Fundamentals of Electric Vehicles (EVs)

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Background

This slide deck was developed for and presented at an Energy Fundamentals Course hosted by the Bangladesh University of Engineering and Technology (BUET) in October 2022. The National Renewable Energy Laboratory (NREL) helped organize this course in partnership with the United States Agency for International Development (USAID). The students in this four-day course were postgraduates and working professionals in the energy sector or related industries in Bangladesh. While some of the content in the slide deck is tailored to Bangladesh specifically, this presentation is intended to be a general primer on electric vehicles that can be utilized for similar purposes by other universities or organizations throughout the world. The content of this slide deck is not intended to be fully comprehensive of all electric vehicle concepts.

Outline

1. EV Trends

a. Global trends
b. Regional trends

2. EV Technology

a. Vehicle types
b. Opportunities
c. Challenges

3. EV Charging

a. Charging infrastructure
b. Impact to grid

4. EV Policies

a. Options
b. Case studies

Image: Capital District Clean Communities Coalition (Albany)

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Image: Capital District Clean Communities Coalition (Albany)

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Global Trends

2021 EV Stock

Passenger cars: 16.7 million (9% of global sales)

Commercial vehicles: 180,000 (1% of global sales)

Buses: 685,000 (44% of global sales)

Two- and Three-Wheelers: 275 million (42% of global sales)

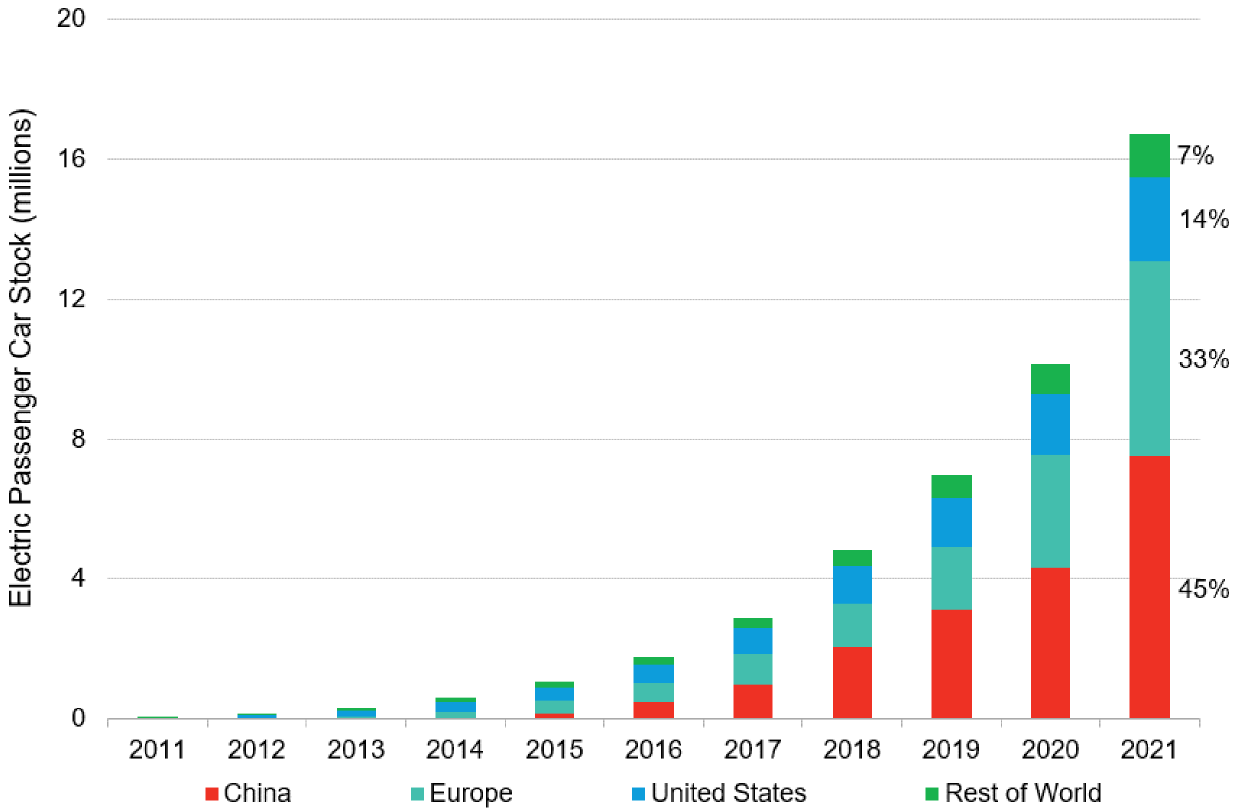


Figure. Global electric passenger car stock, 2011-2021

Data: Bloomberg New Energy Finance (2022)

Global Trends

2040 EV Stock Projections

Passenger cars: 727 million (75% of global sales)

Commercial vehicles: 15.5 million (54% of global sales)

Buses: 1.7 million (83% of global sales)

Two- and Three-Wheelers: 758 million (83% of global sales)

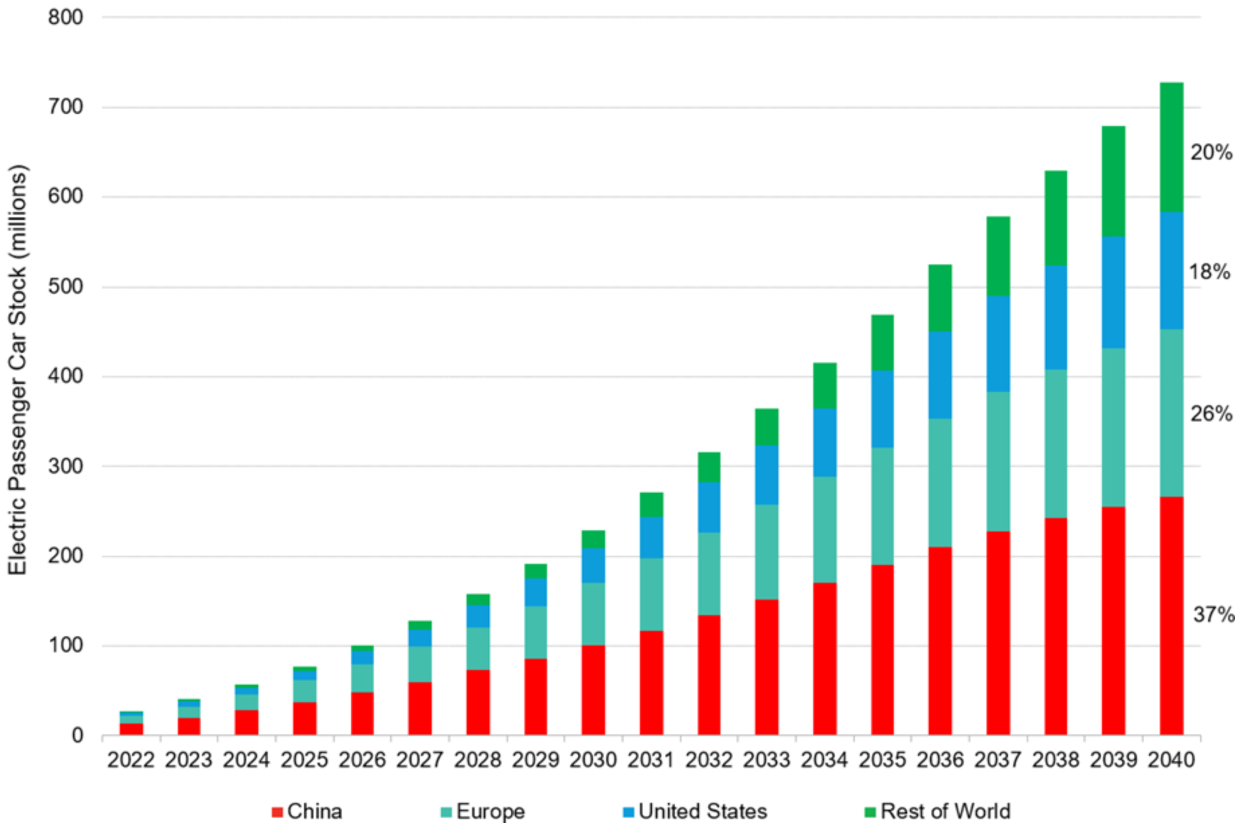


Figure. Global electric passenger car stock projection, 2022-2040

Data: Bloomberg New Energy Finance (2022)

Global Trends

Cost Declines in Batteries

- Higher upfront cost of most EVs compared to internal combustion engine (ICE) counterpart is due to cost of battery.

