Pathways for Decarbonization of South Asia's Transportation Sector

A Product of the South Asia Group for Energy

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Introduction

With more than 1.5 billion people in total, the region of South Asia, comprised of Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and, Sri Lanka, accounted for nearly 20% of the world's population but only 8.6% of the global total greenhouse gas (GHG) emissions in 2018. However, while it has lower per capita emissions relative to global average, it is also one of the regions of the world experiencing fastest growth in emissions, growing about 60% over the past decade (World Bank, 2021). Additionally, this region is globally one of the worst affected by air pollution. For example, India, Pakistan and Bangladesh account for 42 out of the top 50 world's most polluted cities (Forbes, 2021). In these countries, road transport is a dominant cause of air pollution, which provides the context and motivation for this article.

Within this region, given its population and economy, India is the dominant polluter accounting for 80 percent of the region's emissions (World Bank, 2021). It also has the dominant share in terms of new sales of all kinds of transport vehicles (see Table 1).

Table 1: New Vehicle Sales in South Asian Countries in 2019 (Global Economy, 2019)

Country	Passenger Vehicle Sales 2019	Commercial Vehicle Sales 2019
India	2,962,115	854,743
Pakistan	162,689	25,025
Bangladesh	3,000	1,900
Sri Lanka	8,100	1,445
Nepal	7,505	14,300

Therefore, given India's outsized share in aggregate in emissions and given the prior work by this team, the emphasis is on analyses that were conducted in the Indian context. However, while the basic techno-economic arguments and the policy implications are likely generally applicable to the whole region, caution is warranted and additional research is needed on each of the countries in the region including India.

Road transport accounts for a large share of passenger and freight traffic in India, and that share has grown significantly in recent years. India's road transport accounts for 87% of passenger traffic and 60% of freight traffic movement in the country (MORTH-India, 2021). India has the world's fastest growth in transportation-sector energy use, averaging 6.8% per year since 2000 (IEA, 2015). Oil products, mostly diesel and gasoline, supplied

95% of total energy in the sector, and road transport energy demand accounted for 90% of the total oil demand (IEA, 2020). Within the HDV sector, trucking dominates fuel consumption, accounting for 43% of the overall diesel consumption, or about 36 MMT in 2018-19.

Heavy-duty vehicles are a key electrification target because they consumed 55% of total energy in the road transport sector in 2010; by 2030, this heavy-duty vehicle share is expected to reach 67% (S. Sharma, 2017). India imported 76% of its oil in 2011 and is projected to import 91% by 2030 (Ghate, 2017). To effectively decarbonize the transport sector in India and the rest of South Asia, the key sub-sectors to focus on would be trucking, buses and other high mileage vehicles like taxis.

The main alternative drivetrains to petroleum-based drivetrains are electric, natural gas and hydrogen. A comparative analysis of three fuel types—battery-electric, hydrogen fuel cell, and diesel for medium and heavy-duty vehicles—shows that the long-term economics of battery-electric vehicles look more favorable compared to others with a Total Cost of Ownership (TCO) of 0.71 $/mi as against a TCO of 0.78 $/mi for diesel trucks and 0.97 $/ for fuel cell vehicles. However, these numbers are highly dependent on the annual mileage and the cost of fuel (Burke, 2020).

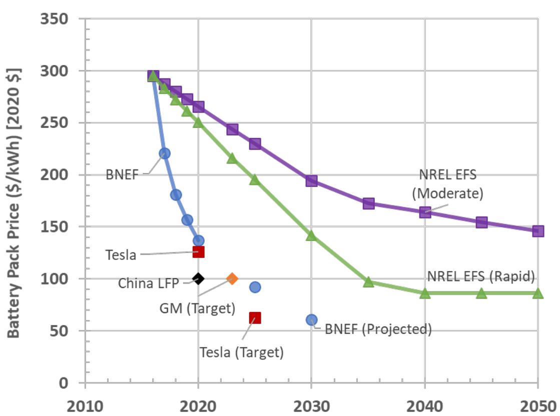

Figure 1: Global average battery pack prices projected and actual (BNEF 2020)

