste (4.3 percent)[3]. The Polish national government has adopted a variety of policies to drive the electrification of its vehicle fleet[4] targeting to deploy 600,000 EVs by 2030 ("Strategy for Sustainable Transport Development until 2030") that also includes a strategy for electric vehicle and charging infrastructure deployment. The strategy is complemented by various incentive schemes such as the (i) "Green Car" incentive scheme to incentivize private individuals and supports the purchase of a new BEV cars; (ii) "eVAN" incentive scheme provides one-time incentives for businesses purchasing or leasing zero-emission delivery vans; and the "Koliber" incentive scheme benefits micro, small, and medium-sized businesses. Poland has also incepted electric vehicle registration tax benefit and electric vehicle usage tax benefits. About 20,181 electric cars were registered at the end 2020, of which 48.3 percent were BEV and 51.7 percent were HEV[5]. The domestic manufacturing market is set to start production of electric vehicles from 2024[6]. Moreover, the draft Energy policy of Poland (EPP2040) has set a target to increase its existing share of renewables to 21 percent by 2030. Offshore wind firms are expected to play a major role in reaching that target[7].

Overall Messages

Despite Poland enjoying several conditions favorable towards electric mobility, such as oil-importing status and relatively low-cost vehicles, these are largely offset by the country's almost exclusive reliance on cars for transportation (Figure 1a). Only in the very minor 2W segment of the fleet is the economic balance favorable to electric mobility, with a lifecycle cost advantage exceeding 10 percent (Table 1). Nevertheless, strongly supportive government policy means that electric mobility is financially advantageous across for all types of vehicles (Figure 1b). Indeed, tax differentials in favor of the purchase of electric vehicles are as high as 23 percent for buses, 46 percent for 4Ws, and 106 percent for 2Ws (Table 3).

The externality benefits of electric mobility in Poland are quite modest, except for the case of electric buses which bring sizable local externality benefits (Figure 1d). Otherwise, fuel cost savings are the main advantage associated with electric mobility in Poland. Given a fiscal regime that taxes petrol and diesel three to four times as heavily as electricity, these fuel cost savings are further accentuated in financial terms; which is another reason why the overall case for electric mobility in Poland looks better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$2.2 billion per year by 2030 (or 0.3 percent of Polish GDP). About two thirds of the required outlay is associated with the incremental capital of private 4W vehicles (Figure 2a). In terms of public investment, the most significant item is the provision of public charging infrastructure for private vehicles (Figure 2a). Given that implicit carbon prices associated with electric 2Ws in Poland is highly negative (Table 3), there is significant scope to cover 30 percent of the incremental capital costs through carbon financing arrangements. However, for 4W electric vehicles, the implicit carbon price exceeds US$1,000 per ton.

The overall negative economic case for electric mobility in Poland certainly does not improve, under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), nor under further decarbonization of the power sector (Green Grid Scenario). On a positive note, the negative balance for electric buses can be very substantially reversed through the adoption of more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, there is no real case for electrification of 4Ws even when it comes to taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). While electrification of 2Ws in Poland is attractive, their limited role in the vehicle fleet, suggests that a more important priority is to focus on improving the efficiency of electric buses, particularly in view of the significant externality benefits they bring.

[1] Two wheelers cover all motorized two-wheeler vehicles registered.
[2] Source: Poland National statistics (2020) Road transport in Poland.
[3] Source: Generation mix comes from a combination of US EIA international database and the World Bank Group data.
[4] Source: "Emerging electric passenger car markets in Europe: Can Poland lead the way?", Working Paper 2020-19, International Council on Clean Transportation, 2020.
[5] Source: https://www.thefirstnews.com/article/popularity-of-electric-cars-in-poland-continues-to-grow-19060
[6] Source: https://www.electrive.com/2020/12/21/polands-first-electric-car-factory-is-being-built-in-jaworzno/
[7] Source: Energy Policy of Poland Until 2040 (Draft), Ministry of Energy, Warsaw, 2018.

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption
BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(29)*	*82*	53	*34*	*9*	96	*263*	316	3.7	11.8
4W	*(460)*	*(886)*	*470*	(876)	*63*	*20*	(793)	*2,725*	1,848	(2.9)	5.3
Buses	*(5,911)*	*(12,412)*	*11,529*	(6,794)	*5,156*	*500*	(1,138)	*15,011*	8,217	(0.5)	3.3

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

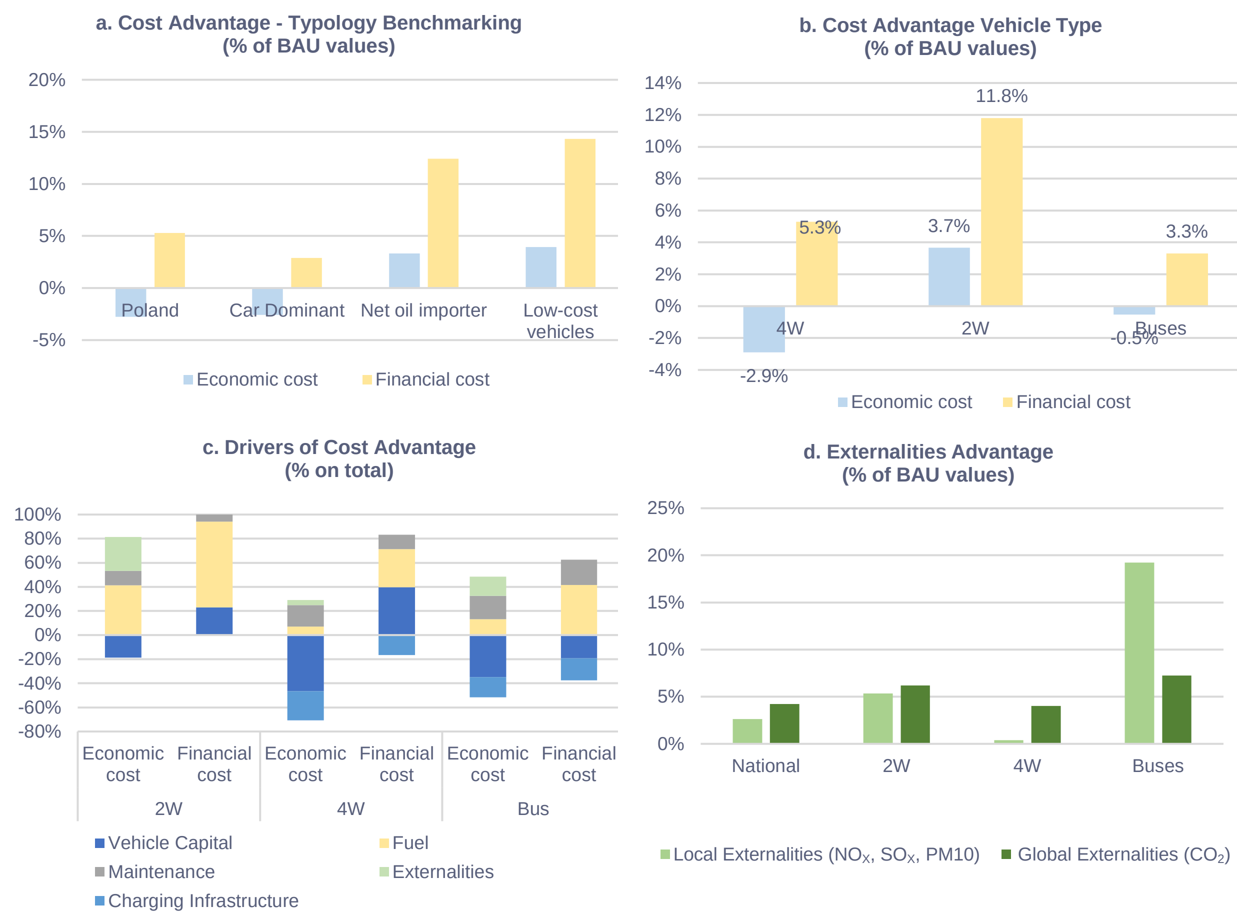


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

a. Breakdown of investment needs US 2,226m or 0.31% of GDP (% of total)

b. Investment needs potentially covered by carbon financing (% of total needs)

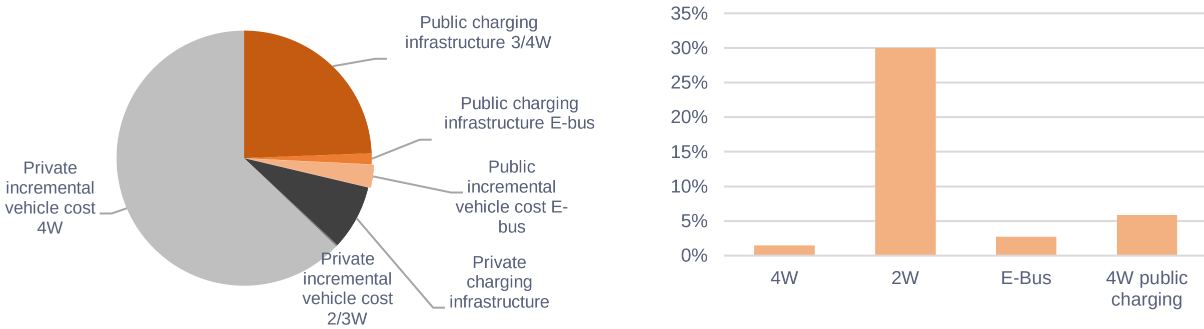


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(26,712)	(26,712)	(41,506)	(26,712)	(12,412)	742	(886)	(886)
Vehicle maintenance cost	10,379	10,379	10,170	10,379	6,888	7,196	337	(651)
Vehicle fuel cost	4,460	4,460	4,460	636	4,641	19,555	134	534
Private charging infrastructure	(3,338)	(3,338)	(3,338)	(3,338)	-	-	(116)	(116)
Public charging infrastructure	(10,435)	(10,435)	(10,435)	(10,435)	(5,911)	(5,911)	(344)	(391)
Sub-total	**(25,646)**	**(25,646)**	**(40,649)**	**(29,470)**	**(6,794)**	**21,582**	**(876)**	**(1,511)**
Local externalities	2,408	5,832	2,408	1,880	5,156	21,965	63	351
Global externalities	652	1,024	652	174	500	2,307	20	101
Economic cost advantage	**(22,586)**	**(18,790)**	**(37,589)**	**(27,415)**	**(1,138)**	**45,854**	**(793)**	**(1,059)**
Fiscal wedge	80,405	80,405	79,980	75,252	15,011	43,903	2,725	4,951
Financial cost advantage	**54,759**	**54,759**	**39,331**	**45,782**	**8,217**	**65,485**	**1,848**	**3,440**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(793)	(668)	(1,291)	(952)				
2W	96	131	86	86				
E-bus	(1,138)	(2)	(8,130)	(3,582)				

TABLE 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	26,080	4W mileage (kms)	8,029	Overall investment needs (US$m)	2,226
Price of 4W EV (US$/vehicle)	18,599	2W mileage (kms)	7,627	-of which 4W purchase	1,399
Price of 2W ICE (US$/vehicle)	890	Bus mileage (kms)	17,799	-of which 2W purchase	5
Price of 2W EV (US$/vehicle)	174	4W lifetime (years)	22	-of which e-bus purchase	65
Price of bus ICE (US$/vehicle)	116,312	2W lifetime (years)	17	Fiscal impact (US$m)	(4,422)
Price of bus EV (US$/vehicle)	135,324	Bus lifetime (years)	20	-of which vehicle duties	(3,117)
Net tax difference on 4W EV (%)	46%	4W second hand (%)	62.0%	-of which vehicle taxes/subsidies	(61)
Net tax difference on 2W EV (%)	106%	2W second hand (%)	0.0%	-of which petrol taxes/subsidies	(1,457)
Net tax difference on E-bus (%)	23%	Bus second hand (%)	10.7%	-of which diesel taxes/subsidies	(79)
Price of petrol (US$/liter)	0.58	Efficiency 4W ICE (MJ/km)	2.13	-of which electricity taxes/subsidies	292
Net petrol tax (US$/liter)	0.81	Efficiency 4W EV (MJ/km)	3.70	Implicit carbon price ($/tonne)	921
Price of diesel (US$/liter)	0.73	Efficiency 2W ICE (MJ/km)	1.08	-of which for 4W	1,041
Net diesel tax (US$/liter)	0.67	Efficiency 2W EV (MJ/km)	0.25	-of which for 2W	(263)
Price of electricity (US$/kWh)	0.13	Efficiency bus ICE (MJ/km)	11.53	-of which for buses	85
Net electricity tax (US$/kWh)	0.04	Efficiency bus EV (MJ/km)	3.91	Pollution reduction (tons)	1
Electricity carbon intensity (g/kWh)	546	4W share (% pax-kms)	92%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	4%	- of which global (CO_2)	1
		Bus share (% pax-kms)	3%	Affordability of 2W EV (Δ cost % GNI pc)	-0.4%
				Affordability of 4W EV (Δ cost % GNI pc)	-5.6%

Country at a Glance – Passenger Electric Mobility in Rwanda

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	IMPORTER	HIGH

Country Background

The vehicle fleet in Rwanda is quite mixed. The leading share goes to two-wheelers[1] (46.6 percent), followed by cars (29.4 percent), and buses (23.9 percent)[2]. In 2018, electricity was generated almost equally from renewable sources (53.4 percent), primarily, hydro (45.6 percent), and fossil fuels (46.6 percent). The Government has recently approved a very aggressive electric mobility strategy that includes:[3] preferential electricity tariffs for charging stations (at industrial tariff level); exemptions in import and excise duties on electric vehicles, spare parts, batteries and charging station equipment; and rent-free land for charging stations for land owned by the Government. In addition, companies manufacturing and assembling electric vehicles will see a reduced 15 percent Corporate Income Tax (CIT) and tax holiday; and there will be ease of market entry by providing free license and authorization for commercial electric vehicles. Several locally operated firms are already successfully rolling out electric motorbikes. In partnership with Siemens and the Government of Rwanda, the car manufacturing company Volkswagen introduced a fleet of four electric cars and one charging station in Kigali in October 2019. The fleet has since expanded to 20 electric cars and an additional charging station.[4] The International Financing Corporations (IFC) is supporting "Electric Bus Concept Validation in Kigali" study and the World Bank is supporting "Rwanda: Inclusive and Electric Last Mile Connectivity Study" in Rwanda[5]. Rwanda's Energy Sector Strategic Plan (2018-2024) set a target of increasing the renewable share in the power generation 52 percent by 2024, which has already been exceeded[6] and will derive in further benefit from accelerating electric mobility adoption.