- Battery pack prices have fallen 89% since 2010, despite recent supply chain issues.

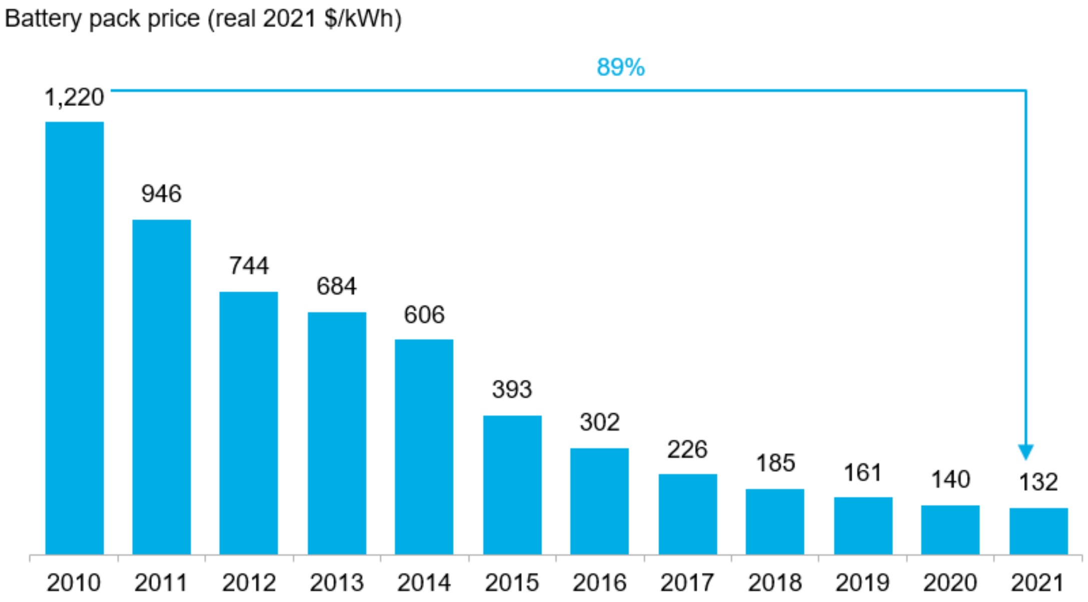
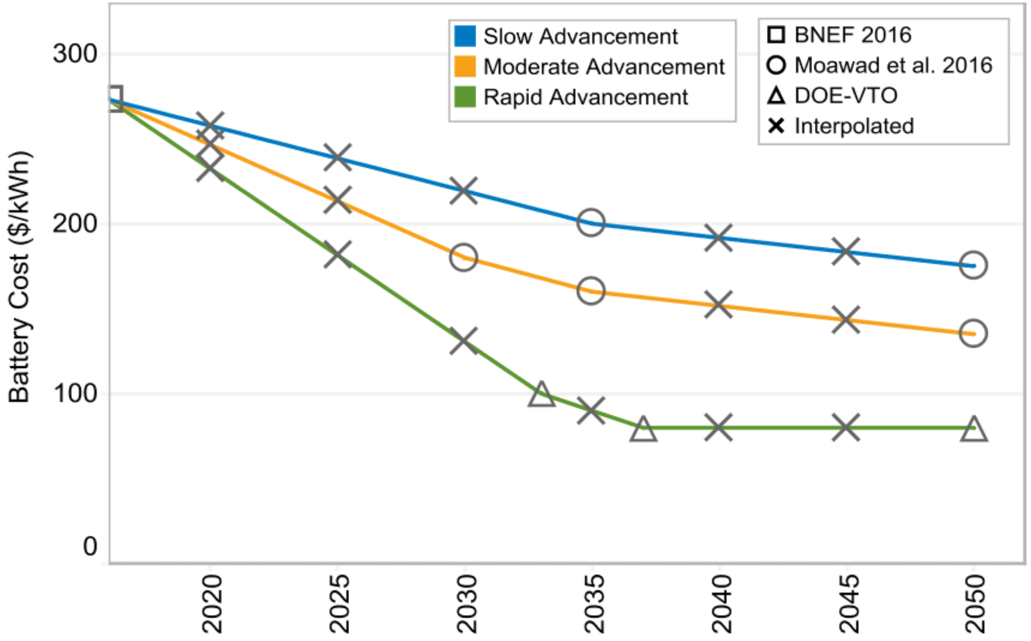


Figure. Decrease in cost of battery packs, 2010-2021

Source: Bloomberg New Energy Finance (2022)

Figure. Projected decrease in cost of batteries, 2020-2050



Source: NREL Electrification Futures Study (Jadun et al., 2017)

- Unsubsidized upfront price parity expected in most vehicle segments and markets by the late 2020s.

- Already, the lifetime operational cost of owning EVs is typically lower than the ICE counterpart due to reduced fuel and maintenance expenses.

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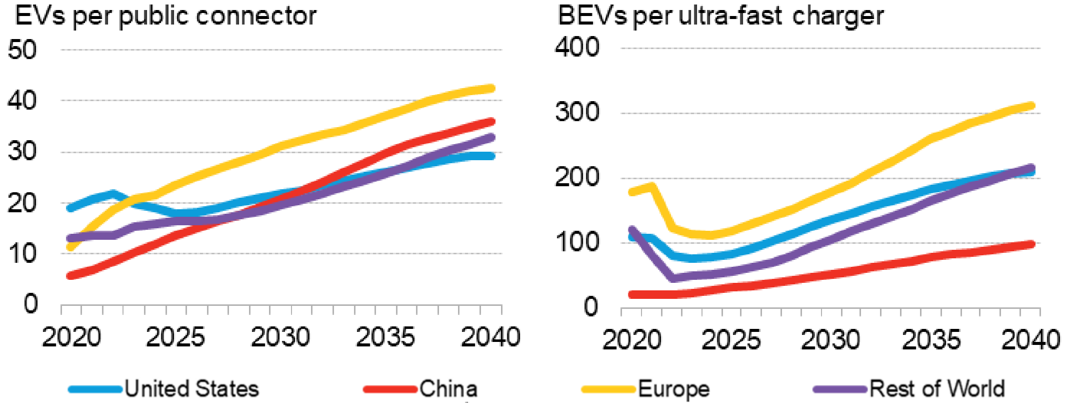
Global Trends

Expansion of Charging Infrastructure

- 40% increase in publicly available charging stations between 2015 and 2021.
- 2021 global average: 10 EVs per charging point.