Historically, the upfront capital cost of electric vehicles has been prohibitively high. Over the past 10 years, however, the cost of battery technology—the main cost component of electric vehicles—has declined dramatically (Figure 1). The actual reduction in battery prices has been greater than even some ambitious projections (Jadun et al., 2017). Lower battery prices have resulted in lower upfront heavy-duty electric vehicle capital costs, which has helped increase their market share globally. For example, electric vehicle sales have doubled in the US (100k to 220k), tripled in the EU (200k to 700k) and become 5 times in China (150k to700k) between 2015 and 2020.In the commercial vehicle sector, the European Union (EU) has proposed a target of making 75% of all buses sold in the EU electric by 2030. In parallel, charging infrastructure is also being expanded rapidly in the US (100k public charging points), EU (350k public charging points) and China (800k public charging points).

India and other countries such as Pakistan and Sri Lanka have announced ambition for moving towards electric mobility. For example, Pakistan has announced a target of 50% of 2Ws/3Ws and urban bus sales to be electric by 2030, while aiming for 30% of passenger vehicles and truck sales to be electric by 2030 (IEA, 2021). India notified Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME) scheme in 2015, and the 2nd phase (FAME-II) of the scheme was rolled out in 2019. Total outlay for subsidizing upfront capital cost of electric vehicles was INR 3,500 crore and INR 10,000 crore in FAME-I and FAME-II respectively. Recently, India's Minister for Road Transport Nitin Gadkari announced that India is aiming to have 80% of 2W/3W sales, 70% of commercial vehicle sales and 30% of passenger vehicle sales to be electric by 2030 (Hindustan Times, 2021). However, these targets are yet to be notified as official Government of India (GoI) policy.

The next section summarizes key insights from recent studies on techno-economic analyses of electric vehicles in India. However, given the similar road transport context in other South Asian countries, and a globally connected battery market, we contend that the analytical conclusions would be applicable to the entire region.

Insights from existing studies

Heavy duty vehicles (HDVs) comprising heavy-duty trucks and buses account for only 10% of the global vehicle stock but are responsible for 46% of the greenhouse gas (GHG) emissions from road transport (IEA, 2020). HDVs account for the majority of oil consumption and emissions from road transport in developing countries such as India. Analysis from the International Council on Clean Transportation (ICCT, 2017) showed that while in the US, 65% of oil was consumed by passenger vehicles, with trucks and buses accounting for ~35%; for India, these statistics are reversed. Given low penetration of passenger cars, 65% of oil consumption is driven by HDVs (trucks and buses). Moreover, India is heavily dependent on crude oil import– nearly 88% of total crude oil consumption, resulting in ~USD 100 billion import bill for oil in 2020 and expected to more than double by 2050. Thus, for decarbonizing the transport sector as well as enhancing energy security of the region, focus must be to move towards zero-emission-vehicle (ZEV) sales in the HDV category.

Additionally, commercial vehicles such as buses, trucks and taxis drive significantly larger distances per day compared to privately owned vehicles. This makes the financial case for electrification more compelling by saving on fossil fuel costs for every km traveled, thereby reducing the payback period for electric vehicles, which have higher upfront costs. Below we summarize three recent studies conducted for India's transportation sector. However, given similar road conditions and driving patterns that exist in most parts of the region, the economics of EVs are expected to be comparable in other South Asian countries.

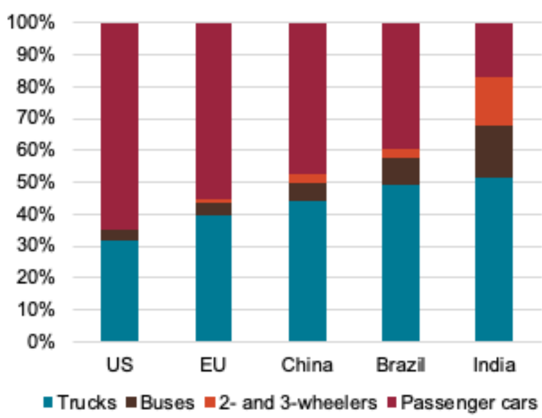

Figure 2: Share of oil consumption by different vehicle categories (ICCT, 2017)

