Evaluation of Electric Vehicle Adoption Potential in Abu Dhabi

Authors

Mohamed Al Hadhrami

Dr. Asha Viswanath

Reem al Junaibi

Dr. Amro Farid (PI)

Dr. Sgouris Sgouridis (PI)

Table of Contents

List of Figures

List of Tables

Abstract

Electric Vehicles (EVs) are a critical option for the sustainable transition of a transportation system. We investigate the potential of EV adoption in the case of Abu Dhabi Emirate in the UAE.

Abu Dhabi is characterized by a hot arid climate with harsh summer temperatures and mild to hot winters. It is an important fossil fuel exporter and an implicit social contract supports domestic fossil fuel consumption in the form of gasoline, diesel, and electricity subsidies. These conditions and the early urban planning have generated a strong automobile-centric transportation system and "car culture".

We structured our study to consider EV adoption holistically:
- Specific challenges of EV operation under hot climatic conditions
- The current status and objective of the Abu Dhabi Transportation policy and its guiding principles under the existing master plan
- A global survey of transportation policy options in support of EV adoption
- EV economics under different configurations and roles (private cars, shared /rental cars, taxis, buses) and under different fuel and battery prices
- Consideration of the attitudes of the local population towards EV adoption through a targeted survey
- EV integration in the Intelligent Transportation System Architecture
- Impacts of EV integration to the grid

We find that EVs today could provide a viable option for Abu Dhabi vehicle uses but they would need to address concerns of the public. This can be done through gradual introduction of EVs and with the attendant build-up of charging infrastructure. Ideal candidates for initial adoption are government fleets and some private fleets (car sharing as a novel application and a portion of taxis). The latter would need to introduce different operational procedures with heavy focus on on-demand services for the EV fleet.

The consolidation of these findings into scenarios of possible EV adoption and their evaluation concludes our efforts. We find that more than 30,000 cars and

over 800 buses could support the transportation needs of Abu Dhabi by 2030 in a total fleet of more than 1 million vehicles and 9000 buses. This would result in cumulative net savings of more than a billion liters of gasoline and diesel (equivalent to 6.4 Million barrels of oil) and would offer a discounted benefit cost ratio of 2.25 under our battery cost, fuel cost, and utilization assumptions. Since the majority of the benefits are in the form of undisbursed fossil fuel subsidies, the government has an incentive to support initial EV adoption. Especially for buses, substantial savings in maintenance costs and pollutants create an additional public benefit stream.

Project Introduction

In the transition towards a low carbon society, transport electrification is a necessary step. The timing and pace of such transition though is governed both by economics but also by technology development and policy decisions that can drive adoption rates. In recent years, there is trend for national governments and urban municipalities to support the accelerated adoption of electric vehicles with a variety of measures.

This study, funded by the Japanese Ministry for Economy, Trade and Industry (METI), aimed at investigating the potential for electric vehicles in Abu Dhabi, UAE. Abu Dhabi is a large and growing metropolis with a population of 1.5 Million and a diverse ethnic mix of residents. Situated on the Arabian Gulf it has a challenging harsh desert climate for the summer months and has traditionally relied on private vehicles for the residents' mobility needs. The strongly developed automobile culture is aided by the fact that the oil-rich nation subsidizes domestic gasoline consumption. This setting is replicated in varying degrees in other Gulf states and therefore the findings of our study have broader implications for the region.

Climate, culture, and fossil resource availability create a literally challenging environment for the widespread adoption of electric vehicles. In order to address this holistically we investigated a number of related areas shown in Figure 0-1.
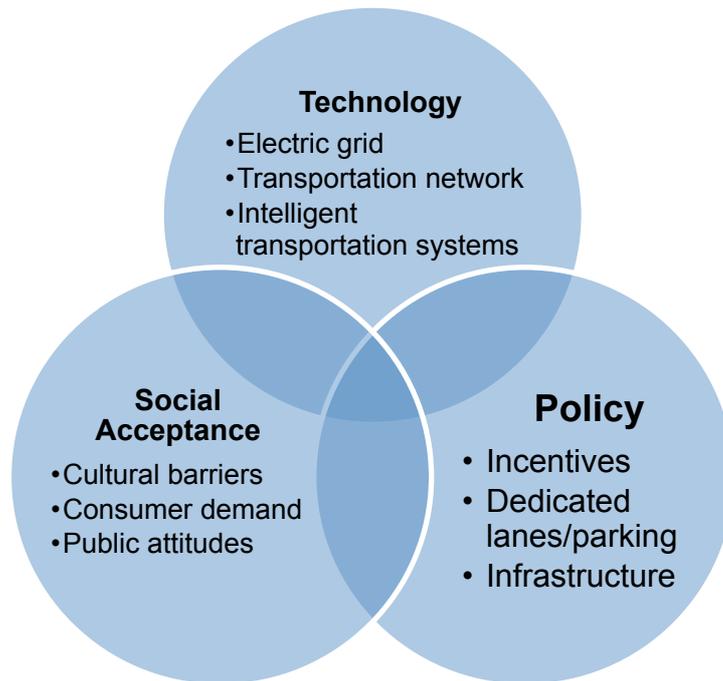
Figure 0-1 Holistic View of EV Adoption Considerations

The structure of the report reflects these components:

- Section1:
    - Introduces the rational for EVs in the region
    - Investigates the current state and direction of Abu Dhabi's transportation policy
    - Provides a comprehensive review of the current policies globally both on a national and urban scale to promote EV adoption
    - Formulates and evaluates policy options in the adoption of EVs
- Section 2 provides the results of an extensive survey on UAE residents' mobility preferences and how they relate to their perception of EVs.
- Section **Error! Reference source not found.**
- Section **Error! Reference source not found.**

1 Rationale and Configuration of Options for Transportation Electrification in Abu Dhabi (Chapter Lead: S. Sgouridis)

1.1 Research Objective

This section's research objective is to determine the need and the available options for transportation electrification in Abu Dhabi. Specifically, we:

- discuss the rational for EVs globally and in the local context
- present a comprehensive review of global policy options for EV adoption
- present the current commercially available electric vehicle and ancillary equipment
- conduct a parametric economic analysis of the adoption of an EV in the Abu Dhabi conditions
- present and evaluate sets of options (scenarios) for the adoption of EVs in Abu Dhabi

1.2 Rational of Electric Vehicles in Abu Dhabi: a Sustainable Transportation Transition

1.2.1 Fossil Fuel Availability and Subsidies

The Abu Dhabi emirate is a major oil exporter with a current production of 2.8 mbpd and has the seventh largest reserves of natural gas in the world. Moreover, it has one of the lowest extraction costs of petroleum compared to the marginal oil extraction from tight oil, tar sands and deep-sea reservoirs. As part of the social contract, the UAE government is offering not only not imposing taxes on but offers energy subsidies that substantially lower the cost of gasoline vehicle operations. Gasoline subsidies remove one of the key incentives for the adoption electric vehicles for the private user (individual or organization) but they do not negate the benefits that the UAE government can gain by the reduction of domestic oil consumption. These include:

- Delaying reserve depletion
- Increasing potential export revenue by making more oil available for export now or in the future
- Reducing domestic greenhouse gas emissions

On the third point, although the UAE is not an Annex I country in the Kyoto protocol, i.e. it has no officially sanctioned mandate to reduce its carbon footprint, it is making significant efforts towards sustainable development as discussed in the Section 1.3.

1.2.2 Electrification: an Integral Part of a Sustainable Transportation Transition

A sustainable transportation system transition can be considered as a component of a sustainable energy transition and therefore can broadly follow the same overarching framework. The framework is summarized in Table 1-1 with green highlighting the areas that are relevant to this work. It would start from reducing the demand by focusing on providing accessibility to services rather than simply mobility in a suboptimal spatial and price in externalities. Then it would attempt to provide transportation services with higher utilization efficiency – i.e. increasing the use of public transport, encouraging car pooling and car sharing. A third step would be to increase the energy conversion efficiency of the processes – in the transportation system this can be done mainly through vehicle electrification (see Box 1-1). Fourthly, it would try to generate energy from renewable resources and facilitate their adoption through the provision of a vehicle-to-grid service. Finally, a de-carbonization step would take place for the processes that cannot be readily electrified through the use of drop-in biofuels (e.g. ethanol, biodiesel) and the development of carbon offset projects.

Table 1-1 Framework for Sustainable Transportation Transition

Demand Management	• Accessibility vs mobility • Mixed Use Planning • **Pricing (congestion/emission charge)**
Utilization Efficiency	• Public Transit • Car-pooling • **Car-sharing**
Process Efficiency	• **Electrification: PHEV, BEV**
Clean generation	• Renewables/nuclear • **Vehicle2Grid**
Decarbonization	• Biofuels • Offsets

Electric vehicles have the advantage of (i) very efficient transformation process and (ii) direct utilization of renewable energy electricity. Even without renewables, the Resource-to-Wheels (RTW) efficiency chain offered by EVs is higher than any internal combustion engine (ICE) vehicle as shown by the typical values that would be applicable in the UAE applied in the figure.
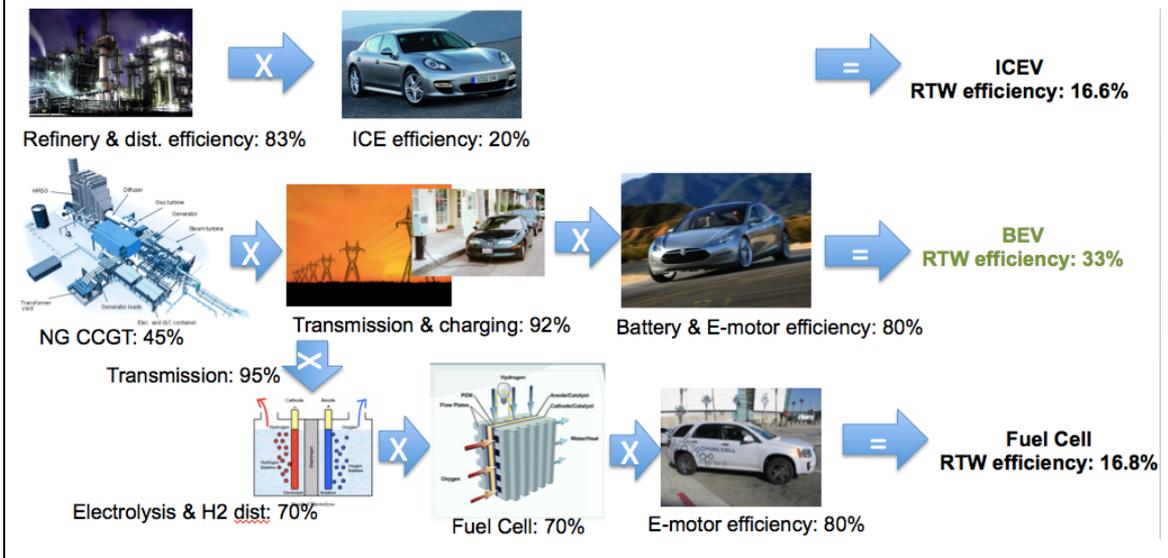
Box 1-1 EV Efficiency Advantage: Comparative Efficiency of Alternative Drive-trains

The efficiency advantage, expectations for higher liquid fuel prices and regulations for reducing greenhouse gas emissions in the developed and pollutant emissions in the developing world has formed the basis for a number of aggressive forecasts for the adoption of EV on an international basis.

Deutsche Bank (2009) (Electric Cars: Plugged In 2 : A Mega-Theme Gain Momentum, 2009) made estimates for the potential of EV uptake in different regions of the world. For 2020, their estimates for the breakdown percentage of new vehicle purchases in different regions are shown in Figure 1-1.
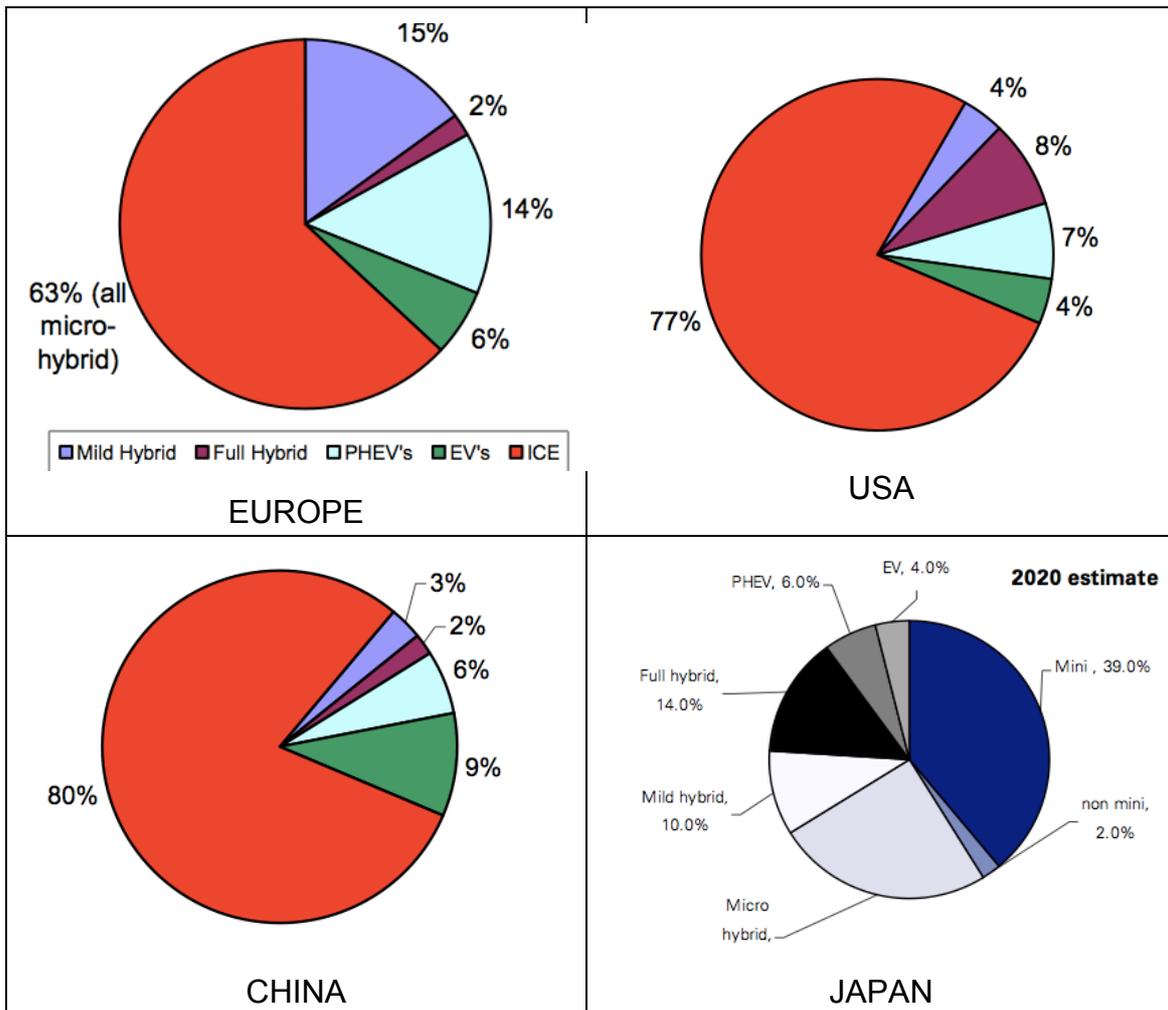
Figure 1-1 Forecast Percentage Breakdown of New Vehicle Purchases by Region (source: (Electric Cars: Plugged In 2 : A Mega-Theme Gain Momentum, 2009))

In a similar vein, a specific analysis of the US market by a UC Berkley team (Becker, 2009) have forecast up to 60% of the total new vehicle sales in the US by 2030 would be EVs with a significant ratio of the total fleet as well (cf. Figure 1-2).
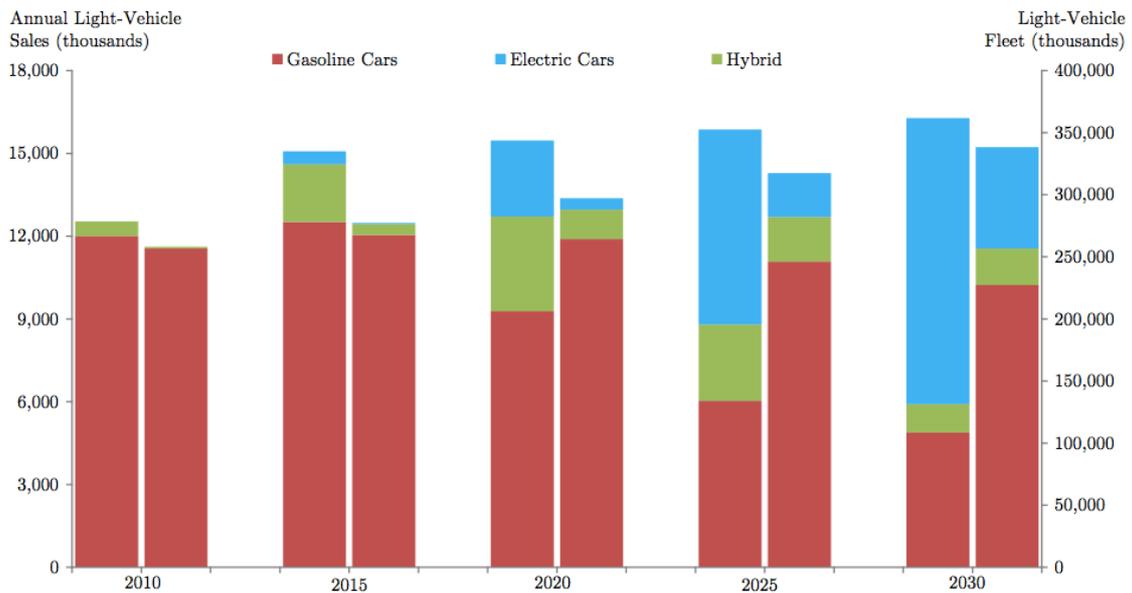
Figure 1-2 Anticipated Vehicle Sales and Fleet Size in the US (source: (Becker, 2009))

1.2.3 BEVs Operations in a Hot Climate

We have seen so far that BEVs should (i) be part of a sustainable transportation system, and (ii) that they provide significant efficiency advantages. Given that UAE's climate is a harsh arid desert climate there are issues concerning the very viability of BEV operations under high temperatures. EVs face additional obstacles in extreme hot climates, namely:

- Reduced range due to AC use,
- Potentially reduced battery lifetime due to higher operating temperatures,
- Reduced maximum charging power to prevent battery overheating (prolonged charging period.

The AC use is inevitable in the high temperatures. It could be optimized by more efficient provision of passenger comfort (e.g. chilled seats) but generally remains a constant load on the battery that has an effect on the range. If range is desired, then a bigger battery pack should be selected with the attendant costs. Figure 1-3 shows the effect of temperature on range for the Nissan Leaf. AC

could draw anywhere from 1000W to 4000W depending on the weather conditions and the size of the vehicle.
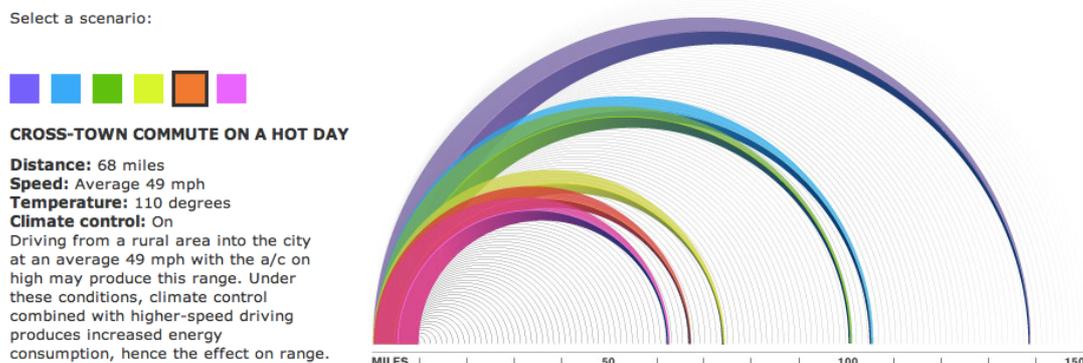
Figure 1-3 Range Impacts of Hot Weather on Nissan Leaf Operations (source: (Leaf))

The issue of reduced battery lifetime due to higher operating temperatures is more significant as the chemistry of Li-Ion batteries that are commonly used for BEVs is sensitive to overheating. Operating temperatures should be maintained below of 40C to prevent accelerated cell deterioration – but which can be at or lower than the ambient temperature in the UAE summer! Manufacturers of BEVs have addressed this by using: active cooling, air cooling, or advanced battery chemistry.