Overall Messages

Rwanda faces many conditions that are favorable towards electric mobility, including net oil importing status and a relatively diversified vehicle fleet, however this is somewhat offset by relatively high-cost vehicles (Figure 1a). Electrification of transport is only marginally economic as a national strategy (Table 2). Nevertheless, there is a strong case for adoption of electrification of 2Ws, which represent close to half of the fleet (Figure 1b), since these carry a lifecycle cost advantage approaching 10 percent (and over 20 percent in financial terms). In addition, the 30 percent capital cost differential associated with electric 2Ws looks relatively affordable, representing no more than 1 percent of GNI per capita (Table 3). By contrast, the economic case for electric 4Ws is only marginally positive, while for electric buses it is marginally negative. This is despite minimal differences in purchase prices due to a sizable 28 percent tax advantage for electric mobility.

The externality benefits of electric mobility in Rwanda are relatively small (Figure 1c), except for the global externality savings associated with electric buses, which are quite sizable (Figure 1d). Otherwise, fuel cost savings are the main advantage associated with electric mobility in Rwanda, primarily due to a fiscal regime that taxes petrol and diesel at 60-90 percent, while subsidizing electricity at 25 percent. Combining the fiscal incentives for vehicle purchase with those affecting operating costs means that electric mobility in Rwanda is much more attractive in financial than in economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$20 million per year by 2030 (or 0.1 percent of Rwandan GDP). Around half of the required outlay is associated with the incremental capital cost of electric buses, and the remainder relates to public investment in charging infrastructure (Figure 2a). Given that implicit carbon price associated with electric 2Ws is strongly negative (Table 3), there is significant scope to cover as much as 90 percent of the incremental capital cost through carbon financing arrangements. However, for electric buses, the implicit carbon price is almost US$70 per ton.

The overall economic case for electric mobility in Rwanda is quite marginal (Table 2). While it improves somewhat under further decarbonization of the power sector (Green Grid Scenario), it is not robust to more conservative assumptions about the cost of batteries (Scarce Minerals Scenario), nor the improved fuel efficiency of internal combustion engines (Fuel Efficiency Scenario). On a positive note, the negative economic balance for electrification of buses can be reversed through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, there is no real case for electrification of 4Ws even when it comes to taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). It is clear that electric mobility in Rwanda needs to prioritize the 2W segment of the fleet, while working to improve the efficiency of electric buses.

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[1] Two wheelers cover all motorized two-wheeler vehicles registered.
[2] Source: National institute of Statistics of Rwanda (2019) Rwanda Statistical Yearbook 2019.
[3] Source: https://www.newtimes.co.rw/news/rwanda-unveils-new-incentives-drive-electric-vehicle-uptake
[4] Source: https://www.engineeringnews.co.za/article/volkswagen-rwanda-unveils-second-charging-station-for-electric-vehicles-2021-04-15#:~:text=Volkswagen%20Mobility%20Solutions%20Rwanda%20(VWMSR,project%20in%20partnership%20with%20Siemens.
[5] Source: The World Bank Group.
[6] Source: Energy Sector Strategic Plan, Rwanda, Ministry of Infrastructure, 2018/19-2023/24.

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle										% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g			
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*		*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(32)*	*148*	115	*3*	*30*	149	*425*	540		8.5	20.4
4W	*(249)*	*18*	*246*	15	*4*	*55*	74	*1,268*	1,283		0.3	4.3
Buses	*(3,054)*	*(7,116)*	*5,825*	(4,346)	*259*	*1,531*	(2,556)	*24,523*	20,178		(1.0)	5.5

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

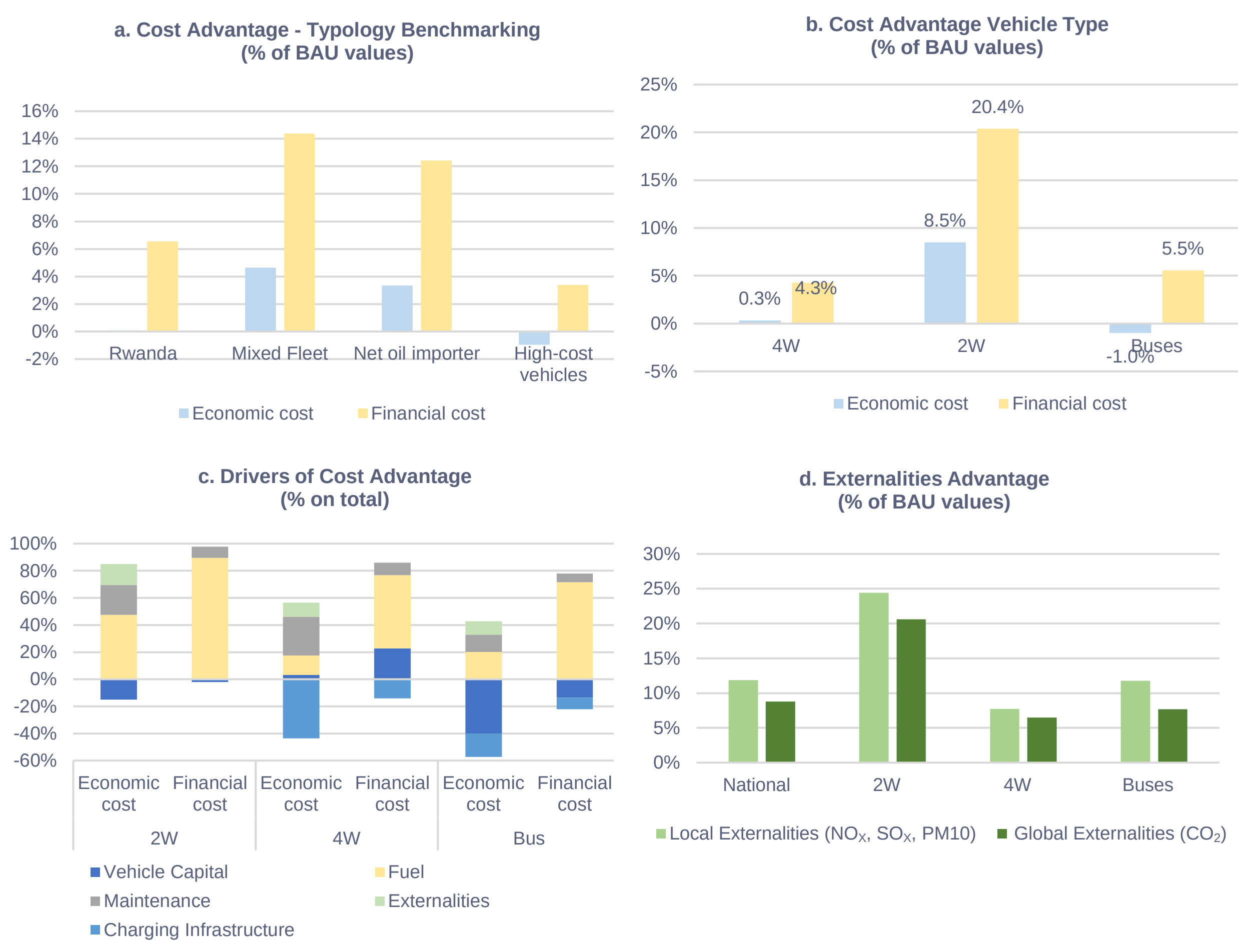
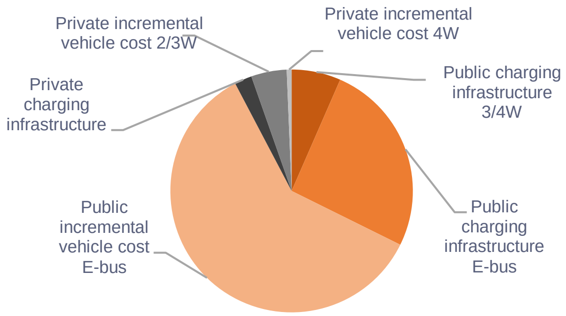


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

a. Breakdown of investment needs US 20m or 0.1% OF GDP (% of total)



b. Investment needs potentially covered by carbon financing (% of total needs)

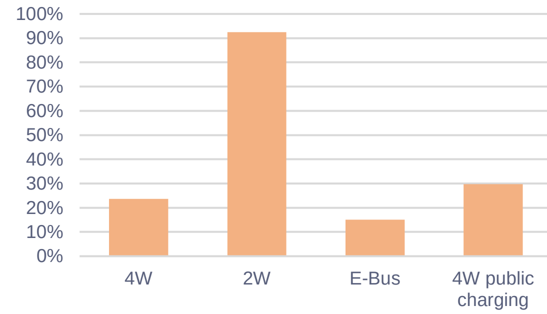


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(5,112)	(5,112)	(6,701)	(5,112)	(7,116)	(2,628)	18	18
Vehicle maintenance cost	2,523	2,523	1,348	2,523	2,242	2,664	163	(389)
Vehicle fuel cost	3,833	3,833	3,833	2,290	3,583	4,470	83	330
Private charging infrastructure	(185)	(185)	(185)	(185)	-	-	(65)	(65)
Public charging infrastructure	(2,577)	(2,577)	(2,577)	(2,577)	(3,054)	(3,054)	(184)	(211)
Sub-total	**(1,518)**	**(1,518)**	**(4,282)**	**(3,061)**	**(4,346)**	**1,452**	**15**	**(317)**
Local externalities	225	411	225	218	259	323	4	15
Global externalities	1,535	1,886	1,535	1,359	1,531	1,913	55	222
Economic cost advantage	**243**	**779**	**(2,522)**	**(1,484)**	**(2,556)**	**3,688**	**74**	**(79)**
Fiscal wedge	25,110	25,110	25,110	24,073	24,523	30,064	1,268	3,910
Financial cost advantage	**23,592**	**23,592**	**20,828**	**21,012**	**20,178**	**31,516**	**1,283**	**3,594**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	74	97	(63)	2				
2W	149	155	140	140				
E-bus	(2,556)	(1,961)	(5,942)	(4,672)				

TABLE 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	31,202	4W mileage (kms)	15,224	Overall investment needs (US$m)	20
Price of 4W EV (US$/vehicle)	31,005	2W mileage (kms)	7,627	-of which 4W purchase	(0.1)
Price of 2W ICE (US$/vehicle)	1,060	Bus mileage (kms)	48,092	-of which 2W purchase	1
Price of 2W EV (US$/vehicle)	1,300	4W lifetime (years)	22	-of which e-bus purchase	12
Price of bus ICE (US$/vehicle)	137,108	2W lifetime (years)	17	Fiscal impact (US$m)	(64)
Price of bus EV (US$/vehicle)	135,324	Bus lifetime (years)	20	-of which vehicle duties	(5)
Net tax difference on 4W EV (%)	28%	4W second hand (%)	96.4%	-of which vehicle taxes/subsidies	(2)
Net tax difference on 2W EV (%)	28%	2W second hand (%)	96.4%	-of which petrol taxes/subsidies	(13)
Net tax difference on E-bus (%)	28%	Bus second hand (%)	87.6%	-of which diesel taxes/subsidies	(30)
Price of petrol (US$/liter)	0.58	Efficiency 4W ICE (MJ/km)	2.34	-of which electricity taxes/subsidies	(14)
Net petrol tax (US$/liter)	0.53	Efficiency 4W EV (MJ/km)	4.68	Implicit carbon price ($/tonne)	22
Price of diesel (US$/liter)	0.73	Efficiency 2W ICE (MJ/km)	0.89	-of which for 4W	(9)
Net diesel tax (US$/liter)	0.47	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	(104)
Price of electricity (US$/kWh)	0.19	Efficiency bus ICE (MJ/km)	16.92	-of which for buses	69
Net electricity tax (US$/kWh)	(0.05)	Efficiency bus EV (MJ/km)	5.44	Pollution reduction (tons)	0
Electricity carbon intensity (g/kWh)	441	4W share (% pax-kms)	17%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	18%	- of which global (CO_2)	0
		Bus share (% pax-kms)	65%	Affordability of 2W EV (Δ cost % GNI pc)	0.9%
				Affordability of 4W EV (Δ cost % GNI pc)	-29.7%

Country at a Glance – Passenger Electric Mobility in Tajikistan

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
CAR DOMINANT	IMPORTER	LOW

Country Background

The transport system in Tajikistan is dominated by cars[1]. Electricity is primarily generated from renewable sources of energy, notably hydropower (93.5 percent), with the balance coming from coal (6.5 percent)[2]. The country is yet to develop an electric vehicle roadmap and policy incentives to foster electric vehicle adoption[3]. Tajikistan will need specific policy incentives to address the issues of high upfront cost, limited charging infrastructure and lack of awareness[4]. The power sector in Tajikistan is highly subsidized. As a result, electricity tariffs are low leading to excessive usage of electricity and other inefficiencies[5]. Recently, the Government approved exemption on VAT and import duties for electric vehicles, for a limited allowance of 100 units of passenger electric vehicles during 2020[6]. With international support, the Government is gradually implanting some electric mobility projects in the country. EBRD has provided an investment grant for the introduction of electric off-wire electric trolleybus for a 15km route[7].

Overall Messages

Unusually for a car-dominated country, Tajikistan presents quite favorable conditions for electric mobility, particularly due to the very low cost of vehicles, as well as the country's status as an oil importer (Figure 1a). Electrification of transport looks to be economically viable overall (Table 2). This is due to the fact that electric 4W vehicles are already *cheaper* (and hence more affordable) to purchase than their conventional counterparts (Table 3), offering modest lifecycle cost advantages of almost three percent (Figure 1b). Electric buses on the other hand, still cost about twice as much to purchase as diesel buses (Table 3), with lifecycle cost advantages closer to two percent (Figure 1b).