Electric trucks are already cost effective

In a forthcoming study, LBNL conducted a bottom-up assessment of total cost of ownership (TCO) of electric trucks in various segments, and assessed the electricity demand and avoided oil consumption in the Indian context (Karali et al forthcoming). The analysis focused on identification of (1) vehicle characteristics, such as battery pack size and weight, based on Indian road conditions, (2) change in TCO for truck operators, (3) impact on diesel requirements, and related CO2 emissions and crude oil import dependence, and (4) change in national electricity demand. The calculations for TCO included capital cost, fuel and maintenance cost, battery replacement every 2000 cycles and general operation cost which includes driver cost, insurance cost, permits and tolls. Figure B below shows the estimates for 12-ton and 25-ton trucks (latter being the most popular truck size in the region). TCO of electric trucks is already lower than diesel trucks; specifically, TCO of 12-ton truck would be 15% lower, while that of a 25-ton truck would be 30% lower, if battery costs are assumed at $100/kWh (current market price of Chinese LFP batteries).
However, the capital cost for an electric truck is 179% and 58% higher than a comparable diesel 12-ton and 25-ton truck respectively. Therefore, upfront capital subsidy or other incentives are needed to drive early adoption by truck owners, which is a very fragmented market. At the same time, fast charging infrastructure along highways would be key to address range anxiety and minimize time spent on charging stops.

Table 2: Cost comparison of electric & diesel trucks in different weight classes

Electric trucks vs diesel trucks	7.5-ton	12-ton	25-ton	40-ton
Difference in capital cost (%)	102%	262%	232%	235%
Difference in TCO (%)	-3%	-10%	-30%	-24%
Payback Period (years)	6.3	4.9	2.5	3.1

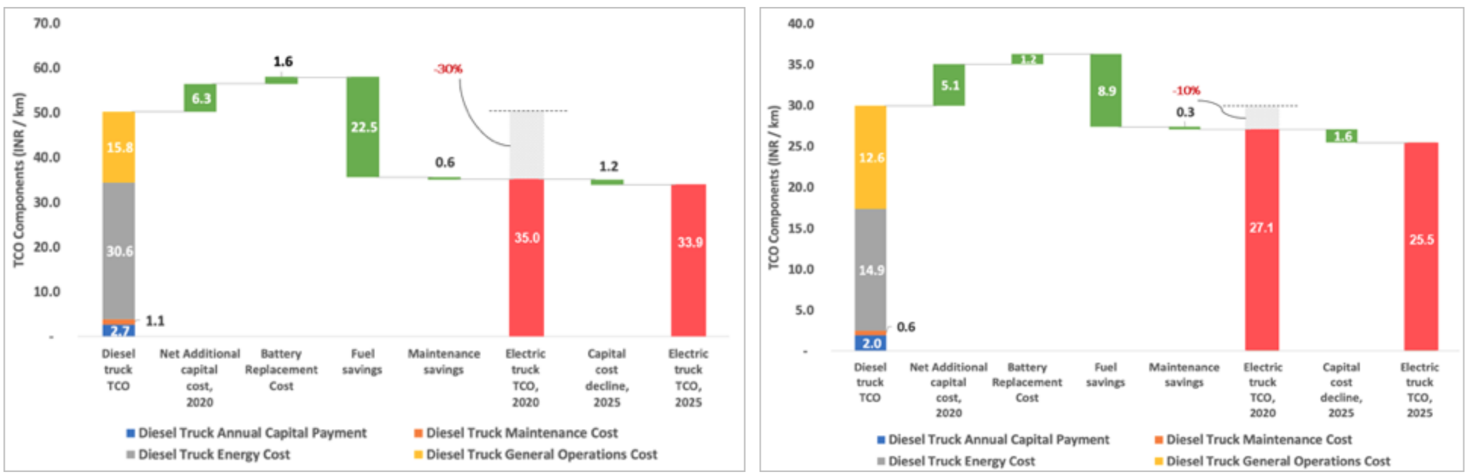

Figure 3: Total Cost of Ownership (TCO) of electric & diesel trucks (left: 25-ton, right: 12-ton)