The Tesla Model S uses active cooling of the battery which makes the system more complicated and creates an additional load for the battery. The Nissan Leaf and Mitsubishi MiEV use air cooling[1]. The ongoing pilot operation of MiEVs at Masdar Institute during the summer indicated that operationally the vehicles did not experience problems. Furthermore, advances in battery chemistry increase the longevity of the batteries under warm weather conditions based on the recent entering into production by A123, a main automotive battery supplier, of the "Nanophospate EXT Li-Ion that allows for higher operating temperatures without degradation of the battery life (cf. Figure 1-4).

---

[1] Nissan has bought back two vehicles in Arizona that indicated accelerated cell deterioration but the vehicles were driven >30,000 km and Nissan considers the deterioration expected (http://www.dailytech.com/Nissan+Expands+Warranty+Coverage+on+Leaf+Battery+Packs/article29505.htm) .

In conclusion, the current technological progress in BEV indicates that hot operating conditions do not pose a significant problem for battery viability (especially if backed by manufacturer warranty) and therefore it does not construe a substantial problem in BEV adoption in countries with hot climatic conditions.
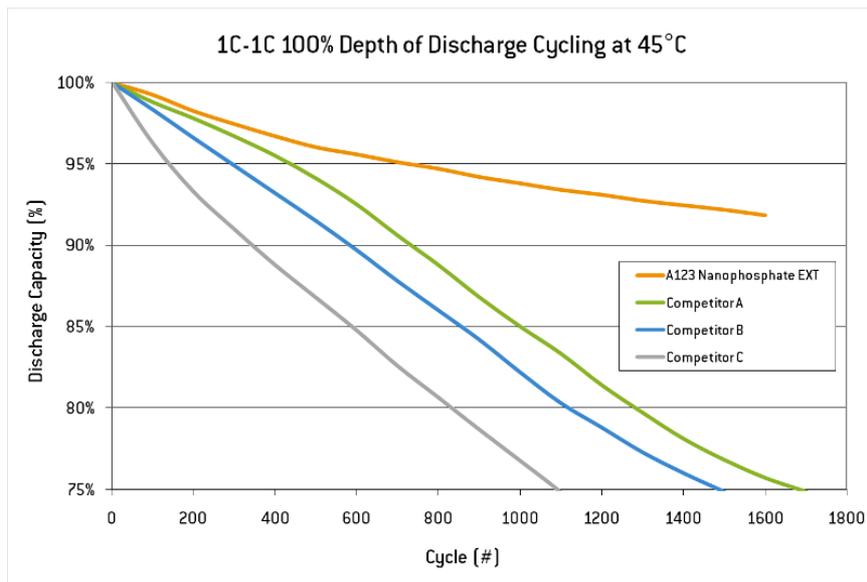
Figure 1-4 Announced discharge capacity for heat-tolerant Li-Ion Chemistry
(Source: (A123 Systems))

1.3 Abu Dhabi Transportation Policy in Context

This section presents an overview of the current Abu Dhabi transportation policy context. We present the Abu Dhabi's Department of Transport (ADDOT) organizational structure and summarize the key guiding document for transportation policy in AD: Abu Dhabi's Surface Transport Master Plan as issued in June 2009 (Abu Dhabi Surface Transport Master Plan: A Vision for Connecting Abu Dhabi -- The Plan, 2009).

1.3.1 Abu Dhabi Department of Transport Organizational Structure

The Department of Transport (DoT) is the main regulatory body that caters to the transportation needs in Abu Dhabi. The DoT was established to "regulate, plan and develop an efficient and well-integrated transport system that serves the public interest by enhancing mobility and delivering safe, secure and environmentally responsible Aviation, Maritime, Public Transport and Highways sectors". According to the DoT official website, "The Department of Transport (DoT) was established pursuant to Law No. 4 of year 2006, amended by Law No. 5 of year 2008 to cover the entire value chain and ensure fully coordinated planning in all aspects of transport policy and development in the Emirate of Abu Dhabi in cooperation with all relevant local, regional and international stakeholders and partners" (Abu Dhabi Department of Transport). Before 2006, the transport modes (civil aviation, maritime transport, highways and road transport, and public transport) were administered by different agencies, with no solid connection or coordination between them. After its establishment, DoT brought all those responsibilities under one roof to regulate, develop, manage and operate any transport related issues.

The organizational structure of the Department of Transport is shown in Figure 1-5:
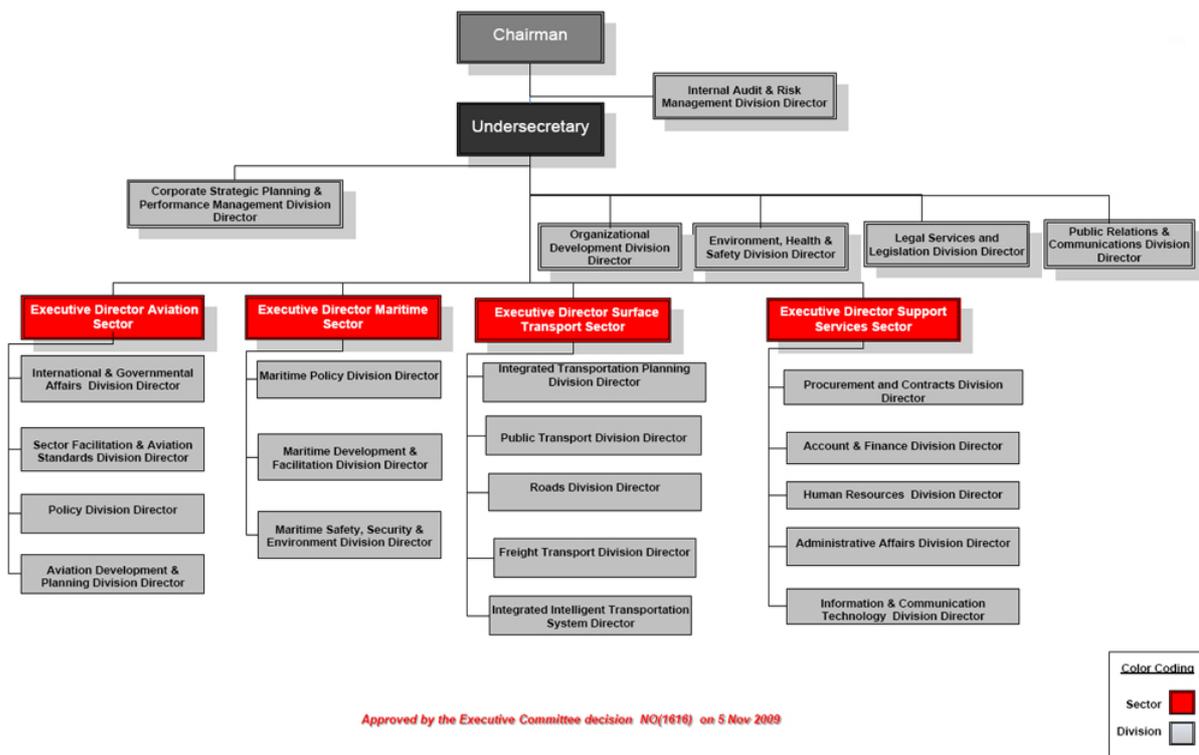
Figure 1-5 Organizational Structure of DoT (Abu Dhabi Department of Transport)

The Center for Regulation of Transport by Hire Cars (TransAD) is a subsidiary of the Department of Transport that was established to develop, regulate, monitor and continually improve the services provided by hire cars in the Emirate of Abu Dhabi. TransAD is a corporate body enjoying financial and administrative independence and a complete legal status to operate under the patronage and guidance of the Chairman of the Department of Transport (DOT) of Abu Dhabi (TransAD).

1.3.2 ADSTMP Context

1.3.2.1 Introduction

The United Arab Emirates in general and Abu Dhabi in specific are undergoing rapid and visionary transformation designed to transform the city into an international capital by the year 2030. An important phase of Abu Dhabi's 2030 plan is to design a world-class transport system, which addresses the regional transport needs of the Emirate as a whole, while focusing particular attention on Metropolitan Abu Dhabi.

1.3.2.2 The Policy Framework

The Surface Transport Master Plan was developed within the framework set by Abu Dhabi plan 2030. The main themes underpin Abu Dhabi's plan are:

a. Sustainability

Use Abu Dhabi's wealth to explore renewable energy production, to reduce the consumption of nonrenewable resources and to educate future generations.

b. Connectivity

Provide multi-layered transport network to connect the downtown core with new growth nodes and the developed islands.

c. Transportation

Establish two city centers, one in the downtown area of Abu Dhabi Island and the other in the new Capital District, which will be connected with highly advanced transport grid to facilitate a balanced traffic flow.

1.3.2.3 Vision for Transport in Abu Dhabi

The Plan's vision is to develop 'A world-leading transport system that meets the needs of residents, visitors and businesses in the most efficient, safe, attractive and environmentally sustainable way.' In order to be a widely recognized system, it should be:

- Reduced dependency on the use of private cars and promotion of non-motorized movements
- A high proportion of trips made by public transport
- A high degree of integration within the transport system
- Reduced carbon emissions

1.3.2.4 Goals and Objectives

According to Plan Abu Dhabi 2030, the three main pillars of sustainable development are as follows:

- **Goal 1: Economy:** promote economic competitiveness and vitality through efficient, high-quality transport services for passengers and freight
- **Goal 2: Society and culture:** protect and enrich people's lives by maximizing safety and access to opportunities for all
- **Goal 3: Environment:** deliver world-leading performance in environmental sustainability, through responsible use of resources, minimizing pollution, and preserving Abu Dhabi's unique environment.

1.3.2.5 The Process:

The study was completed in three main phases, which were:
- **Phase1: Assessment:** review of existing conditions, policies and plans.
- **Phase2: Evaluation:** analysis of the probable impacts of alternative scenarios for the management and development of the transport system.
- **Phase3: Implementation Plan:** deriving implementation schedules and action plans, together with recommendations.

1.3.2.6 Consultation and Participation

The main participants in creating and commissioning the ADSTMP are:
- Department of Transport (leading)
- Abu Dhabi Urban Planning Council
- Abu Dhabi Municipality
- Al Ain Municipality
- Al Gharbia Municipality

1.3.3 The Transportation Challenges Addressed by ADSTMP

The main challenges that are addressed by the ADSTMP are the following:
- Economic growth
- Economic diversification
- Spatial Change
- Environmental Implications
- Mobility
- Social and Cultural Implications

1.3.3.1 Economic Growth

One of the most important challenges facing the implementation of plan Abu Dhabi 2030 is the rapid increase in the population of Abu Dhabi; Figure 1-6 below shows the expected growth in population in year 2030, compared to the population in year 2008.
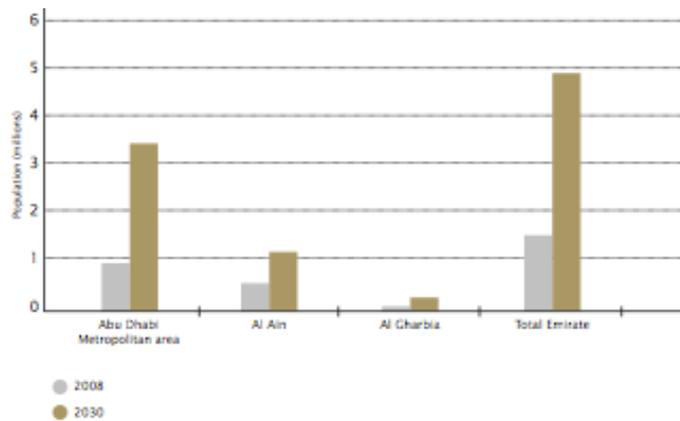
Figure 1-6 Expected Population Growth (Transport, 2009)

1.3.3.2 Economic Diversification

As per the plan objectives, it is designed to reduce the domination and dependency on the oil sector, and expand other means of economies. Statistics shows that the commercial and tourism sectors will grow four to five folds by 2030 as illustrated in Figure 1-7.
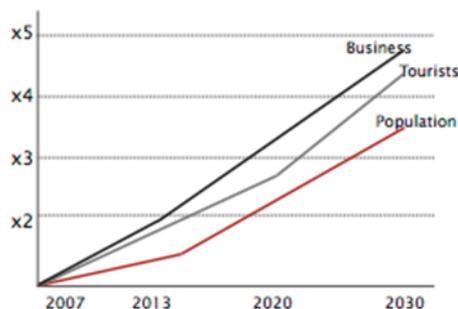
Figure 1-7 Expected Growth in Business and Tourism   (Transport, 2009)

1.3.3.3 Spatial Change

The preliminary plan indicates that changes will occur in land use distribution in order for the economic plans to be achieved.

Some of the key challenges this poses for the Plan are:

- The construction of the CapitalCity District on the mainland will alter the urban structure of the Metropolitan area, and therefore increase the travel demand.
- Access points should be provided to the new developments in the islands.
- Facilitate trips to different locations within the new developments in terms of cost and time.

1.3.3.4 Mobility

The transportation system in the UAE in general and Abu Dhabi in specific is a car dominant system. The majority of surface transport in the Emirate is by private car, taxi or bus, with a small but rapidly developing public bus system. Figure 1-8 shows 2008 base year model split, where less than 1% of surface transport is by public transportation means.
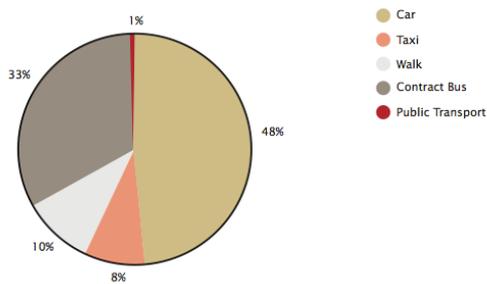
Figure 1-8 2008 Base Year Modal Split   (Transport, 2009)

1.3.3.5 Environmental Implications

The UAE has one of the highest per capita carbon emissions in the world, and a significant amount of which is transport generated (cf. Figure 1-9). According to Kyoto Protocol, all industrialized countries were required to reduce their total emissions of greenhouse gases by about 5 % by 2012 compared to 1990 levels. Although UAE is not part of the protocol, it will face pressure in the near future to reduce its carbon emissions.
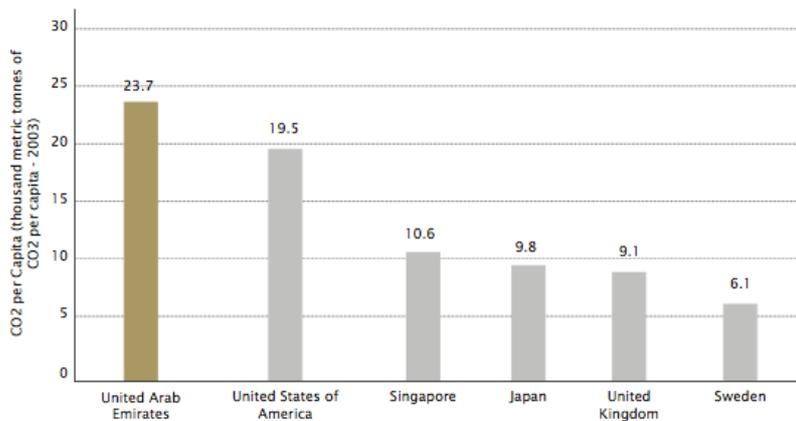
Figure 1-9 Per Capita Emissions (Transport, 2009)

1.3.3.6 Social and Cultural Implications

One of the most significant challenges facing the shift toward the use of public transport modes is the unique cultural mix of Abu Dhabi, where less than 15% of the population is UAE nationals and the remaining 85% are expatriates. This conveys an important issue that the expats population consists of several different categories ranging from professionals to modestly paid industrial labors.

1.3.4 The Choices

In the first stage, four alternative scenarios were defined and subject to a broad evaluation against the project objectives. In the second stage, an Emerging Preferred Scenario emerged and was subject to testing.

A Strategic Evaluation Framework (SEF) along with a transport model was developed in order to develop, test and evaluate the alternative scenarios.

1.3.4.1 ADSTMP Investigated Scenarios

A number of four scenarios are investigated in the ADSTMP, in order to come up with a fifth preferred scenario as shown below.

Scenario 1

A highways-based scenario designed to facilitate road based transport. It comprises of the existing reference case in addition, among others, to traffic management and safety measures.

Scenario 2

A public transport and car alternatives scenario designed to encourage use of non-car modes. It comprises the reference case plus the main addition of metros, rails, trams, and LRTs.

Scenario 3

A demand management scenario designed to influence the mode of travel through the application of the Public transport scenario plus mechanisms such as pricing.

Scenario 4

A low carbon scenario designed to reduce carbon emissions through the application of the Public Transport Scenario plus:

- Use of alternative fuels
- Provision of passive cooling and shading rather than air-conditioning, where feasible
- Introduction of a low emission zone for Abu Dhabi, Suwa, Al Reem and Saadiyat Islands, Capital City District.
- Introduction of emission tax and subsidies for alternative fuels
- Improved management of parking
- Freight deliveries by low pollution means
- Provision of improved cycle facilities around interchanges and cycle hire schemes
- Test the impact of a wide range of carbon reduction measures.
- Development of Personal Rapid Transit (PRT) networks.

The Enhanced Transport Model was used to test the Reference Case and each of the alternative scenarios. To achieve the plan vision, a hybrid of all the scenarios would be required. A significant number of tests were conducted that examined proposed changes which had come from stakeholder workshops, experts' feedback, feedback from Public Consultation exercise, individual sessions with stakeholders, and technical sessions with DoT and ADUPC.

Preferred Scenario

Table 1-2 Preferred Scenario   (Transport, 2009)

Element	Description
Regional Passenger Rail	590km system of inter-regional rail forming part of a future UAE and GCC-wide passenger rail system
Freight Rail (Union Railway)	1300km system of inter-regional rail forming part of a future UAE and GCC-wide freight rail system
Metro	130km of segregated railway in Abu Dhabi Metropolitan area
Tram	340km of street running tram in Abu Dhabi Metropolitan area
Personal Rapid Transit	Demand-responsive system planned for Masdar, and potentially Lulu
Bus	A fine grained bus network will be provided in all urban areas not served by tram or metro
Water Transport	A system of scheduled ferry services along both sides of Abu Dhabi island
Highways	1500km of new or upgraded highways
Parking charges	Charge of AED10 per hour in the CBD and Capital City District
Global fuel tax	Tax equivalent to AED1 per km on all vehicles
Congestion charge on inner cordon (bridges to Abu Dhabi Island)	Charge of AED20 per cordon crossing
Congestion charge on outer cordon (Shahama Freeway and Mid Island Parkway)	Charge of AED10 per cordon crossing

The Preferred Scenario was evaluated on 3 main aspects:

1. The Environmental Evaluation

It measured the contribution of the Preferred Scenario towards the environmental goal of: 'Delivering world leading performance in environmental sustainability, through responsible use of resources, minimizing pollution, and preserving Abu Dhabi's unique environment.'

This goal has the following second level objectives:

- o Develop a low carbon economy in Abu Dhabi by 2030
- o Preserve the critical natural environment in Abu Dhabi
- o Protect and enhance cultural heritage, landmarks, symbols and monuments
- o Other environmental evaluation criteria including: Local air quality and Noise

In comparison, the Preferred Scenario showed a 35% reduction in CO_2 emissions compared with the 2030 Reference Case. Far greater effort is needed to fulfill international obligations of a reduction of 80% in CO_2 emissions by 2050. As this analysis doesn't consider the emissions from the electricity generation for the electrified transport, the emissions would be further lowered if the electricity comes from a renewable source.