The externality benefits of electric mobility in Tajikistan are relatively modest for 4Ws, but quite substantial for buses (Figure 1c,d). Otherwise, fuel cost savings are the main advantage associated with electric mobility. Given a fiscal regime that taxes petrol and diesel by 20-40 percent, while subsidizing electricity by 80 percent, these fuel cost savings are further accentuated in financial terms (Figure 1c). This makes the overall case for electric mobility in Tajikistan much better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$3.2 million per year by 2030 (or 0.03 percent of Tajik GDP). Close to half of the investment relates to the incremental capital cost of vehicles and charging infrastructure incurred by the private sector, and much of the remainder is public investment in public infrastructure charging stations (Figure 2a). Given that implicit carbon prices associated with electric 4Ws in Tajikistan are strongly negative (Table 3), there is significant scope to cover 60-80 percent of the incremental private and public investments associated with electric 4Ws through carbon financing arrangements (Figure 2b).

The overall economic case for electric mobility in Tajikistan is favorable (Table 2). This finding is robust to more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), and only improves with further decarbonization of the power sector (Green Grid Scenario). On a positive note, the emerging advantage associated with electrification of buses can be as much as doubled through the more efficient procurement and operation of vehicles (Efficient Bus Scenario), while the case for electric 4W is greatly strengthened when it comes to taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). Tajikistan is unusual in that the case for electric mobility is primarily driven by 4Ws, with potential for electric buses to also play a role.

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[1] Source: OICA (2020) Passenger cars sales.
[2] Source: Generation mix comes from a combination of US EIA international database and WB data.
[3] Source: E-Mobility options for ADB developing member countries, Jurg M Grutter and Ki-Joon Kim, 2019.
[4] Source: https://development.asia/insight/how-electric-vehicles-can-make-tajikistan-emissions-free
[5] Source: Environmental Performance Review, Tajikistan, UNECE, 2017.
[6] Source: https://cis-legislation.com/document.fwx?rgn=126129
[7] Source: Going electric, A pathway to zero-emission buses, policy paper, EBRD.

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
4W	(221)	115	505	399	3	92	494	677	1,077	2.8	5.5
Buses	(2,098)	(6,226)	10,114	1,790	2,206	1,987	5,983	11,437	13,227	2.2	5.1

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

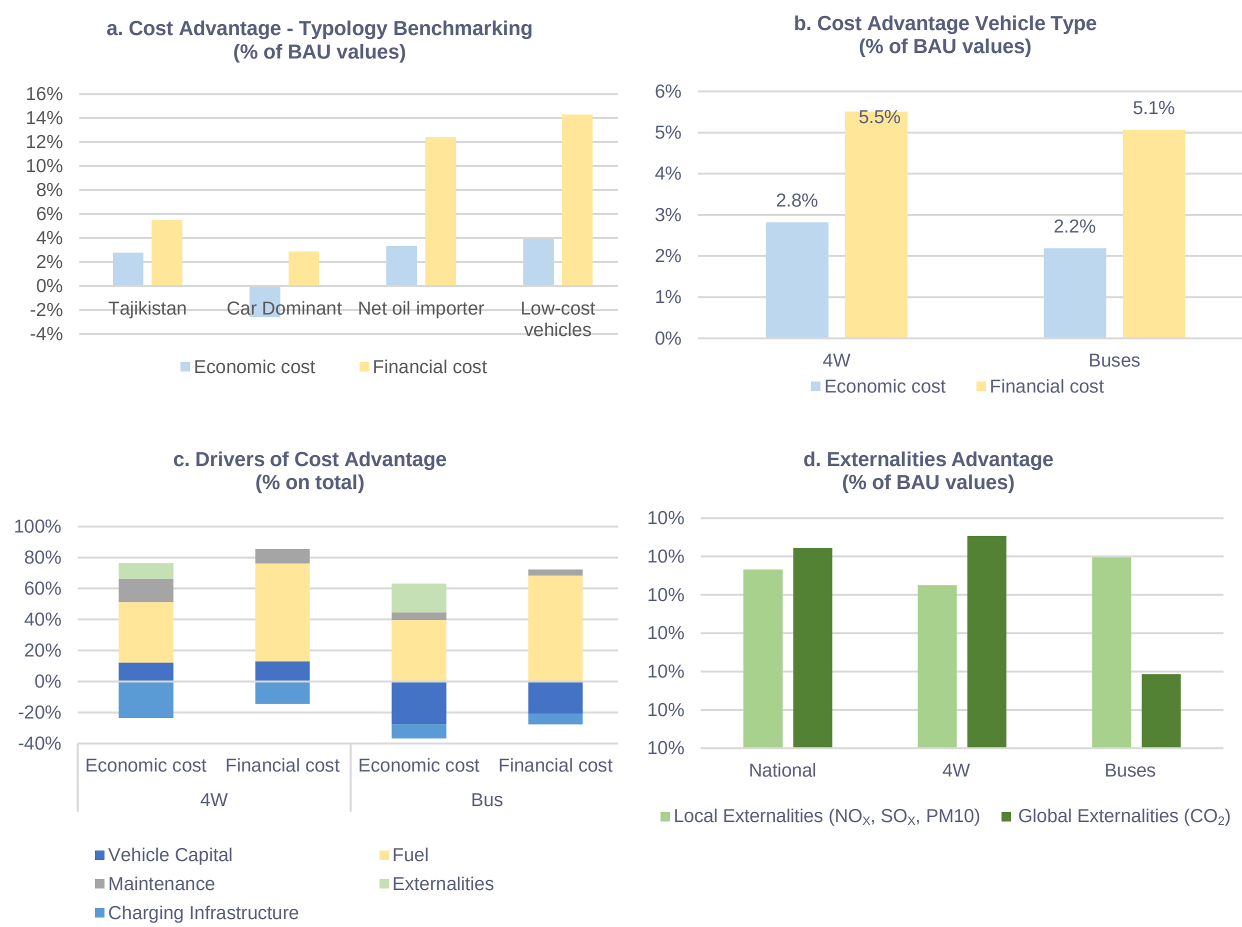
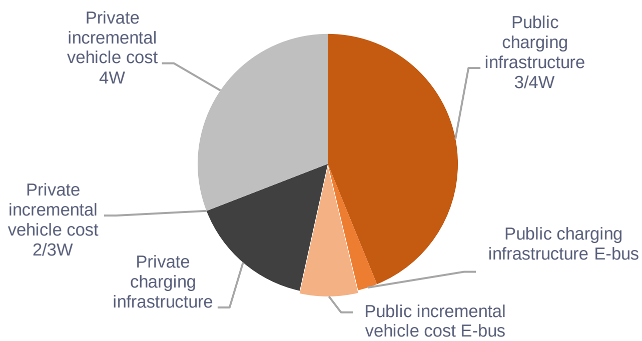


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

a. Breakdown of investment needs US 3.2m or 0.03% of GDP (% of total)



b. Investment needs potentially covered by carbon financing (% of total needs)

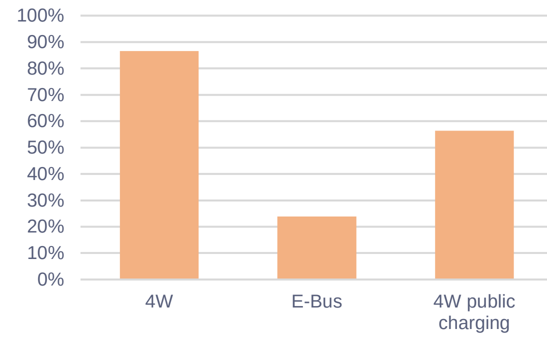


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenari o**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	1,351	1,351	818	1,351	(6,226)	(3,860)	115	115
Vehicle maintenance cost	2,228	2,228	2,136	2,228	1,145	1,517	140	(353)
Vehicle fuel cost	6,209	6,209	6,209	5,540	8,969	11,190	365	1,461
Private charging infrastructure	(892)	(892)	(892)	(892)	-	-	(58)	(58)
Public charging infrastructure	(2,638)	(2,638)	(2,638)	(2,638)	(2,098)	(2,098)	(163)	(186)
Sub-total	**6,258**	**6,258**	**5,633**	**5,589**	**1,790**	**6,749**	**399**	**979**
Local externalities	192	192	192	190	2,206	2,752	3	12
Global externalities	1,542	1,542	1,542	1,462	1,987	2,480	92	367
Economic cost advantage	**7,991**	**7,991**	**7,366**	**7,240**	**5,983**	**11,980**	**494**	**1,358**
Fiscal wedge	11,174	11,174	11,174	10,987	11,437	14,245	677	2,459
Financial cost advantage	**17,431**	**17,431**	**16,807**	**16,576**	**13,227**	**20,994**	**1,077**	**3,438**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	494	494	463	449				
E-bus	5,983	5,983	3,727	5,115				

TABLE 3: Supporting Information on Parameters and Results

Parameters	**Value**	**Parameters**	**Value**	**Other results for 30x30 Scenario**	**Value**
Price of 4W ICE (US$/vehicle)	14,975	4W mileage (kms)	15,224	Overall investment needs (US$m)	3.2
Price of 4W EV (US$/vehicle)	13,966	2W mileage (kms)	7,627	-of which 4W purchase	(3)
Price of 2W ICE (US$/vehicle)	486	Bus mileage (kms)	48,092	-of which 2W purchase	0
Price of 2W EV (US$/vehicle)	586	4W lifetime (years)	22	-of which e-bus purchase	1
Price of bus ICE (US$/vehicle)	67,994	2W lifetime (years)	17	Fiscal impact (US$m)	(17)
Price of bus EV (US$/vehicle)	135,324	Bus lifetime (years)	20	-of which vehicle duties	(1)
Net tax difference on 4W EV (%)	18%	4W second hand (%)	99.8%	-of which vehicle taxes/subsidies	(0.5)
Net tax difference on 2W EV (%)	18%	2W second hand (%)	99.8%	-of which petrol taxes/subsidies	(3)
Net tax difference on E-bus (%)	18%	Bus second hand (%)	98.2%	-of which diesel taxes/subsidies	(2)
Price of petrol (US$/liter)	0.58	Efficiency 4W ICE (MJ/km)	2.50	-of which electricity taxes/subsidies	(9)
Net petrol tax (US$/liter)	0.22	Efficiency 4W EV (MJ/km)	5.83	Implicit carbon price ($/tonne)	(108)
Price of diesel (US$/liter)	0.73	Efficiency 2W ICE (MJ/km)	0.89	-of which for 4W	(113)
Net diesel tax (US$/liter)	0.13	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	
Price of electricity (US$/kWh)	0.11	Efficiency bus ICE (MJ/km)	18.11	-of which for buses	(52)
Net electricity tax (US$/kWh)	(0.09)	Efficiency bus EV (MJ/km)	6.24	Pollution reduction (tons)	0
Electricity carbon intensity (g/kWh)	65	4W share (% pax-kms)	94%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	0%	- of which global (CO_2)	0
		Bus share (% pax-kms)	6%	Affordability of 2W EV (Δ cost % GNI pc)	
				Affordability of 4W EV (Δ cost % GNI pc)	-12.9%

Country at a Glance – Passenger Electric Mobility in Turkey

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
CAR DOMINANT	IMPORTER	HIGH

Country Background

The dominant vehicle type in Turkey is cars (80.3 percent), followed by buses (13.4 percent), and two-wheelers[1] (6.3 percent).[2] Electricity is primarily generated from fossil fuels (66.7 percent), including gas (37.3 percent) and coal (28.6 percent); and to a lesser extent from renewable sources (33.3 percent), notably hydro (20.5 percent) and wind (6.8 percent).[3] The national policies and plans related to EV uptake include[4]: an automotive support program to improve domestic production capabilities in sensors, batteries, fuel cells and software; development of workforce capable of adapting digitalization and technological development; development of national production and R&D activities in the automotive industries; establishment of effective infrastructure for vehicles with alternative power systems; increase investment in the battery sector for electrical automotive production; and increase the use of domestically manufactured electrical buses in urban and sub-urban transport. From the power sector perspective, the EV strategy includes the Adoption of cost-based pricing practices in the electricity and natural gas markets; introduction of nuclear based power plant in the country; reduction in imported sources of electricity generation; integration of renewable energy generation facilities into the grid; and reducing the use of natural gas in the electricity generation and increase the use of renewable sources from 33% to 39% by 2023. A series of incentives were introduced including (ICCT, 2019b)[5]: reductions in Special Consumption Tax (ÖTV) rates were introduced in 2016 for EVs with electric engine power of >50 kW (and cylinder volume <1,800 cm3) and >100 kW (and cylinder volume <2,500 cm3) from 90 percent to 45 percent, and from 145 percent to 90 percent. According to the Turkish Statistical Institute, the number of electric vehicles registered in Turkey reached 15,000 in 2019.[6] The domestic EV manufacturing industries are growing in Turkey. A factory is being built in Gemlik, with an annual capacity of 175,000 units, which expects to begin production in 2022[7]. The domestic car project named Automotive Joint Venture Group (TOGG), which is a joint venture between Anadolu Group, BMC, Kok Group, Turkcell and Zorlu Holding, kick-started in 2019[8].

Overall Messages

Turkey faces many conditions that are less favorable towards electric mobility, including a car-dominated fleet and relatively high-cost vehicles, notwithstanding oil-importing status (Figure 1a). While electrification of transport does not yet look economically favorable as a national strategy (Table 2), this is largely driven by the fact that the electrification of 4W vehicles is not attractive under current conditions, given significant (and unaffordable capital) cost differentials (Table 1). By contrast, there is a strong case for adoption of 2W electric motorbikes (Figure 1b), which present a lifecycle cost advantage of around 7 percent (or 17 percent in financial terms). However, the percentage capital cost differential for electric 2Ws is relatively high at over 40 percent and represents almost 3 percent of GNI per capita, suggesting an affordability barrier in the absence of finance. Furthermore, electric buses also offer modest economic advantages of the order of 4 percent of lifecycle cost and are only 20 percent more expensive in capital cost terms. Across all vehicle categories, the fiscal regime offers a 21 percent reduced tax incentive for the purchase of electric vehicles.

