

Performance Assessment of Massively Electrified Transportation Infrastructure: An Abu Dhabi Example

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What impact does transportation electrification have on:

- CO_2 emissions,
- transportation system congestion,
- electric power system reliability,
- Investment and operating costs?

Motivation: Emergence of Transportation Electrification

- Transportation electrification is an emerging sustainability trend
- Electric Vehicles have greater well-to-wheel efficiency → key technology in reducing domestic fossil fuel consumption
- Limitations still exist on charging times & range



- Technical, economic, and social barriers are easing
- Despite this, true challenge of EV integration requires integration w/ infrastructure
  - Transportation System: Impacts on traffic dynamics
  - Electric Power System: Impacts on power grid dynamics
  - Intelligent Transportation System: Use Case Driven Informatic Integration

∴Electric Vehicles couple the transportation & electrical infrastructure

Motivation: Shared & Intelligent Transportation Systems



Enhances Transportation System:

- Convenience
- Safety
- Congestion
- Sustainability & Energy Management
- Integral to Surface Master Plans

∴Intelligent informatic services can enhance the transportation system

Motivation: Emergence of Connected & Automated Vehicle



Connectivity: 100Mbs Ethernet, Bluetooth, Wifi Connectivity

Supports:

- Peer-to-Peer Communication
- Peer-to-Host Communication

∴Connected Vehicles are a key enabling technology for full ITS deployment

Motivation: Opportunities for Operations Management Decisions

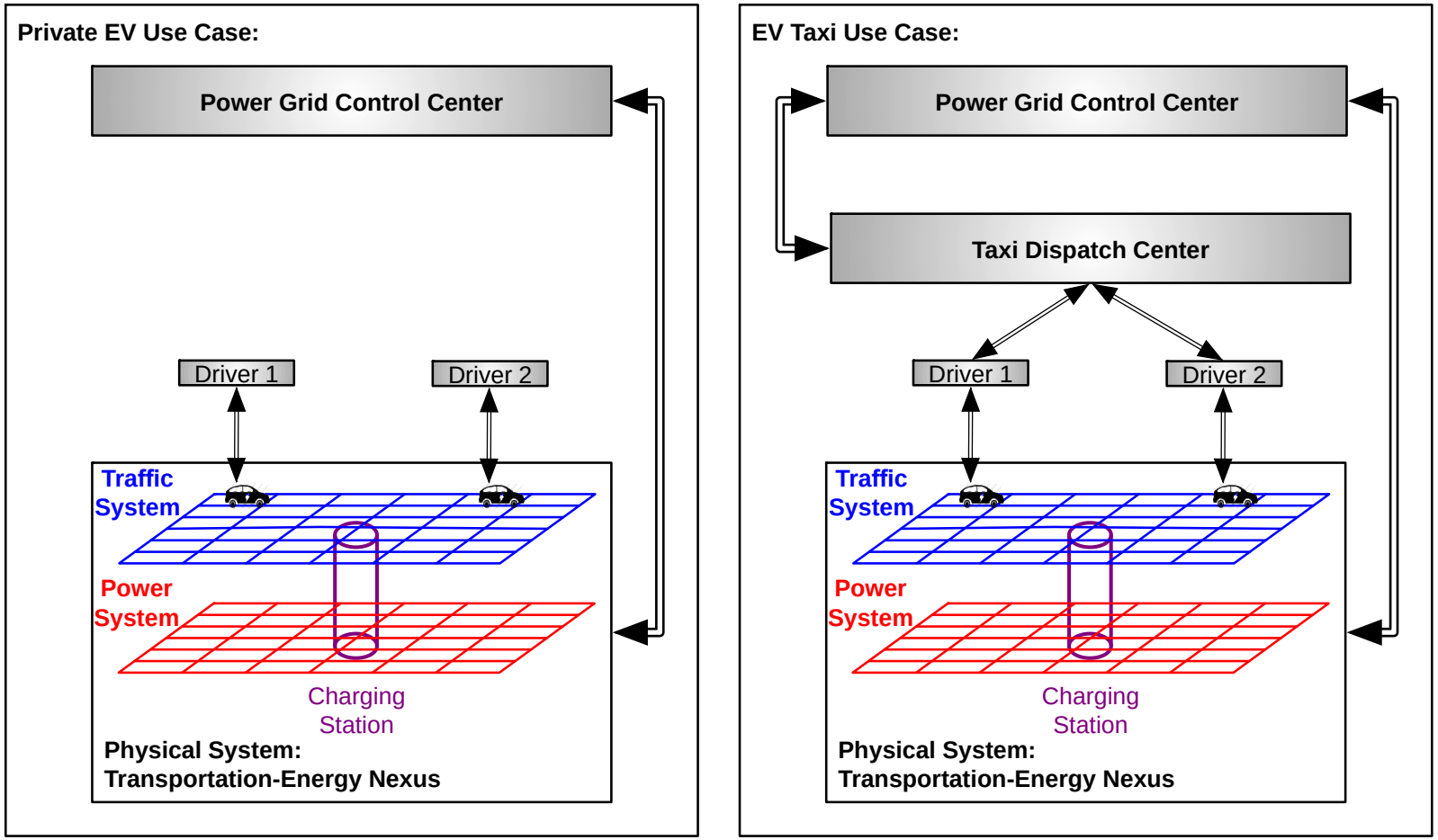
ITS Connected Electric Vehicles enable five energy operations management. Consider the Connected Taxi Use Case:

	Conv. Taxi	Elec. Taxi
Traffic Dispatch: When should a given EV take a given route *(origin, destination)*	✓	✓
Route Choice & Congestion Management: How to get from origin to destination	✓	✓
Charging Station Queue Management: Where should a given EV go to charge keeping in mind the development of queues at charging stations		✓
Coordinated Charging: At a given charging station, when should the EVs charge to meet customer demand and power grid constraints		✓
Vehicle-2-Grid Stabilization: Given the dynamics of the power grid, how can EVs be used as storage for stabilization		✓

∴**Big opportunity for savings w/o huge investment in physical infrastructure**

∴**Operations Management Decisions are Fundamentally Coupled!**

Electric Vehicle Integration Use Cases



∴Who is making which transportation & power grid decisions?

Abu Dhabi Electric Vehicle Integration Study



∴Conducted using a holistic hybrid-dynamic system model of EV integration

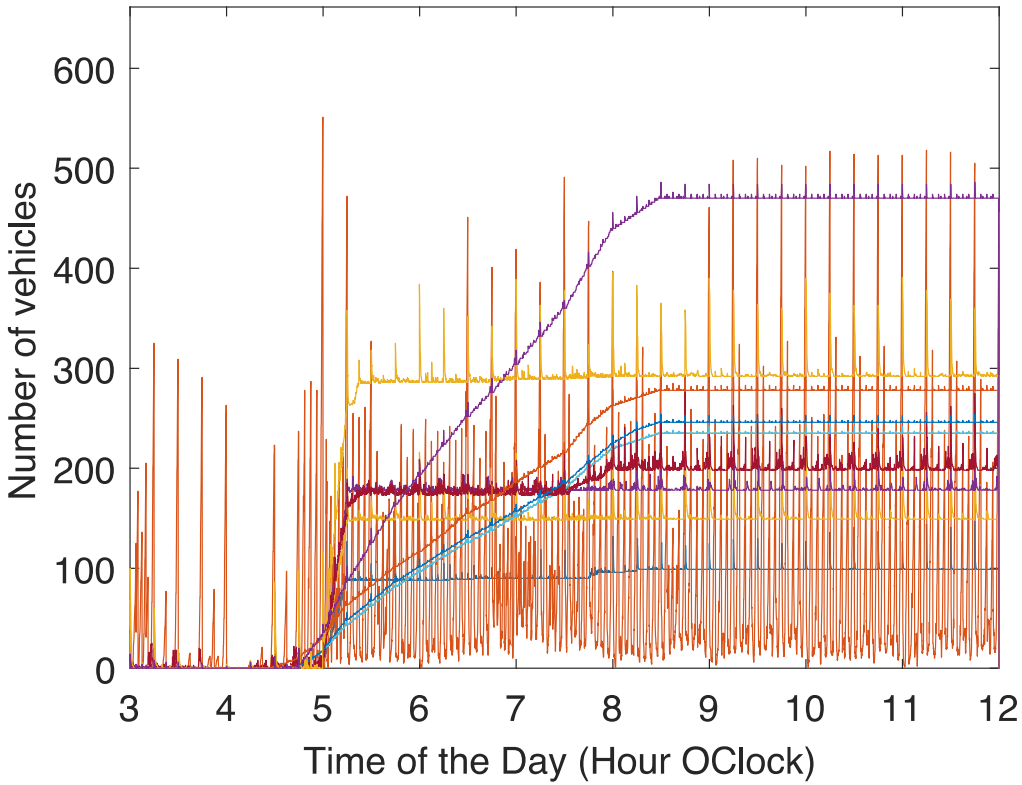
Big Data Analytics in Transportation Electrification