2. Social Evaluation

It aims at "Protecting and enriching people's lives by maximizing safety and access to opportunities" and has five second level objectives of improving connectivity within Abu Dhabi, regionally, and internationally; as well as improving the health and safety and the pedestrian realm.

3. Economic Evaluation

The goal is 'Promoting economic competitiveness and vitality through efficient, high-quality transport services for passengers and freight.' This goal has three-second level objectives as follows: minimize congestion, Reduce reliance on cars, and encourage sustainable and efficient freight distribution.
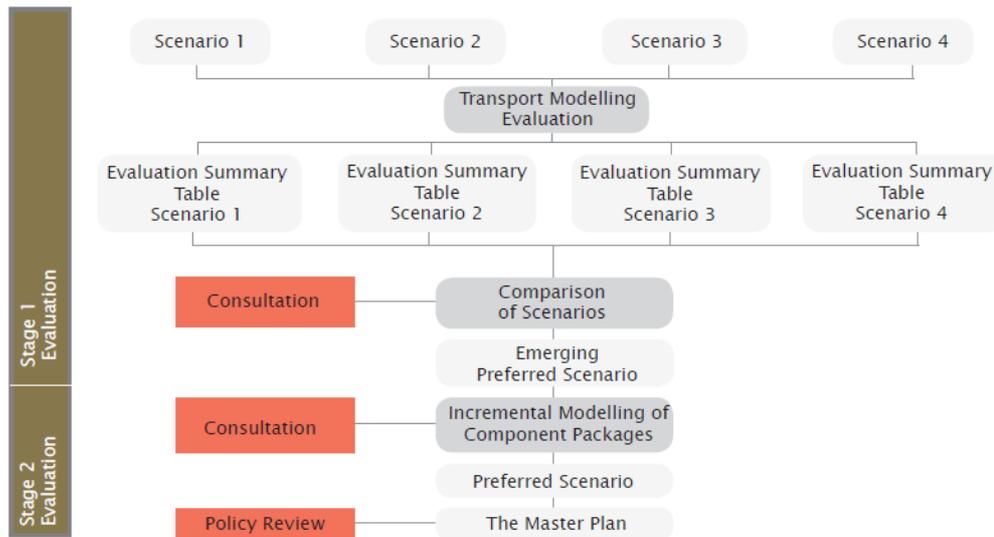
Figure 1-10 The Evaluation Process (Transport, 2009)

1.3.4.2 Strategic Evaluation Framework

This framework aims at evaluating the scenarios and ensuring all relative aspects and impacts are included. It is created using a worldwide best practice in coordination with Abu Dhabi's existing guidelines (cf. Table 1-3).

Table 1-3 ADSTMP Evaluation Framework (Transport, 2009)

Objective	Indicator
ENVIRONMENT GOAL	
Develop a low carbon economy in Abu Dhabi by 2030	CO_2 emissions Qualitative assessment of impact on fuel and energy use
Preserve the critical natural environment that makes Abu Dhabi unique	Qualitative assessment of impact on natural environment (biodiversity, water, soil)
Protect and enhance the cultural heritage, landmarks, national symbols and monuments of Abu Dhabi	Qualitative assessment of impact on townscape character, landscape & heritage
Other Environment (noise and local air	Qualitative assessment of impact on noise

quality)	and local air quality
SOCIETY & CULTURE GOAL	
Improve the international connectivity of Abu Dhabi	Qualitative assessment of access to neighboring Emirates & countries and airports
Improve regional connectivity within the Emirate of Abu Dhabi	Qualitative assessment of access between Abu Dhabi metropolitan area, Al Ain and Al Gharbia
Improve connectivity within the Abu Dhabi Metropolitan area	Qualitative assessment of access to key employment, business and tourist destinations within Abu Dhabi Metropolitan area, including Suwa Island, Saadiyat Island, Marina Mall, Capital District, Central Market Station
Encourage sustainable and efficient freight distribution	Qualitative evaluation of sustainability of multi-modal access to Mussafah and KPIZ
Improve health and safety for the workforce passengers and communities	Qualitative assessment of impact on number of road traffic accidents
Enhance the pedestrian realm	Qualitative assessment of impact on pedestrian realm
ECONOMY GOAL	
Minimize congestion on Abu Dhabi's road network for residents, visitors and businesses	Vehicle hours delay per vehicle
Reduce reliance on the automobile and encourage alternative modes of travel	Percent mode share of public transport

1.3.5 The Plan

The Plan is a well-coordinated and integrated multi-modal transport solution that will provide users with seamless travel throughout the network. The Plan will be implemented through a series of seven strategies:

1.3.5.1 Congestion Management

Congestion management will include providing high-quality alternatives to the car. These alternatives will include: new public transport hierarchy (regional rail, metro, trams, buses, taxis, and ferries), cycling routes and facilities, high-quality passenger experience, simple ticketing, and integrated public transport schemes.

Congestion management also includes providing an appropriate and well managed highway network through implementing an effective road hierarchy (freeway, highway, rural, urban), traffic management and control, reliable journey time information, and efficient incidents management. Moreover, a shift towards transit and pedestrian development (through effective land use controls, regulated parking standards, and travel plans) as well as demand management strategies will be required for a successful congestion management.

1.3.5.2 Accessibility

This strategy aims at developing a high accessibility to transport through minimizing access times; providing access for the handicapped, women, and children, in addition to implementing inclusive fare policies.

1.3.5.3 Health, Safety and Security

The objective of this strategy is to create an integrated transport system of road and rail options that is safe and secure through enhancing road safety (speed limits, pedestrian access, driver training schemes, road safety audits…etc.), public transport safety (through safety assurance process and public safety education), transport security (CCTV for instance), and overall transport and health (all transport projects will be subject to Health Risk Assessment).

1.3.5.4 Pedestrian Realm Improvement

This strategy will be achieved through two main scopes: improving pedestrian environments (through implementing the recommendations of "Abu Dhabi Urban Street Design and Mobility Standards Manual", mainly making the environment more pedestrian-friendly) and better execution of pedestrian walkways.

1.3.5.5 Freight Management

The aim of this strategy is to enhance the effectiveness and efficiency of freight movement within Abu Dhabi by supporting freight transhipment and modal shift through developing regional distribution centers and facilitating the freight rail line. In addition, more efficient freight traffic management (by optimizing truck routes and promoting alternative ones) would improve the quality of the freight haulage industry.

1.3.5.6 Low Carbon

The Low Carbon Strategy aims to implement the concept of sustainable transport in Abu Dhabi by reducing the carbon footprint. This concept will be implemented through the Sustainable Transport Taskforce, which will comprise high-level representatives from DoT, Masdar, EAD and ADUPC. The Low Carbon Strategy will require integration of congestion management, freight management, pedestrian realm, and environmental protection strategies.

Other strategies to achieve the low-carbon target include: energy policy for mass transit, environmentally-friendly public transport fleets, vehicle registration schemes, low-emission zones, priority parking for low emission vehicles, and holding campaigns to increase awareness.

1.3.5.7 Environmental Protection

In addition to the Sustainable Transport Taskforce, a strong commitment to sustainable transport is essential, as well as regulatory framework integration.

1.3.6 Delivery

The DoT has full responsibility for delivering the Plan. They need full support from other government agencies (ADUPC, National Transport Authority, EAD, Union Rail, and municipalities), integration of new executive agencies (ADTCo and RoadCo), private sector engagement, and strong governance through the EHS MS framework.

Private sector engagement will be through coordination, design and development, operation and maintenance, and financing projects.

The program will be funded by a combination of developer cost-sharing contributions, private finance, government grant and government-backed borrowing. The balance of these sources of funds should be determined by the Abu Dhabi Government.

Monitoring the Plan's delivery progress will be through monitoring key

outcomes, providing a hierarchy of performance indicators, making best use of reliable data, including targets and trajectories, monitoring external factors, and adding indicators for technical performance, value for money and customer satisfaction.

Assessments and adjustments to the plan will be carried out through monthly, quarterly, annual, and 5-yearly meetings. The last will result in revised plan document.

1.3.7 Action Plan

The Action Plan for implementation is broken down into a series of five-year plans, as follows:

- 2009 to end 2010 – the 2010 Action Plan
- 2011 to end 2015 – the 2015 Action Plan
- 2016 to end 2020 – the 2020 Action Plan
- 2021 to end 2025 – the 2025 Action Plan
- 2026 to end 2030 – the 2030 Action Plan

Each contains:

- A summary of the schemes and strategies to be completed in each period.
- An implementation schedule for each infrastructure component.

1.3.8 Section Review and Conclusions

The current ADSTMP version is driven by an overarching sustainable transportation vision. The sustainability aspects are highlighted in Strategy 6 (Low Carbon) and 7 (Environmental Protection) of the master plan. Although, low emission vehicles are already referenced, the use and support for electric vehicles is not explicitly referenced. Given that EVs are fundamentally capable to support the other initiatives, e.g. low emissions zones, they should be part of the portfolio of options. The rest of this report evaluates the extent and the role EVs can play in the AD transportation system.4

1.4 Current Vehicle Fleet Operations, Types and Size Estimates in Abu Dhabi

The vehicle fleets that operate in Abu Dhabi include:

- cars (private vehicles, taxis, rental fleets, government fleets),

- buses (light and heavy), and
- trucks (light and heavy).

This report considers all the car fleet types and the heavy buses especially those operated by the ADDOT. In this section, we present and estimate the current fleet sizes in Abu Dhabi.

1.4.1 Government Fleets

According to the official Abu Dhabi Portal website (Abu Dhabi Portal), there are 99 government entities in Abu Dhabi. These entities include court, central government, government agencies, state-owned enterprises, subsidiary state-owned enterprises, federal entities, and others. Examples of each type can be found in the table below (cf. Table 1-4).

Table 1-4 Types of Government Organizations in Abu Dhabi

Type	Example of Entity
Central Government	Abu Dhabi Authority for Culture & Heritage (ADACH)
	Abu Dhabi Tourism Authority (ADTA)
Government Agency	Abu Dhabi Chamber of Commerce & Industry (ADCCI)
	Department of Municipal Affairs - Municipality of Abu Dhabi City (ADM)
Court	Abu Dhabi Judicial Department (ADJD)
	Crown Prince Court (CPC)
State-owned Enterprise	Abu Dhabi Airports Company (ADAC)
	Abu Dhabi Health Services Company (SEHA)
Subsidiary of a State-owned Enterprise	Masdar (Abu Dhabi Future Energy Company)
	Abu Dhabi Distribution Company (ADDC)
Federal Entity	Emirates Authority for Standardization & Metrology (ESMA)
	Emirates Telecommunications Corporation (Etisalat)
Other	Emirates Driving Company (EDC)

	Sultan bin Zayed's Cultural and Media Centre (CMC)

Vehicle fleets in these government entities are normally hired from and managed by certain vehicle rental companies such as, among others, Emirates Transport and Al Wathba Company for Central Cervices. Emirates Transport provides transportation services to most ministries, courts, and government departments in Abu Dhabi. As a subsidiary of ADWEA, Al Wathba's main clients are ADWEA's group of companies in addition to a few others.

Emirates Transport supplied us with the following data on their clients' fleet sizes (cf. Table 1-5):

Table 1-5 Fleet Sizes for Emirates Transport

Sr.	Entity	Fleet Size (cars)
1	National Council for Tourism and Antiquities	1
2	Audit Bureau	2
3	GCAA	3
4	Federal National Council	4
5	Federal Authority for Human Resources	4
6	National Center for Statistics	4
7	NATIONAL TRANSPORT	6
8	Ministry of Foreign Trade	6
9	Family Development Foundation and the Zayed Higher Organization for Humanitarian Care	6
10	Ministry of Environment and Water	8
11	General Secretariat of the Council of Ministers	10
12	The Ministry of Education	10
13	Ministry of Social Affairs	10
14	Ministry of Economy	15
15	Department of Energy	16
16	National Media Council	16
17	Quran Centers	17
18	Ministry of Higher Education	18

19	Ministry of Finance	20
20	Authority of Islamic Affairs and Endowments	27
21	Ministry of Health	30
22	Ministry of Culture and Youth	31
23	Ministry of Foreign Affairs	33
24	ADEC Education	37
25	Ministry of Works	70
26	Ministry of Justice	101
27	Department of Economic Development	170
28	Abu Dhabi Judicial Department	180
	Total	**855**

Most notably, this data does not include any information on the ADNOC or ADWEA groups of companies' fleets. Instead, the data is more biased towards ministries, which tend to have smaller fleet sizes compared to field-related work places like ADNOC and ADWEA. These companies have relatively large fleet sizes, usually not less than 100. For instance, Abu Dhabi Sewerage Services Company (a former subsidiary of ADWEA) has 116 cars in its fleet. Applying this logic to obtain the fleet sizes:

ADNOC (ADNOC Group) has 16 subsidiary companies:

- Fleet size for ADNOC companies = 16 x 100 = 1600 cars

ADWEA (ADWEA Group) has 5 subsidiary companies:

- Fleet size for ADWEA companies = 5 x 100 = 500 cars

Therefore, total government fleet size in Abu Dhabi
= 855 + 1600 + 500 + 116 + {31 x [99 – (28 + 16 + 5 + 1)]} = 4,590 cars

Personal communications with one ministry fleet manager indicated that vehicle utilization can be as low as 20km/day but this was a ministry with not strong mobility needs. It is expected that other agencies have much higher utilization rates.

1.4.2 Taxis

The taxi operations are run in Abu Dhabi by TransAD, a subsidiary of the DoT (cf. Section 1.3.1). There are 6 taxi operators and 8 limousine operators

monitored by TransAD. Each taxi driver is assigned to a specific car and is required to generate minimum daily revenue. As such, no roaming/working hours are enforced for each driver. Many taxis operate by roaming and picking passengers on the way or waiting in taxi queues at high demand areas (airport, stations, malls). An on-demand service is operated by TransAD successfully and is expected to increase the number of taxi trips.

According to the data provided by TransAD, the total number of taxis in Abu Dhabi Emirate is 7,148 taxis (2012). Based on the detailed historical log of a single taxi over 147 days, the average daily revenue distance was close to 195 km but the average total distance was more than double at around 405 km indicating the large percentage of roaming.

1.4.3 Rental Cars

There are numerous private-owned rental car companies in Abu Dhabi. These cars are registered as private cars and, hence, they should be included in the private car number above. The Statistical Yearbook doesn't mention a number for those cars.

Although there is no official number of the private rental fleets in Abu Dhabi, this number could be estimated. There are 613 car rental companies in Abu Dhabi, and 102 companies in Al Ain as listed in the Business List website (BusinessList.AE). The fleet sizes for these companies range from a few cars to tens. No car rentals are listed in the Western Region, but we would assume there are 10. From practice, we estimate the average number of cars per company would be 14.

Estimated total number of rental cars, therefore = (613 + 102 + 10) x 14 = 10,150 cars

1.4.4 Private Cars

Due to the lack of a well-developed public transport system in Abu Dhabi, in addition to other factors, the greatest portion of travel demand is supplied by private cars.

According to the Statistical Yearbook of Abu Dhabi 2011, the number of registered private cars in Abu Dhabi region was 389,536 cars in 2009. In Al Ain, the number was 153,123 cars while the Western Region had 17,636 in 2009. Assuming a yearly growth rate of 3%,

Year	2009	2010	2011	2012

Number	560,295	577,104	594,417	612,250

As the number of rental cars with private plates = 10,150 cars,

And the number of government fleets with private plates = 4,590 cars

Therefore, number of private cars in Abu Dhabi Emirate = 612,250 − 10,150 − 4,590 = 597,510 cars

1.4.5 Car Sharing

There is no car sharing scheme in Abu Dhabi; thus no car sharing fleet as of its date. A car-sharing system with dedicated parking spots throughout the city would operate similar to other systems globally (cf. Section 1.5.3.3.)

1.4.6 Buses

While buses include the heavy buses run by the public transport division of the DOT, there are also buses that are utilized by other government and private entities (school and labor transport buses, respectively). According to the Statistical Yearbook of Abu Dhabi 2011 (Statistical Yearbook of Abu Dhabi 2011, 2011), the number of registered buses (light and heavy) in 2009 is 11,101 buses in Abu Dhabi region. In Al Ain, the number is 2,537, while in the Western Region there are 437 buses.

Assuming a yearly growth rate of 2.5%,

Year	2009	2010	2011	2012
Number	14,075	14,427	14,787	15,157

We estimate that approximately half of that number are heavy buses (7,579).

Estimation of the DoT Bus Fleet Size

In this estimation, we used the timetables for the bus services in Abu Dhabi City, Shahama, and Baniyas to estimate the minimum required size of the bus fleet. The minimum number of buses required for each route is calculated from basically dividing the two-direction route's total duration (time it takes a bus to take the full loop and return to origin, to start a new loop) by the headway (the time variance between each two consecutive departures). One challenge faced is that the headway is not constant in many cases throughout the day, which

made the estimation harder. Therefore, the time the bus returns to its origin is found. Then we find the number of the departures within the time interval of one two-directional trip. The maximum number of departures within a two-directional trip time interval in a service peak time is the minimum number of buses needed for the route (cf. Table 1-6, Table 1-7, and Table 1-8).

A couple of assumptions are made:

- A one-direction time duration from origin to destination equals the one-direction time duration to reach back the same origin.