The externality benefits of electric mobility in Turkey are relatively small (Figure 1c), except for local externalities associated with buses that are very large (Figure 1d). Otherwise, fuel cost savings are the main advantage associated with electric mobility in Turkey, further accentuated in financial terms by a fiscal regime that taxes petrol and diesel at 50-100 percent. Hence, the overall case for electric mobility in Turkey looks better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$3.4 billion per year by 2030 (or 0.3 percent of Turkish GDP). About two thirds of the required outlay is associated with the incremental capital cost of 4W electric vehicles (Figure 2a). In terms of public investment, the most significant items are the additional capital cost associated with electric buses, as well as the provision of public charging infrastructure for private vehicles (Figure 2a). Implicit carbon prices associated with electric 2Ws and buses in Turkey are negative, but in the case of 4Ws exceeds US$4,000 (Table 3). As a result, there little scope to cover investment needs through carbon financing arrangements.

The overall economic case for electric mobility in Turkey is negative, and this does not change even with further decarbonization of the power grid (Green Grid Scenario), let alone under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario). On a positive note, the emerging advantage associated with electrification of buses can be hugely increased through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, there is no real case for electrification of 4Ws, even when it comes to taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). It is clear that electric mobility in Turkey needs to prioritize the 2W segment of the fleet, and work to further enhance the advantages of electric buses.

[1] Two wheelers cover all motorized two-wheeler vehicles registered.
[2] Source: OICA (2020) Passenger cars sales Turkish statistical institute (2020) Transportation summary tables.
[3] Source: Generation mix comes from a combination of US EIA international database and WB data.
[4] Source: Turkey Eleventh Development Plan (2019-2023), Presidency of Strategy and Budget, Presidency of Republic of Turkey, 2019.
[5] Source: Transport sector transformation: Integrating electric vehicles into Turkey's distribution grids report, SHURA Energy Transition Centre, 2019.
[6] Source: https://www.trtworld.com/magazine/electric-car-use-in-turkey-rises-by-150-percent-45425
[7] Source: https://en.wikipedia.org/wiki/TOGG_Turkish_national_car
[8] Source: Electric car use in Turkey rises by 150 percent (trtworld.com)

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(368)*	*376*	8	*132*	*26*	166	*461*	469	7.2	16.6
4W	*(574)*	*(2,172)*	*583*	(2,163)	*360*	*11*	(1,792)	*1,338*	(825)	(4.9)	(1.7)
Buses	*(6,088)*	*(12,982)*	*17,814*	(1,256)	*10,536*	*1,090*	10,370	*13,684*	12,428	3.9	4.1

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

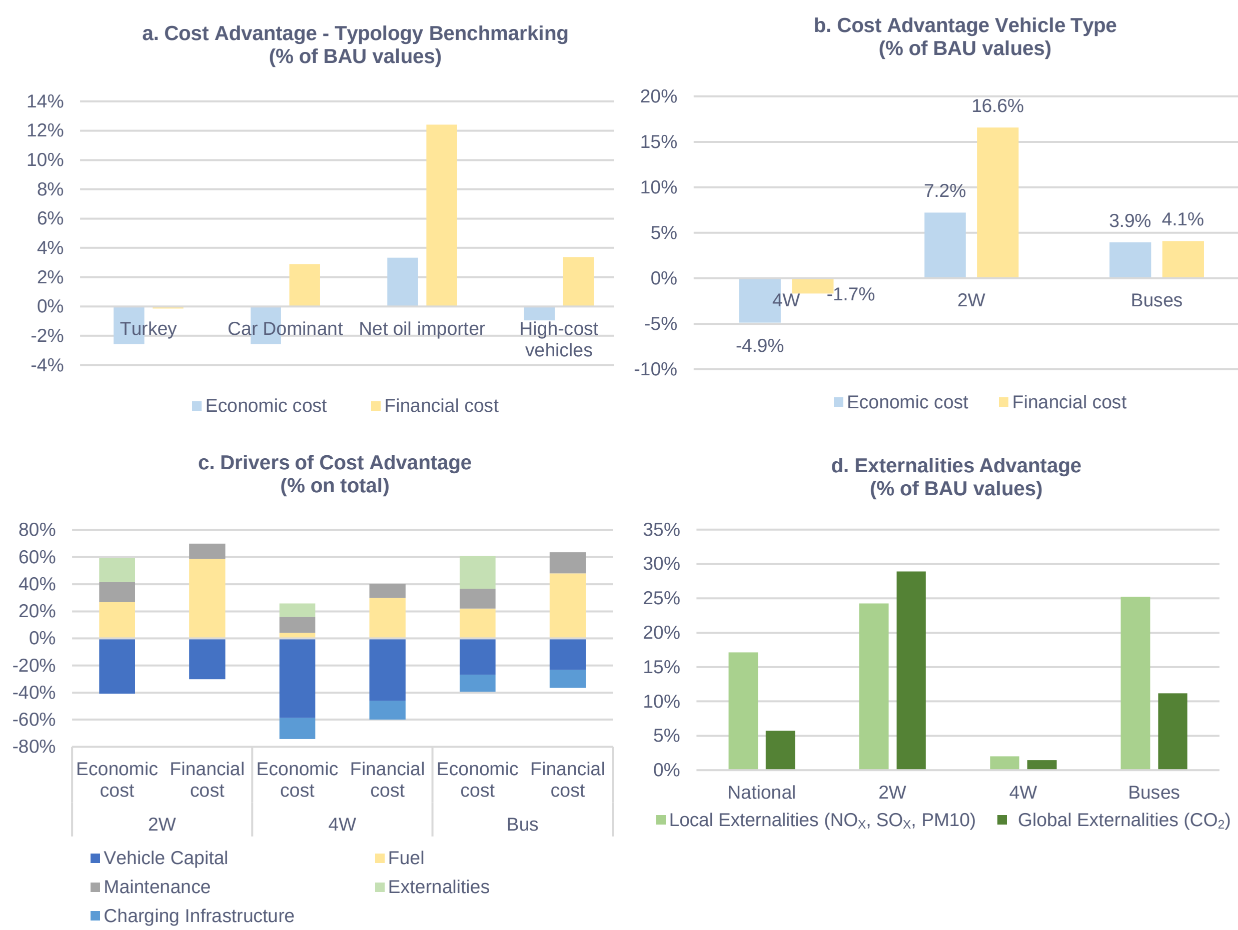


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

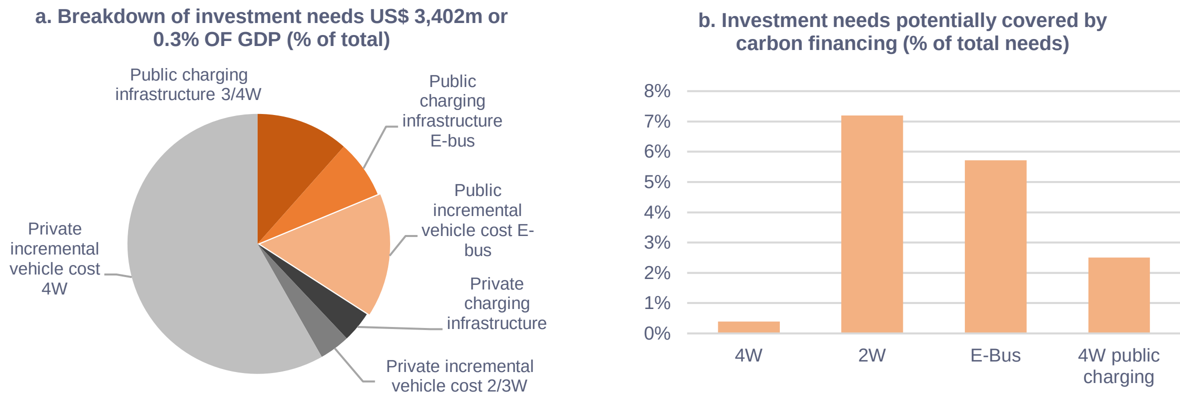


TABLE 2. Sensitivity Analysis Results– Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(31,494)	(31,494)	(43,733)	(31,494)	(12,982)	710	(2,172)	(2,172)
Vehicle maintenance cost	8,699	8,699	7,633	8,699	7,176	7,477	429	(792)
Vehicle fuel cost	7,824	7,824	7,824	3,150	10,638	21,022	154	618
Private charging infrastructure	(1,568)	(1,568)	(1,568)	(1,568)	-	-	(144)	(144)
Public charging infrastructure	(7,630)	(7,630)	(7,630)	(7,630)	(6,088)	(6,088)	(431)	(489)
Sub-total	**(24,169)**	**(24,169)**	**(37,475)**	**(28,842)**	**(1,256)**	**23,121**	**(2,163)**	**(2,979)**
Local externalities	9,551	14,662	9,551	7,774	10,536	21,056	360	1,874
Global externalities	754	1,041	754	208	1,090	2,217	11	72
Economic cost advantage	**(13,865)**	**(8,465)**	**(27,171)**	**(20,860)**	**10,370**	**46,394**	**(1,792)**	**(1,033)**
Fiscal wedge	23,127	23,127	19,050	19,754	13,684	29,388	1,338	4,588
Financial cost advantage	**(1,042)**	**(1,042)**	**(18,426)**	**(9,089)**	**12,428**	**52,509**	**(825)**	**1,609**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(1,792)	(1,444)	(2,660)	(2,208)				
2W	166	204	81	130				
E-bus	10,370	13,362	3,154	5,583				

TABLE 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	32,156	4W mileage (kms)	13,776	Overall investment needs (US$m)	3,402
Price of 4W EV (US$/vehicle)	38,111	2W mileage (kms)	3,960	-of which 4W purchase	1,981
Price of 2W ICE (US$/vehicle)	1,104	Bus mileage (kms)	37,952	-of which 2W purchase	130
Price of 2W EV (US$/vehicle)	1,598	4W lifetime (years)	22	-of which e-bus purchase	522
Price of bus ICE (US$/vehicle)	136,866	2W lifetime (years)	17	Fiscal impact (US$m)	(1,934)
Price of bus EV (US$/vehicle)	170,959	Bus lifetime (years)	20	-of which vehicle duties	(414)
Net tax difference on 4W EV (%)	21%	4W second hand (%)	1.5%	-of which vehicle taxes/subsidies	85
Net tax difference on 2W EV (%)	21%	2W second hand (%)	1.5%	-of which petrol taxes/subsidies	(704)
Net tax difference on E-bus (%)	21%	Bus second hand (%)	0.7%	-of which diesel taxes/subsidies	(844)
Price of petrol (US$/liter)	0.58	Efficiency 4W ICE (MJ/km)	1.75	-of which electricity taxes/subsidies	(58)
Net petrol tax (US$/liter)	0.64	Efficiency 4W EV (MJ/km)	1.11	Implicit carbon price ($/tonne)	501
Price of diesel (US$/liter)	0.73	Efficiency 2W ICE (MJ/km)	0.85	-of which for 4W	4,319
Net diesel tax (US$/liter)	0.40	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	(137)
Price of electricity (US$/kWh)	0.10	Efficiency bus ICE (MJ/km)	8.42	-of which for buses	(220)
Net electricity tax (US$/kWh)	(0.00)	Efficiency bus EV (MJ/km)	2.83	Pollution reduction (tons)	2
Electricity carbon intensity (g/kWh)	451	4W share (% pax-kms)	60%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	3%	- of which global (CO_2)	2
		Bus share (% pax-kms)	37%	Affordability of 2W EV (∆ cost % GNI pc)	2.9%
				Affordability of 4W EV (∆ cost % GNI pc)	15.8%

Country at a Glance – Passenger Electric Mobility in Ukraine

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
CAR DOMINANT	IMPORTER	LOW

Country Background

The dominant vehicle type in Ukraine is cars (87.0 percent), followed by buses (8.5 percent), and two-wheelers[1] (4.5 percent)[2]. Electricity is primarily generated from nuclear power (53.4 percent), followed by fossil fuels (38.0 percent) – mainly coal (31.9 percent) – and much less from renewable sources (8.6 percent) – mainly hydropower (6.9 percent)[3]. Ukraine's electric car market has shown significant growth in recent years. The Ministry of Infrastructure of Ukraine has developed strategies to foster EV adoption that includes[4] the inception of tax incentives such as introducing no corporate income tax on lithium extraction and battery production for the next 15 years to promote industries for domestic electric vehicles and battery production. The strategy also calls for reducing the cost of ownership of EVs through tax incentives such as VAT reduction, income tax discounts and no registration fee for the next 5 years; and non-monetary policies such as free parking and free bus lane usage for the next 15 years. The government expects to reduce the EV costs by up to 40 percent through these tax incentives combined. The strategy also incorporates targets to increase the share of renewable sources for power generation to 15 percent by 2035[5]. One of the main challenges for the EV market is developing a suitable regulatory framework for charging infrastructure. According to Ukraine's legal code, those who install charging stations don't have the right to take payment as electrical energy can officially only be sold by the large state companies who are licensed to do so.[6] The European Bank for Reconstruction and Development (EBRD) has allocated funding for the development and introduction of a billing system in Ukraine for organizing commercial services for charging electric vehicles[7]. The European Investment Bank (EIB) provided a Euro 200 million loan to modernize the public transport system, including through the purchase of electric buses.