Figure. Projected EV charger trends by region, 2020-2040



Source: Bloomberg New Energy Finance (2022)

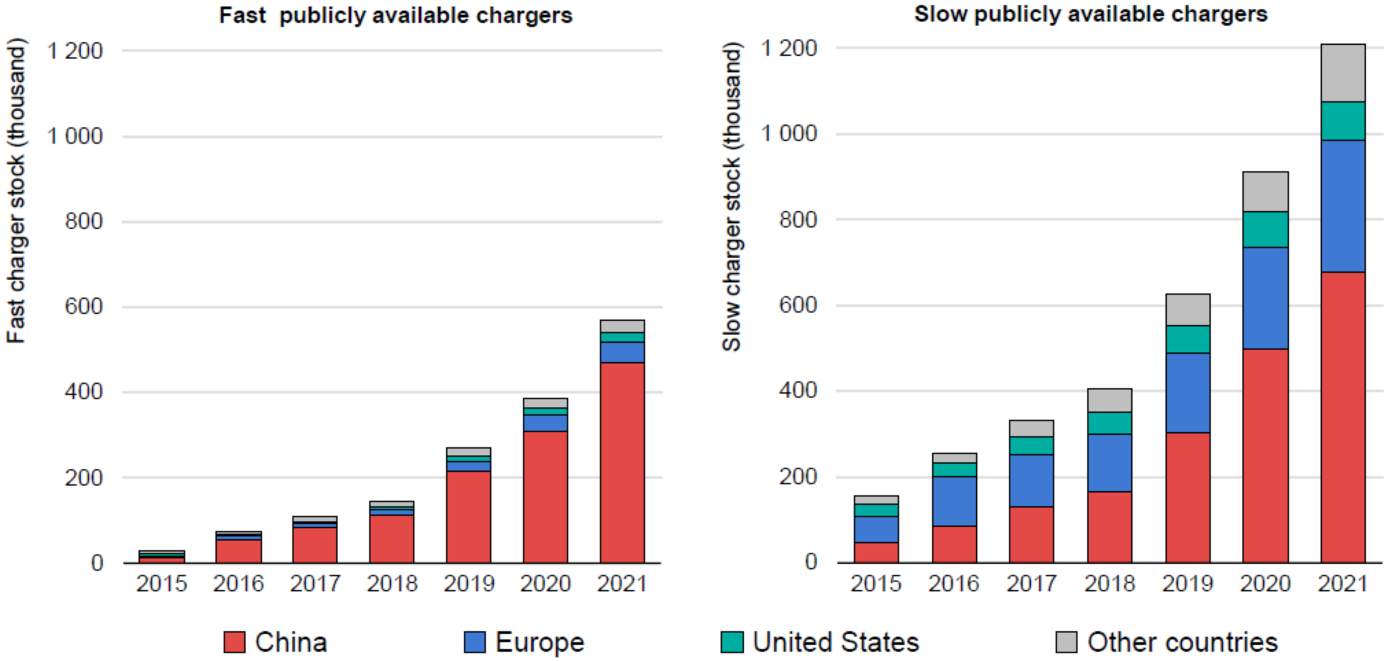


Figure. Publicly accessible light-duty vehicle charging points by power rating and region, 2015-2021

Source: International Energy Agency (2022)

- Bloomberg 2040 projections: 30-40 EVs per public charger and 100-300 EVs per ultra-fast charger.

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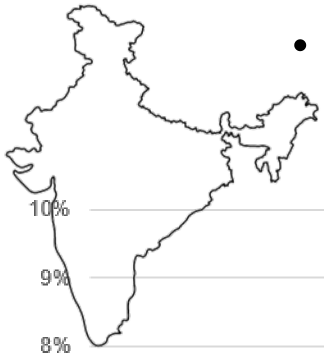
Regional Trends



- India has set the following 2030 EV sales goals: 30% passenger cars, 70% commercial vehicles, and 80% of two- and three-wheelers.

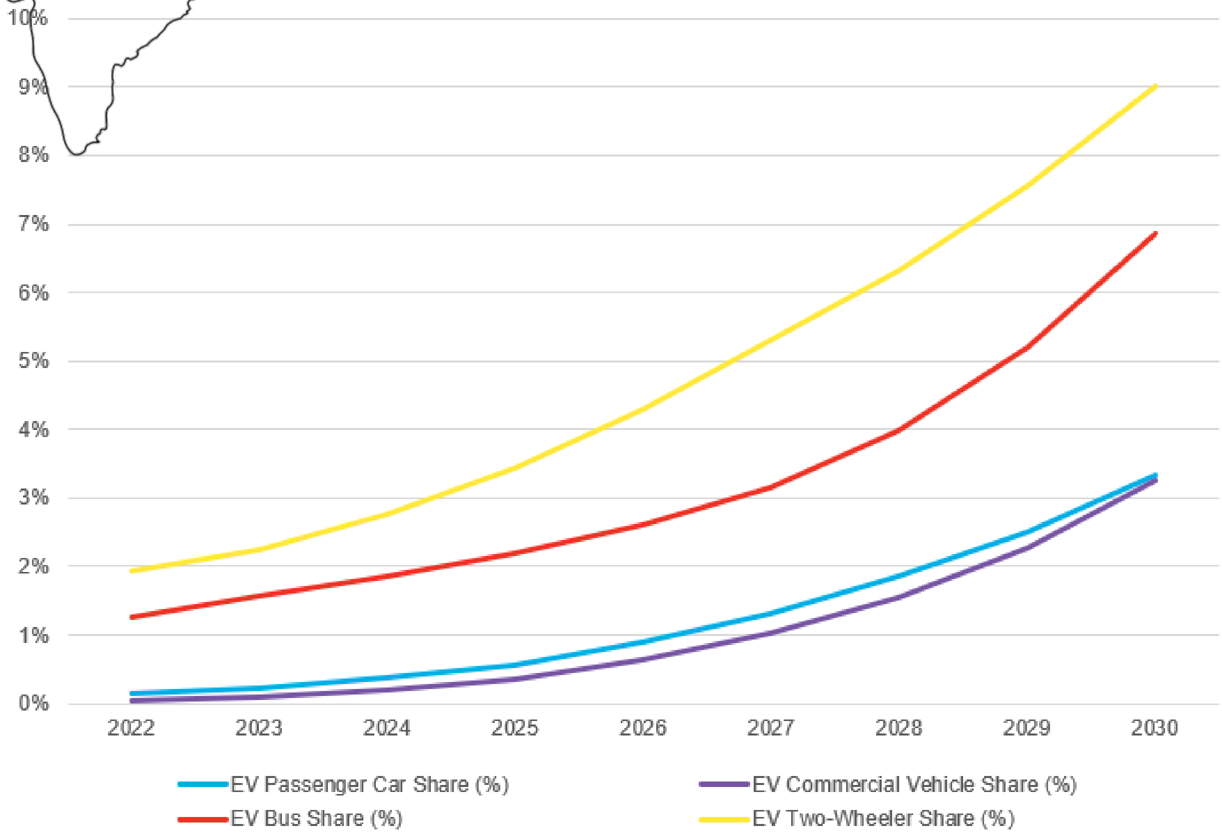


Figure. Projected EV shares in India, 2022-2030

Data: Bloomberg New Energy Finance (2022)

<u>Commitments by Japanese Automakers</u>

Toyota: EVs constitute 40% of annual sales by 2030

Nissan: 50% sales from EVs and hybrids by 2030

Honda: 30 EV models and production of 2 million units by 2030

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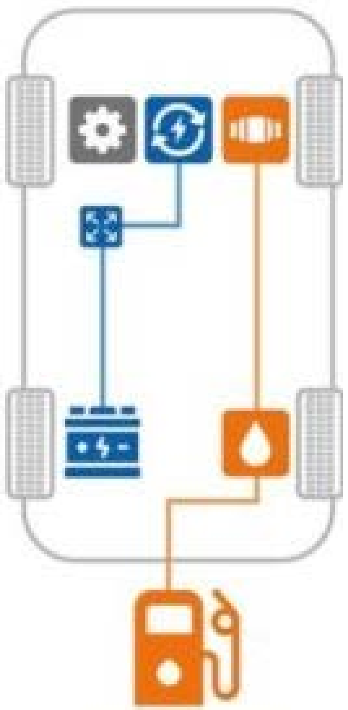
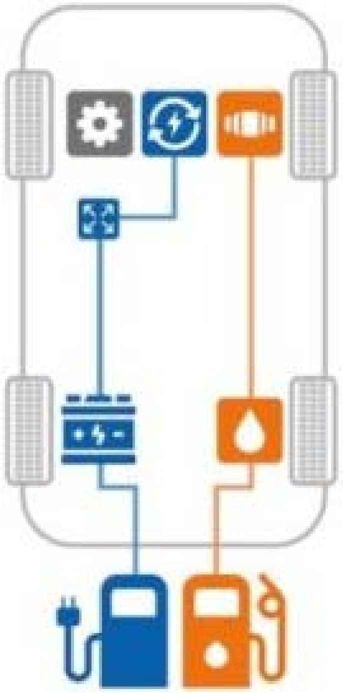
Image: Capital District Clean Communities Coalition (Albany)