- The calculations below are based on Saturday to Thursday timetables

Table 1-6 Estimated Bus Fleet Size Required for Abu Dhabi City

Route	Origin Time	Destination Time	Duration	Duration Back	Total Duration	Back at Origin Time	Number of Other Departures Between Origin to Origin Times	Number of Buses at Peak	Minimum Number of Buses Needed Per Route
	4:45	5:25	0:40	0:40	1:20	6:05	4		
	6:05	6:55	0:50	0:50	1:40	7:45	0		
	8:15	9:05	0:50	0:50	1:40	9:55	0		
	14:30	15:20	0:50	0:50	1:40	16:10	0		
005	21:50	22:40	0:50	0:50	1:40	23:30	2	4	5
	5:30	6:30	1:00	1:00	2:00	7:30	4		
	8:10	9:15	1:05	1:05	2:10	10:20	2		
	14:40	15:40	1:00	1:00	2:00	16:40	0		
006	22:40	23:45	1:05	1:05	2:10	0:50	2	4	5
	4:30	5:10	0:40	0:40	1:20	5:50	4		
007	21:55	22:45	0:50	0:50	1:40	23:35	5	5	6
	4:25	5:10	0:45	0:45	1:30	5:55	3		
	6:05	7:00	0:55	0:55	1:50	7:55	0		
	13:45	14:35	0:50	0:50	1:40	15:25	3		
008	22:00	22:55	0:55	0:55	1:50	23:50	3	3	4
	3:50	4:45	0:55	0:55	1:50	5:40	3		
	8:00	9:10	1:10	1:10	2:20	10:20	2		
	14:30	15:35	1:05	1:05	2:10	16:40	2		
009	21:50	23:00	1:10	1:10	2:20	0:10	4	4	5
	3:40	4:35	0:55	0:55	1:50	5:30	3		
	14:25	15:30	1:05	1:05	2:10	16:35	2		
011	22:15	23:20	1:05	1:05	2:10	0:25	3	3	4
	0:00	1:20	1:20	1:20	2:40	2:40	1		
	4:00	5:15	1:15	1:15	2:30	6:30	4		
	6:30	7:55	1:25	1:25	2:50	9:20	3		
032	22:20	23:50	1:30	1:30	3:00	1:20	3	4	5
	4:20	5:10	0:50	0:50	1:40	6:00	3		
	6:10	7:10	1:00	1:00	2:00	8:10	0		
	8:30	9:35	1:05	1:05	2:10	10:40	1		
	14:30	15:30	1:00	1:00	2:00	16:30	1		
034	21:40	22:45	1:05	1:05	2:10	23:50	4	4	5
	5:00	6:10	1:10	1:10	2:20	7:20	3		
	8:25	9:45	1:20	1:20	2:40	11:05	2		
044	21:25	22:40	1:15	1:15	2:30	23:55	6	6	7
	4:00	4:50	0:50	0:50	1:40	5:40	3		
	14:40	15:45	1:05	1:05	2:10	16:50	0		
052	20:40	21:50	1:10	1:10	2:20	23:00	6	6	7
	5:00	6:10	1:10	1:10	2:20	7:20	2		
	7:50	9:15	1:25	1:25	2:50	10:40	1		
	13:45	15:05	1:20	1:20	2:40	16:25	3		
054	21:40	22:55	1:15	1:15	2:30	0:10	5	5	6
	4:20	5:40	1:20	1:20	2:40	7:00	4		
	14:20	15:45	1:25	1:25	2:50	17:10	2		
056	21:40	23:10	1:30	1:30	3:00	0:40	5	5	6
								Total	65

Table 1-7 Estimated Bus Fleet Size Required for Baniyas City

Route	Origin Time	Destination Time	Duration	Duration Back	Total Duration	Back at Origin Time	Number of Other Departures Between Origin to Origin Times	Number of Buses at Peak	Minimum Number of Buses Needed Per Route
	5:45	6:35	0:50	0:40	1:30	7:15	2		
	6:15	7:05	0:50	0:50	1:40	7:55	3		
	8:15	9:05	0:50	0:50	1:40	9:55	2		
	18:45	19:35	0:50	0:50	1:40	20:25	3		
	20:45	21:35	0:50	0:50	1:40	22:25	3		
444	22:45	23:35	0:50	0:50	1:40	0:25	1	3	4
447 (constant 1 hour headway all day)	5:50	6:35	0:45	0:45	1:30	7:20	1		
	7:50	8:35	0:45	0:45	1:30	9:20	1		
	8:50	9:35	0:45	0:45	1:30	10:20	1		
	9:50	10:35	0:45	0:45	1:30	11:20	1		
	21:50	22:35	0:45	0:45	1:30	23:20	1	1	2
								Total	6

Table 1-8 Minimum Bus Fleet Size Required for Shahama City

Route	Origin Time	Destination Time	Duration	Duration Back	Total Duration	Back at Origin Time	Number of Other Departures Between Origin to Origin Times	Number of Buses at Peak	Minimum Number of Buses Needed Per Route
222 (constant headway of 1 hour all day)	5:55	7:20	1:25	1:25	2:50	8:45	2		
	6:55	8:20	1:25	1:25	2:50	9:45	2		
	7:55	9:20	1:25	1:25	2:50	10:45	2		
	8:55	10:20	1:25	1:25	2:50	11:45	2		
	21:55	23:20	1:25	1:25	2:50	0:45	2	2	3
224 (constant headway of 1 hour all day)	4:55	6:20	1:25	1:25	2:50	7:45	2		
	5:55	7:20	1:25	1:25	2:50	8:45	2		
	6:55	8:20	1:25	1:25	2:50	9:45	2		
	19:55	21:20	1:25	1:25	2:50	22:45	2	2	3
225 (constant headway of 1 hour all day)	6:05	7:20	1:15	1:15	2:30	8:35	2		
	7:05	8:20	1:15	1:15	2:30	9:35	2		
	8:05	9:20	1:15	1:15	2:30	10:35	2		
	9:05	10:20	1:15	1:15	2:30	11:35	2		
	20:05	21:20	1:15	1:15	2:30	22:35	2	2	3
								Total	9

Therefore, the estimated number of AD DoT urban and suburban bus fleet size is 65 + 6 + 9 = 80 buses approximately for the 2011 timetable (latest update). DOT actually operates 250 urban buses and there are plans to expand the bus fleet to 750 buses (urban) and 250 regional. DOT's bus utilization is very heavy with approximately 700km / day / bus.

1.5 International Best Practices for EV Policy Options and Current Results

This section overviews the international best practice on transportation policy for promoting EV adoption. National, regional, and municipal authorities internationally recognize that there is a societal value in promoting the use of EVs for their ability to reduce pollutants but that the commercial price and infrastructure development to date is not sufficient to induce widespread adoption. As a result, a number of policies have been introduced to support EV adoption. These policies can be divided into five main domains:

- Infrastructure development
- Initial purchase incentives
- Operational incentives
- Demonstration projects
- Research and development and loan guarantees

We review each policy by type and provide successful examples of implementation cases internationally.

1.5.1 Infrastructure Development

Infrastructure development can take the form of installation of charging stations (the most common option which we review in Section 1.6) or battery switching stations.

Amsterdam, Netherlands

Amsterdam plans to have 1000 public charging stations on the streets and a similar number for semipublic and business premises by 2013. In a world's first, the locations and availability of these chargers can be viewed through an Application Programming Interface (API), which will enable communication between software and an operating system.   (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012)

Barcelona, Spain

The government of Catalonia, through its LIVE Barcelona (Logistics for the Implementation of the Electric Vehicle) program, is working to install 4400 slow charging stations and 20 fast charging stations in Barcelona by 2014.

Moreover, in 2011, electric motorcycle charging stations were established at hotels and universities. To encourage using electric motorcycles, charging was made available for free. Locating charging stations will also be possible through a mobile application. (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012)

France

Since 2012, the French Government made the Installation of charging stations a requirement in new residential apartments' car parking. Moreover, charging sockets will also be mandatory in office buildings' car parking from 2015 onwards (Soylu, 2011).

Berlin, Germany

By 2015, 1400 public charging stations are planned in Berlin to account for the needs of its expected 15000 electric vehicles by the same year. (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012)

North East England, UK

The U.K. Government, through its 'Plugged-In Places' program, has allocated £30 million for funding of eight pilot projects that will install EV infrastructure. The program has committed to providing these funds to businesses and public sector partners to install up to 8,500 charging points in lead places across the UK, namely: East of England, Greater Manchester, London, Midlands, Milton Keynes, North East, Northern Ireland, and Scotland (Recharging Infrastructure).

The North East of England's network of 'Plugged-in Places', named Charge Your Car (CYC) and was launched in 2010, is the UK's largest regional recharging network. It has over 300 public standard chargers, 8 quick chargers and 80 home charging points already installed. In 2011, the network was the first to introduce pay-as-you-go recharging, using a pay-by-phone system (ChargeYourCar).

As each area in the UK has a different charging network, subscriptions and fees were different from one place to another. This made regional travel between different places in the UK inconvenient for EV drivers. To address this, it was decided in June 2012 to expand CYC from a regional to a national network, with a first stage target of 10,000 public access charge points. For example by March 2013, Charge Your Car will have connected 785 charge

points across Scotland to the Charge Your Car network (ChargeYourCar).

Shanghai, China

China is pushing Shanghai to lead its efforts in EV readiness, as in January 2011, China appointed Shanghai as the EV pilot city in China. The Jiading district of Shanghai was also announced as the EV international demonstration zone. As such, Shanghai plans to maintain a ratio of 1.2-1.5 charging stations for every electric vehicle, while the EV Zone has installed 81 AC level 1 charging poles. To maintain the mentioned ratio, Shanghai plans to build 700 future charging locations. On the other hand, SINOPEC, a Chinese petroleum company, has completed a "refilling and charging" station with four DC fast charging and six AC slow charging poles (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Other cities in China

Not so far from Shanghai's targets, Shenzhen is planning to install a charging pole for every electric vehicle (PEV or PHEV) being deployed. The city of Jinan aims to build 9 advanced charging stations and 300 regular charging stations in 4-years' time with a total estimated cost of 510 million RMB. The city of Hefei is to build centralized charging parking lots for the bus companies and distributed charging stations for cars. Changchun has allocated 3 to 4 million RMB to build one charging station in its High and New Technology Industrial Development Zone   (Jie Zhenga, 2011).

Nagasaki, Japan

In 2009, the Nagasaki Prefecture established a collaborative effort by industry, academia and government named the Nagasaki EV&ITS Consortium. The purpose of it is the promotion of EVs and intelligent transportation systems (ITS) in Nagasaki, which by 2013, will be home to 500 EVs and PHEVs. Moreover, Nagasaki has the Goto Islands which is a major natural tourist attraction for the prefecture, and a thriving EV ecosystem. Thus, up to 40 quick chargers are planned in the prefecture by 2013. (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012)

Kanagawa, Japan

Kanagawa Prefecture Government aims to install 1,000 100/200V outlets

and 100 DC quick chargers in the prefecture by the end of 2014. The government is providing subsidies to the companies who are installing DC quick chargers at different locations such as petrol stations, convenience stores, and shopping centers to meet its targets. As with Nagasaki, Kanagawa has its natural tourist attraction in Hakone. Therefore, the government is working on the installation of charging stations in hotels, museums, businesses, and other sightseeing attractions. These chargers will be important for the current EVs, and also the proposed sharing and taxi fleets. (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012)

New York, US

New York State's electric vehicle charging stations are supported by a joint effort by the New York State Energy Research and Development Authority (NYSERDA)'s Electric Vehicle Supply Equipment Demonstration Program and the U.S. Department of Energy. Currently, New York City has more than 70 public charging points. In June, 2012, New York governor announced a grant awarded to ten companies, municipalities and other entities to install more than 325 new electric vehicle charging stations across New York State (NYSERDA, 2012).

Additionally, Coulomb Technologies, an American EV infrastructure company and the largest charging stations network owner, has launched a program called ChargePoint America that aims to provide electric vehicle charging infrastructure to nine selected regions in the United States, namely: Boston, MA; Bellevue/Redmond, WA; Sacramento, CA; San Jose/San Francisco Bay Area; Los Angeles, CA; Austin, TX; Southern Michigan (including Grand Rapids, Lansing, Ann Arbor, Detroit); New York City, NY; Washington DC/Baltimore; and Orlando/Tampa, FL. As part of the program, individuals will pay for the installation of the private level 2 (220V) charging station, but charging will be offered for free to selected owners (ChargePoint America).

Los Angeles, US

The Los Angeles Department of Water and Power offers free public EV chargers on its property. The department has also upgraded over 2,400 distribution transformers and replaced over 800 poles of the city's electrical infrastructure to support the increased power demand that would come from the increased EV diffusion. Additionally, the city's current building codes contain

EV-readiness requirements for all new construction as of January 1st, 2011. (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012)

Portland, US

The U.S. Department of Energy funded The EV Project, whose value is estimated at $230 million (The EV Project), to deploy 2,000 charging stations in Portland and the surrounding area by 2013. Most of those will be Level 2 (220V) charging, but DC Fast chargers will also be available in selected areas. As in the case with ChargePoint America, charging will be free to participants who agree to anonymous data collection (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012). According to its official website, the "EV Project collects and analyzes data to characterize vehicle use in diverse topographic and climatic conditions, evaluates the effectiveness of charge infrastructure, and conducts trials of various revenue systems for commercial and public charge infrastructures" (The EV Project).

The EV Project is deploying charge infrastructure in major cities in nine states and the District of Columbia; and is therefore claimed to be the largest deployment of electric vehicles' charging stations in history (The EV Project).

Research Triangle, North Carolina, US

The City of Raleigh installed 29 Electric Vehicle charging stations just in the period between November 2010 and December 2011; 18 public charging stations and 11 fleet charging stations. As part of the city's participation with Project Get Ready (PGR) initiative that aims for a wider spread of electric vehicles, the City of Raleigh addressed and city ordinances and building and electrical codes related to uniform standards, signage, parking, and fees for charging electric vehicles. The city also streamlined the permitting and inspections process for electric charging stations installation (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Additionally, and in association with Progress Energy Carolinas, the City of Rayleigh launched a two-year evaluation project for two solar-powered charging stations. According to Progress Energy, this project has different goals, such as:
- Testing the ability to charge plug-in vehicles using electricity generated by the sun and stored in an on-site battery;
- Analyzing the effect on the electric grid from a solar-powered charging

station;
- Evaluating electric vehicle battery performance;
- Comparing the side-by-side performance of two solar panel manufacturers; and
- Monitoring the influences of weather on solar power production.

(Progress Energy, 2011)

Estonia

In a move to reduce the carbon footprint and spur the adoption of EVs, the Republic of Estonia has completed the mass installation of a nationwide network of 165 EV fast chargers. According to Reuters, the financing came from the government's sale of 10 million surplus CO_2 emission permits to Japan's Mitsubishi Corporation. The deal also included Mitsubishi providing "500 electric cars and the financing of a subsidiary system for people to purchase electric cars". (Estonia Is 1st Country In The World To Install Nationwide System Of Fast Chargers For EVs, 2013)

Tesla Motors

Tesla Motors, the maker of the Tesla Model S EV, has launched a network of solar 'superchargers'. A solar carport system provides the electricity for the superchargers, while the technology of the chargers is developed in-house and is basically a variation of what the Model S already uses. Interestingly, these two factors enabled Tesla to provide the service for free to its customers. This system generates more electricity than what the cars would consume year round; thus allowing the supercharger system to net-export to the grid and thus provides net zero carbon charging for EVs.

The Superchargers have a rated power of up to 100kW each, and can replenish 3 hours of driving at 60mph in half an hour. They are currently installed on highways throughout California, parts of Nevada and Arizona with plans to expand to high traffic corridors across the continental United States, as well as Europe and Asia in the second half of 2013 (Tesla Motors Launches Revolutionary Supercharger Enabling Convenient Long Distance Driving, 2012).

Battery Switching Stations

Battery switching stations are used to replace the empty battery of an EV with a fully charged one. The main advantage this facility provides over battery

charging stations is time saving. In switching stations, an EV's empty battery can be switched for a charged one in around one minute (Better Place).

Currently, the pioneering enterprise in battery switching is Better Place. While it also offers conventional battery charging solutions in the US, Better Place battery switching services operate in different places worldwide such as Denmark, Netherlands, Australia, China, "Israel", and a pilot project in Japan.

A downside of battery switching is that not all EVs are engineered with an easily replaceable battery. The Renault Fluence ZE is the first car to be engineered for the robotic battery switching at Better Place (Better Place). Mitsubishi Heavy Industries have also announced intension to start battery switching stations in Japan for its electric buses (Auto Observer).

1.5.2 Initial Purchase Incentives

In order to reduce the effect of the upfront costs of the vehicle to private (and in cases to corporate users) a set of incentives have been introduced including: tax and fee exemptions/reduction, and subsidies/grants.

1.5.2.1 Tax and Fees Exemptions/Reduction

Electric vehicles exemption from taxes normally applied for conventional vehicles is a common measure to stimulate demand for electric vehicles. For local or national authorities that rely on the vehicle taxes either as a general budget resource or as a source for road infrastructure improvement such measures could create a revenue shortfall and therefore can only be expected to last as initial incentives and eventually be withdrawn as electric vehicles become a significant percentage of the total vehicles registered. According to the European Automobile Manufacturers Association (ACEA, 2012), the following tax exemptions apply:

Austria: Electric vehicles (including hybrids) are exempt from the fuel consumption tax and from the monthly vehicle tax.

Belgium: In Flanders, electric vehicles are exempt from registration tax. In Brussels and Walloon, EV owners pay the lowest rate of registration tax (€ 61.50). Additionally, in the three regions, they pay under the annual circulation tax (€ 73.79). As for company cars, the deductibility rate for their purchase and use expenses is 120% for zero-emissions vehicles and 100% for vehicles emitting between 1 and 60 g/km of CO_2.

Czech Republic: Electric, hybrid and other alternative fuel vehicles are exempt from the road tax, which applies to cars used for business purposes only.

Denmark: Electric vehicles weighing less than 2,000 kg are exempt from the registration tax.

Germany: Electric vehicles are exempt from the annual circulation tax for a period of five years from the date of their first registration.

France: Electric vehicles are exempt from the company car tax. Hybrid vehicles emitting less than 110 g/km are also exempt in the first two years.

Finland: Electric vehicles owners pay the least registration tax (5%), which is CO2-emission based.

Ireland: Electric vehicles are exempt from the registration tax up to a maximum of € 5,000. To a lesser extent, plug-in hybrids also benefit from this tax relief, but to a maximum of € 2,500. Other low-carbon vehicles benefit from a relief of up to € 1,500.

Italy: Electric vehicles are exempt from the annual circulation tax (ownership tax) for a period of five years from the date of their first registration. After that, they benefit from a 75% reduction of the tax rate applied to equivalent petrol vehicles in many regions.

Netherlands: Electric vehicles are exempt from the registration tax and from the annual circulation tax. Other vehicles including hybrid vehicles are also exempt from these taxes if they were diesel-powered emitting less than 95 g/km, or petrol-powered that emit less than 110 g/km.

Portugal: Electric vehicles are exempt from the registration tax and from the annual circulation tax. Hybrid vehicles benefit from a 50% reduction of the registration tax.

Romania: Electric and hybrid vehicles are exempt from the pollution tax paid at registration.

Sweden: Electric vehicles with an energy consumption of 37 kWh per 100 km or less and hybrid vehicles with CO_2 emissions of 120 g/km or less are exempt from the annual circulation tax for a period of five years from the date of their first registration.
Compared to conventional vehicles, EVs and PHEVs get a 40% reduced taxable value of the car for the purposes of calculating the benefit in kind of a company car under personal income tax. The maximum reduction of the taxable value is SEK 16,000 per year.

United Kingdom: Electric vehicles and all vehicles with emissions below 100 g/km are exempt from the annual circulation tax, which is based on CO_2 emissions. Electric cars are also exempt from company car tax until April 2015, and electric vans are exempt from the van benefit charge until that date too (ACEA, 2012).

India: Not only does the Delhi government provide a 15% rebate on the retail price of a REVA (local EV manufacturer) EV, but also a VAT exemption of 12.5%, and exemption from road tax and registration expenses. In Madhya Pradesh, Kerala, Gujarat, and West Bengal the excise tax on EVs is reduced by up to 4%. Other sttes reduced the road tax or vehicle registration fees (IDFC, September 2010).

Japan: Kanagawa Prefecture Government provides a five-year 100% relief from automobile acquisition tax (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012). On the national level, reductions/ exemptions are applicable to the acquisition tax and tonnage tax, since April and May 2012 respectively, for the purchase of new vehicles that comply with Japan's 2015 fuel efficiency standards (JAMA, 2012).

United States: The federal government currently offers a tax credit of up to $7,500 for Plug-in EV purchases. In Arizona, Alternative Fuel Vehicles get a license tax reduction and vehicle tax exemption. In Washington D.C, alternative fuel and fuel-efficient vehicle are qualified for an exempt from the excise tax. In

Illinois, registration fees are reduced for EVs to no more than $18 per year. Utah reduces fuel tax to 3/19 of the original tax for electricity and propane propelled vehicles. Washington and Wisconsin go one step further and offer a fuel tax exemption for alternative fuel vehicles (National Council of State Legislatures).

1.5.2.2 Grants and Tax Subsidies for Electric Vehicle Purchases

Spain: Regional governments of Aragon, Asturias, Baleares, Madrid, Navarra, Valencia, Castilla la Mancha, Murcia, Castilla y Léon, Cantabria, Catalonia, Galicia, Pais Vasco, and Extremadura grant incentives of € 2,000 to € 7,000 for the purchase of electric, hybrid, fuel cell, CNG and LPG vehicles. In Andalucía, the incentive is a maximum of 70% of the investment.

France: Vehicles that emit 50 g/km of CO2 or less benefit from a premium of a maximum value of €5,000 provided it doesn't exceed 20% of the vehicle purchase price including VAT.

Luxemburg: Purchasers of vehicles emitting 60 g/km or less of CO2 (including EVs) receive a premium of €5,000 until 31 December 2012, provided the purchaser buys electricity from renewable energy sources.

Sweden: A 'Super green car premium', which applies for private persons and companies, was introduced for the purchase of vehicles emitting 50 g/km or less of CO2. As for companies, the premium (or rebate) is 35% of the price difference between the super green car and a comparable conventional fuel car, with a maximum of SEK 40,000.