- Abu Dhabi Electric Vehicle Study was the first ***full-scale*** study of its kind
- 1 Million Vehicles on the Road in Microscopic Traffic Simulation
- Charging & Queueing behavior of all charging stations
- Generated Data: 200GB
- Largest Output File: 40GB
- 16-Core Dell Workstations used in Analysis (32GB RAM)
- Matlab Code: Customized & optimized for computational speed and RAM usage



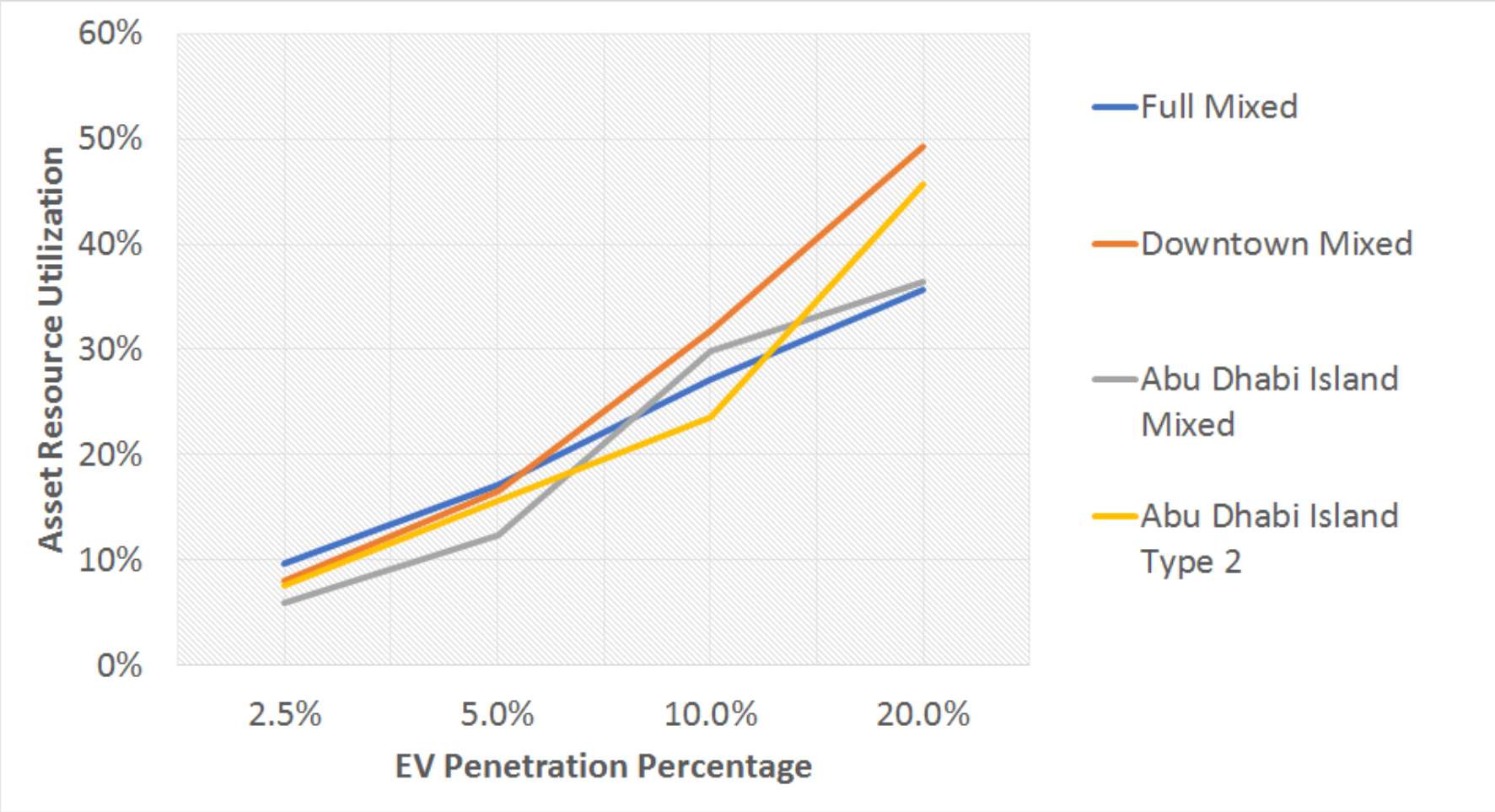
∴EV integration study requires Big Data analytics capabilities