Electric Drive Trains



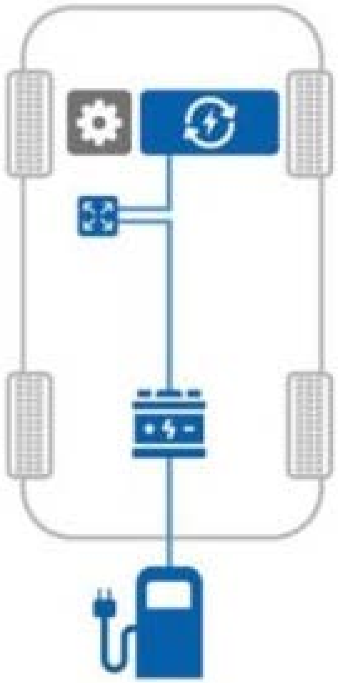
Hybrid Electric Vehicle

- ICE and electric motor
- Batteries are charged by engine (no external charging)



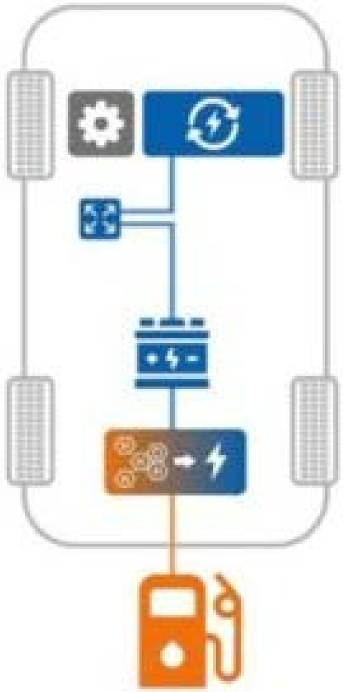
Plug-in Hybrid Electric Vehicle

- ICE and electric motor
- Batteries are rechargeable



Battery Electric Vehicle

- 100% electric motor
- Batteries are rechargeable



Fuel Cell Electric Vehicle

- 100% electric motor
- Fuel cell converts hydrogen and oxygen into electricity
- Requires hydrogen distribution infrastructure

Images: National Motorists Association Blog (2020)

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Vehicle Categories

Passenger Cars

Commercial Vehicles

Buses

Two- and Three-Wheelers

Source: Bangladesh Road Transport Authority (2021)

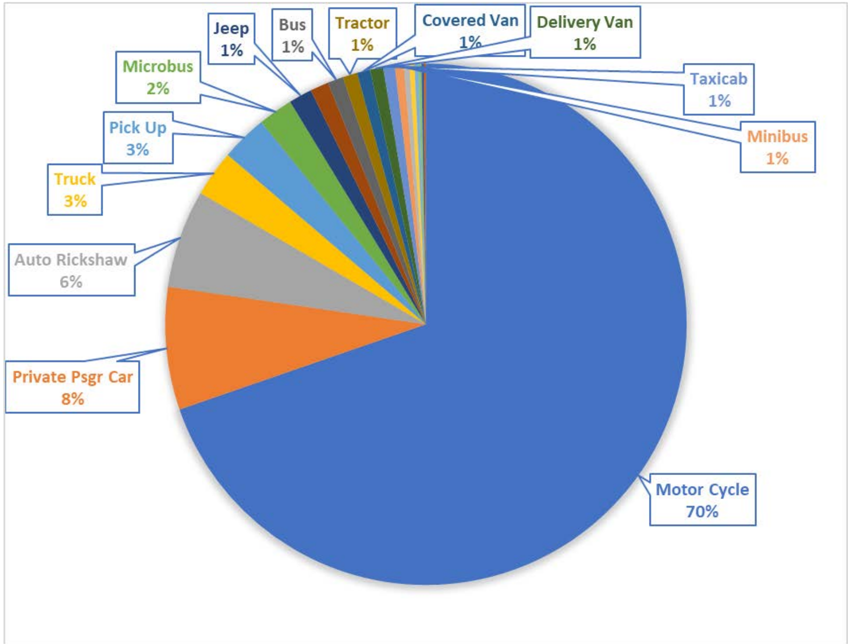

Figure. Vehicle registrations in Bangladesh by type, 2021

Fleet Electrification

- Vehicle fleets (taxi services with passenger cars or three-wheelers, delivery vans, transit buses, etc.) can take advantage of lower operating costs of EVs.
  - High vehicle-kilometers-traveled, fixed-route operation, and predictable schedules tend to be ideal for electrification and alleviates the need for fast charging.

Source: Aznar et al. (2021)

Vehicle Images: Erik Nelsen (ICF), P.J. Ray (PNM Resources), Erik Nelsen (NREL), Dennis Schroeder (NREL), Margaret Smith (Akimeka), Virginia Clean Cities, Erik Nelson (NREL), and Mahindra Electric

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Opportunities

Figure. EV net social benefits in U.S. under various scenarios ($/year)

Source: Melaina et al. (2016)

Reduced maintenance and fuel costs	Increased fuel efficiency	Reduced greenhouse gas emissions	Economic and job opportunities
Zero tailpipe emissions and improved air quality	Falling costs for batteries	Enhanced energy security	Performance benefits and quiet operation

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Challenges

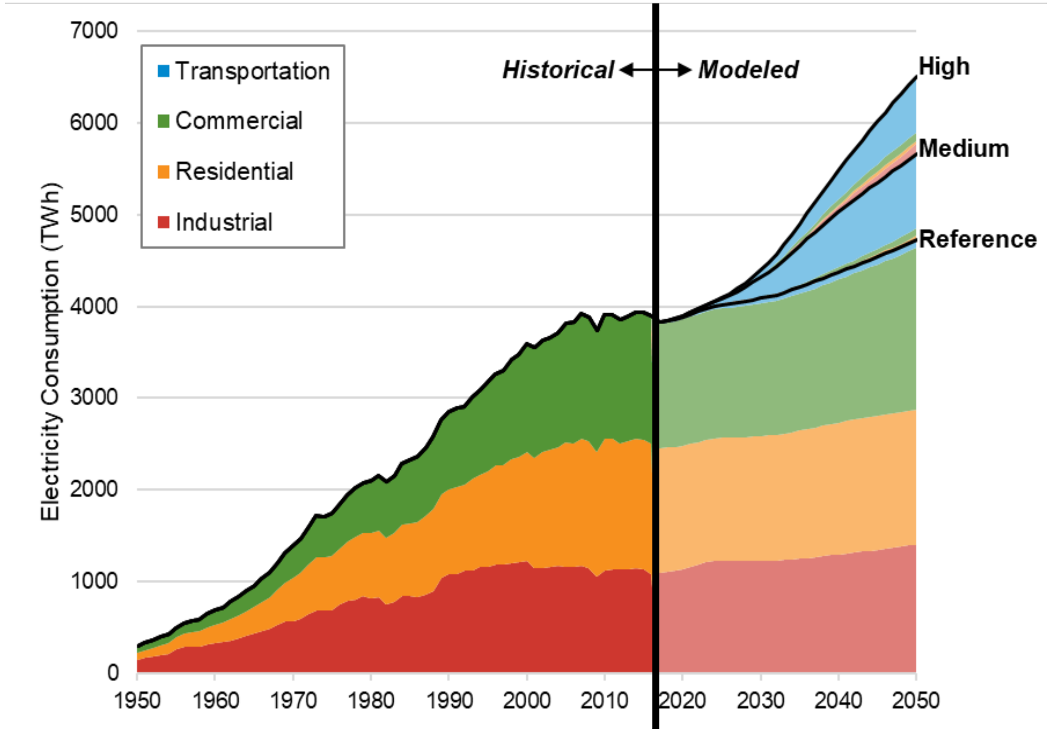

Figure. Potential increase in U.S. electricity demand due to transport electrification, 2020-2050