United Kingdom: A premium of 25% of the value of a new car (to a maximum of £ 5,000) is awarded for purchasers of EVs and PHEVs that emit no more than CO2 75 g/km of CO2. For purchases of electric vans, the premium is up to 20% of the van's value to a maximum of £8,000.   (ACEA, 2012)

China: The Chinese government provides national subsidies of 50,000 RMB for plug-in hybrid electric vehicles and 60,000 RMB for pure electric vehicles. In addition, the City of Shanghai offers 20,000 RMB and 40,000 RMB, respectively. Public service vehicles, such as light duty commercial trucks and buses, also receive subsidies. (Kerin Cantwell, 2012)

India: Cash subsidies of 33% of the electric vehicle retail price are available to organized entities in India for electric vehicles that are above a certain carrying capacity threshold. Additionally and as earlier mentioned, Delhi provides a 15% rebate on the retail price of a REVA EV (IDFC, September 2010).

United States: The federal government currently offers a tax credit of up to $7,500 for Plug-in EV purchases. In addition, state-level incentives include:

- Louisiana offers an income tax credit of up to 50% for purchase of an alternative fuel vehicle. Maryland offers a tax credit of up to $2,000.
- City of Riverside in California offers its residents eligibility for a rebate (worth up to $2,000 for a new vehicle, $1,000 for a used vehicle) toward the purchase of a qualified hybrid electric vehicle purchased in the City of Riverside.
- Oklahoma offers a one-time income tax credit for 50% of the cost of purchasing, and a 10% tax credit of up to $1,500.
- In Oregon, tax credits for 25% of the cost or $750 (whichever is less) are available for the purchase or conversion of an alternative fuel vehicle and the purchase of alternative fuel infrastructure.
- West Virginia offers a 35% income tax credit for purchasing an alternative fuel vehicle.
- South Carolina offers Residents who claim the federal vehicle tax credit eligibility for a state income tax credit equal to 20% of the federal credit.
- In addition to the $7,500 federal government tax rebate, California offers its residents a rebate of up to $2,500 for Plug-in EV purchases.
- In New York, Long Island Power Authority offers a $500 rebate to its customers who purchase EVs.
- Portland provides Up to $750 for residential charging installations (National Council of State Legislatures).

1.5.3 Operational Incentives

1.5.3.1 Dedicated Lane Access for EVs

Permission of EVs to use specialty lanes, such as the High Occupancy Vehicle (HOV) lane and bus and taxi lanes potentially reduces travel times providing an advantage to the EV driver. These measures have been applied to several cities worldwide.

United States: In the United States; Arizona, California, Florida, Georgia, Illinois, Hawaii, Maryland, Los Angeles, New Jersey, New York, North Carolina, Tennessee, Utah, and Virginia offer EVs HOV lane exemption (National Council of State Legislatures). In 2001, Virginia was the first state to offer HOV lane access for Hybrid vehicles. In 2005, other states started to follow suit (Diamond, 2008). The exemption included also alternative fuel vehicles, and by 2011 hybrids were no longer covered under it (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Norway: In Oslo, Norway, EVs are allowed to drive in lanes of public transport. This incentive was reported to reduce travel time for EVs in Oslo to up to 7 hours a week. (Kneeshaw, 2012)

1.5.3.2 Support for Fleet-scale EV Adoption

In the effort to overcome the natural inertia of individual vehicle owners to purchase what they perceive as expensive and untested vehicles, governments can opt to promote the use of EVs in vehicle fleets either owned or regulated by them. This approach solves the early adopter problem and provides volume for manufacturers to descend down the learning curve and reduce production costs.

China: The first Chinese government pilot program to promote EVs took off in 2009 under the banner "10 Cities, 1000 Vehicles Plan" (The China New Energy Vehicles Program: Challenges and Opportunities, 2011). This program applied only to public purchases such as government fleets, taxis, and electric buses (Kerin Cantwell, 2012). Under this program, each city was required to deploy 100 EVs that were subsidized by the central government to stimulate electric vehicle development and address related issues. In 2010, the number of cities was increased to 25. Currently, the city of Shenzhen has the world's largest EV fleet of 1300 e-buses and 700 taxis bringing the total to 2000 vehicles (Business Wire).

London, UK: Transport for London (TfL) has created a procurement framework consisting of 1000 electric vehicles for the government and public transport fleet by 2015. Along with an extensive network of charging stations, this project will cost around £51.6 million (US$77.5 million) for London and an additional £15.4 million (US$23.1 million) if used by other organizations. This

step comes under the mayor's efforts to make London the electric vehicle capital of Europe (Transport for London).

Catalonia, Spain: One of the government's measures to promote EV demand in Catalonia is the introduction of electric vehicles in the government fleet. The plan is for the total electric vehicles to reach 76,000 vehicles by 2015. Government's EVs will be making up to 15% of the government's total fleet of vehicles (Jordi Perdiguero, 2012).

Berlin, Germany: Being the leading German city in electro-mobility, various projects with electric vehicles fleets and sharing programs are either underway or are planned in Berlin. One of these projects is the "Initiative 120 project", under which alternative drive systems are used in patrol cars at the Berlin police department. Another example is E-Logistics which uses electric vans for commercial transport (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Hamburg, Germany: Currently, there are 60 EVs between state departments, public institutes, and municipal companies. By 2015, this number is supposed to increase up to 500 EVs and PHEVs (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Amsterdam, Netherlands: The city of Amsterdam started running 10 EV taxis in May 2011. Currently, the number of EV taxis is estimated to be around 40 (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).
Brabant stat, Netherlands
Five electric buses were introduced in 2011 with plans to expand to 15 buses in 2013 (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

United States: As the US Department of Energy (2011) aims to put 1 million electric vehicles on the country's roads by 2015, a series of measures have been taken in several states. In New Mexico, the requirement is that 75% of state government and educational institution fleet vehicles purchased be bi-fuel, dedicated alternative-fuel vehicles (AFVs), or hybrids (HEVs).
- The latest of these efforts came in late 2011, where the city of Los

Angeles started using electric buses to shuttle passengers to and from the terminals at LAX airport. Not only do these buses reduce carbon emissions, but they can also be up to $500,000 cheaper than normal buses over their lifespan (ThinkProgress).

- In New York, and by 2010, the requirement was to have 100% of all new light-duty vehicles as AFVs, with the exception of designated specialty, police, or emergency vehicles. In 2011, the city purchased 50 Chevrolet Volts and 10 Ford Transit Connects and acquired 10 electric eStar trucks. These fleet additions bring the entire electric fleet to 430 vehicles, which include neighborhood electric vehicles and scooters. Moreover, the New York Power Authority is working with Metropolitan Transit Authority and New York State Energy Research and Development Authority to electrify buses, trucks, delivery vans and airport vehicles. (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

- Connecticut made it mandatory that at least 50% of all cars and light-duty trucks the state purchases to be hybrid electric vehicles, plug-in hybrid electric vehicles, or capable of using alternative fuel.

- In a step to support the renewable energy technologies in Illinois, the state will receive a limited number of Mitsubishi's iMiEV as state fleet.

- In Indiana, moreover, it is required that each state entity purchases or leases a clean energy vehicle, given that this vehicle can cope with its intended use and costs no more than 10% a comparable conventional vehicle.

- A similar requirement is made in Massachusetts regarding the acquisitions of AFVs and HEVs. Additionally, this acquirement must be at a rate of at least 5% annually for all new motor vehicle purchases so that by 2018 not less than 50% of the state motor vehicles will be HEVs or AFVs.

- While a target percentage isn't specified, Nevada required fleets containing 50 or more vehicles that are owned, leased, or operated by the state, a state agency, or a political subdivision of the state in a county with a population of 100,000 or more must acquire AFVs or certified Ultra Low Emission Vehicles.

- North Carolina required that at least 75% of new or replacement state government light-duty cars and trucks must be AFVs or low emission vehicles.

- Texas created a requirement that state fleets with more than 15 vehicles, excluding emergency and law enforcement vehicles, must purchase or lease a motor vehicles that use compressed natural gas, liquefied natural gas, biofuels, or electricity. Covered state agency fleets must consist of at least 50% of vehicles that are able to operate on alternative fuels and use these fuels at least 80% of the time the vehicles are driven.
- Vermont required the consideration of AFVs when purchasing vehicles for state use, as long as the alternative fuel is suitable for the vehicle's operation, available where the vehicle will be used, and competitively priced with conventional fuels.
- Finally, Virginia required the state's replacement vehicles to be those that operate using natural gas, electricity, or other alternative fuels, to the greatest extent practicable (Clean State Energy Actions: 2011 Update. Lead By Example. Alternative Fuel and Vehicle Fleets, 2011).

Private entities: Courier companies like UPS, TNT, and DHL are using electric vehicles in the US and cities like Hannover, Barcelona, and Lyon (Jordi Perdiguero, 2012) (Fabian Kley, 2011). However, the largest single EV commitment comes from General Electric (GE) as it announced plans to convert half of its vehicle fleet to EVs by 2015. To achieve this target, it purchased 25,000 electric vehicles (General Electric).

1.5.3.3 EV car sharing and renting programs

Provide EV car sharing programs provides a volume for manufacturers' to descend down the learning curve and also familiarize the public with the use of EVs. An EV car sharing program would have the combined effect in CO2 reduction coming from using EVs, and sharing cars. As for the sharing side, some studies show that after joining a car sharing scheme, most members drive less than before (57% in Switzerland and 50% in Germany) (Public Transport and Car-Sharing: Together for the Better, 2002).

Car2Go: Car2Go is a subsidiary of Daimler that operates a car sharing program in several cities in Europe and North America. Their fleet purely consists of Smart ForTwo, in conventional and EV forms. Customers can pick up a car from certain locations scattered around the city, and drop it at their destination. Customers can locate and book vehicles through an online website

and a smart phone application (Car2Go).

The first application of Car2go was in Ulm, Germany in 2008. In late 2009, Daimler brought the service to the United States as a pilot program in Austin, Texas (Capital Business, 2011). Their electric fleet currently operates in San Diego, US; and Amsterdam, Netherlands with a fleet of 300 vehicles in each city (Car2Go). By 2013, Car2go is planning to expand to an additional eight cities, including Stuttgart, Germany, where it will deploy a fleet of 500 Smart EVs (O'Connor, 2012).

DriveNow: DriveNow is a joint venture car sharing scheme of BMW and Sixt that was launched in June 2012 in San Francisco, CA. Currently, DriveNow operates in four cities in Germany as well as San Francisco, CA. Similar to Car2go; DriveNow is a flexible, fleet-based car-sharing program. It offers customers a fleet of premium cars including the electric BMW ActiveE. The fleet of 70 ActiveE vehicles is located at ten DriveNow Stations around the San Francisco Bay Area. All those vehicles are equipped with MyCityWay app, which is a GPS-based city guide (MyCityWay, 2012).

Barcelona, Spain: In association with Massachusetts Institute of Technology (MIT), Barcelona is working on an EV car sharing program based on the "Mobility On Demand" concept. This new system is an improvement over current sharing systems, since users can pick up or drop off vehicles where they choose.

In its efforts to support electric mobility, the city has launched a program called LIVE (Logistics for the Implementation of the Electric Vehicle). This program is an open platform that provides information to users about everything from charging stations to opportunities for new innovation and investment (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Berlin, Germany: Four governmental departments are involved in the nationwide "Showcase E-mobility" initiative, which are: the ministry of commerce, transportation, environment and research. One of this initiative's programs is CarZapp, which is an EV car sharing program in association with Renault, Peugeot, Vodafone, E.ON and Capgemini. CarZapp's fleet consists of electric cars owned by private car owners who can instantaneously provide their cars for rental via a smartphone application. The primary innovation is the ZappKit,

which is an inexpensive and theft-proof hardware that allows car owners to rent their cars without physically handing over keys (CarZapp).

Paris, France: On 5th December 2011, Paris's own electric vehicles sharing program, currently called Autolib', entered service with 250 Bollore' Bluecars and 250 rental stations (Autolib'). In a similar fashion to Car2Go or CarZapp, cars' availability can be assessed through an on-line phone app. Unlike the other two, however, rentals must be picked up and returned to dedicated Autolib' rental stations. The company aims to deploy 3,000 vehicles and 1,120 citywide parking and charging stations by 2013 (The Economist, 2011).

Brussels, Belgium: Zen Car is an all-EV car sharing program operating in Brussels. It was launched in March, 2011 with a fleet that consists of 29 Tazzari Zero electric vehicles. Bookings can be made either on-line or by phone, and cars need to be returned to their origin station after use within a predetermined time (ZenCar).

Chicago, US: Zipcar, a car rental company, has added 5 Chevrolet Volt plug-in hybrid electric vehicles to its fleet in the first quarter of 2012, as a start point for its electric vehicle pilot program. The electric fleet is expected to grow to 700 by the year's end, according to a company official. In September 2012, ZipCar announced the introduction of the 2013 Honda Fit EV to its fleet in San Fransisco (ZipCar, 2012).
Within Chicago, I-Go, another car rental company, plans to have the largest fleet of all-electric vehicles in the midwest by project completion. The fleet size is going to be 36 vehicles, and 18 solar-powered chargers. It is currently considering Nissan's Leaf and Mitsubishi's i-MieEV. (Wong, 2012)

Rotterdam, Netherlands: The largest car sharing corporation in Netherlands, Greenwheels, acquired 25 EVs and set up charging infrastructure for its fleet. Its customers now have the option to choose between electric and conventional vehicles (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

1.5.3.4 Parking Incentives for Electric Vehicles
Parking incentives could take several forms, from free parking spots for

battery-powered vehicles, to preferential parking, to dedicated EV and PHEV parking spots complete with charging poles.

Spain: EVs are granted free parking in controlled parking lots. Furthermore, in Barcelona, one of the LIVE (Logistics for the Implementation of Electric Vehicles) initiative objectives is to create recharge stations in public and private parking lots in Barcelona's metropolitan area (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Finland: As a part of the national electric vehicle system program, parking facilities in shopping malls, office buildings, and dedicated parking houses in Finland are equipped with charging stations (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Japan: Kanagawa Prefectural Government provides half-price discounts for prefectural tolls, expressway tolls, and parking lots and within the prefecture (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Netherlands: Rotterdam is installing charging points at strategic locations in the city center and public parking areas (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Sweden: New parking facilities in Stockholm are equipped with charging units. The latest, named Högalidsgaraget, was opened in September 2011 and features 200 parking places equipped with EV chargers (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

United States: All parking spaces on "Electric Avenue" in the south end of downtown Portland are reserved for vehicles in the process of charging, with a single DC Quick Charger available for up to one hour and Level II charging stations that serve seven parking spaces (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012). In Arizona, carpool operators parking facilities are allowed for alternative fuel vehicles' owners regardless of occupancy level. New Haven in Connecticut provides free parking on all city streets for qualified alternative fuel vehicles and hybrids registered in New

Haven (National Council of State Legislatures). San Jose (San Jose Downtown Parking) and Santa Monica (DriveClean) also offer free parking for EVs.

1.5.4 Support for Research and Development

In addition to the efforts made by individual countries separately, the world's leading cities in EV deployment recognize the importance in knowledge sharing to achieve common goals. This international network consists of the Electric Vehicles Initiative (EVI), a multi-government initiative of the Clean Energy Ministerial; Project Get Ready, a Rocky Mountain Institute (RMI) initiative; and the International Energy Agency's Implementing Agreement for Cooperation on Hybrid and Electric Vehicle Technologies and Programs (HEV IA); with the support of the C40 Cities in partnership with the Clinton Climate Initiative (CCI). The current fruit of this cooperation is the "EV City Casebook 2012" which provides a global perspective on the electric vehicle movement. This publication will provide basic information for the "World EV Cities and Ecosystems web portal", which will capture EV deployment progress in cities worldwide and will serve as a central hub for harmonizing efforts, leveraging existing resources and participants, and disseminating best EV deployment practices to global stakeholders (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Below are some of the research and development efforts made in different countries

United States: The United States started its support for research in electric vehicles in as early as 1973, in a project called "Electric and Hybrid Vehicle Research, Development, and Demonstration Act". The aim was to develop the technology behind the electric cars' batteries and motors. The initiative failed to meet its goals and was canceled later on (Jordi Perdiguero, 2012).

More recently, the resources allocated for energy industry investments are greatly expanded through the "American Recovery and Reinvestment Act (ARRA)". This support is targeted for the manufacturers; as these resources include tax credits for manufacturers to build battery-powered vehicles (Jordi Perdiguero, 2012). Moreover, the US Department of Energy is also funding the first Community-wide PEV Readiness Plan which has an objective of expanding the PEV industry in North Carolina (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Support for R&D aims sometimes at evaluating the feasibility of a given solution. A good example is a recently embarked two-year R&D project by the City of Raleigh and Progress Energy Carolinas. This project aims to evaluate solar-powered EV charging stations by installing two charging stations in Raleigh that are connected to a solar photovoltaic (PV) array and battery system (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Other ways of support target research institutions. The US Department of Energy has also encouraged investments channeled through the Massachusetts Institute of Technology to its Office of Science in basic research in transport electrification (Jordi Perdiguero, 2012).

China:　　　In its pursuit to become the world's largest producer of EVs, the Chinese government has initiated a ten billion Yuan ($1.46 billion) program to help its industry with automotive innovation in addition to supporting consumption of the EV through generous fiscal incentives (Stephen Brown , David Pyke , Paul Steenhof, 2010).

Back in 1991, the Ministry of Science and Technology (MOST) promoted ''Research on the Key Technologies of EVs'' as a National Key Scientific and Technological Project. In 2001, an "EV Key Project" was included in the agenda and chose the new generation of EV technology as the major direction of auto technology innovation. In 2009, General Office of the State Council issued the ''Plan on Shaping and Revitalizing the Auto Industry'', which sets out a production target of 500,000 battery-powered vehicles and included a ''National Energy-Conservation and Alternative Fuel Vehicle Demonstration Program''. The plan stated a total of 10 billion RMB to be invested in the advancement of auto technologies, including the R&D of AFVs (Jie Zhenga, 2011).

Japan:　　　The Ministry of International Trade and Industry in Japan (MITI) has promoted battery powered vehicles (BPEVs) since 1971, launching a five-year government-industry R&D program. Moreover, MITI has also funded company R&D programs, and supported battery powered vehicles leasing projects. Through MITI, the Japanese government has promoted research on lithium batteries, and development of high-energy efficient hybrid vehicles (Jordi Perdiguero, 2012).

By 2030, Ministry of Economy, Trade and Industry (METI) and New Energy and Industrial Technology Research Organization (NEDO) aim to reduce the price of

batteries to one fortieth of the current and increase driving range to 500 km per charge. For fiscal 2009, the top priority was given to research in innovative power storage techniques for the batteries (Ishitani, 2009).

Europe:

According to the ACEA, The auto industry is the largest private investor in R&D in Europe. The ACEA members invest annually over 26 billion Euros in R&D, which is equivalent to 5% of their turnover (ACEA, 2012). Hereafter are some of the initiatives taken by European countries:

Spain: The Catalonian administration promotes R&D in electro-mobility as it attempted to establish a battery pack manufacturer in Catalonia. It also established communication projects between grids and electric vehicles that cost around 35 million Euros for 2011 and 2012. Further, a budget of 173 million Euros was spent on other projects promoting research on electric vehicles (Jordi Perdiguero, 2012).

Barcelona is also a member of IMPACTS (International Network of European and North American Capital and Major Metropolitan Cities for exchanging information and experience on Urban Mobility and Transport Policies) and the European initiative, Green e-Motion, as a Demo Region. Barcelona created the public-private platform called LIVE (Logistics for the Implementation of Electric Vehicles) with the aim to improve the infrastructure and development of electric vehicles (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

France: In 2009, the Ministry for Ecology, Energy, Sustainable Development, and the Sea presented a national 14-point plan to lead to the production of two million EVs and PHEVs (combined) by 2020. Furthermore, the French government allocated a budget of 50 million Euros for funding a prototype development for electric vehicles (Meyer, 2009).

Germany: The German departments of Economics, Transport, Environment, and Education & Research drafted a National Development Plan for Electro-Mobility. This initiative aims at deploying one million EVs and PHEVs by 2020. The first implementation phase, between 2009 and 2011, provided investment opportunities of 500 million Euros in electric vehicles R&D. this

phase covered the topics of energy storage systems, vehicle technologies, vehicle-to-grid interfaces, and demonstrations and field operational test. The second (2012-2016) and third (2017-2020) implementation phases will be dealing with market launch and business development (Meyer, 2009).