The study also assessed the impact of electrification of trucks on their payload capacity, while considering potential for reducing truck weight in future using lighter materials, such as aluminum, instead of steel for the truck body. The effective payload capacity of a 12-ton electric truck is 13% lower than a corresponding diesel truck without lightweighting, and 6% lower with lightweighting. Similarly, for a 25-ton electric truck, payload capacity is 11% lower than that of a diesel truck without lightweighting, though only 5% lower with lightweighting. Thus, we do not anticipate additional battery weight to be a major obstacle to electrification.

Intercity buses could be more profitable by going electric

Using a bottom-up model, a recent study assessed TCO of electric and diesel buses (12 m AC/non-AC) over three inter-city route lengths in India: 0–150 km, 151–250 km, and 251–350 km (Khandekar et al., forthcoming). Popular routes in the western and southern regions of India were used for simulation of bus operations and travel times. TCO included capital cost, fuel cost, maintenance and driver costs. Assuming a current diesel price of Rs.75/l and electricity price of Rs.7/kWh, this analysis showed that electric buses can reduce TCO by 20% compared with diesel buses today without subsidy, including the cost of charging infrastructure and battery replacement. The TCO for a 12-m AC electric bus, including the charging infrastructure cost, was determined to be 38.6 INR/km, compared to 45.8 INR/km for a diesel bus, for 600-km daily distance traveled over 16 hours (based on data from Maharashtra State Road Transport Corporation, MSRTC). Fuel costs (diesel and compressed natural gas) account for the majority of the material costs for State Road Transport agencies, or the SRTUs. For instance, MSRTC spends 32% of TCO on diesel expenses. Deployment of electric buses would enhance profitability up to 45% on intercity AC service routes, thereby helping SRTUs improve their financial condition while providing a better passenger experience.
For non-AC buses, TCO of an electric bus is comparable to a diesel one.

Table 3: TCO components for 12-m AC and non-AC diesel and electric buses

Parameter	12-m AC electric bus	12-m AC diesel bus	12-m non-AC electric bus	12-m non-AC diesel bus
Capital cost (INR)	9,507,717	6,168,619	7,510,282	2,848,111
Fuel cost (INR/km)	9.1	25.0	8.4	16.7
Daily distance traveled (km)	600	600	600	600
Maintenance cost (INR/km)	4.0	8.0	4.0	8.0
Charging infrastructure cost (INR/km)	2.9	-	2.9	-
Payback period (years)	1.4	-	11.1	-
TCO (INR/km)	38.6	45.8	34.8	36.3