Source: NREL Electrification Futures Study (Jadun et al., 2017)

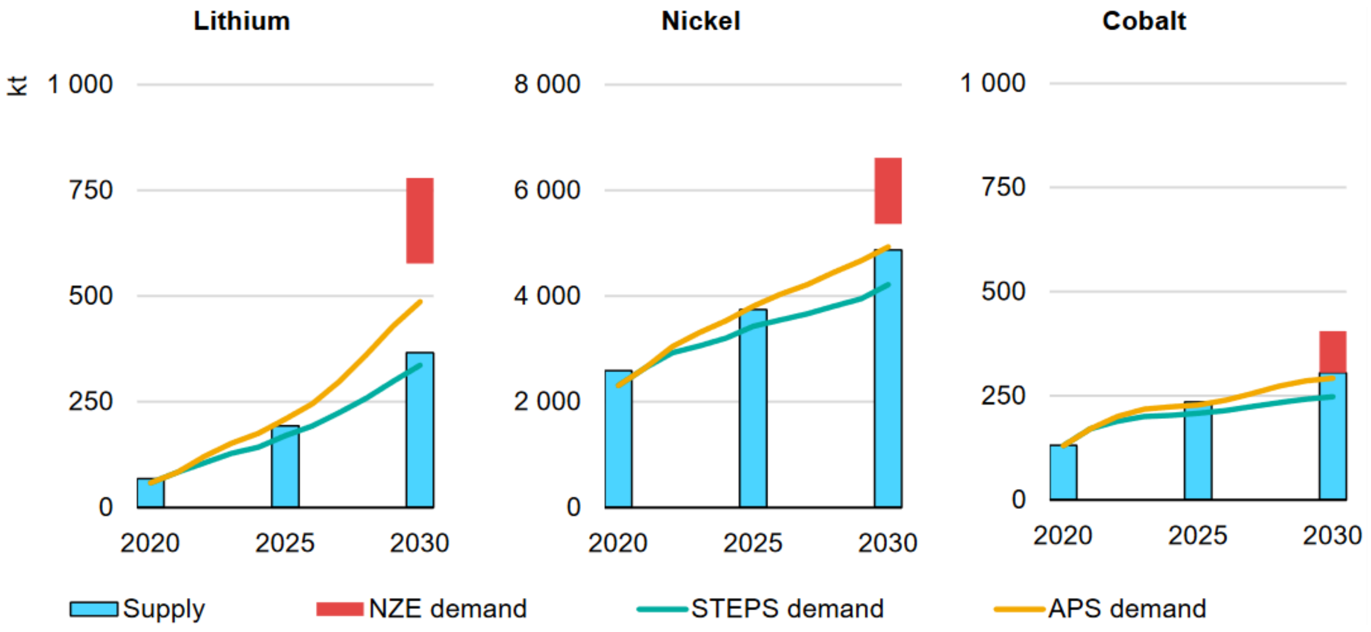

Figure. Projected supply and demand for critical minerals in EV batteries, 2020-2030

Source: International Energy Agency (2022)

NZE: net zero emissions by 2050 scenario
STEPS: stated policies scenario
APS: announced pledges scenario

- Increased electricity demand
- Higher upfront costs for some segments
- Charging infrastructure buildout
- Access to critical minerals for batteries
- Workforce development

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Image: Capital District Clean Communities Coalition (Albany)

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EV Charging

Purpose of Charging Stations (all types):

- Connects EV to grid
- Dedicated circuit prevents overloading
- Safe connection before power can flow
- Prevents EV battery damage

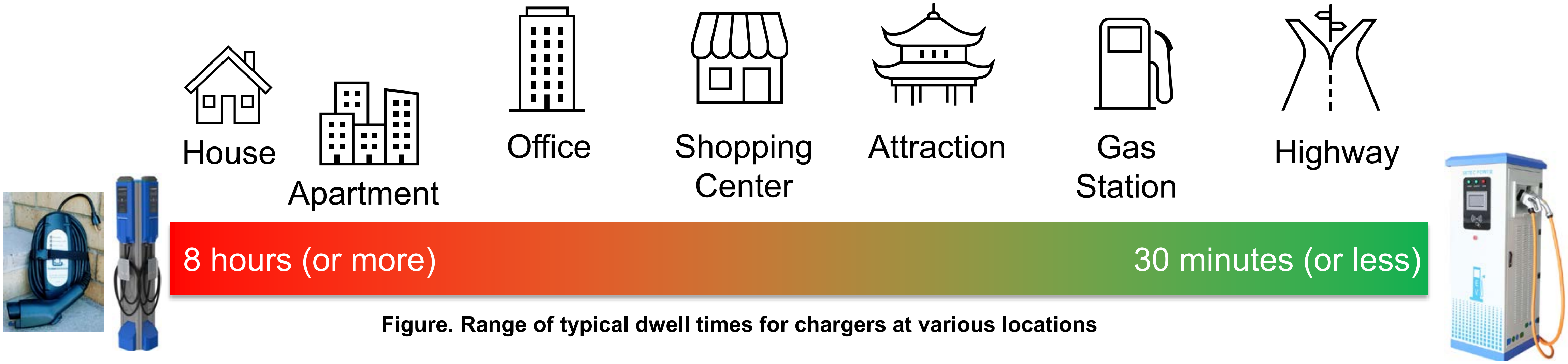

Figure. Range of typical dwell times for chargers at various locations

Source: Bopp et al. (2020)

Residential Charging

- Most established markets focused on residential charging first.
- Internationally, 50%-80% of all charging events occurred at residences (Hardman et al. 2018).
- Lack of residential charging availability is often found to be a barrier to EV adoption (Funke et al. 2019).
- Residential charging can use Level 1 or Level 2 EV supply equipment (EVSEs).

Level 1 EVSE

- 3–8 km per hour of charging
- Charging speed often limited by vehicle
- Alternating Current
- 120 V

Source: Aznar et al. (2021)

Image: Erik Nelsen (NREL)

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Public Charging

Level 2 EVSE

- 16–32 km per hour of charging
- Charging speed often limited by vehicle
- Alternating Current
- *7.2 kW, 240 V

*power ratings vary

- ➢ Public and home charging
- ➢ Less expensive to install and operate than DCFC
- ➢ AC charging power is limited by the capabilities of the vehicle's on-board charger
- ➢ Can process payments and data
- ➢ Can be networked

DC Fast Charger

- 95–128 km per hour of charging
- Direct Current
- *50 kW, 480–600 V
- Can be up to 350 kW

*power ratings vary

- ➢ Expensive to install and operate
- ➢ Faster charging
- ➢ Can process payments and data
- ➢ Can be networked
- ➢ Incompatible with many 2- and 3-wheelers

Source: Bopp et al. (2020), Images: Erik Nelsen (ICF)

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Battery Swapping

- Easier for motorcycles/scooters because liftable size and less expensive to carry redundant batteries
- Rickshaws use multiple batteries but can be compatible
- More compatible with renewables than EVSE
- Reduces the upfront cost of scooters and increases lifespan
- Largest networks operated by Gogoro (Taiwan), Immotor (China), KYMCO (Taiwan)
- Honda, KTM, Piaggio, and Yamaha have formed a swappable battery consortium for standards

Source: Aznar et al. (2021)

Image: electrek.co

What Are Some Common Standards?