Overall Messages

Despite being with a car-dominated fleet, Ukraine faces other conditions more favorable to electric mobility, such as relatively low-cost vehicles and oil-importing status (Figure 1a). While electrification of transport does not yet look economically favorable as a national strategy (Table 2), this is largely driven by the fact that the electrification of 4W is not attractive under current conditions. Although the capital cost differential for electric 4Ws is relatively small, it is not fully compensated by operating cost advantages (Table 1). By contrast, there is a strong case for adoption of 2W electric motorbikes (Figure 1b), which present a lifecycle cost advantage of almost 12 percent (and over 30 percent in financial terms). In addition, the 12 percent capital cost differential associated with electric 2Ws looks relatively affordable, representing no more than 1-2 percent of GNI per capita. Furthermore, electric buses are only 20 percent more expensive and are beginning to offer modest economic advantages of the order of 3 percent of lifecycle cost.

The externality benefits of electric mobility in Ukraine are substantial in the case of buses, but relatively small for private vehicles (Figure 1d). Fuel cost savings present the main operating cost advantage of electric vehicles, and are substantial in the case of 2Ws and buses (Figure 1c). Given a fiscal regime that taxes petrol and diesel at 50-100 percent, while subsidizing electricity by 70 percent, these fuel cost savings are further accentuated in financial terms. Hence, the overall case for electric mobility in Ukraine looks better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$537 million per year by 2030 (or 0.38 percent of Ukrainian GDP). About half the required outlay is associated with the incremental capital cost of private electric vehicles - mainly 4W (Figure 2a). In terms of public investment, the most significant items are the additional cost of acquiring electric buses and the provision of public charging infrastructure for private vehicles (Figure 2a). The implicit carbon prices associated with electric 2Ws and buses in Ukraine are negative, while that for electric 4Ws exceeds US$150 (Table 3). Consequently, the most promising areas for pursuing carbon financing arrangements are electric 2Ws and public charging infrastructure, where approximately 30-40 percent of investment costs could be covered from this source.

The overall economic case for electric mobility in Ukraine is negative, even considering the prospect for further decarbonization of the power sector (Green Grid Scenario), let alone under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario). On a positive note, the emerging advantage associated with electrification of buses can be as much as tripled through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, there is no real case for electrification of 4Ws even when it comes to taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). It is clear that electric mobility in Ukraine needs to prioritize buses and 2Ws, until such time as the case for 4Ws further improves.

[1] Two wheelers cover all motorized two-wheeler vehicles registered.
[2] Source: OICA (2020) Passenger cars sales UKrAutoprom (2020) First registrations of new buses and minibuses.
[3] Source: Generation mix comes from a combination of US EIA international database and WB data.
[4] Source: Electric mobility – Global Trends and What we do in Ukraine, Alexander Ozeran, Ministry of Infrastructure of Ukraine.
[5] Source: Energy Policy Master Plan for Ukraine, Ministry of Economy, Trade and Industry, 2015.
[6] Source: https://www.kievcheckin.com/discover-kiev/are-we-entering-the-era-of-the-electric-car-heres-everything-you-need-to-know
[7] Source: https://frontnews.eu/news/en/13853

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(128)*	*301*	173	*25*	*56*	253	*789*	961	11.9	33.1
4W	*(393)*	*(712)*	*491*	(615)	*11*	*100*	(503)	*2,396*	1,781	(1.7)	4.9
Buses	*(4,525)*	*(10,558)*	*14,748*	(334)	*8,363*	*2,882*	10,911	*37,988*	37,653	3.1	10.4

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

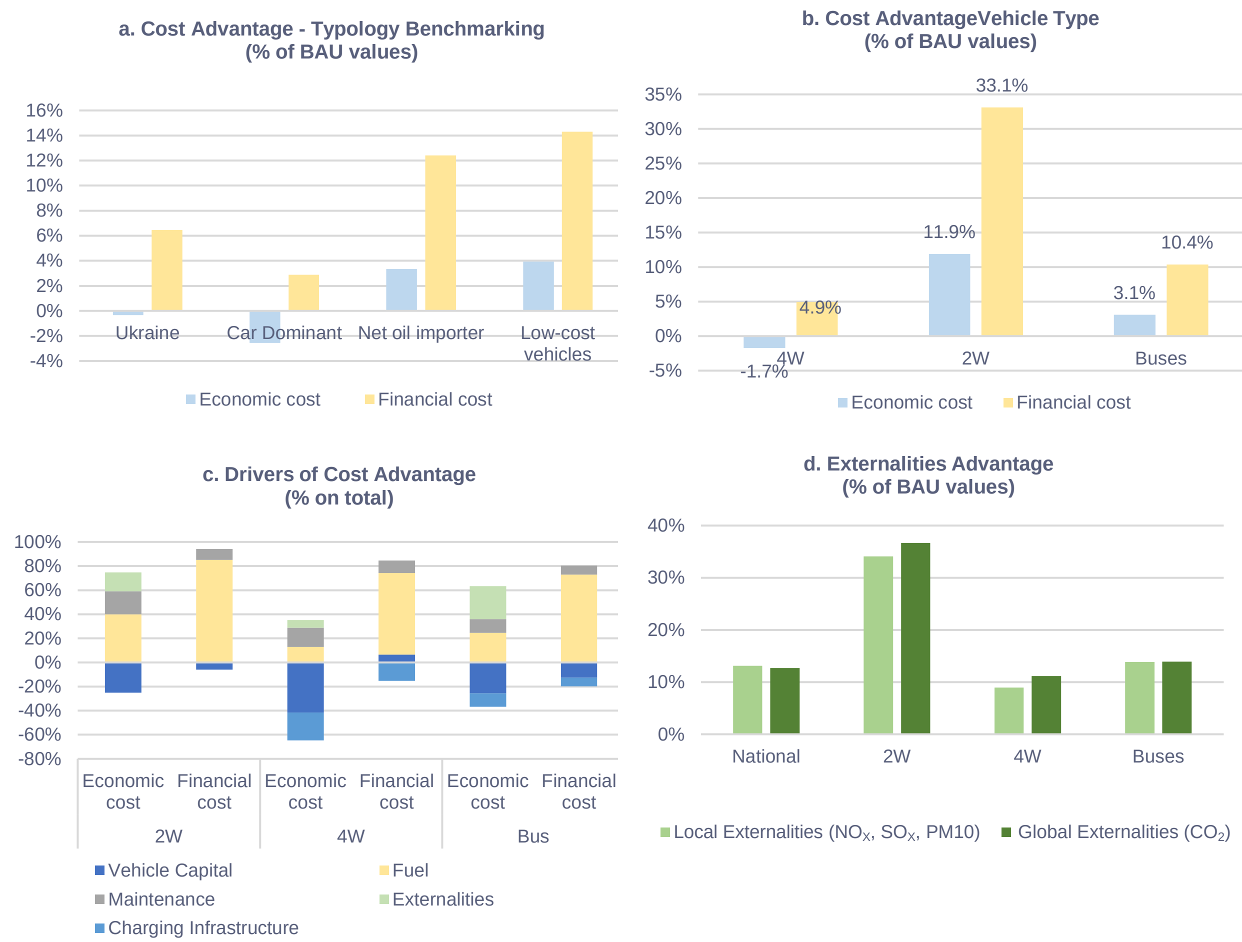


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

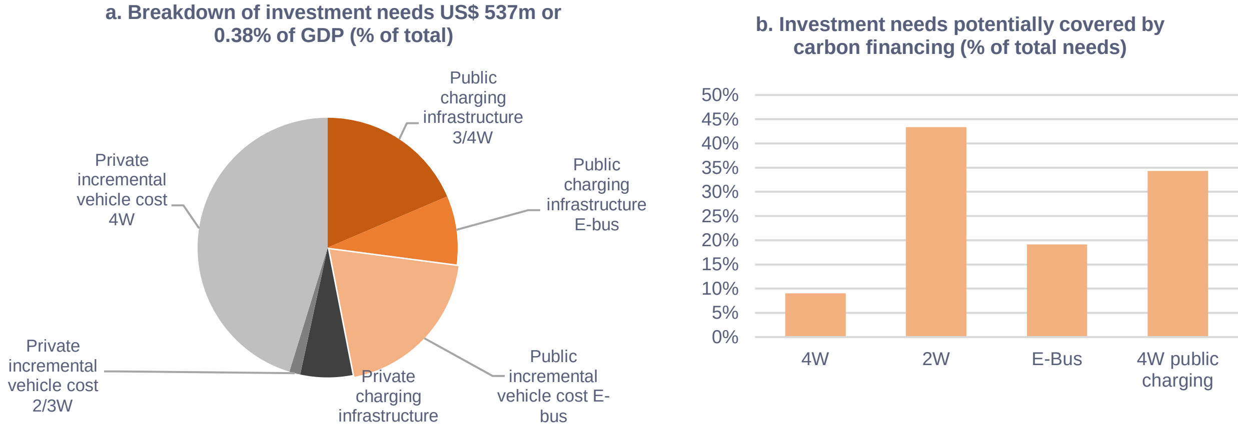


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(11,376)	(11,376)	(17,040)	(11,376)	(10,558)	(1,606)	(712)	(712)
Vehicle maintenance cost	4,628	4,628	3,992	4,628	4,635	4,998	272	(590)
Vehicle fuel cost	6,008	6,008	6,008	2,113	10,114	15,772	219	875
Private charging infrastructure	(1,104)	(1,104)	(1,104)	(1,104)	-	-	(102)	(102)
Public charging infrastructure	(4,633)	(4,633)	(4,633)	(4,633)	(4,525)	(4,525)	(292)	(333)
Sub-total	**(6,478)**	**(6,478)**	**(12,776)**	**(10,372)**	**(334)**	**14,638**	**(615)**	**(862)**
Local externalities	2,862	3,033	2,862	2,834	8,363	13,044	11	50
Global externalities	2,119	2,318	2,119	1,652	2,882	4,515	100	417
Economic cost advantage	**(1,497)**	**(1,127)**	**(7,796)**	**(5,887)**	**10,911**	**32,198**	**(503)**	**(395)**
Fiscal wedge	39,734	39,734	39,614	37,604	37,988	58,132	2,396	6,937
Financial cost advantage	**33,256**	**33,256**	**26,837**	**27,232**	**37,653**	**72,770**	**1,781**	**6,074**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(503)	(483)	(920)	(743)				
2W	253	258	210	222				
E-bus	10,911	11,346	5,667	5,569				

TABLE 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	26,219	4W mileage (kms)	15,224	Overall investment needs (US$m)	537
Price of 4W EV (US$/vehicle)	24,581	2W mileage (kms)	7,627	-of which 4W purchase	243
Price of 2W ICE (US$/vehicle)	887	Bus mileage (kms)	48,092	-of which 2W purchase	7
Price of 2W EV (US$/vehicle)	1,031	4W lifetime (years)	22	-of which e-bus purchase	107
Price of bus ICE (US$/vehicle)	110,826	2W lifetime (years)	17	Fiscal impact (US$m)	(1,247)
Price of bus EV (US$/vehicle)	135,324	Bus lifetime (years)	20	-of which vehicle duties	(310)
Net tax difference on 4W EV (%)	20%	4W second hand (%)	65.8%	-of which vehicle taxes/subsidies	(22)
Net tax difference on 2W EV (%)	20%	2W second hand (%)	65.8%	-of which petrol taxes/subsidies	(176)
Net tax difference on E-bus (%)	20%	Bus second hand (%)	71.9%	-of which diesel taxes/subsidies	(268)
Price of petrol (US$/liter)	0.54	Efficiency 4W ICE (MJ/km)	2.21	-of which electricity taxes/subsidies	(470)
Net petrol tax (US$/liter)	0.46	Efficiency 4W EV (MJ/km)	4.05	Implicit carbon price ($/tonne)	44
Price of diesel (US$/liter)	0.73	Efficiency 2W ICE (MJ/km)	0.87	-of which for 4W	156
Net diesel tax (US$/liter)	0.31	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	(92)
Price of electricity (US$/kWh)	0.15	Efficiency bus ICE (MJ/km)	16.84	-of which for buses	(72)
Net electricity tax (US$/kWh)	(0.11)	Efficiency bus EV (MJ/km)	5.74	Pollution reduction (tons)	3
Electricity carbon intensity (g/kWh)	274	4W share (% pax-kms)	66%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	3%	- of which global (CO_2)	3
		Bus share (% pax-kms)	31%	Affordability of 2W EV (Δ cost % GNI pc)	1.4%
				Affordability of 4W EV (Δ cost % GNI pc)	-3.7%

Country at a Glance – Passenger Electric Mobility in Uruguay

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	IMPORTER	HIGH

Country Background

Uruguay has a mixed vehicle fleet though cars dominate the mix (57.6 percent), followed by two-wheelers[1] (40.2 percent), and buses (2.2 percent)[2]. Electricity is primarily generated from renewable sources (97.6 percent), including hydro (44.7 percent), wind (32.5 percent) and biomass and waste (17.5 percent)[3]. The national Government has taken several steps to foster e-mobility. Efforts are underway to generate funds to support EV adoption through the Green Climate Fund (GCF) to replace approximately 120 ICE buses with electric buses.[4] Measures encouraging bus operators to transition into electric vehicles include establishing tax breaks and subsidies for bus purchases. As a result of tax incentives and subsidies, the price difference between an electric bus and a diesel bus has become marginal to an operator[5]. There is also an awareness program to encourage private operators to take up electric buses[6]. In 2019, the first call for subsidies for the purchase of e-buses was launched under a specific e-bus subsidy regulation to replace 4 percent of the total bus fleet[7]. There are several plans and ongoing programs: The MOVÉS project promotes the use of electric vehicles, helps banks develop green credits for the purchase of EVs, and gives specific credits for medium-sized enterprises[8]. A vehicle manufacturing facility is planned to be developed in Uruguay. The factory is scheduled to go into operation in 2024 with a product line of small electric cars and electric delivery vans. The locally produced electric cars are expected to be on the road by 2023[9]. UNDP is supporting the national Government in developing sustainable and efficient urban mobility system in Uruguay. The program is partly focusing on reforming the current regulations and incentives for promoting electric vehicles in the public transport sector[10].