Abu Dhabi Morning Commute Road Congestion



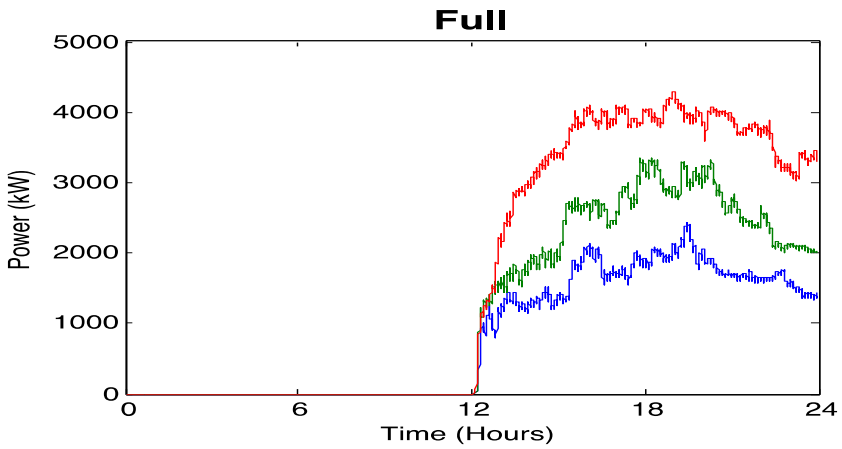
∴Simulating driving patterns is first step to assessing electric charging loads