- <u>SAE J1772</u> – North America
  - 5-pin AC charging port (Type 1)
  - 7-pin DC charging port: Combined Charging Standard (CCS1)
- <u>IEC 61851/62196</u> – Europe and emerging markets
  - 7-pin AC charging port (Type 2)
  - 9-pin DC charging port (CCS2)

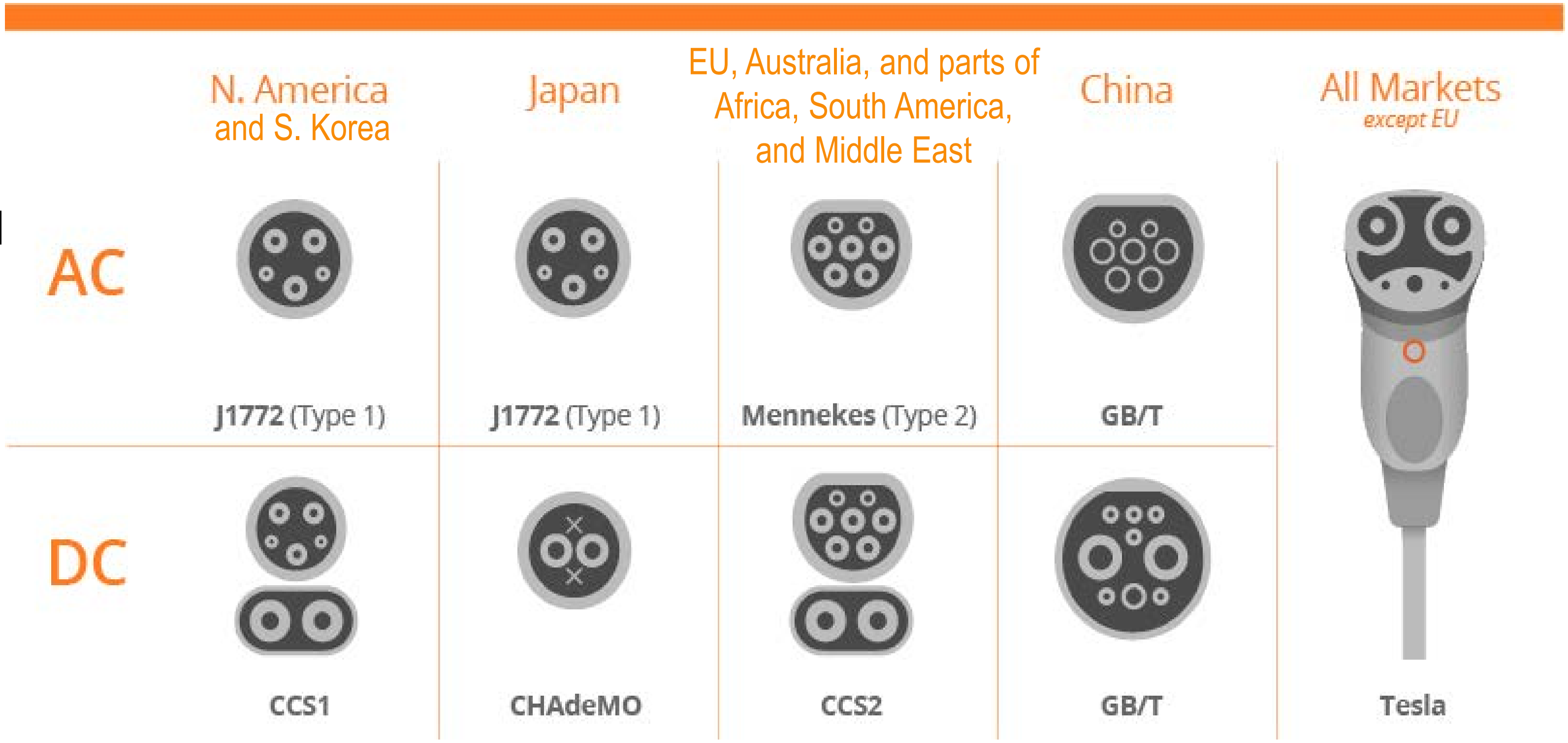

Figure. Predominant charging standards in different regions

Image: Enel X

- DC charging uses two additional dedicated DC pins.
- All chargers require additional pins for communication or controls.
- India has Bharat Standards (low power), CCS, CCS2, CHAdeMO, and Tesla.

Source: Bopp et al. (2020)

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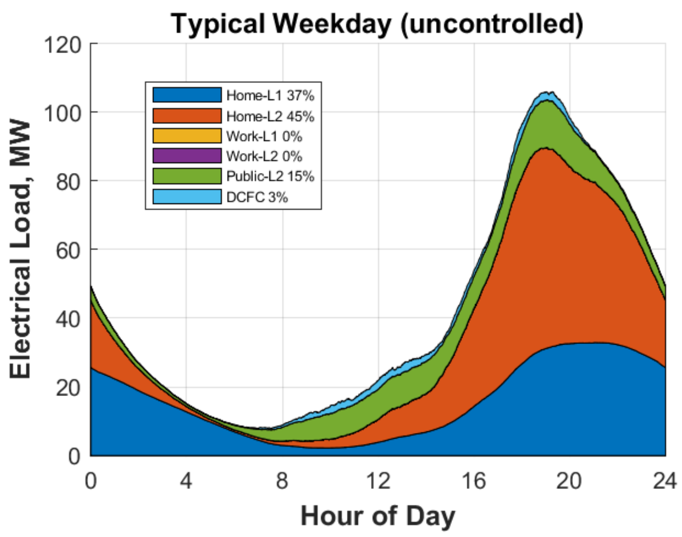
Managing Grid Impacts

Home-Dominant Charging



Source: NREL EVI-Pro Model

No Home Charging

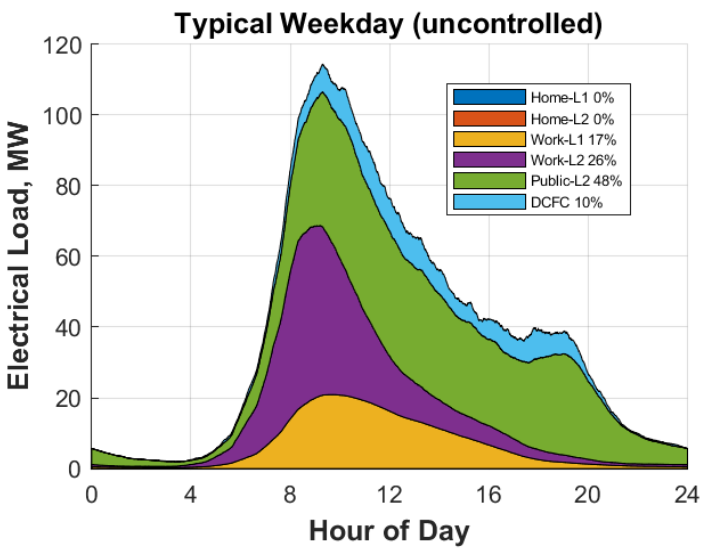
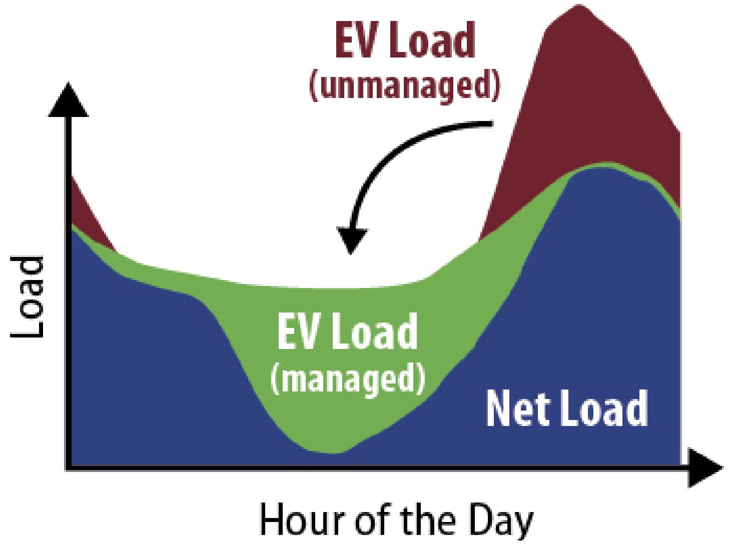


Figure. Different charging profiles for EVs

Managed Charging



Source: Anwar et al. (2022)

- EVs are not just a “burden” to the grid; flexible EV charging can satisfy mobility needs while also supporting the grid and integration of renewable energy.
- Vehicles are underutilized assets: Parked ~95% of the time (in United States).
  - EV charging profiles can look significantly different if vehicles are charged at different locations or times.
- Flexibility is secondary to mobility needs and is enabled by charging infrastructure.