Sweden: The Swedish Road Administration and the Swedish Energy Agency made a public-private Joint Vehicle Research Program with Swedish Governmental Agency for Innovation Systems (Vinnova) to accelerate development of the local automotive industry. Accordingly, about 90 million Euros are annually provided in the period 2009-2013 for innovation activities. Moreover, in early 2008 Sweden signed a Memorandum of Understanding for a joint R&D program on plug-in hybrid electric vehicles with the US Department of Energy (Meyer, 2009).

Italy: The Ministry of Economic Development launched the program "Industria 2015", which included funding opportunities for electric vehicles. In early 2009, a funding budget of 180 million Euros has been distributed (Meyer, 2009).

United Kingdom: The Technology Strategy Board, through the Low Carbon Vehicles Innovation Platform, launched a competition for innovation in the field of electrification of road transport.   This competition provides up to £10 million for business-led collaborative research and development (Meyer, 2009).

1.5.5 Demonstration Projects

Not only do demonstration projects help advance the research and development efforts by understanding the driving habits and putting the technology to the market, but they also play a key role in building the public's awareness and pave the way to generate greater public's acceptance for electric vehicles.

Shanghai, China: Shanghai was nominated by the Chinese government as the EV International Pilot City in China, and Jiading district in Shanghai as the EV International Demonstration Zone. In addition to exploring EV feasibility and market potential, the demonstration aims to educate the general public about the merits of electric vehicles. Therefore, a Test-Drive/Ride Center of China was opened in 2011 in Jiading to familiarize people with driving EVs, in addition to providing them with information about the technology and history behind it. Next

to the Test-Drive/Ride Center, a multi-brand dealer for EVs and PHEVs was opened.

Shanghai also offers professional driving demonstrations that enable drivers to use EVs and PHEV on a regular basis to better understand driving habits. A demonstration project for a fleet of 33 e-buses operates on fixed routes in Jiading, as well (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

Berlin, Germany: In its aim to push Berlin to be the leading metropolis for electro-mobility in Europe, the Berlin Agency for Electro-mobility (eMO) has set Berlin as a demonstration zone that covers the whole spectrum of the electro-mobility value chain; from research and development to production, usage, and educational training. As such, Berlin currently houses the highest number of electric vehicles, charging stations, and future related projects in Germany.

Implemented demonstration projects in Berlin include EV car sharing, E-truck cargo transport, and individual EV usage (Electromobility in Berlin).

Helsinki, Finland: The Finnish Funding Agency for Technology and Innovation (Tekes) has coordinated The Electric Vehicle Systems (EVE) program with a budget of approximately 100 million Euros. This program provides a testing environment for electric vehicles through three main initiatives in the Greater Helsinki area (and two outside it): Electric Traffic in Helsinki Test Bed, Eco Urban Living (EUL), and Electric Commercial Vehicles (ECV).

The Electric Traffic project in the Greater Helsinki area develops test environments for electric public and private transport. The aim is to speed the EV deployment in Finland, with the emphasis on traffic solutions for large cities. EUL, on the other hand, aims to research and demonstrate the features and functionality of full EVs as well as the feasibility of the related solutions. This program operates in Espoo, a part of Helsinki. ECV specializes in commercial vehicles, providing R&D network as well as a development platform for the vehicles and their components. Their approach extends to cover demonstration platforms and fleet tests   (Koskue, September 2012).

Rotterdam, the Netherlands: Rotterdam houses the New Electric Drive Transportation Hub (iHNR-EV), which is a demonstration platform for EVs of

multiple brands. This platform is available for enterprises and individuals. (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

New York, US: In a demonstration project led by Toyota in 2010, 160 Prius PHEVs were placed in New York in order to demonstrate the technology and educate and inform the public. Some of these vehicles were assigned to over 40 citizens around Oregon for 60 days to test the vehicles' performance characteristics on everyday use.   Noteworthy, this program led to commercializing these vehicles to the general public in 2012 (EV City Casebook: A Look at the Global Electric Vehicle Movement, 2012).

1.5.6 Policy Options for Electric Vehicles' Adoption – Relevancy to UAE

In this section, we evaluate the best practices and policy options for applicability to Abu Dhabi and their relevance to ADSTMP. We inform this evaluation by the results of the survey as presented in Section 2 and discussions with DOT (workshop) and TRANSAD. Table 1-9 provides a summary view.

Table 1-9 Overview of Options and Applicability to Abu Dhabi

Incentive	Type	Places	Applicability in Abu Dhabi	Justification
EV-dedicated Lane Access	Non-monetary	United States Norway	Applicable	Complement planned bus lanes
Support for Fleet-scale EV adoption	Non-monetary	China United Kingdom Spain Germany Netherlands United States Private Companies	Highly Applicable	Government fleets mandate
EV Car Sharing and Renting Programs	Non-monetary	Netherlands United States Spain Germany	Applicable	Complementing improving accessibility

		France		
		Belgium		
Availability of Charging Infrastructure (EVSE)	Monetary / Non-monetary	China United Kingdom Netherlands Spain Germany Japan United States	Highly Applicable	Required infrastructure to break a critical barrier for EV deployment
Availability of Battery Switching (EVSE)	Non-monetary	Netherlands Australia China Japan Denmark "Israel"	Somewhat Applicable	Battery swapping is not yet standardized by manufacturers and its adoption in the UAE (a small market) is not recommended before international standardization..
Tax Exemptions and Reductions for EV Owners	Monetary	Austria Belgium Czech Republic Denmark Germany France Finland Ireland Italy Netherlands Portugal Romania Sweden United Kingdom India Japan United States	Not Applicable	Low to nonexistence taxes

Grants and Tax Subsidies for EV Purchases	Monetary	Spain Luxemburg France China United Kingdom India United States	Somewhat Applicable	Low to nonexistence taxes
Parking Incentives	Monetary / Non-monetary	Spain Netherlands Japan Finland United States Sweden	Highly Applicable	Leveraging the scarcity of parking spaces in Abu Dhabi to increase EV acceptance. CBD.
Support for R&D	Monetary / Non-monetary	France China Spain United States Germany Japan Italy Sweden United Kingdom	Not Applicable	
Demonstration Projects	Non-Monetary	Netherlands Finland	Highly Applicable	There is potential for further expanded EV demos at Masdar, government fleets, TRANSAD etc.

As shown from the experience of application cases (cf. Section 1.5), the successful adoption of alternative transportation and EVs in particular requires the reduction of the thresholds of acceptability and network effects for the initial adopters. As a result, we considered a number of policy options that would need to be implemented in a staged approach to achieve a certain level of EV penetration. These measures include fleet measures, infrastructure, and operational incentives. These relevant measures are outlined below:

1.   Support for fleet-scale EV adoption

Fleet-scale purchases of EVs to be used in government car fleets and taxi fleets in Abu Dhabi can provide a real incentive for manufacturers to address region-specific EV drawbacks (e.g. battery life at hot weather, high AC use) and thus descend the learning curve in these cases. It will also familiarize the people of Abu Dhabi with the concept of EVs solving the early adopter conundrum for what is perceived as untested.

2.   EV car sharing and renting programs

As with government fleets, EV sharing and renting programs will increase the public's familiarity with the technology and increase their acceptance level in an application that is well suited for EV performance characteristics.

3.   Installation of electric vehicle supply equipment (EVSE)

The initial installation and availability of charging stations is an important component for resolving range anxiety and utility of EVs. Installing two types of charging stations, i.e., level 2 and fast chargers, is needed at several key locations around the city.

4.   Grants and Tax Subsidies for EV Purchases

An initial measure to incentivize EV purchases is to reduce their relative high costs. This can be done by providing grants and cash-backs for EV buyers.

5.   Parking Incentives

Since parking is a major concern for Abu Dhabi city residents, providing preferential or dedicated EV parking spots can be a strong incentive to buy an EV.

6.   Provision for dedicated lane access

A provision for EV access into a dedicated lane can be a deciding factor on people's acceptance of using EVs. As Abu Dhabi is planning to deploy bus lanes (see Section 1.3), it would be supporting EV adoption rates if EVs could have the added advantage of using the bus lanes, in addition to the normal lanes, which would remain vacant for a large percentage of the time. If effectively applied on the right roads, it could provide travel time reductions for EV owners, and thus an

additional incentive for buying an EV.

7.   Demonstration Projects

As with EV sharing schemes, demonstration projects will familiarize the public with EVs. Additionally, these projects can be used to evaluate different EVs' performance and provide a better estimate at investigating the user behavior.

1.5.7 Section Review and Conclusions

This section presented an extensive review of existing policy and best practice to support adoption of EVs. It demonstrated that governments across the world are seriously considering EVs as a viable and important transportation option. Table 1-10 provides an overview of both the policy types and the countries that have adopted them. With the exception of battery switching, R&D support and tax exemptions, we find that the rest of the policy options are applicable at varying degrees in UAE (cf. Table 1-11).

Table 1-10 Overview of International Best-Practice and Application by Country

Policy Type Places	Infrastructure Support		Operational Incentives				Initial Purchase Support		R&D and Demonstration	
	Availability of Electric Vehicle Supply Equipment (EVSE): Mass installation of Charging Stations	Availability of Electric Vehicle Supply Equipment (EVSE): Battery Switching Stations	Dedicated Lane Access for EVs	Support for Fleet Scale EV Adoptions	EV Car Sharing and Renting Programs	Parking incentives for EVs	Tax Exemptions and Reductions for EV Owners	Grants and Tax Subsidies for EV Purchases	Support for Research and Development	Demonstration Projects
Australia		√								
Austria							√			
Belgium					√		√			
China	√	√		√				√	√	√
Czech Republic							√			
Denmark		√					√			
Finland						√	√			√
France					√		√	√	√	
Germany	√			√	√		√		√	√
India							√	√		
Ireland							√			
Italy							√		√	
Japan	√	√				√	√		√	
Luxemburg								√		
Netherlands	√	√		√	√	√	√			√
Norway			√							
Portugal							√			
Romania							√			
Spain	√			√	√	√		√	√	
Sweden						√	√		√	
United Kingdom	√			√			√	√	√	
United States	√		√	√	√	√	√	√	√	√
"Israel"		√								
Private Companies				√						

Table 1-11 Summary Policy Option Applicability for UAE

Policy Type	Places	Applicability to Abu Dhabi	Justification
Infrastructure Support	Installation of Charging Stations	✓	Required infrastructure to break a main barrier for EV deployment
	Battery Switching Stations	✗	Not an industry standard—yet
Operational Incentives	Dedicated Lane Access for EVs	✓	Complement Existing Bus Lanes
	Support for Fleet Scale EV Adoptions	✓	Government fleet EV mandatory
	EV Car Sharing and Renting Programs	✓	Complementing improving accessibility
	Parking incentives for EVs	✓	Lack of parking spaces in Abu Dhabi CBD.
Initial Purchase Support	Tax Exemptions and Reductions for EV Owners	✗	Low to nonexistent taxes
	Grants and Tax Subsidies for EV Purchases	✓	Low to nonexistence taxes eliminate need for tax subsidies. Grants can work
R&D and Demonstration	Support for Research and Development	✗	No car industry in UAE
	Demonstration Projects	✓	Masdar City in Abu Dhabi can accommodate bigger plans for EV demos.

1.6 BEV Commercial Availability and Charging/Infrastructure Equipment

Having reviewed the policy practices, it is necessary to also review the current status of the commercially available BEVs and ancillary equipment and their costs and specifications. We present in a table format:

- a list of the electric cars currently on sale internationally (but not yet for the UAE) in Table 1-12,
- a similar list of the available electric buses in Table 1-13, and
- a comparison and a list of charger options (cf. Table 1-14, Table 1-15, and Table 1-16).

We also briefly discuss the vehicle conversion options.

1.6.1 BEV Commercial Availability

Driving ranges and top speeds have been converted to km and km/h. Although some cars are not directly on sale in the United States, their prices have been converted so that all prices below are shown in 2012 dollars for easier benchmarking. Some models have different levels of specifications and battery capacities; hence different driving ranges and top speeds.

Table 1-12 List of Commercially Available BEVs in 2012 and their Specifications

Car Type	Battery Capacity (kWh)	Driving Range (combined, kms)	Consumption (kWh/100km)	Consumption equivalent to MPGe (l/100km)	Top Speed (km/h)	Price ($, starting)	
Mitsubishi iMiEV	16	100 (EPA 5-cycle)	16	2.10	130	21,625	
Nissan Leaf	24	117 (EPA 2-cycle)	20.51	2.38	145	27,700	
Tesla Model S	40, 60, 85	257, 370, 483	15.56, 16.62, 17.60	2.64	177, 193, 201, 209	52,400	

Smart ForTwo Electric Drive	17.6	145	12.14	2.70	125	28,752	
BYD e6	60	300	20	3.79	140	35,000	
Toyota Rav4 EV	41.8	166	25.18	3.09	137, 161	49,800	
CODA Sedan	31	201	15.42	3.22	137	38,145	
Renault Fluence ZE	22	185	11.89	-	135	28,342	
Honda Fit EV	20	132	15.15	1.99	148	36,635	
Ford Focus Electric	23	122	18.85	2.240	135	39,200	

References: (iMiEV), (Leaf), (Tesla Model S), (Smart ED), (Austin, 2010), (e6), (Berman, 2011), (Rav4 EV) , (Coda Automotive), (Fluence ZE), (Drone, 2011), (Renault Fluence ZE), (Fit EV), (Ridden, 2012), (Focus Electric), (Ford Motors)

Although electric buses cost at least twice as much as their equivalent internal combustion units   (Russia wants 13,000 pure electric buses ASAP, 2011), they do promise great savings in operating expenditures. These savings come from the cost of fuel and the cost of maintenance, which are substantially low or nonexistent in the case of electric buses. Running costs for an electric bus are estimated to be fifth that of a diesel one over its lifetime (Ankai Expands Pure Electric Bus Production , 2012).

The table below lists some of the pure electric buses available in the

international market today. Obtaining the exact specifications and, indeed, prices is more difficult than it is in the case with electric cars. That is most probably because the specifications can vary depending on the customer requirements, and the prices would vary accordingly. However, for reference and indication, AsiaOne website mentions that the price of the BYD electric bus ranges from (converted to today's USD) $318,000 to $477,000 (AsiaOne Motoring, 2010). On the other hand, the US-based DesignLine quotes a premium of approximately $600,000 to $700,000 for their electric bus over the price of a comparable diesel bus (DesignLine Buses)

Table 1-13 List of Commercially Available BE Buses and their Specifications

Make and Model	Country	Motor	Consumption	Range	Seating Capacity	Additional Features	
BYD eBus	China		100 kWh / 100 km	250 km	50	Recyclable Fe battery	
Zonda YCK6118HEC	China	120 kW		500 km	38	battery lifespan of above 500,000 km	
Ankai HFF6121G03EV EV City Bus	China	100 kW	116 kWh /100 km	250 km (with A/C)			
Proterra EcoLiner	USA	100 kW				- Overhead fast charging (through head-charge at stations) -Regenerative braking	
DesignLine ECO-Smart	USA	250 kW total		160 km	42	Remote tracking of vehicle operation	

The data have been collected from multiple sources including, but not limited to, the manufacturers' official websites. Blanks show data that were not available. Sources: (BYD eBus), (Truck & Bus), (Ankai), (Proterra - Company News), (DesignLine Buses), (Michaux, 2012)

In addition to the dedicated full electric cars and buses available in the market, some private entities provide conversion services of existing ICE vehicles to electric. Conversions consist mainly of removing all the ICE components from a vehicle (engine, exhaust…etc.), and installing electric drivetrain components (motor, battery…etc.).

These conversions not only have the benefit of being a cheaper alternative to a dedicated electric vehicle, but they also provide better utilization of the used vehicles' bodies after the combustion engines' lifetime expire. Some of these entities include Electro Automotive (ElectroAuto, 2012), Electric Blue (ElectricBlue, 2012), and Complete Coach Works (CCW) (Complete Coach Works, 2013). For instance, in an interview on their website (CompleteCoachWorks, 2013), the vice president of CCW claimed their recycling and conversion of a 1996 New Flyer diesel bus costs quarter the price of a new electric bus.

1.6.2 Commercial Charging Infrastructure and Specifications

There are three types of charging equipment as shown in Table 1-14 dependent primarily on the available power for charging which in turn translates to the time of charge. The higher the power, the faster the charge but also the cost both in terms of the equipment itself but also in terms of the connection to the electricity grid.

Table 1-14 Type of Charging Equipment

Type	Level 1	Level 2	Level 3 (Fast Charger)

Picture			
Charging Rate	2 to 5 miles/hour	10 to 20 miles /hour	60 to 80 miles in 20 minutes
Charging Time (for a 20kWh, 82-mile of range EV)	16.4 to 41 hours on average	4 to 8 hours on average	16 to 22 minutes on average (80% fast charge)
Power (kW)	1.9 (maximum)	19.2 (maximum)	50
Current	AC	AC	DC
Voltage	120 v	240 v or 208 v	480 v input to EVSE
Additional Equipment	Not required	Requires a dedicated circuit	Requires a dedicated circuit
Standard Connector	SAE J1772	SAE J1772	CHAdeMO
Price of Unit ($)	Less than 500	1,000 to 7,000	20,000 to 50,000
Installation Cost ($)	500 to 860	1,000 to 7,400	7,400 upwards
Reported Total	Up to 1,000	12,000 to 18,000	45,000 to

Installed Cost ($)			100,000
Cost of Additional Unit ($)	-	4,000 – 8,000	-
Cost of Maintenance ($)	25 to 50 per year	25 to 50 per year	25 to 50 per year

Data collected from various sources, such as the RMI project website (James W. May and Matt Mattila, 2009), the EV-Project website (eTec, 2010), Hydro Quebec website (Electrical Vehicle Charging Stations: Technical Installation Guide, 2012), and the Alternative Fuels Data Center website (Cities, 2012)

Noteworthy, in the table above charging rates and charging times are approximate, while costs have been cross-gathered from the earlier mentioned sources. It is also worth mentioning that some references (Charging Stations Installation Handbook for Electrical Contractors and Inspectors, 2011) list four types of chargers: level 1, 2, 3, and DC charger. In those references, 240-v, 100-A and up chargers are considered level 3; while 480-v DC are the quick chargers. In this context, we are using the most common classification as noted in Table 1-14 above.

Table 1-15 shows some of the available level 2 chargers with their quoted characteristics and unit costs (James W. May and Matt Mattila, 2009).

Table 1-15 Level 2 Charger Types

Manufacturer	Model	Voltage (v)	Current (A)	Power (kW)	Cost ($)	Picture/ Comments
Coulomb Technologies	CT2000	240	32	7.7	3,500 (Plus an additional $1,000 for the gateway	

					unit)	
GoSmart Technologies	Charge Spot	-	-	Up to 16.8	2,200-3,800	
eTec	EVI DS-200-DL	240	60	14.4	2,800	Can charge two vehicles simultaneously
eTec	EVI DS-50	240	30	7.2	1,450	ideal for residential and fleet charging
eTec	EVI DS-100	240	24	5.8	1,800	Ideal for public charging

Table 1-16 shows examples of level 3 chargers (Plug-in America). Fast chargers normally charge an EV's battery to 80% of its capacity. While prices per unit of those normally cost $20,000 to $50,000, Nissan has released two DC chargers that undercut these prices (Nissan QC). In addition to the Advanced Nissan charger listed below, there's also a reference to a cheaper Basic model at $9,900 (Nissan Sumitomo low-cost EV Quick Charger , 2011). However, no official information and specifications could be found about it.

Table 1-16 Level 3 Type Chargers

Manufacturer	Model	Maximum Amps	Power (kW)	Cost ($)	Picture/ Comments
Aerovironment	Fleet Fast Charging Station Line	550	60	39,900	
Andromeda Power	ORCA-Mobile	125	50	24,990 (pre-orders at 17,000)	
Nissan	Advanced DC Quick Charger	-	44	15,500	

1.7 Parametric Analysis of BEV Use in the UAE Conditions

While the global market for electric vehicles is evolving, the environmental, behavioral and regulatory conditions of the GCC countries create a special environment that needs to be considered independently. The parameters that affect vehicle performance are interdependent and they are uncertain or likely to change over time. The key variables for such analysis fall under the following categories:

- vehicle economics,
- vehicle utilization,
- regulations and subsidies and
- environmental conditions.