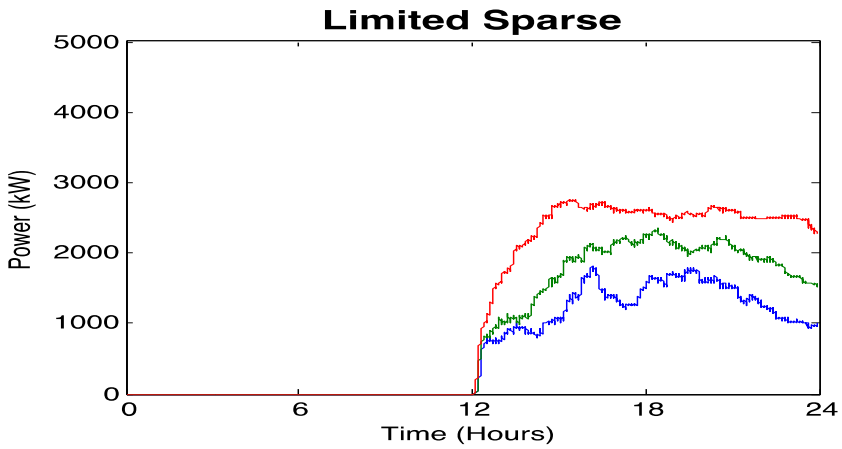
Charging System Utilization

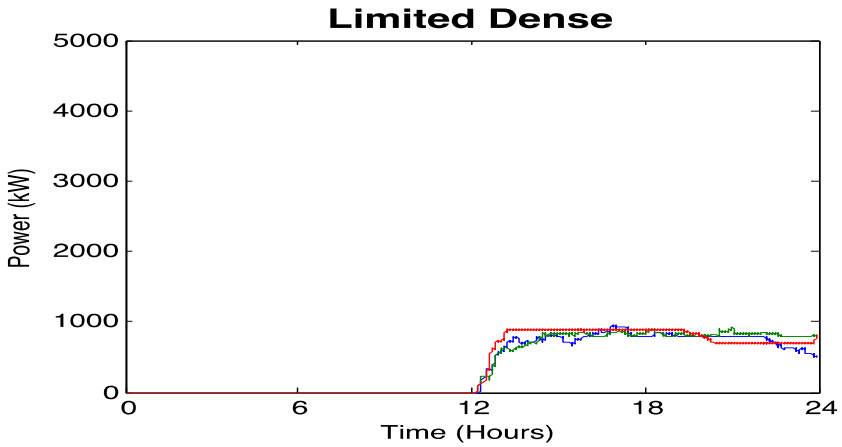


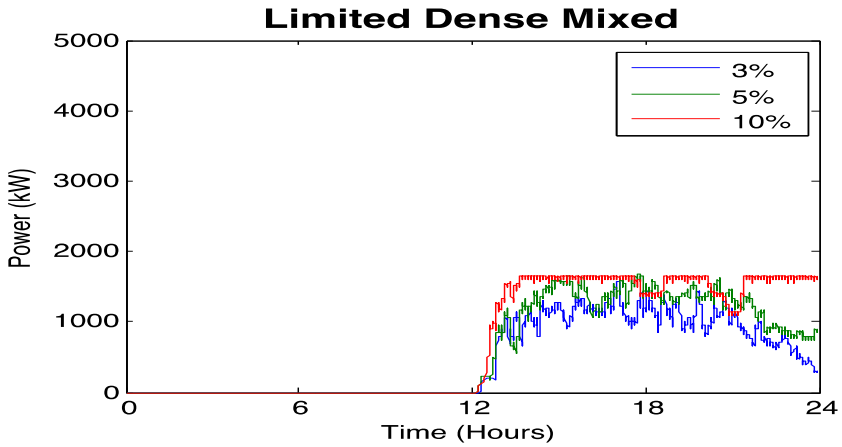
∴Charging system asset utilization depends on placement & EV penetration