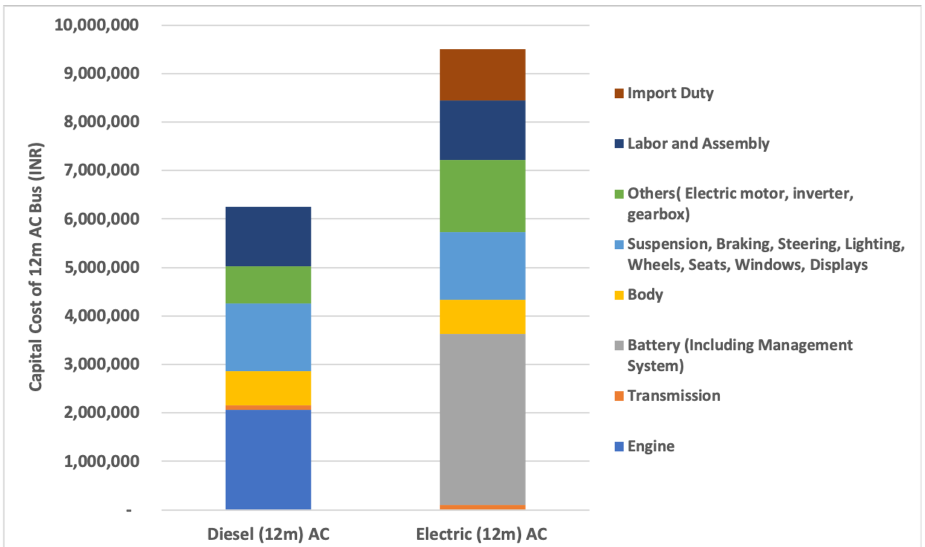

Figure 4: Bottom-up capital cost of 12-m AC diesel and electric bus (Khandekar et al 2018)

The manufacturing cost of a 12-m AC electric AC bus is 50% higher than the cost of a comparable diesel bus, assuming a \$156/kWh battery cost. However, taking the recent market battery pack price of \$100/kWh, and 30% import duty on assembled battery packs, upfront cost of an electric bus is estimated to be 35% higher than a diesel bus today. This estimate assumes a 324-kWh battery that gives 200-250 km on a single charge. 1C charging (i.e. the battery can be charged 0 to 80% within an hour) is commercially available and deployed in several countries, and a 25-minute midpoint stop and 30-minute turnaround time at the end of the route would provide plenty of time for the bus battery to charge while completing 600 km/day on average. Given the gap in upfront cost, strategic policy initiatives would be needed to nudge the market towards adoption.

Electrification of commercial taxi fleets could drive significant economic and environmental benefits

A forthcoming study on electric taxi fleet for the city of New Delhi developed a general framework for spatially-detailed estimation of charging infrastructure, and the economic and environmental benefits of commercial fleet electrification (Rajagopal et.al. 2022*)*. Using a real-world dataset comprising ~730,000 app-taxi trips spanning ~15 million kilometers (km) in Delhi (shared by Ola, a premier on-demand taxi service in India), the analysis concluded that deploying 23,000 electric taxis having 200 km range per full-charge along with a network of 3000 50 kW chargers could meet 100% of app-taxi demand in Delhi. An electric taxi fleet would reduce levelized cost per km by 21% and 37% relative to CNG and diesel vehicles respectively. This assumes a battery price of \$160/kWh, a subsidy of Rs. 10,000/kWh for batteries, and charging tariff of Rs 5.5/kWh (preferential tariff for EV charging provided by Delhi government).

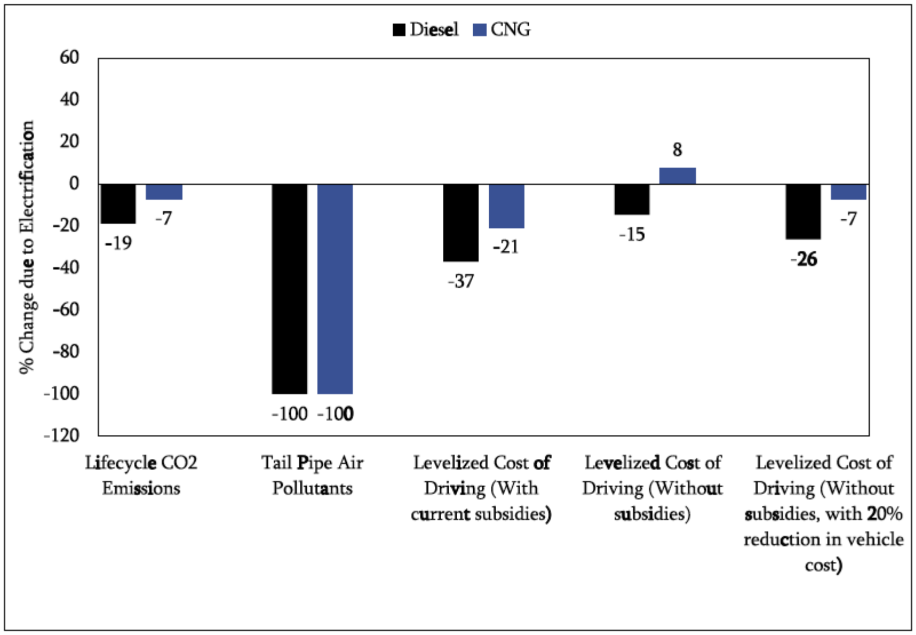

Figure 5: Impact of electrification on CO_2 emissions and the levelized cost of driving under different scenarios for diesel and CNG vehicles