Source: Muratori (2020)

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EV Tariff Design

Two Types of Tariffs

Tariff between electric utility and EVSE owner

Tariff between EVSE owner and customer

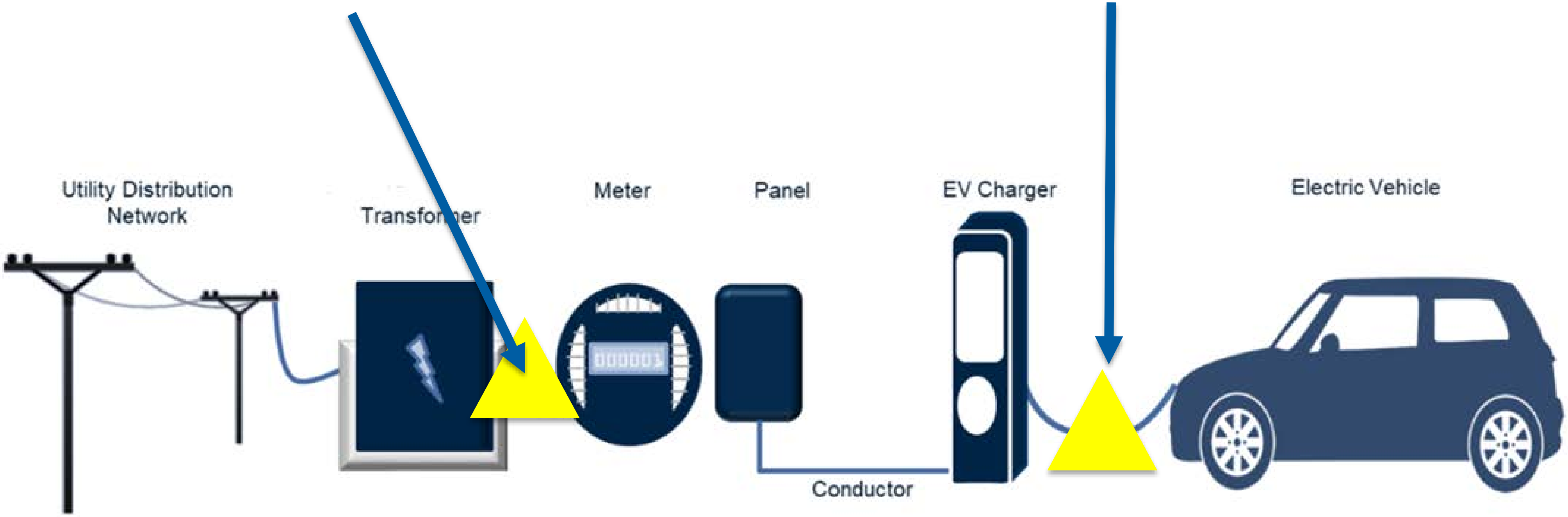

Figure. Locations along EV charging paths with tariff considerations

Source: Zinaman et al. (2020)

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Policy Options

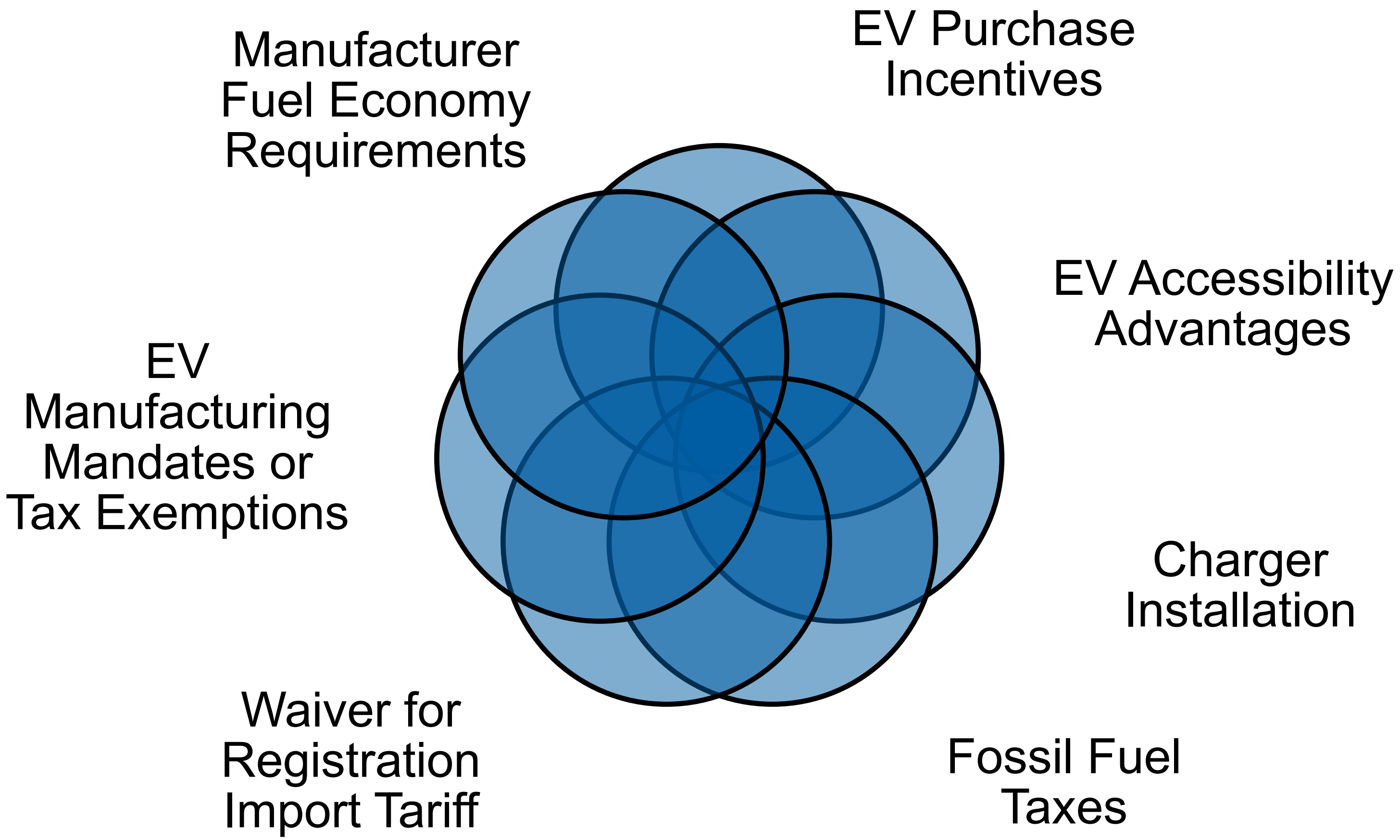


Figure. Ecosystem of policy options for EVs and EVSE

<u>Key hurdles to address:</u>

1. Higher upfront cost (currently)

2. Limited locations to recharge, shorter range, and longer recharge time

Source: Aznar et al. (2021)