Charging System Aggregate Load Curves



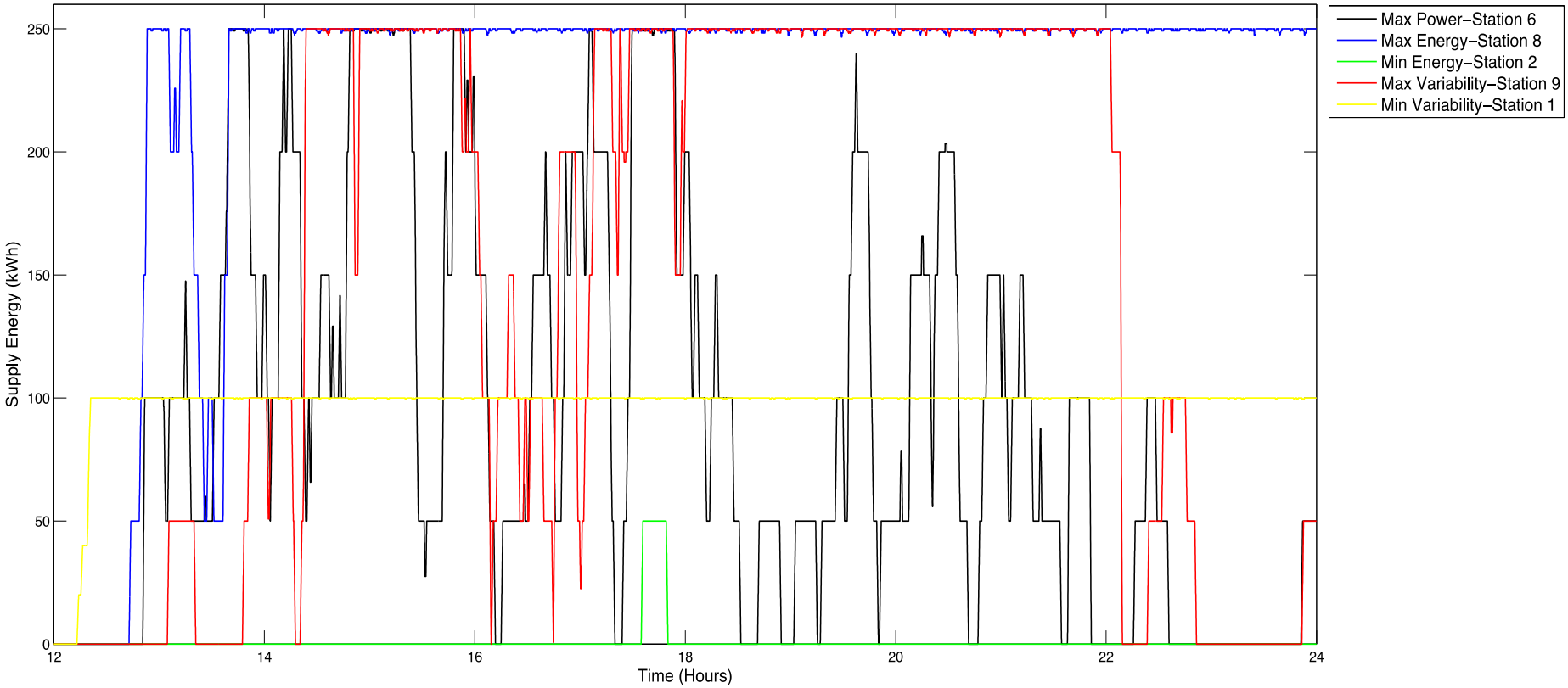






∴Maximum power and variability require grid balancing solutions

Charging System Individual Load Curves



∴Individual charging station load curves have very different grid impacts

A Static Well to Wheel Analysis: Electric Vehicle

GASOLINE-ONLY

Conventional cars run on gasoline and tend to be dirtier and more expensive to fuel than EVs.



381 GRAMS OF CO_2e PER MILE

AVERAGE EMISSIONS NATIONWIDE



PLUG-IN HYBRID ELECTRIC

Plug-in hybrids use both gasoline and electricity and can be recharged from an outlet.



209 GRAMS OF CO_2e PER MILE



BATTERY ELECTRIC

Battery electric vehicles run on electricity and are some the cleanest and cheapest cars to drive.