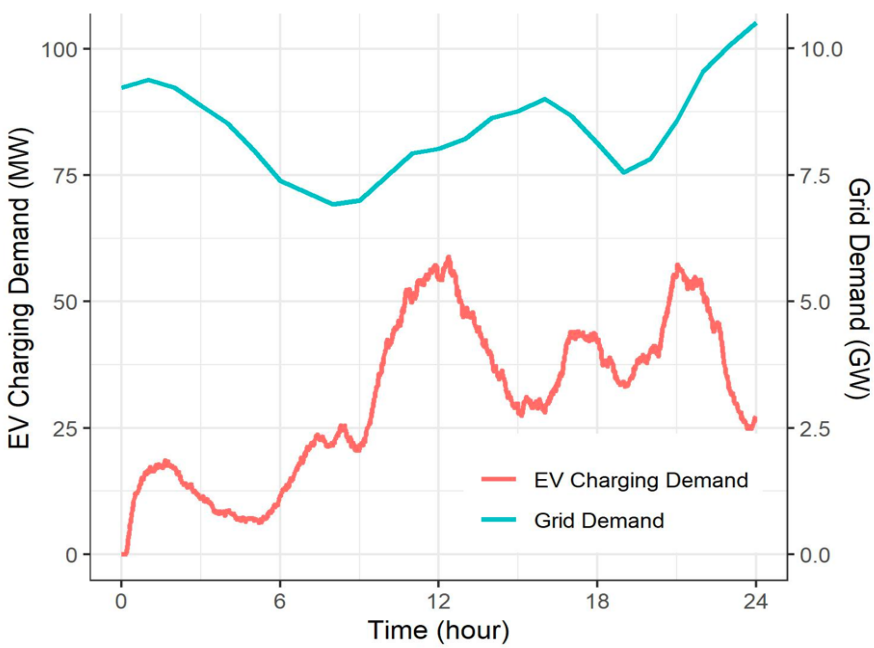

Figure 6: Daily average grid demand and EV charging demand in Delhi

Battery-electric vehicles are 2-3 times more efficient than ICE vehicles, and would reduce commercial fleet operation costs while reducing GHG emissions and avoiding tailpipe emissions at the point of use. Various studies have found that road transport accounts for 20-30% of PM2.5 emissions in Delhi NCR[1]. Given the urgency of tackling severe levels of air pollution in Delhi, especially during the winter months, electrification could be an economically and environmentally sound strategy. Several major cities around the world have initiated similar schemes, for instance, London is working with all major taxi providers to only use electric taxis in the city by 2025.

The impact of aggregate charging demand from the entire app-taxi fleet on Delhi's power grid would be miniscule, increasing the peak grid demand by less than 1%. Since 60% of the charging would happen between 6 am and 6 pm, this demand could be primarily met by solar resources, which would further improve the economics by lower solar tariffs (~Rs.2/kW).

[1] https://urbanemissions.info/blog-pieces/whats-polluting-delhis-air/

Challenges and Policy Recommendations

Given their air quality concerns, limited domestic crude oil production, and recent major developments in alternatives to petroleum-based drivetrains, most importantly, electric vehicle technology and renewable electricity, countries in the South Asia have the opportunity to leapfrog to a cleaner and more sustainable transportation system, while improving energy security and reducing air pollution related impacts. A combination of supply push and demand-pull strategies can help kick-start this transition, which some countries are beginning to undertake, most notably, India.