Overall Messages

Despite facing relatively high vehicle costs, Uruguay presents many conditions that are more favorable towards electric mobility, including a mixed fleet, and oil-importer status (Figure 1a). While electrification of transport does not yet look economically favorable as a national strategy (Table 2), this is largely driven by the fact that the electrification of 4W vehicles is not attractive under current conditions (Table 1). By contrast, there is a strong case for adoption of 2W electric motorbikes (Figure 1b), which present a lifecycle cost advantage of almost 16 percent (over 30 percent in financial terms) and are relatively affordable with incremental capital costs representing no more than 1 percent of GNI per capita. The case for electric buses is also good, offering lifecycle cost advantages of 7-8 percent, against an incremental capital cost under 30 percent, and these are more relevant to Uruguay given that they represent a much larger share of transportation than 2Ws.

The main externality benefits of electric mobility in Uruguay are associated with the reduced carbon emissions of buses (Figure 1d). Fuel cost savings are also important, despite the fact that electricity is taxed almost as heavily as petroleum at close to 140 percent. Considering also a 20 percent tax advantage in favor of the purchase of electric vehicles, the overall case for electric mobility in Uruguay looks significantly better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$352 million per year by 2030 (or 0.45 percent of Uruguayan GDP). About four fifths of the required outlay is associated with the incremental capital cost of private electric vehicles (Figure 2a). In terms of public investment, the most significant item is the provision of public charging infrastructure for private vehicles (Figure 2a). Given that implicit carbon prices associated with electric buses in Uruguay are quite negative (Table 3), there is significant scope to cover almost 80 percent of the incremental capital cost of bus procurement through carbon financing arrangements. However, for 4W electric vehicles, the implicit carbon price exceeds US$260 per ton.

The overall economic case for electric mobility in Uruguay is negative in economic terms, although – due to government incentives – strongly positive in financial terms. This outcome is further accentuated under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), nor is there much scope for further decarbonization of the power sector (Green Grid Scenario). On a positive note, the significant advantage associated with electrification of buses can be further increased through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, even when it comes to taxi fleets and other intensively used vehicles, the case for electric 4Ws remains marginal (Taxi Fleet Scenario). It is clear that electric mobility in Uruguay needs to prioritize the bus segment of the fleet, in view of the many advantages offered.

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1 Two wheelers cover all motorized two-wheeler vehicles registered.
2 Source: OICA (2020) Passenger cars sales Uruguay Instituto Nacional de Estadistica (2020) Parque automotor del país según tipo de vehículo utilizado.
3 Source: Generation mix comes from a combination of US EIA international database and WB data.
4 Source: http://www.uemi.net/montevideo---uruguay.html
5 Source: https://www.bnamericas.com/en/features/spotlight-the-future-of-electric-vehicles-in-the-southern-cone
6 Source: http://www.uemi.net/montevideo---uruguay.html
7 Source: The World Bank Group
8 Source: The World Bank Group
9 Source: https://www.electrive.com/2021/02/24/spanish-ev-startup-plans-plant-in-uruguay/
10 Source: UNDP, Annotated Project Document template for nationally implemented projects. Towards a sustainable and efficient urban mobility system in Uruguay

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption
BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	*0*	*(404)*	*751*	347	*30*	*88*	466	*1,156*	1,503	16.7	30.7
4W	*(555)*	*(2,866)*	*1,250*	(2,171)	*6*	*214*	(1,951)	*5,085*	2,914	(4.7)	4.4
Buses	*(6,013)*	*249*	*27,870*	22,106	*859*	*5,096*	28,060	*11,764*	33,869	7.7	6.8

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

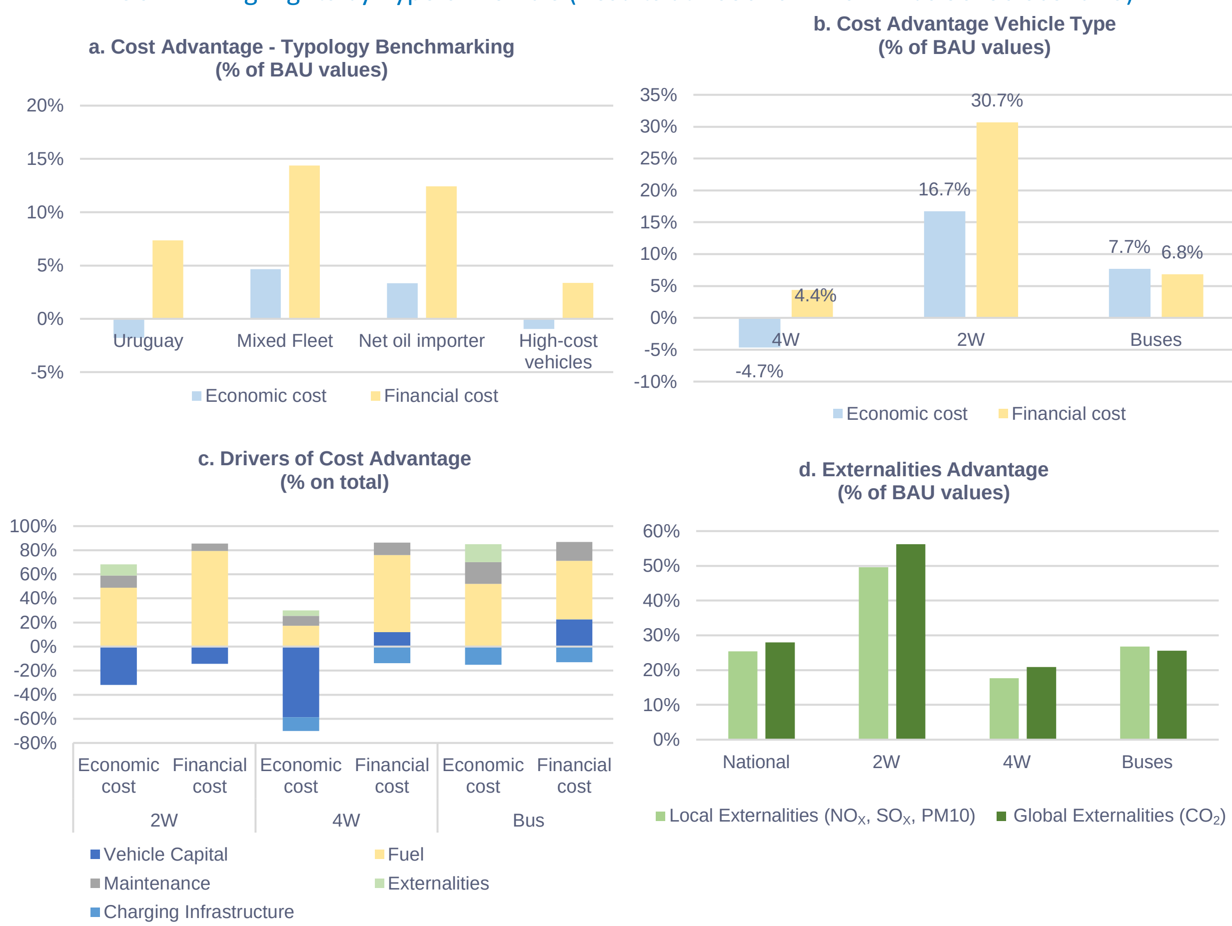

FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

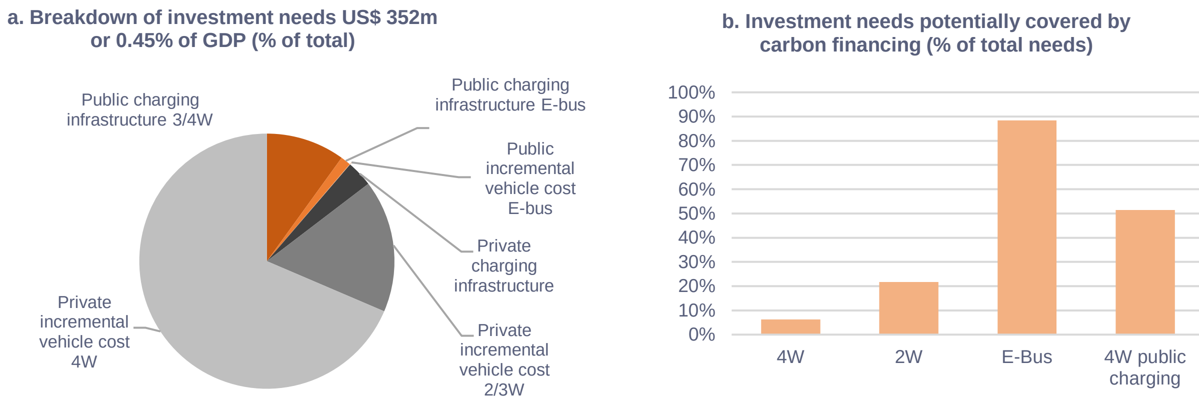

TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(37,121)	(37,121)	(50,012)	(37,121)	249	13,729	(2,866)	(2,866)
Vehicle maintenance cost	7,251	7,251	7,046	7,251	7,218	7,519	407	(771)
Vehicle fuel cost	21,964	21,964	21,964	15,837	20,652	25,766	843	3,370
Private charging infrastructure	(1,445)	(1,445)	(1,445)	(1,445)	-	-	(139)	(139)
Public charging infrastructure	(4,897)	(4,897)	(4,897)	(4,897)	(6,013)	(6,013)	(416)	(473)
Sub-total	**(14,247)**	**(14,247)**	**(27,343)**	**(20,375)**	**22,106**	**41,001**	**(2,171)**	**(879)**
Local externalities	687	687	687	678	859	1,071	6	23
Global externalities	4,300	4,300	4,300	3,585	5,096	6,372	214	885
Economic cost advantage	**(9,260)**	**(9,260)**	**(22,356)**	**(16,112)**	**28,060**	**48,444**	**(1,951)**	**30**
Fiscal wedge	74,957	74,957	74,567	65,733	11,764	12,975	5,085	10,294
Financial cost advantage	**60,710**	**60,710**	**47,223**	**45,358**	**33,869**	**53,976**	**2,914**	**9,415**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(1,951)	(1,951)	(2,971)	(2,447)				
2W	466	466	365	414				
E-bus	28,060	28,060	20,937	20,025				

TABLE 3: Supporting Information on Parameters and Results

Parameters	**Value**	**Parameters**	**Value**	**Other results for 30x30 Scenario**	**Value**
Price of 4W ICE (US$/vehicle)	34,261	4W mileage (kms)	15,224	Overall investment needs (US$m)	352
Price of 4W EV (US$/vehicle)	37,429	2W mileage (kms)	7,627	-of which 4W purchase	242
Price of 2W ICE (US$/vehicle)	1,193	Bus mileage (kms)	48,092	-of which 2W purchase	59
Price of 2W EV (US$/vehicle)	1,569	4W lifetime (years)	22	-of which e-bus purchase	(0.2)
Price of bus ICE (US$/vehicle)	171,910	2W lifetime (years)	17	Fiscal impact (US$m)	(607)
Price of bus EV (US$/vehicle)	135,324	Bus lifetime (years)	20	-of which vehicle duties	(182)
Net tax difference on 4W EV (%)	23%	4W second hand (%)	6.5%	-of which vehicle taxes/subsidies	(123)
Net tax difference on 2W EV (%)	23%	2W second hand (%)	6.5%	-of which petrol taxes/subsidies	(466)
Net tax difference on E-bus (%)	23%	Bus second hand (%)	1.9%	-of which diesel taxes/subsidies	(21)
Price of petrol (US$/liter)	0.63	Efficiency 4W ICE (MJ/km)	2.40	-of which electricity taxes/subsidies	185
Net petrol tax (US$/liter)	1.02	Efficiency 4W EV (MJ/km)	1.20	Implicit carbon price ($/tonne)	82
Price of diesel (US$/liter)	0.70	Efficiency 2W ICE (MJ/km)	0.85	-of which for 4W	261
Net diesel tax (US$/liter)	0.51	Efficiency 2W EV (MJ/km)	0.11	-of which for 2W	(111)
Price of electricity (US$/kWh)	0.11	Efficiency bus ICE (MJ/km)	15.52	-of which for buses	(117)
Net electricity tax (US$/kWh)	0.15	Efficiency bus EV (MJ/km)	5.08	Pollution reduction (tons)	1
Electricity carbon intensity (g/kWh)	23	4W share (% pax-kms)	63%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	28%	- of which global (CO_2)	1
		Bus share (% pax-kms)	9%	Affordability of 2W EV (Δ cost % GNI pc)	1.4%
				Affordability of 4W EV (Δ cost % GNI pc)	-2.3%

Country at a Glance – Passenger Electric Mobility in Vanuatu

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	IMPORTER	HIGH

Country Background

Vanuatu has a mixed vehicle fleet with the largest share being of buses (60.5 percent), followed by cars (35.6 percent), and two-wheelers[1] (3.9 percent)[2]. Electricity is primarily generated from fossil fuels (85.6 percent) – mainly coal (85.6 percent) – and less from renewable sources (14.4 percent) – notably solar (7.6 percent) and wind (6.8 percent). There are no current transport policies to promote the adoption of electric vehicles. The Intended Nationally Determined Contribution (INDC) plan has set an ambitious target to increase to 100 percent the share of renewable energy by 2030[3]. The plan targets to reduce GHG by 100 percent in the power generation sub-sector and by 30 percent for the whole energy sector. A recent update of the plan (2020) has set the following target for EV adoption in the country by 2030[4]: 10 percent of the public transport buses to be electric; 10 percent of the Government fleet to be electric; and the number of electric 2W and 3W to be increased to 1,000. EV penetration in the country has been extremely low. Recently, some private initiatives have taken place to introduce EVs. On Wheels has introduced electric cars and scooters in the country in 2020[5].

Overall Messages

Despite having some conditions favorable to electric mobility, such as a mixed fleet and oil importing status, Vanuatu is held back by relatively high-cost vehicles (Figure 1a). Electrification of transport does not yet look economically favorable as a national strategy (Table 2). Even with buses, the economic case for electric mobility is only marginally favorable and turns substantially negative in financial terms (Table 1). For 2Ws, the opposite occurs, with electric mobility being uneconomic, yet financially attractive (Figure 1b). In any case, the capital cost differentials associated with electric 2Ws and 4Ws, at around 30 percent, are unaffordable representing 10-20 percent of GNI per capita.