In order to study this interdependency, we develop a parametric model to investigate their relationship in the case of a single BEV that replaces an equivalent ICEV. We conduct the analysis for a typical car and a typical bus below.

1.7.1 Parametric Analysis for Electric Car in UAE

Typical values of an electric car in the UAE conditions are shown in below (cf. Table 1-17) for the case of a passenger vehicle along with their representative values with blue entries denoting derivative values. A brief explanation on parameter meaning and choice follows.

Table 1-17 Parameter Values for Electric Car analysis

Vehicle characteristics	Battery	Battery capacity	20	kWh		
		Usable battery capacity ratio	0.9			
		Cycles	2500			
		Hot weather battery life penalty	0.9	ratio of actual to spec cycles		
		Battery life	2070	days	5.7	years
		Max vehicle life	5	years		
		Battery-dependent vehicle life	5.0			
	Consumption	Consumption (combined assuming reg	150	Wh/km		
		Hot Weather effective consumption	216.7	Wh/km		
		Average effective consumption	195.7	Wh/km		
	Displaced ICEV	Consumption	10	l/100km		
		Reservoir size	70	l		
		Refueling point	25%			
		Refueling time	10	min		
		Pollutant Emissions				
		CO	5.8409	g/km		
		VOC	0.6425	g/km		
		NO x	0.4306	g/km		
		SO x	0.0000	g/km		
		PM	0.0053	g/km		
		Maintenance penalty ICEV	100	$/10,000km		
	EV Range	Standard	120	km		
		Hot weather	83.1	km		
Vehicle Economics		Battery cost	500	$/kWh		
		Base vehicle cost	10000	$		
		Incremental premium for EV	0	$/vehicle		
		Battery salvage value	10%	%		
		EV cost	20000	$		
		EV Premium	10000	$		
Vehicle utilization		Average speed	60	km/h		
		Plug-in time	1	min		
		Vehicle utilization	100	km/day		
Environmental		# days with average temp > 25C	250	days/year		
		Hot weather AC consumption penalty	4000	Wh/hour		
Regulatory	Liquid fuel	Gasoline price	0.47	$/lit	1.72	AED/lit
		Unsubsidized gasoline cost	0.79	$/lit	2.9	AED/lit
		Gasoline subsidy	0.32	$/lit		
		User cost of vehicle hour time	20.00	$/hour		
	Electricity	Electricty price	0.027	$/kWh	0.1	AED/kWh
		Unsubsidized electricity cost	0.10	$/kWh	0.367	AED/kWh
		Electricity subsidy	0.07	$/kWh	0.27	AED/kWh
		Electricity grid emissions				
		CO2	400.0	g/kWh		
		CO	0.027			
		VOC	0.019			
		NO x	0.095			
		SO x	0.002			
		PM	0.022			
	Pollutant Valuation	CO	$0	$/tonne		
		VOC	$1,700			
		NO x	$6,700			
		SO x	$39,600			
		PM	$185,500			
		CO2 price	30			
	EV Inventives	Infrastructure cost share by user	30%			
		EV premium share by govt	5%			
		Discount rate	5%			
Infrastructure	Chargers	Level 2 charging station cost	2000	$		
		Level 3 charging station cost	50000	$		
		Level 2 stations per vehicle	0.8			
		Level 3 stations per vehicle	0.02			
		Charge efficiency	0.9			
		Charger life	10	years		

Vehicle characteristics are based on representative vehicles as shown in Section1.6.1. The displaced ICE vehicle is a medium sedan. Pollutant emissions are taken from US EPA (Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks, 2008) for that vehicle type. Maintenance penalty for ICEV varies. Anecdotal evidence of EV owners reporting zero engine maintenance cost (not including battery depreciation). Deluchi and Lipman estimated a 27% reduction of maintenance costs for EVs (Delucchi, M. A., & Lipman, T. E., 2001). A recent study of electric vehicle use in Europe assuming very low mileage for UAE conditions estimated a 35% reduction on annual costs (Diez, Willi, January 2012). With average dealer maintenance cost around $400 / 10,000km in UAE we estimate the penalty of ICEV at $100 / 10,000 km or 25% reduction.

Vehicle utilization and weather parameters are estimated based on actual vehicle operations in Abu Dhabi. Refueling time and vehicle-time valuation is reflective of Abu Dhabi conditions and based on NHTSA CAFE 2012. Vehicle life is calculated based on an absolute maximum and compared against the actual expected battery life. If battery life is less than the maximum then vehicle life is reduced to equal battery life. This is consistent with the sole consideration of the battery cost as the additional EV premium. The battery end of life residual (salvage) value is considered because it is likely that the batteries will maintain part of their value being repurposed for non-automotive uses (cf. (ABB and GM: Reusing EV batteries for energy storage works!, 2012)). We assume a residual value of 10% on their original premium.

The forecasts of future battery costs are generally optimistic estimating values of around $200/kWh by 2020 (e.g. (Russell Hensley, John Newman, and Matt Rogers , 2012)). Tesla is reported as having a battery cost of $400/kWh today for the Model S while the Roadster had a battery cost of $700/kWh.

Gasoline prices are the UAE Federally mandated price, and electricity price is the Abu Dhabi is expatriate price. The unsubsidized costs are based on the tax-free US prices. Grid pollutant emissions are based on the US EPA estimates for a combined cycle gas turbine (CCGT) plants (Stationary Gas Turbines) as these are comprising 99% of the UAE electricity generation. GHG emissions are based on the average annual emissions from Lin et al (P. Lin, A. Khalid, S.Kennedy, and S. Sgouridis, 2011). Pollutant valuations are USD 2012 based on the NHTSA Table VIII-B CAFE 2012 (Corporate Average Fuel Economy for MY 2017-MY 2025 - Passenger Cars and Light Trucks, pp. 1–

1178., 2012) except for the particulate matter which is based on CAFE 2008 (Corporate Average Fuel Economy for MY 2013-MY 2020 - Passenger Cars and Light Trucks , 2008) as the 2012 values were only for PM2.5 and they are CPI–adjusted. For comparison purposes, we include the UK-DEFRA issued pollutant valuations below although we still use the EPA ones for calculations. The significant differences indicate the need for UAE to conduct their own independent estimates.

Values in US$ 2012	DEFRA (UK)	EPA (US)
CO	-	$0
VOC	-	$1,700
NO x	$1,592	$6,700
SO x	$2,722	$39,600
PM	(Central London) $369,543	$185,500

(Data Sources: CAFE 2012, UK DEFRA 2011

 http://www.defra.gov.uk/environment/quality/air/air-quality/economic/damage/)

The cost shares are arbitrarily chosen as they depend on the actual regulation in place – the focus being on the combined costs. Charger costs are based on Section 1.6.2.   Discount rate of 5% is reflective of current commercial loan interest rates for car buyers available in Abu Dhabi. It also happens to be a reasonable discount rate for government projects.

Because of the energy subsidies in both the electricity and the liquid fuel sectors, there exists a principal-agent problem. Both the user and the government share the savings from the avoided gasoline consumption and the costs of the additional electricity consumption due to the BEV operation. In the following we provide the three perspectives distinctly (user, government, and combined). Their relationship depends on the level of the subsidy itself, but the absolute benefit (combined view) is critically dependent on (i) the BEV premium (effectively linearly correlated to the cost of the battery) and (ii) the vehicle utilization. Table 1-18 shows the impact of range of utilization and battery cost in the net benefit/cost of adoption of BEVs.

The parametric analysis does not include some effects, which are discussed below. The impacts of the second order impact of fuel costs, i.e. the potential "rebound effect" from the lower cost of use of EVs may induce higher travel demand. We assume that travel demand remains the same. We assume

that there is no time penalty in the recharging of EV aside from the time to actually plug-in– i.e. that all charging happens at destination.

Table 1-18 Annual Net Benefit of Electric Car for a range of Battery Cost and Vehicle Utilization

Combined Benefit/Cost

		$/kWh of Battery Cost				
$/Year	**100**	**200**	**300**	**400**	**500**	**600**
40	376.8	-48.9	-474.7	-900.4	-1326.2	-1752.0
50	661.6	235.9	-189.9	-615.6	-1041.4	-1467.1
60	946.5	520.7	94.9	-330.8	-756.6	-1182.3
70	1231.3	805.5	379.8	-46.0	-471.7	-897.5
80	1516.1	1090.3	664.6	238.8	-186.9	-612.7
90	1800.9	1375.2	949.4	523.7	97.9	-327.9
100	2085.7	1660.0	1234.2	808.5	382.7	-43.0
110	2370.6	1944.8	1519.1	1093.3	667.5	241.8
120	2634.1	2187.0	1740.0	1292.9	845.8	398.8

Vehicle Utilization (km/day)

Private Benefit/Cost

		$/kWh of Battery Cost				
$/Year	**100.0**	**200**	**300**	**400**	**500**	**600**
40	272.2	-132.3	-536.7	-941.2	-1345.7	-1750.1
50	466.6	62.2	-342.3	-746.8	-1151.2	-1555.7
60	661.0	256.6	-147.9	-552.4	-956.8	-1361.3
70	855.5	451.0	46.5	-357.9	-762.4	-1166.9
80	1049.9	645.4	241.0	-163.5	-568.0	-972.4
90	1244.3	839.8	435.4	30.9	-373.6	-778.0
100	1438.7	1034.3	629.8	225.3	-179.1	-583.6
110	1633.1	1228.7	824.2	419.7	15.3	-389.2
120	1807.3	1382.6	957.9	533.2	108.5	-316.2

Vehicle Utilization (km/day)

Government Benefit/Cost

		$/kWh of Battery Cost				
$/Year	**100.0**	**200**	**300**	**400**	**500**	**600**
40.0	104.6	83.3	62.0	40.8	19.5	-1.8
50.0	195.0	173.7	152.4	131.2	109.9	88.6
60.0	285.4	264.1	242.8	221.5	200.3	179.0
70.0	375.8	354.5	333.2	311.9	290.7	269.4
80.0	466.2	444.9	423.6	402.3	381.1	359.8
90.0	556.6	535.3	514.0	492.7	471.5	450.2
100.0	647.0	625.7	604.4	583.1	561.9	540.6
110.0	737.4	716.1	694.8	673.5	652.3	631.0
120.0	826.7	804.4	782.0	759.7	737.3	715.0

Vehicle Utilization (km/day)

As shown in Table 1-18, the government consistently benefits from any level of EV adoption while for the user the subsidy for gasoline consumption overshadows the benefit from lowering gasoline consumption. This is a reason that strengthens the argument for initial government-supported incentives. In

other words, if the government provides at the minimum the same level of incentive as the last part of the table that equals its "benefits" it will be breaking even.

The specific breakdown of these benefits/costs on an annual basis is shown in Figure 1-11 for the case of 100 km/day and $500/kWh battery cost and parameter values as in Table 1-18.
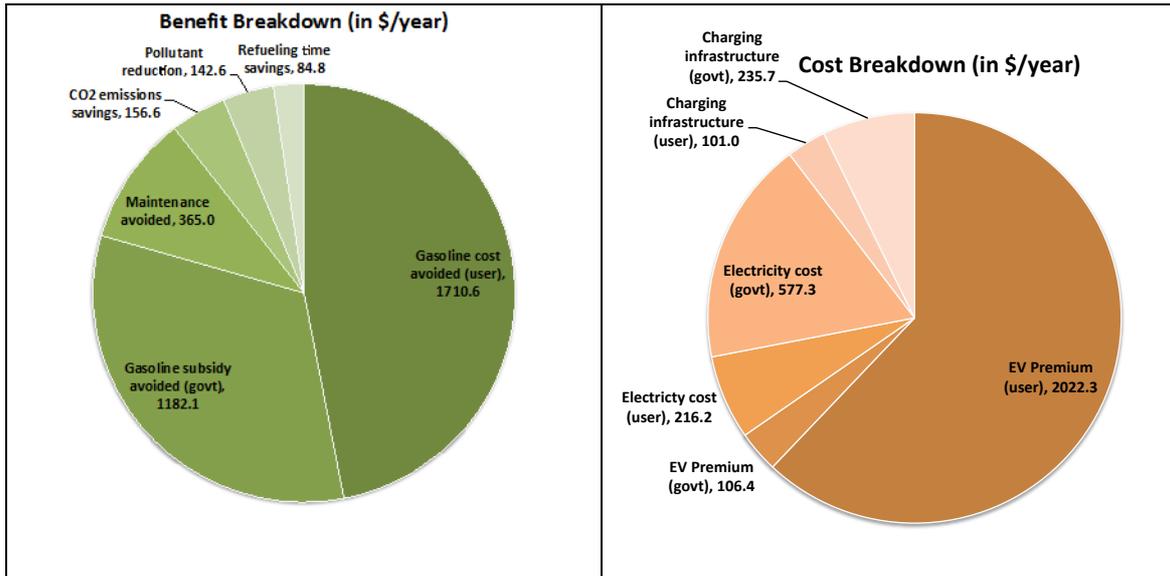
Figure 1-11 Annual Stakeholder Benefit and Cost Breakdown for a Single EV ($500/kWh &100km/day)

Parametric Analysis for Electric Taxi in Abu Dhabi Conditions

One of the most demanding vehicle operations due to the higher utilization levels would be the taxi operations. In order to investigate the compatibility of taxi operations with EVs we analyzed the typical scheduling of a taxi based on historical record for a taxi vehicle over a six-month period (Sep. 25th 2012 to Feb 19th 2013). The histogram of the actual distances traveled is shown in Figure 1-12. It is clear that the vast majority of the trips fall within the single range charge of current EV offerings with modest battery capacities.
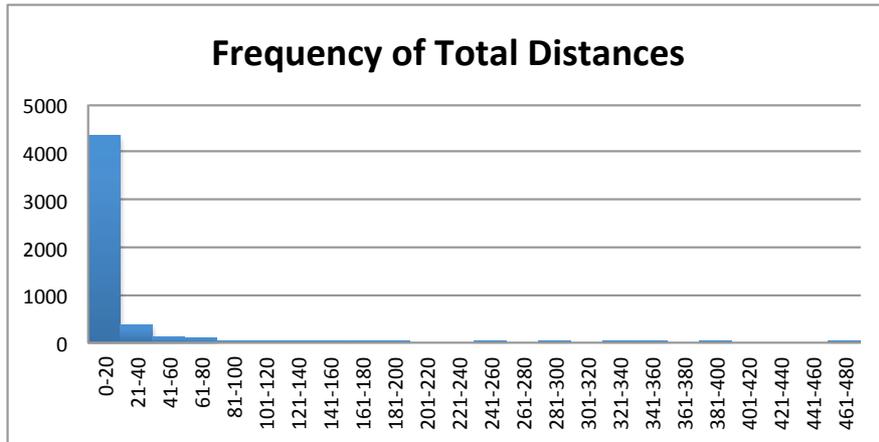
Figure 1-12 Revenue Trip Distance Histogram for Sample AD Taxi Operations

Nevertheless, the importance is the sequence of operations – i.e. how the vehicle is operated within the day. To estimate the ability of an EV to complete the trip sequence of the typical taxi we conducted a parametric analysis. We assumed that the taxi operates on an on-demand basis (i.e. it is parked and charging when not providing a revenue-passenger service as opposed to roaming. To replicate this in our data set we have (i) increased the revenue passenger distance by 10% - to account for the drive to pick up the passenger, and (ii) considered the time between passengers as stopped. The taxi would charge only if a certain threshold charge is possible (in this case 1.5 kWh). If for a given trip the taxi battery would be lower than 2 kWh of reserve power the trip is considered as not possible to complete.

We have conducted a parametric study relating battery size and charging power to the percentage of historical trips that could be completed under the above assumptions by an EV. These results are shown in Table 1-19. It is demonstrated that with a reasonably fast charging system (8kW level 2 charger) and a wide network of chargers, even a modest battery capacity (30kWh) would allow more than 97% of the trips to be completed **at the same time intervals as with current taxi operations**. The ICEV displaced was assumed to follow the same revised on-demand operations but with the difference that it would idle during the waiting time.

Table 1-19 Parametric Analysis of Taxi Trip Completion Ratio Using Historical

Operations

Taxi Trip Completion Ratio

Battery Capacity in kWh

%	10	20	30	40	50	60
3	57.5%	62.0%	68.0%	70.9%	72.7%	71.9%
4	65.0%	70.8%	76.4%	78.9%	83.8%	90.5%
6	77.6%	84.7%	90.7%	96.6%	98.9%	99.8%
8	85.0%	93.1%	97.2%	99.2%	99.9%	100.0%
10	89.3%	96.4%	99.1%	99.8%	99.9%	100.0%
15	93.5%	99.0%	99.7%	99.9%	100.0%	100.0%
20	95.0%	99.3%	99.7%	99.9%	100.0%	100.0%

(Row labels under "Charging rate in kW")

Given the trip completion ratio, for a taxi that is usable for more than 99% of the operations, we increase the battery capacity to 40kWh with the benefit and costs changes shown in Figure 1-13.
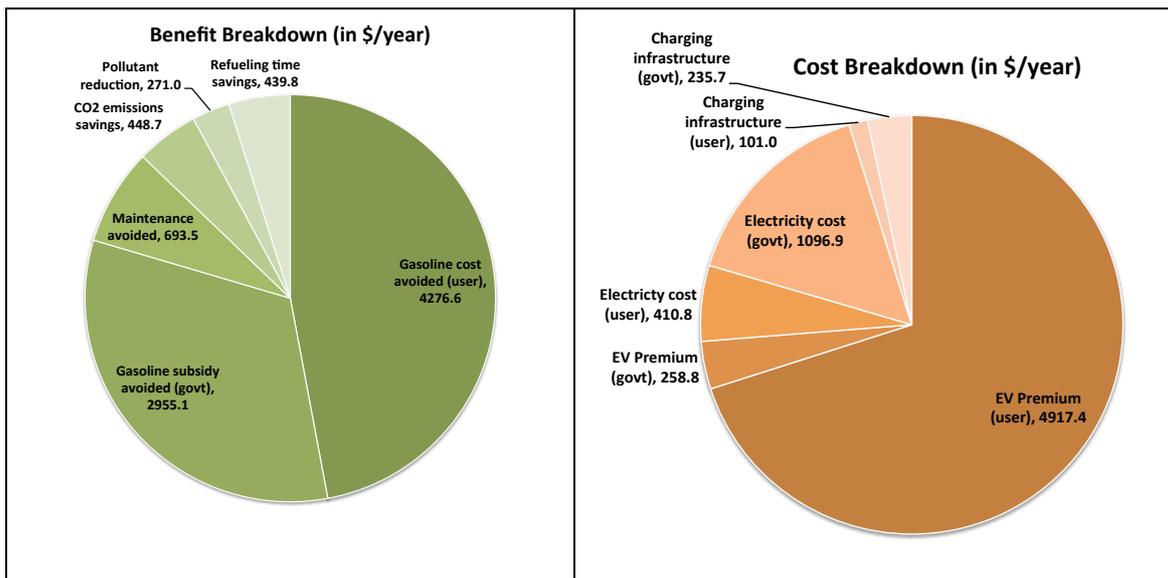
Figure 1-13 Annual Stakeholder Benefit and Cost Breakdown for a the Taxi Single EV (40kWh battery, $500/kWh, 190km/day)

1.7.2 *Parametric Analysis for Electric Bus in UAE Conditions*

Similar to the previous section, we have conducted an analysis for the electric bus segment. The baseline parameter values are shown Table 1-20. It varies in the following ways from the sedan parameters: Abu Dhabi diesel prices are used, bus battery costs are lower per kWh, average vehicle speed is lower, subsidy level for diesel fuel is lower, baseline ICEV emissions are Euro II

limits (based on the observation by DOT that Euro IV buses operated with the currently distributed as of 2013 diesel fuel only meet Euro II standards).