EV Purchase Incentives: Effectiveness in the United States

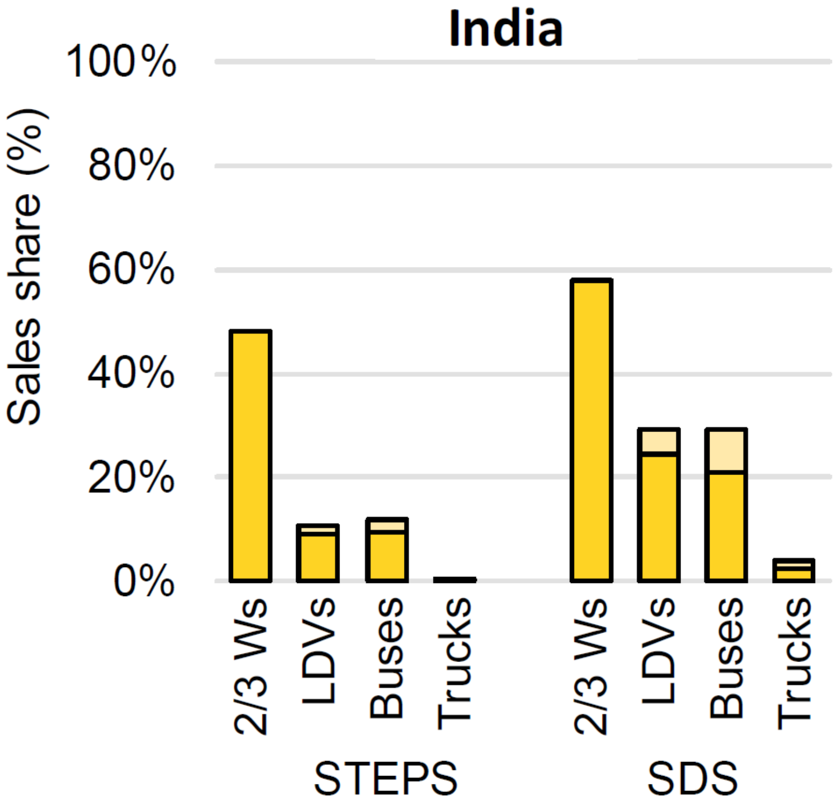
State Level Correlation of Plug-In EV (PEV) Market Variables on Per Capita PEV Purchases		PEVs	Plug-In Hybrid EVs	Battery EVs
Explanatory Variables	**Increase/Decrease by**	**Increases purchases by**	**Increases purchases by**	**Increases purchases by**
Charging stations per hundred thousand population	1	3.1%	2.6%	7.2%
Tax credit (in dollars)	$1,000	2.3%	Not significant	5.3%
Rebate (in dollars)	$1,000	4.8%	Not significant	7.7%
Sales tax waiver (in dollars)	$1,000	3.6%	Not significant overall; 1.6% for Volt	5.9%
High-occupancy vehicle lane access (Yes or No)	if Yes	8.3%	8.1%	14.5%
Home EVSE credit	If Yes	Not significant	Not significant overall; 26.0% for Volt	Not significant
Home charging discount	If Yes	Not significant	Not significant	Not significant
Gasoline price	1%	0.6%	0.5%	0.8%

Source: Narassimhan and Johnson (2018)

Case Study: India

- National target of 30% EV sales by 2030
- Set stringent fuel economy standards aligned with Euro 6 in April 2020
- Faster Adoption and Manufacturing of EVs (FAME II):
  - Purchase incentives of $1.4B USD for 1.6M EVs and hybrids 2019-2024
  - Phased-in localization of component manufacturing
  - Charging infrastructure funding of $133M USD
  - Direct subsidies to purchase electric buses (nearly 6,000 so far) and 1 charger per bus
  - EV adoption far behind schedule:
    - Possibly due to no zero-emission vehicle sales requirements or ICE phase-out targets (IEA 2021)
    - EV manufacturers blame the aggressive localization criteria before large enough market (Chaliawala 2021)
    - Others blame the limited availability of inexpensive EV models.
- Large municipal fleets (especially New Delhi) are leading in electrification

Figure. Projected EV share of vehicle sales by mode and scenario in India, 2030



STEPS = Stated Policies Scenario
SDS = Sustainable Development Scenario

Source: International Energy Agency (2022)

Case Study: Barbados

- Highest number of EVs per capita in the Caribbean
- 430 EVs on the road, 45 public chargers, 200 private chargers
- Target of 100% electric buses and public fleets by 2030
- Policies:
  - Reduced import taxes on EVs (from 45% to 10%)
  - Pilot projects
  - EV maintenance course development for technicians
  - Independent companies operate EV charging infrastructure (viewed as an access service and not electricity delivery, so not in the exclusive domain of the electric utility)

Image: Google Maps

Source: Joshi et al. (2022, forthcoming)

New Zealand

- 10,574 EVs sold in 2021
- Emission Reduction Plan promotes EVs, walking, cycling, and public transit
- Currently, public chargers every 75 km on highways, but more are needed to support increasing number of EVs
- Clean Car Discount Program: Rebates for vehicles (new and used) emitting less than 146 grams of CO_2 per kilometer, and fees on vehicles above the limit
- Low Emission Transport Fund: Supports EV chargers, car shares, bus fleets, e-bike storage, and more

Image: Google Maps

Source: Joshi et al. (2022, forthcoming)

Thank you!

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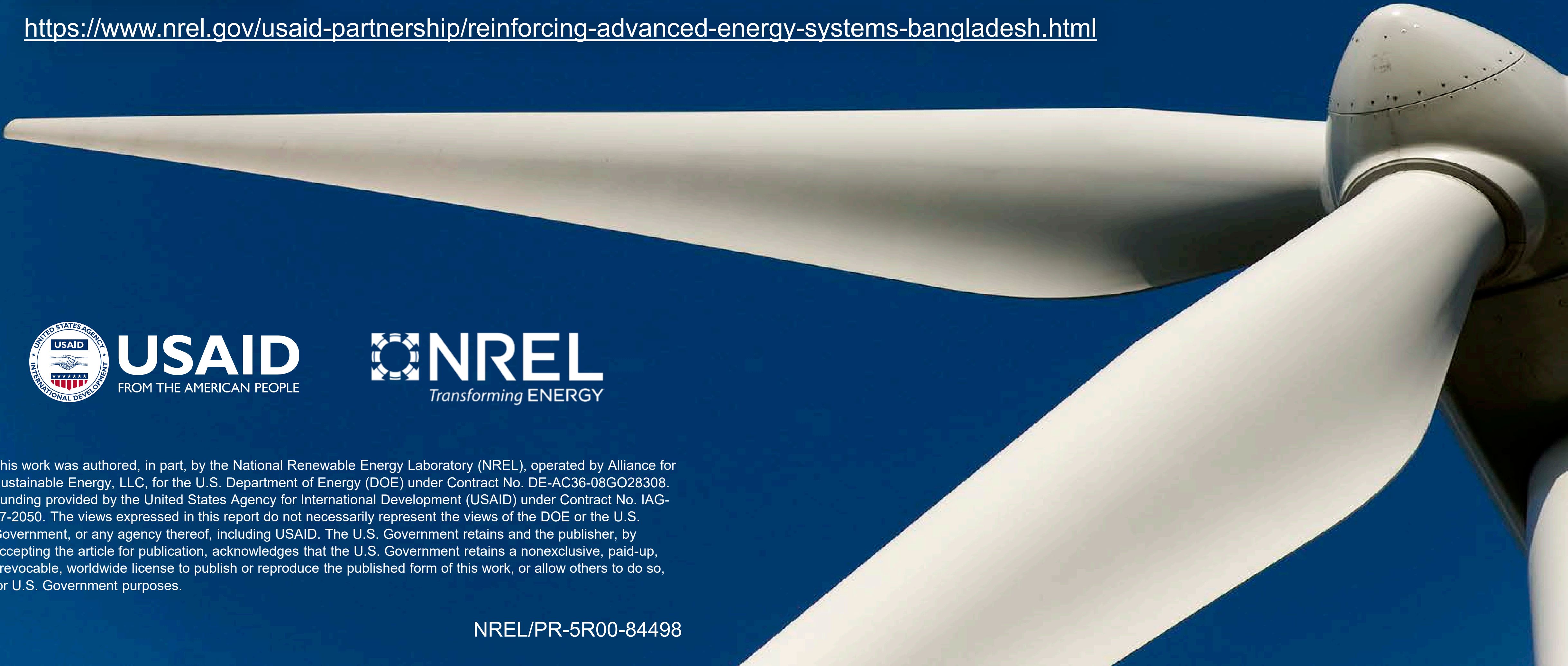
https://www.nrel.gov/usaid-partnership/reinforcing-advanced-energy-systems-bangladesh.html



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