The externality benefits of electric mobility in Vanuatu are only substantial in the case of buses, which yield important carbon savings (Figure 1c). Otherwise, maintenance cost savings are the main advantage associated with electric mobility. Fuel costs do *not* typically present savings, since electricity is very costly and additionally taxed much more heavily than petrol at 110 percent. This accounts for the unusual finding that the case for electric mobility in Vanuatu looks substantially worse in financial than in economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$2.5 million per year by 2030 (or 0.21 percent of Vanuatu's GDP). Over half of the required outlay is associated with the incremental cost of public charging infrastructure for buses (Figure 2a). In terms of private investment, the most significant item is the incremental capital cost of electric 4Ws (Figure 2a). Given that implicit carbon prices associated with electric buses in Vanuatu are negative (Table 3), there is significant scope to cover 40 percent of the incremental cost of electric buses through carbon financing arrangements. However, for 4W electric vehicles, the implicit carbon price approaches US$1,150 per ton.

The overall economic case for electric mobility in Vanuatu is negative and certainly does not improve, under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario); however, it does become marginally positive with further decarbonization of the power sector (Green Grid Scenario). On a positive note, the emerging advantage associated with electrification of buses can be as much as tripled through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, there is no real case for electrification of 4Ws, even when it comes to taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). It is clear that electric mobility in Vanuatu needs to prioritize the bus segment of the fleet.

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[1] Two wheelers cover all motorized two-wheeler vehicles registered.
[2] Source: Pacific Datahub (2011) Vanuatu registered vehicle 2000-2011.
[3] Source: Intended National Determined Contribution (INDC), Ministry of Energy, Vanuatu, 2020.
[4] Source: Vanuatu's First Nationally Determined Contribution (NDC) (Updated Submission 2020).
[5] Source: https://www.facebook.com/vilatimesvanuatu/posts/mobility-technology-the-first-electric-car-in-vanuatu-vanuatu-starts-to-adopt-a-/939742129889957/

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption
BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	***Vehicle Capital Cost***	***Vehicle Operating Cost***	***Sub-Total***	***Local Externality***	***Global Externality***	***Cost Advantage (Economic Analysis)***	***Net Taxes and Subsidies (Fiscal Wedge)***	***Cost Advantage including Fiscal Wedge (Financial Advantage)***	***Cost Advantage (Economic Analysis)***	***Cost Advantage including Fiscal Wedge (Financial Advantage)***
2W	*0*	*(351)*	*283*	(68)	*6*	*48*	(15)	*469*	401	(0.5)	8.3
4W	*(550)*	*(2,473)*	*227*	(2,796)	*0*	*63*	(2,733)	*1,094*	(1,702)	(6.1)	(2.8)
Buses	*(6,082)*	*996*	*7,367*	2,281	*228*	*2,084*	4,594	*(46,122)*	(43,840)	1.2	(10.4)

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

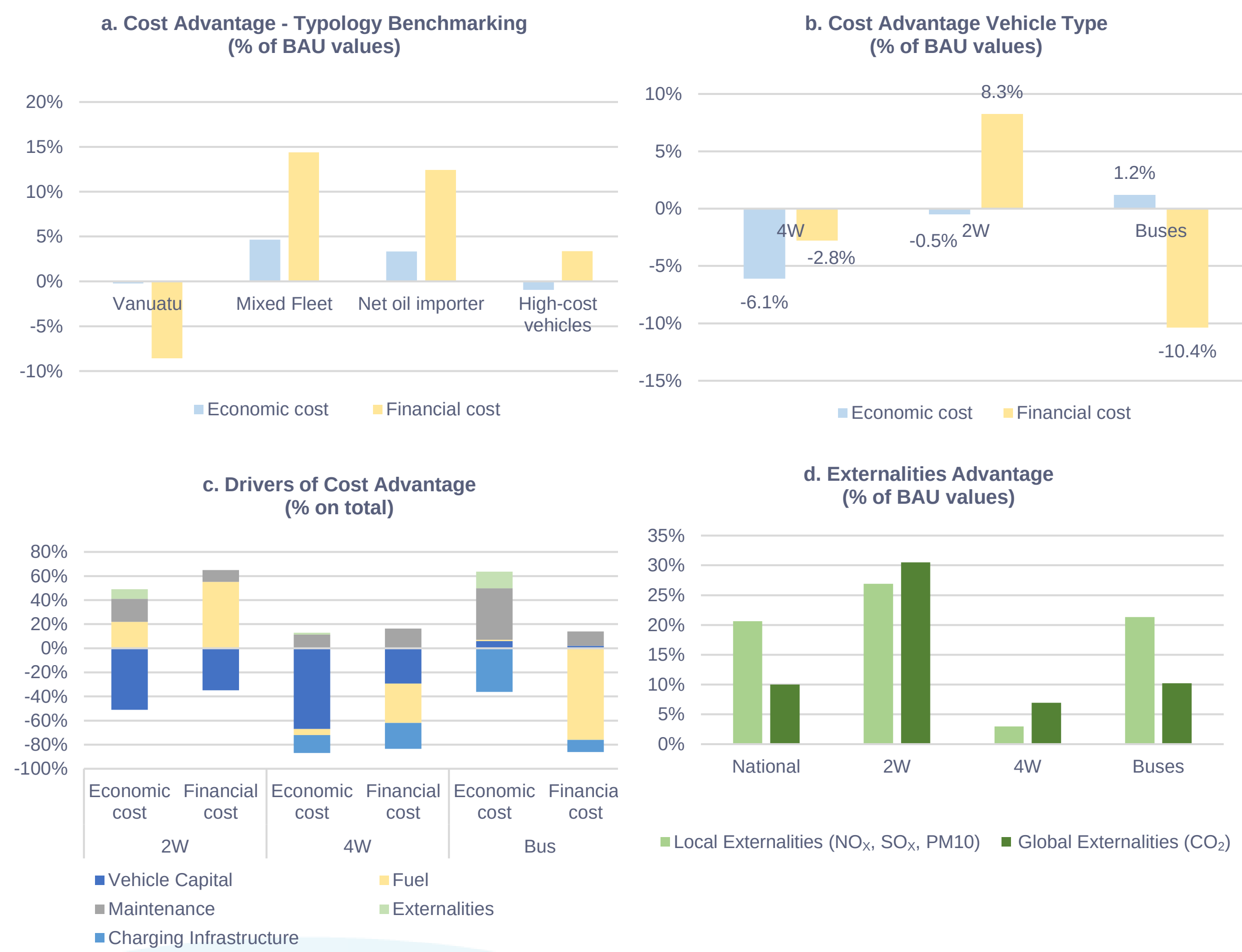
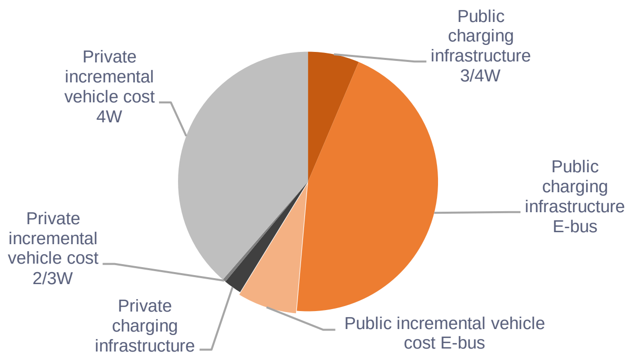


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

a. Breakdown of investment needs US$ 2.5m or 0.21% of GDP (% of total)



b. Investment needs potentially covered by carbon financing (% of total needs)

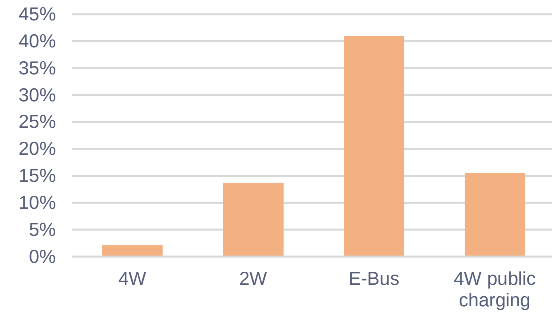


TABLE 2. Sensitivity Analysis Results– Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(3,915)	(3,915)	(10,604)	(3,915)	996	14,670	(2,473)	(2,473)
Vehicle maintenance cost	7,386	7,386	5,359	7,386	7,167	7,467	418	(788)
Vehicle fuel cost	(165)	(165)	(165)	(7,968)	200	200	(191)	(764)
Private charging infrastructure	(274)	(274)	(274)	(274)	-	-	(142)	(142)
Public charging infrastructure	(6,354)	(6,354)	(6,354)	(6,354)	(6,082)	(6,082)	(408)	(466)
Sub-total	**(3,322)**	**(3,322)**	**(12,039)**	**(11,126)**	**2,281**	**16,256**	**(2,796)**	**(4,634)**
Local externalities	210	236	210	208	228	228	0	2
Global externalities	2,036	3,274	2,036	1,160	2,084	2,084	63	281
Economic cost advantage	**(1,076)**	**187**	**(9,792)**	**(9,758)**	**4,594**	**18,568**	**(2,733)**	**(4,351)**
Fiscal wedge	(40,029)	(40,029)	(41,823)	(41,568)	(46,122)	(41,712)	1,094	(808)
Financial cost advantage	**(43,352)**	**(43,352)**	**(53,862)**	**(52,694)**	**(43,840)**	**(25,456)**	**(1,702)**	**(5,442)**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(2,733)	(2,682)	(3,822)	(3,133)				
2W	(15)	2	(122)	(66)				
E-bus	4,594	5,864	(2,615)	(4,041)				

TABLE 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	34,719	4W mileage (kms)	15,224	Overall investment needs (US$m)	2.5
Price of 4W EV (US$/vehicle)	44,329	2W mileage (kms)	7,627	-of which 4W purchase	1
Price of 2W ICE (US$/vehicle)	1,282	Bus mileage (kms)	48,092	-of which 2W purchase	0
Price of 2W EV (US$/vehicle)	1,859	4W lifetime (years)	22	-of which e-bus purchase	(0.2)
Price of bus ICE (US$/vehicle)	163,189	2W lifetime (years)	17	Fiscal impact (US$m)	9
Price of bus EV (US$/vehicle)	155,622	Bus lifetime (years)	20	-of which vehicle duties	0
Net tax difference on 4W EV (%)	0%	4W second hand (%)	2.7%	-of which vehicle taxes/subsidies	(1.0)
Net tax difference on 2W EV (%)	0%	2W second hand (%)	2.7%	-of which petrol taxes/subsidies	(0.7)
Net tax difference on E-bus (%)	0%	Bus second hand (%)	0.6%	-of which diesel taxes/subsidies	(1.4)
Price of petrol (US$/liter)	0.60	Efficiency 4W ICE (MJ/km)	2.08	-of which electricity taxes/subsidies	12
Net petrol tax (US$/liter)	0.97	Efficiency 4W EV (MJ/km)	0.84	Implicit carbon price ($/tonne)	40
Price of diesel (US$/liter)	0.74	Efficiency 2W ICE (MJ/km)	0.85	-of which for 4W	1,142
Net diesel tax (US$/liter)	0.09	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	34
Price of electricity (US$/kWh)	0.21	Efficiency bus ICE (MJ/km)	15.80	-of which for buses	(31)
Net electricity tax (US$/kWh)	0.23	Efficiency bus EV (MJ/km)	5.31	Pollution reduction (tons)	0
Electricity carbon intensity (g/kWh)	551	4W share (% pax-kms)	12%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	0.2%	- of which global (CO_2)	0
		Bus share (% pax-kms)	88%	Affordability of 2W EV (Δ cost % GNI pc)	10.5%
				Affordability of 4W EV (Δ cost % GNI pc)	16.9%

Country at a Glance – Passenger Electric Mobility in Vietnam

Country Typology

Vehicle Fleet Composition	Net Oil Trading Status	Relative Cost of Vehicles
MIXED FLEET	IMPORTER	HIGH

Country Background

The dominant vehicle type in Vietnam is the two-wheeler (82.9 percent), followed by cars (9.1 percent), three-wheelers (6.2 percent) and buses (1.8 percent). Electricity is primarily generated from fossil fuels (63.6 percent) – mainly gas (33.4 percent) and coal (29.7 percent) – plus a significant contribution from renewable sources (36.4 percent) – almost exclusively hydro (36.1 percent)[1]. Government has targeted to increase the electric vehicle stock (a combination of hybrid and electric cars) to 6 million by 2020,[2] from a low starting point at around 306,000[3]. Vietnam is second only to China as a leader in electric two-wheelers, with an established high market share that reached 14 percent in 2020[4]. VinFast, a part of Vietnam's biggest private enterprise Vingroup, is spearheading the domestic electric vehicle manufacturing. It plans to produce electric motorbikes, electric buses and electric cars in their production plants in the country. VinFast is expecting to invest US$ 1-1.5 billion with a target to produce 100,000-200,000 vehicles per year, including five-seat sedans, SUVs and electric motorbikes[5]. The UN Environmental Program (UNEP) is supporting the introduction of electric two and three-wheelers in Vietnam, along with some other Asian countries[6]. The GIZ has a major technical assistance program to support transport initiatives under Vietnam's NDC. The program includes building mechanisms, policies and roadmaps to advance e-mobility development at national and city levels[7]. The World Bank Group is developing an e-mobility roadmap for the country and an operational plan for a pilot city[8].

Overall Messages

Vietnam faces many conditions that are favorable towards electric mobility, including a mixed fleet and oil-importing status, albeit vehicle costs are relatively high (Figure 1a). Electrification of transport looks to be viable as a national strategy (Table 2); with the exception of the 4W segment, due to significant (and unaffordable) capital cost differentials (Table 1). By contrast, there is a strong case for adoption of 2W electric motorbikes (Figure 1b), which present a lifecycle cost advantage of around 13 percent (almost 20 percent in financial terms). However, a significant barrier to uptake is the 50 percent capital cost differential associated with electric 2Ws, which represents 8.7 percent of GNI per capita and looks unaffordable even with consumer finance. Furthermore, electric buses also offer significant economic advantages of the order of 6 percent of lifecycle cost, against a capital cost differential of just over 10 percent.