The second-phase of India's FAME policy, introduced in 2019, builds on the framework laid out by FAME -I with substantially larger budget outlay of USD 1.5 Billion primarily for subsidies to promote vehicle adoption and a smaller portion set aside for subsidies for investments in charging infrastructure. Unlike EV policies in most other countries of the world, it is notable for prioritizing adoption of EVs in the public bus transport sector, which received over 40% of the subsidies followed by subsidies for 2-wheeler and 3-wheelers which are used by poorer households and the least allocation for cars which are mainly used by wealthier households. An additional innovative aspect of subsidies for buses is that these were to be disbursed based on kilometers of actual bus operation rather than as a flat vehicle purchase subsidy. As a consequence, FAME demonstrates a strong focus on high-mileage vehicles for electrification, which will accrue larger environmental benefits and appear more equitable compared to the typical clean vehicle subsidy one comes across world over.

However, and the disruption caused by the Covid-19 global pandemic notwithstanding, progress in terms of achieving targeted level of sales under these schemes has been slow for a variety of reasons including lacunae in the policy ecosystem which necessitate some additional complementary policies. Policies for clean vehicle adoption would do well to implement lessons from the success India has achieved in the renewable electricity generation which has seen a virtuous cycle of large-scale procurement driven by guaranteed long-term contracts which reduce risk and uncertainty for investors which led to low cost power procurement. Similarly, building standard tender practices across local and state governments would help in efficient electric bus procurement. Upfront incentives for capital cost, tax subsidies, concessional financing rates for operators, and adoption of innovative leasing models for electric vehicles are some additional policy levers that could be deployed. Zero-emission-vehicle (ZEV) mandates on OEMs with tradable credits could provide a trajectory for domestic OEMs and accelerate EV sales, as observed in California.

Secondly, investing in research and development and building indigenous capacity of both Li-ion battery and EV production would be crucial to ensure that transition to electric transportation yield important additional benefits to emissions reduction in the form of employment and domestic value creation. For instance, with the huge dependence of India's manufacturing GDP on the auto sector (~50%), there is a need to enable a thriving domestic EV manufacturing sector that can deliver quality vehicles at affordable costs, and remain globally competitive. In 2021, Government of India has announced $3.5 billion of production linked incentives (PLI) for EV production over the next five years, which is expected to create over 7.5 lakh additional jobs. Along with the PLI scheme for battery manufacturing, with an outlay of $2.5 billion, domestic manufacturing of batteries along with electric vehicles is being incentivized. China currently dominates Li-ion battery production with a share of over 75% of batteries that were sold globally in 2020.

Thirdly, a robust network of charging stations would also be critical to enable faster adoption by addressing range anxiety of drivers. India's Ministry of Power has notified guidelines to install one charging station in a 3x3 km grid in large cities, and one charging station every 25 km along major highways. Our preliminary assessment shows that by investing ~$2 billion a year, India can build ~1000 HDV charging stations along major highways every year. As the fleet size grows, the cost of charging infrastructure as a percentage of TCO falls rapidly. Preferential EV tariffs would play a key role in early adoption by reducing payback period. Even though some Indian states have announced preferential EV tariffs, a streamlined process with the local distribution companies needs to be set up. Additionally, dedicated renewable energy contracts for EV charging could provide cheap clean power, nominally fixed for 25 years, especially to HDVs such as trucks. As trucks transport the majority of freight in these countries, low operating costs could be an inflation-control tool as the region undertakes energy transition. It should be noted that additional electricity load due to EVs even with aggressive rates of adoption could be managed so as to mitigate adverse impacts on the electricity infrastructure and markets. At the same time, focusing on commercial vehicles (taxi fleets, buses and trucks) could also present interesting smart charging opportunities for cost-effective grid integration of RE and accessing low cost RE power, especially during solar hours.

Finally, it is worth reiterating that much of this article is based on work carried in the Indian context and more specifically on battery electric vehicles, and therefore cannot simply be extrapolated to other South Asian countries. There is a clear need for greater research into the techno-economics, infrastructure needs, and potential policy mechanisms relevant to not just battery electric vehicles but clean transportation in general that are specific to the environmental, economic, political and social context of each country in the south Asian region.

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