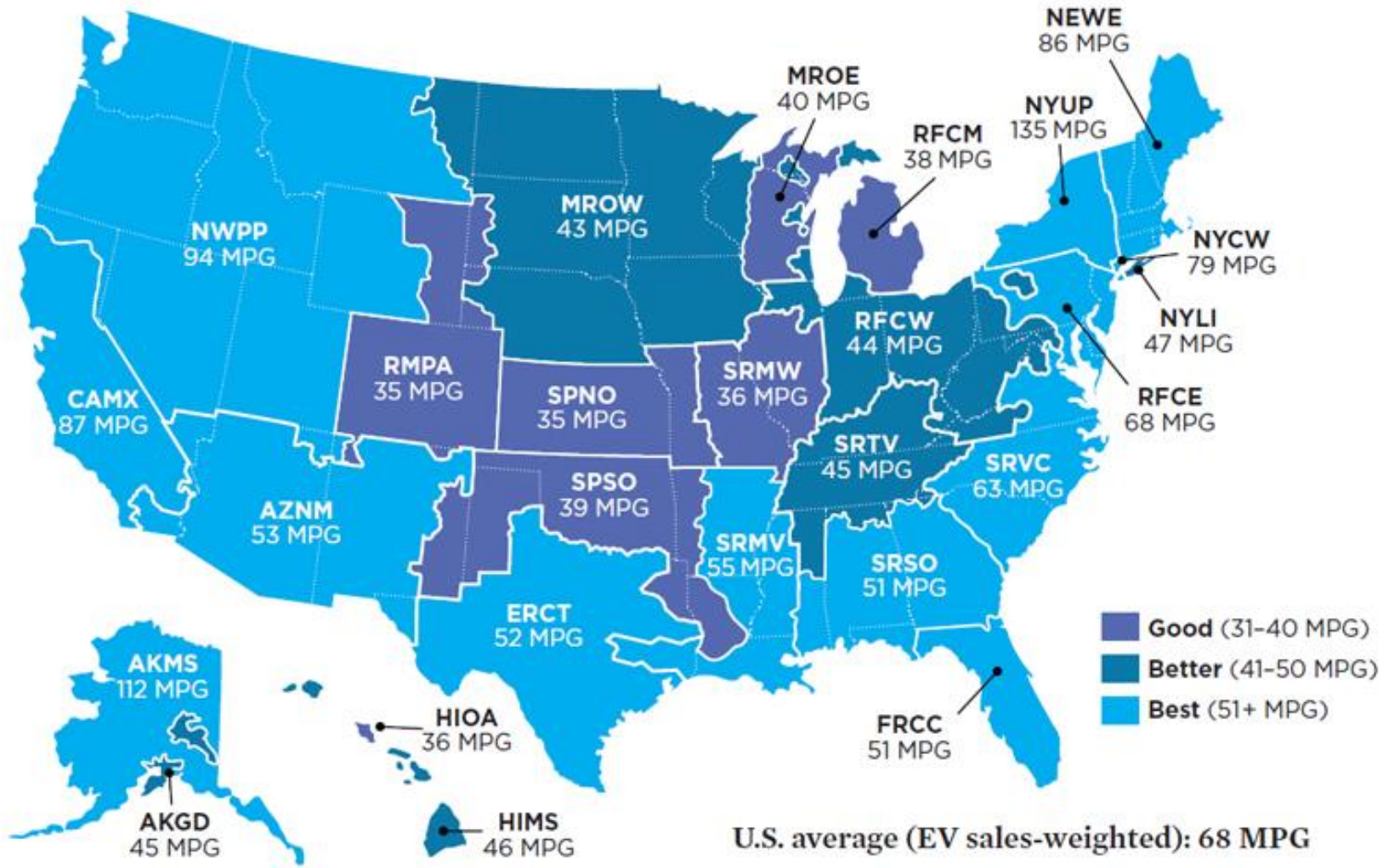


154 GRAMS OF CO_2e PER MILE



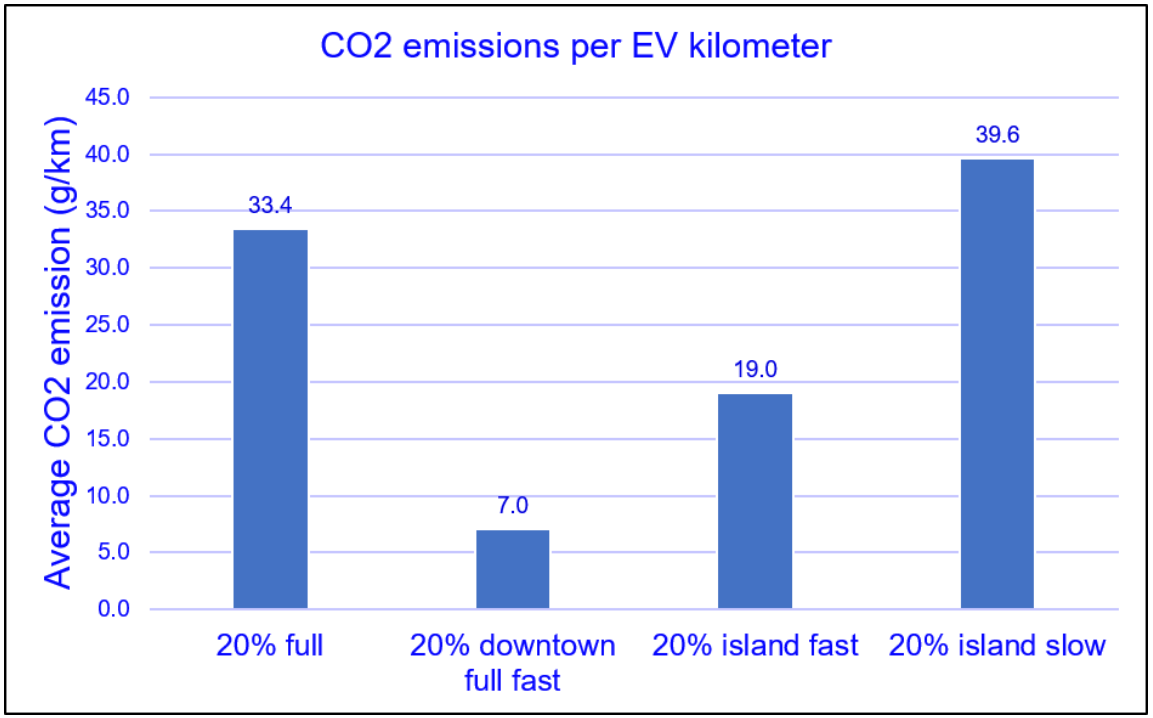
(Vanek et al. 2012 Energy Systems Engineering)

A Geographic Well to Wheel Analysis: EV vs ICV



(Union of Concerned Scientists 2016)

A Dynamic Well-to-Wheel Analysis



Factors impacting EV CO_2 emissions:

- Base case km driven
- Km driven to charging station
- Topology & type of charging station infrastructure
- Capacity of each charging station
- Generation fleet mix when the vehicle charges
- The average heat rate of generation fleet when the vehicle charges

∴Assessment of CO2 emissions needs a Holistic Dynamic System Model

Conclusions

- The development of transportation sits within three large scale trends:
  - the shared-intelligent transportation systems,
  - connected & automated vehicles,
  - electrified transportation systems
- Electric vehicles fundamentally couple transportation, electric and informatic-cloud infrastructure
- Dynamic operations-centric assessment approaches are necessary to assess the impacts of EV integration.
- Holistic system performance (CO_2 emissions, transportation congestion, power system reliability, investment & operating costs) depends on:
  - EV penetration rate,
  - Driving patterns,
  - Charging station topologies (capacity, placement, charger type, and management)
- Synergistic coordination between the transportations system and the electric power system is imperative to realize synergistic cost/benefit ratios