The externality benefits of electric mobility in Vietnam are particularly significant for buses, both in terms of local air quality and savings in carbon emissions (Figure 1c). Otherwise, fuel cost savings are the main advantage associated with electric mobility in Vietnam, given that petrol is taxed at 60 percent and electricity is tax exempt (Table 3). Furthermore, electric buses and 4Ws enjoy a tax differential of 45 percent. As a result, the overall case for electric mobility in Vietnam looks even better in financial than economic terms (Figure 1a).

The total investment needs associated with the 30x30 Scenario amount to US$3.8 billion per year by 2030 (or 0.85 percent of Vietnamese GDP). About four fifths of the required outlay is associated with the incremental capital of private electric vehicles, mainly 2Ws (Figure 2a). In terms of public investment, the most significant item is the incremental capital cost of electric buses (Figure 2a). Given that implicit carbon prices associated with electric 2Ws and buses in Vietnam are negative (Table 3), there is scope to cover 20 percent of incremental investments associated with these vehicle categories through carbon financing arrangements. However, for 4W electric vehicles, the implicit carbon price is approaching US$700 per ton.

The overall economic case for electric mobility is very positive in Vietnam, even under more conservative assumptions about the cost of batteries (Scarce Minerals Scenario) and the fuel efficiency of internal combustion engines (Fuel Efficiency Scenario), and only improves with further decarbonization of the power sector (Green Grid Scenario). On a positive note, the important advantage associated with electrification of buses is substantially increased through the more efficient procurement and operation of vehicles (Efficient Bus Scenario). However, there is not yet any case for electrification of 4Ws even when it comes to taxi fleets and other intensively used vehicles (Taxi Fleet Scenario). It is clear that electric mobility in Vietnam needs to prioritize the bus and 2W segments of the fleet, with efforts needed to reduce the capital cost.

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[1] Source: Generation mix comes from a combination of US EIA international database and the World Bank Group data.
[2] Source: Global Electric Vehicle Policy Database.
[3] Source: Powertrain mix comes from country specific sources. Additional data on EVs is provided from separate data provided by WB. Otherwise, if data is still missing, we assume 100 percent ICE vehicles and assume 50:50 split for petrol and diesel for cars, 100 petrol for 2 wheelers and 100 percent Diesel for buses. For 3 wheelers, the shares are used from India data as this is one of the largest markets for 3 wheelers in the world.
[4] Source: Hyperdrive Daily: The EV Revolution Rides on Two Wheels - Bloomberg
[5] Source: Vinfast and the Electric Vehicle Market in Vietnam, Dylan Pastoor, 2019. (www.netherlandswolrdwide.nl)
[6] Source: https://www.unep.org/explore-topics/transport/what-we-do/electric-mobility/electric-mobility-projects-asia-and-pacific
[7] Source: The World Bank
[8] Source: https://www.arup.com/news-and-events/accelerating-e-mobility-in-vietnam

TABLE 1. Cost Advantage at year 2030 of Accelerated EV Adoption BAU Scenario minus 30x30 Scenario (average over fleet additions)

	$/vehicle									% of BAU values	
	a	b	c	d=a+b+c	e		f=d+e	g	h=d+g		
	Charging Infrastructure	*Vehicle Capital Cost*	*Vehicle Operating Cost*	*Sub-Total*	*Local Externality*	*Global Externality*	*Cost Advantage (Economic Analysis)*	*Net Taxes and Subsidies (Fiscal Wedge)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*	*Cost Advantage (Economic Analysis)*	*Cost Advantage including Fiscal Wedge (Financial Advantage)*
2W	0	(348)	605	258	80	76	413	506	764	13.3	19.7
4W	(569)	(3,004)	942	(2,631)	110	93	(2,427)	1,872	(759)	(6.7)	(1.4)
Buses	(6,102)	(14,234)	34,576	14,239	5,257	4,457	23,953	13,784	28,023	5.7	6.2

Note: results normalized by new vehicles entering the market in 2030.

FIGURE 1. Highlights by Type of Vehicle (Results at 2030 for BAU minus 30x30 Scenario)

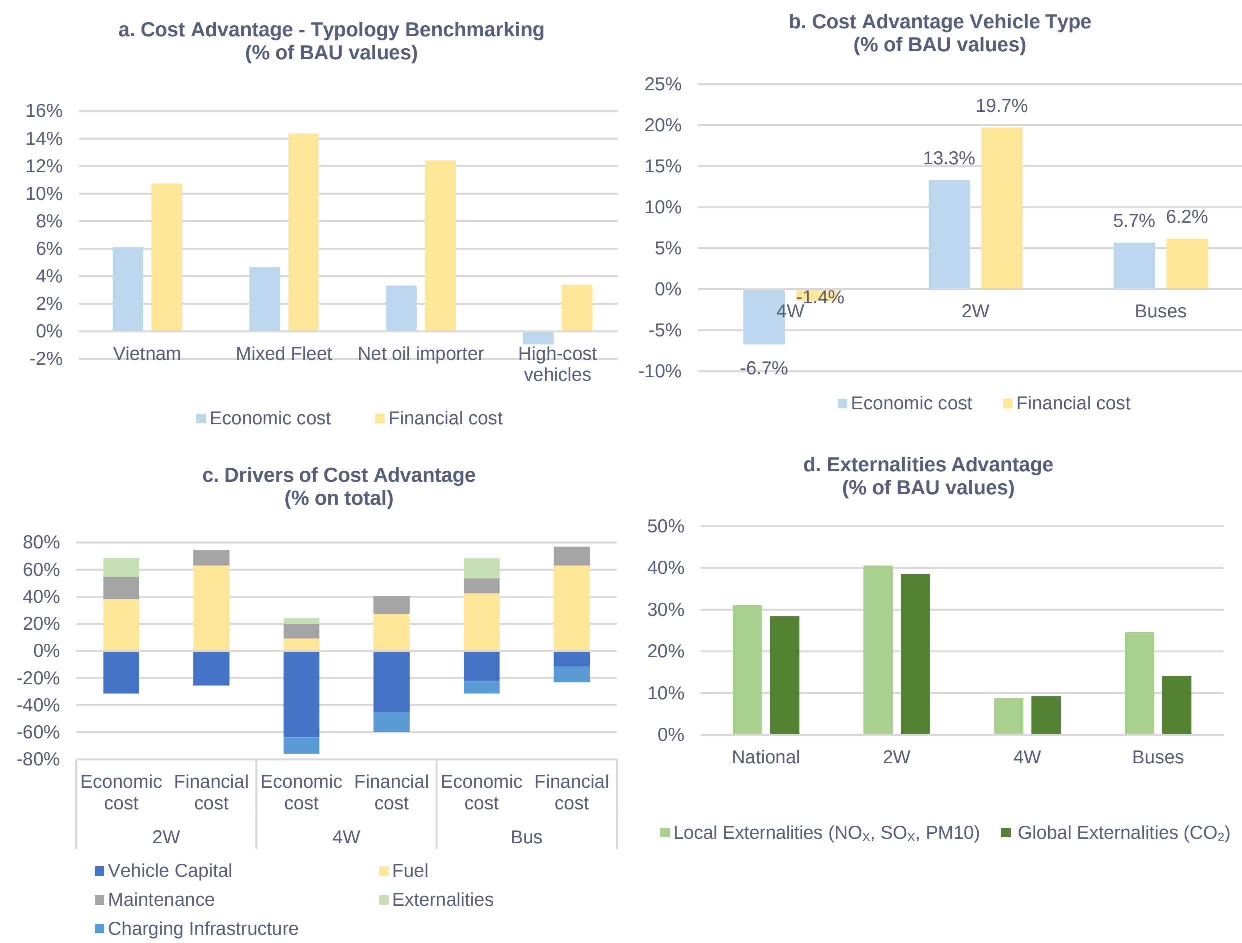
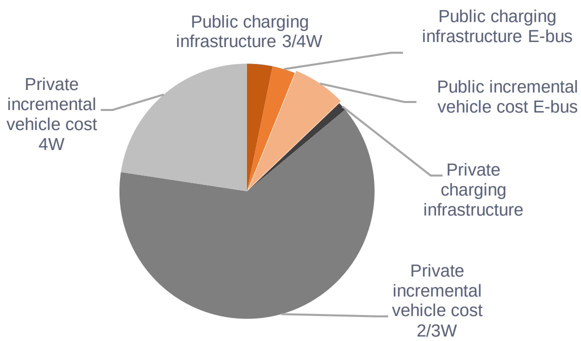


FIGURE 2. Investment and Financing Needs (Results at 2030 for BAU minus 30x30 Scenario)

a. Breakdown of investment needs US$ 3,817m or 0.85% of GDP (% of total)



b. Investment needs potentially covered by carbon financing (% of total needs)

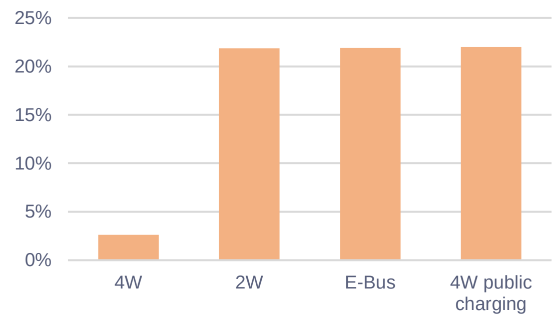


TABLE 2. Sensitivity Analysis Results – Cost Advantage

	NATIONAL RESULTS				BUS ONLY		4W ONLY	
Results at 2030 Business-As-Usual Baseline minus Named Scenario	**30x30 Scenario**	**Green Grid Scenario**	**Scarce Minerals Scenario**	**Fuel Efficiency Scenario**	**30x30 Scenario**	**Efficient Bus Scenario**	**30x30 Scenario**	**Taxi Fleet Scenario**
	$/mnpaxvkm				$/vehicle			
Vehicle capital cost	(22,595)	(22,595)	(28,694)	(22,595)	(14,234)	(499)	(3,004)	(3,004)
Vehicle maintenance cost	9,186	9,186	8,929	9,186	7,200	7,500	504	(722)
Vehicle fuel cost	21,892	21,892	21,892	17,876	27,376	27,376	438	1,751
Private charging infrastructure	(265)	(265)	(265)	(265)	-	-	(144)	(144)
Public charging infrastructure	(1,490)	(1,490)	(1,490)	(1,490)	(6,102)	(6,102)	(425)	(484)
Sub-total	**6,728**	**6,728**	**374**	**2,712**	**14,239**	**28,274**	**(2,631)**	**(2,603)**
Local externalities	4,195	5,602	4,195	3,847	5,257	5,257	110	520
Global externalities	3,916	4,604	3,916	3,355	4,457	4,457	93	403
Economic cost advantage	**14,839**	**16,935**	**8,484**	**9,914**	**23,953**	**37,988**	**(2,427)**	**(1,681)**
Fiscal wedge	26,451	26,451	24,579	24,826	13,784	17,795	1,872	3,739
Financial cost advantage	**33,179**	**33,179**	**24,953**	**27,538**	**28,023**	**46,070**	**(759)**	**1,135**
Economic Cost Advantage by type of vehicle ($/vehicle)								
4W	(2,427)	(2,244)	(3,367)	(2,825)				
2W	413	443	321	350				
E-bus	23,953	28,562	16,720	10,688				

TABLE 3: Supporting Information on Parameters and Results

Parameters	Value	Parameters	Value	Other results for 30x30 Scenario	Value
Price of 4W ICE (US$/vehicle)	32,230	4W mileage (kms)	15,330	Overall investment needs (US$m)	3,817
Price of 4W EV (US$/vehicle)	37,262	2W mileage (kms)	7,373	-of which 4W purchase	863
Price of 2W ICE (US$/vehicle)	1,051	Bus mileage (kms)	77,380	-of which 2W purchase	2,047
Price of 2W EV (US$/vehicle)	1,562	4W lifetime (years)	35	-of which e-bus purchase	258
Price of bus ICE (US$/vehicle)	141,332	2W lifetime (years)	34	Fiscal impact (US$m)	(4,146)
Price of bus EV (US$/vehicle)	155,622	Bus lifetime (years)	20	-of which vehicle duties	(463)
Net tax difference on 4W EV (%)	45%	4W second hand (%)	0%	-of which vehicle taxes/subsidies	261
Net tax difference on 2W EV (%)	5%	2W second hand (%)	0%	-of which petrol taxes/subsidies	(3,716)
Net tax difference on E-bus (%)	45%	Bus second hand (%)	0%	-of which diesel taxes/subsidies	(89)
Price of petrol (US$/liter)	0.50	Efficiency 4W ICE (MJ/km)	2.08	-of which electricity taxes/subsidies	(138)
Net petrol tax (US$/liter)	0.31	Efficiency 4W EV (MJ/km)	0.73	Implicit carbon price ($/tonne)	(72)
Price of diesel (US$/liter)	0.64	Efficiency 2W ICE (MJ/km)	0.85	-of which for 4W	698
Net diesel tax (US$/liter)	0.04	Efficiency 2W EV (MJ/km)	0.20	-of which for 2W	(115)
Price of electricity (US$/kWh)	0.11	Efficiency bus ICE (MJ/km)	15.85	-of which for buses	(113)
Net electricity tax (US$/kWh)	(0.00)	Efficiency bus EV (MJ/km)	5.35	Pollution reduction (tons)	24
Electricity carbon intensity (g/kWh)	441	4W share (% pax-kms)	11%	- of which local (SOx, NOx, PM10)	0
Discount rate (%)	6.6%	2W share (% pax-kms)	55%	- of which global (CO_2)	24
		Bus share (% pax-kms)	18%	Affordability of 2W EV (Δ cost % GNI pc)	8.7%
				Affordability of 4W EV (Δ cost % GNI pc)	38.6%

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