As mentioned in Section 1.4.6, the DOT buses operate heavy schedules of 700 km/day on average while other heavy buses (e.g. school, worker) may not operate as frequently. We use a 350 km/day figure which would require one complete charge during the daily use of the vehicle.

Table 1-20 Baseline Parameter Values for Electric Bus Analysis

Category	Subcategory	Parameter	Value	Unit	Value2	Unit2
Vehicle characteristics	Battery	Battery capacity	300	kWh		
		Usable battery capacity ratio	0.85			
		Cycles	3000			
		Hot weather battery life penalty	0.9	ratio of actual to spec cycles		
		Battery life	1497	days	4.1	years
		Max vehicle life	7	years		
		Battery-dependent vehicle life	4.1			
	Consumption	Consumption (Urban + regen braking)	1160	Wh/km		
		Hot Weather effective consumption	1385.0	Wh/km		
		Average effective consumption	1314.1	Wh/km		
	Displaced ICEV	Consumption	55	l/100km		
		Reservoir size	300	l		
		Refueling point	10%			
		Refueling time	10	min		
		Pollutant Emissions				
		CO	4.6400	g/km		
		VOC	1.2760	g/km		
		NO x	8.1200	g/km		
		SO x	0.0000	g/km		
		PM	0.1740	g/km		
		Maintenance penalty ICEV	1500	$/10,000km		
	EV Range	Standard	219.8	km		
		Hot weather	184.1	km		
Vehicle Economics		Battery cost	450	$/kWh		
		Base vehicle cost	150000	$		
		Incremental premium for EV	0	$/vehicle		
		Battery salvage value	10%	%		
		EV cost	285000	$		
		EV Premium	135000	$		
Vehicle utilization		Average speed	40	km/h		
		Plug-in time	1	min		
		Vehicle utilization	350	km/day		
Environmental		# days with average temp > 25C	250	days/year		
		Hot weather AC consumption penalty	9000	Wh/hour		
Regulatory	Liquid fuel	Diesel price	0.98	$/lit	3.6	AED/lit
		Unsubsidized diesel cost	1.10	$/lit	4.0	AED/lit
		Diesel subsidy	0.12	$/lit		
		User cost of vehicle hour time	0.00	$/hour		
	Electricity	Electricty price	0.027	$/kWh	0.1	AED/kWh
		Unsubsidized electricity cost	0.10	$/kWh	0.367	AED/kWh
		Electricity subsidy	0.07	$/kWh	0.27	AED/kWh
		Electricity grid emissions				
		CO2	400.0	g/kWh		
		CO	0.027			
		VOC	0.019			
		NO x	0.095			
		SO x	0.002			
		PM	0.022			
	Pollutant Valuation	CO	$0	$/tonne		
		VOC	$1,700			
		NO x	$6,700			
		SO x	$39,600			
		PM	$185,500			
		CO2 price	$30			
	EV Inventives	Infrastructure cost share by user	100%			
		EV premium share by govt	5%			
		Discount rate	5%			
Infrastructure	Chargers	Level 2 charging station cost	2000	$		
		Level 3 charging station cost	50000	$		
		Level 2 stations per vehicle	0			
		Level 3 stations per vehicle	0.3			
		Charge efficiency	0.9			
		Charger life	10	years		

Table 1-21 Annual Net Benefit for Electric Bus for a Range of Utilization and Cost

Combined Benefit/Cost

	$/kWh of Battery Cost					
$/Year	100	200	300	400	500	600
100	19399.4	14583.3	9767.1	4951.0	134.9	-4681.3
200	45557.5	40741.4	35925.3	31109.1	26293.0	21476.8
300	69897.7	63263.6	56629.5	49995.3	43361.2	36727.1
400	94134.7	85579.5	77024.4	68469.2	59914.0	51358.8
500	118369.1	107890.3	97411.4	86932.5	76453.7	65974.8
600	142602.2	130198.4	117794.5	105390.7	92986.8	80582.9
700	166834.6	152505.0	138175.4	123845.8	109516.2	95186.6
800	191066.5	174810.7	158554.9	142299.0	126043.2	109787.4
900	215298.1	197115.7	178933.4	160751.0	142568.7	124386.3

Vehicle Utilization (km/day)

Transit Benefit/Cost

	$/kWh of Battery Cost					
$/Year	100.0	200	300	400	500	600
100	17197.0	12621.7	8046.4	3471.1	-1104.3	-5679.6
200	40912.0	36336.6	31761.3	27186.0	22610.7	18035.3
300	62899.8	56597.4	50295.0	43992.6	37690.2	31387.8
400	84789.7	76662.3	68534.9	60407.5	52280.1	44152.7
500	106677.2	96722.3	86767.3	76812.4	66857.5	56902.6
600	128563.4	116779.7	104996.0	93212.3	81428.7	69645.0
700	150448.8	136835.7	123222.6	109609.4	95996.3	82383.2
800	172333.9	156890.8	141447.8	126004.8	110561.7	95118.7
900	194218.6	176945.4	159672.1	142398.9	125125.6	107852.4

Vehicle Utilization (km/day)

Government Benefit/Cost

	$/kWh of Battery Cost					
$/Year	100.0	200	300	400	500	600
100.0	2202.4	1961.6	1720.8	1480.0	1239.1	998.3
200.0	4645.6	4404.7	4163.9	3923.1	3682.3	3441.5
300.0	6997.8	6666.1	6334.4	6002.7	5671.0	5339.3
400.0	9345.0	8917.2	8489.4	8061.7	7633.9	7206.2
500.0	11692.0	11168.0	10644.1	10120.1	9596.2	9072.2
600.0	14038.9	13418.7	12798.5	12178.3	11558.1	10937.9
700.0	16385.8	15669.3	14952.8	14236.3	13519.9	12803.4
800.0	18732.6	17919.9	17107.1	16294.3	15481.5	14668.7
900.0	21079.5	20170.4	19261.3	18352.1	17443.0	16533.9

Vehicle Utilization (km/day)

Table 1-21 indicates that the Electric Bus has a much higher potential for cost savings if operated at multiples of its range even with a $600/kWh battery cost. The non-DOT government benefits are comparatively much lower to the transit agency benefit given the much lower diesel fuel subsidy. This is also shown in greater detail in the cost/benefit breakdown in Figure 1-14.
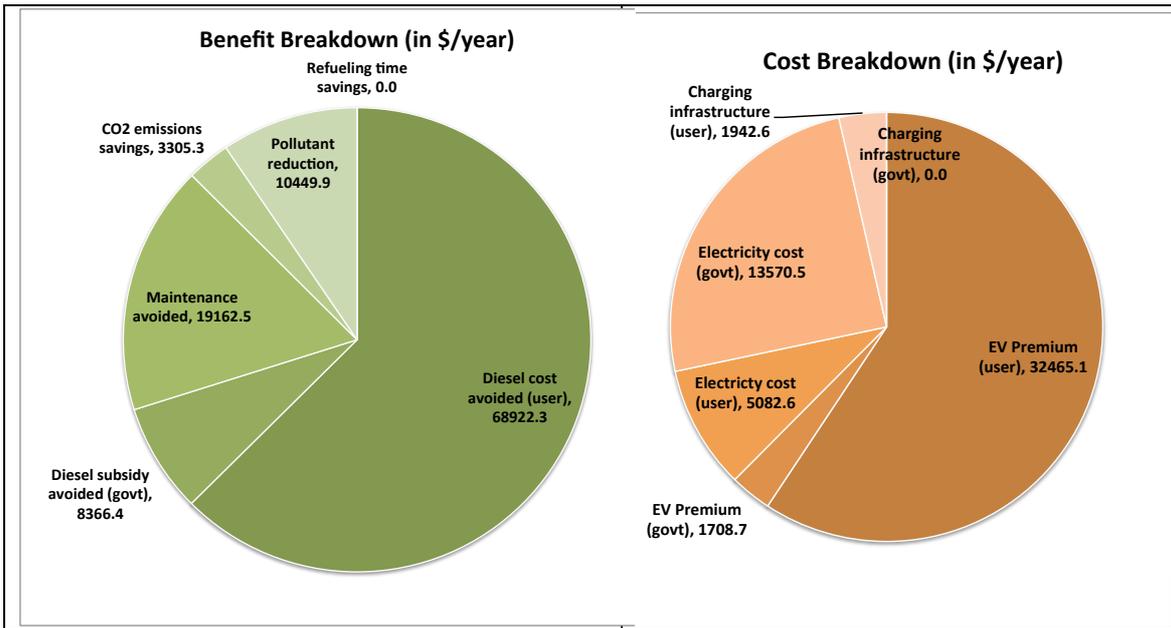
Figure 1-14 Annual Single Vehicle Electric Bus Cost and Benefit Breakdown by Stakeholder ($450/kWh, 350 km utilization)

1.8   Scenario Analysis of Policy Options for EV Vehicle Adoption

We find that both international experience (cf. Section 1.5) and the results of the survey (cf. Section 2) indicate the importance of having a developed charging station network before large-scale adoption by private users. Users are also reluctant to adopt what they consider an untested technology. Furthermore, in Section 1.7, we show that the economics of electric vehicles with the additional distortion of liquid fuel subsidy are not economically attractive for private users at the current level of battery prices and expected daily utilization (~60km/day) indicating that an early stage government support is needed both for infrastructure development and for overcoming the economic barrier while the government would benefit directly by the reduction in the liquid fuel subsidy. Finally, there is uncertainty with regard to the operational capacities and long-term performance of EVs in the region and expectations that battery prices will be lower in the future as production capacity increases push the learning curve.

The above reasons indicate that a staged approach in terms of the adoption of EVs would be more appropriate. This section investigates variations in the options for the adoption of EVs in the form of scenarios. These scenarios are:

- *Environmentalist*: early adoption rate of EVs and a focus on the environmental benefits spurs wide-spread adoption
- *Pragmatist:* a staged approach while expanding infrastructure mitigates risks and takes advantage of lower future prices but without weighting financial or environmental performance
- *Cautious:* A late start and slow uptake poses the least direct financial cost but also reduces drastically the amount of savings in terms of both avoided fuel consumption and environmental impact.

We present each scenario with a brief description, a likely set of policy options that could be introduced to support it, the starting year and cumulative results and costs by that year and graphs showing their performance. The scenarios consider the adoption rate for six types of vehicle fleets as presented in Section 1.4:

- Car sharing
- Long-term rental
- Taxi
- Government

- Private, and
- Bus

The adoption rate for electric vehicles after their introduction is maintained as a steady percentage of total new vehicle purchases until 2030, the last year of the period under investigation. Total new vehicle purchases are calculated as the sum of the turnover of the existing fleet which dependent on the average life of the typical car in the fleet and the new vehicle purchases to meet the underlying growth expectations. Monetary annual values are based on the costs and benefits of the parametric analysis in Section 1.6. These values are then converted to current using net present value (NPV) discounting. Absolute values in terms of carbon emissions reduction and gasoline avoided consumption from the baseline are also reported. Exogenous assumptions that remain constant across scenarios are:

- Underlying growth rate of the total vehicle fleet in Abu Dhabi
- Battery costs fall at a 5% p.a. reduction - more conservative than McKinsey's battery study expectations (Russell Hensley, John Newman, and Matt Rogers , 2012), and
- Oil prices increasing (1% p.a.).

1.8.1 Environmentalist Scenario

This scenario is starting with electric vehicles early on across the board and fairly aggressive adoption goals as shown in Table 1-22. All government related entities are early adopters and there is a strong support with both incentives and infrastructure deployment to induce private sector (rentals) and personal vehicles to adopt them widely.

Table 1-22 Environmentalist Scenario Input

Total Vehicle fleet	Total ICE fleet size in 2012	% Expected Change of total fleet	% share of EV in new vehicles	Year starting	% of EV in total fleet in 2030	Vehicle Life (years	Utilization (km/day)
Car sharing	0	8%	100.0%	2015	100%	4.00	120
Rental cars	10150	2%	3.0%	2019	9%	4.00	120
Government cars	4590	1%	10.0%	2014	41%	4.00	50
Taxi cars	7148	2%	7.0%	2016	25%	4.00	190
Private cars	597510	3%	1.0%	2019	2%	5.00	70
Buses	7579	1%	2.5%	2016	9%	4.10	350

Expected Battery Cost Drop %	5%
Discount rate	5%
Expected Unsubdized Gasoline Price Ch	1%

The policies that need to be implemented to achieve this level of adoption are essentially the whole policy suite.

Suggested Policy	Application Intensity			Desired Effect
	low	medium	high	
Provision for EV-dedicated lane access			√	Shorter travel times for EV drivers
Support for fleet-scale EV adoption			√	Familiarize the public with EVs
EV car sharing and renting programs			√	Familiarize the public with EVs
Availability of electric vehicle supply equipment (EVSE): Availability of charging stations and poles			√	Preliminary step to mainstream EVs
Grants and Tax Subsidies for EV Purchases			√	Lower the cost variance between conventional and EV
Parking Incentives			√	Perk incentive to buy EVs
Demonstration Projects			√	

For heavy buses, we assume that DOT obtains a 20% EV fleet by 2030 while the private sector buses are 6.5% electric for the remaining fleet.

Such an effort would result in the number of vehicles shown in Figure 1-15, and benefits and costs shown in

Figure 1-16 and Figure 1-17 respectively.

Figure 1-15 Environmentalist Scenario EV Number
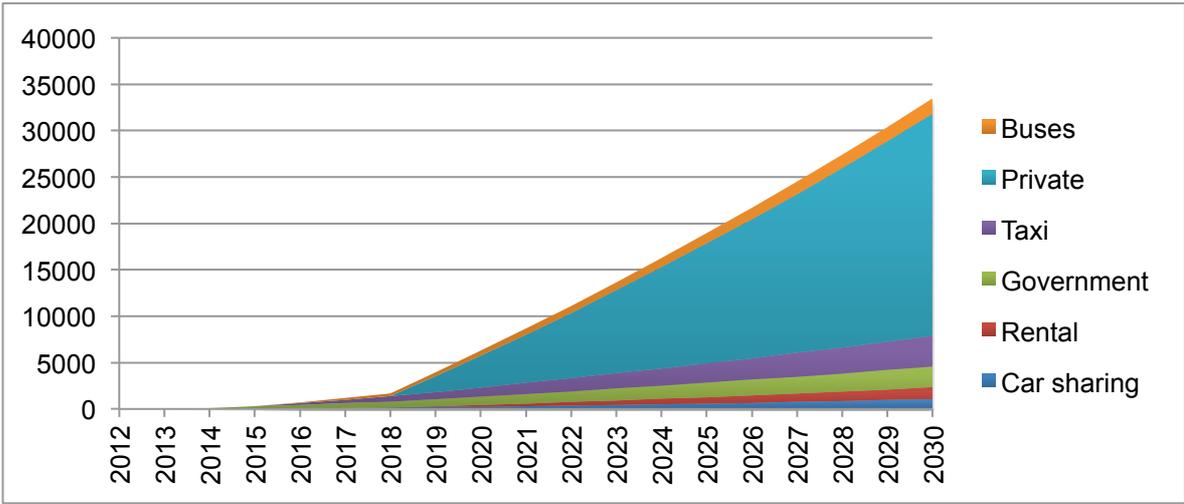
Figure 1-16 Environmentalist Scenario Benefit (Undiscounted 2012$)
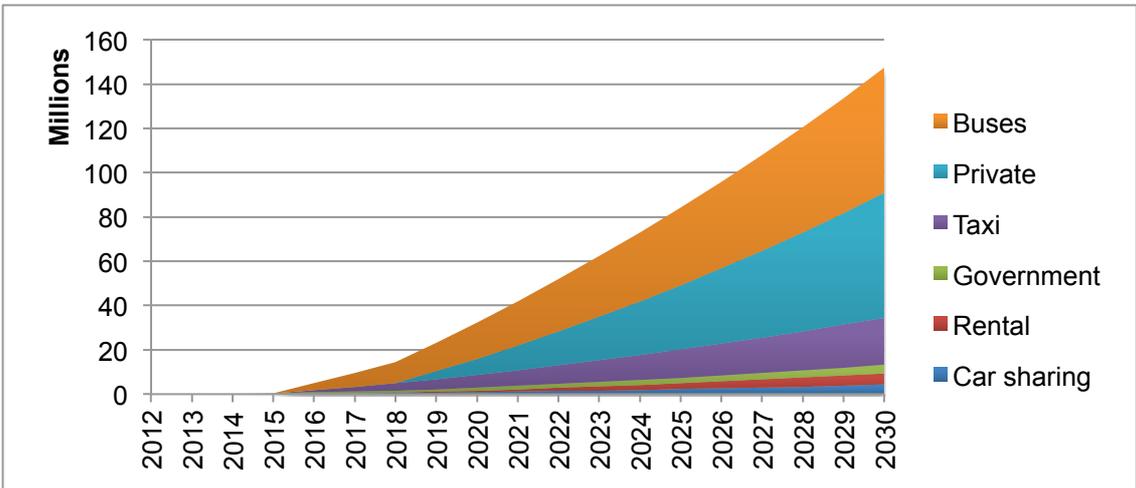
Figure 1-17 Environmentalist Scenario Cost (Undiscounted 2012$)
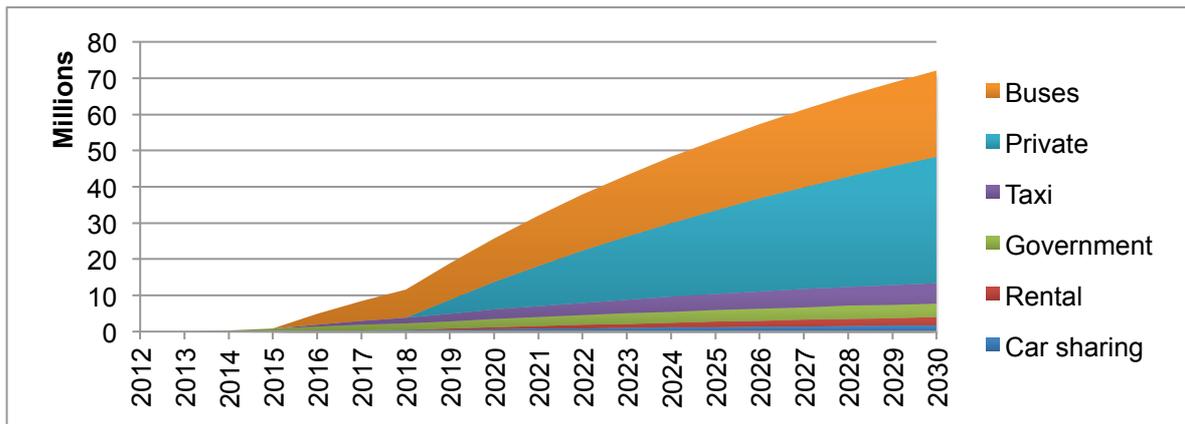
The *cumulative* discounted values and material savings in gasoline/diesel and CO2 tonnes avoided are summarized every five years in Table 1-23. Electricity consumption and required power (assuming all vehicle charge in the same 3 hours of the day) is also shown. The estimated power draw for this ambitious scenario is 0.11 GW whereas the installed system capacity by 2030 is expected to be above 20GW. This reinforces the notion that EVs would not present an unmanageable load in total power requirements (even in a conservative assumption that all charging occurs within 3 hours of the day).

Table 1-23 Summary Cumulative Values for Environmentalist Scenario

ENVIRONMENTALIST							
Year	**Cumulative Costs** (discounted $2012)		**Cumulative Benefits** (discounted $2012)		**Net Benefit**	
	EV Premium	**Infrastructure**	**Fuel Savings**	**Ancillary**		
2015	$ 1,065,558	$ 124,417	$ 442,881	$ 155,032	$ (592,061)	
2020	$ 37,412,927	$ 4,145,313	$ 53,848,764	$ 25,902,597	$ 38,193,121	
2025	$ 131,112,242	$ 19,263,921	$ 211,423,259	$ 92,683,464	$ 153,730,560	
2030	$ 241,087,201	$ 42,847,698	$ 453,360,773	$ 186,641,946	$ 356,067,820	

Year	**# Car EV**	**# Bus EV**	**Cumulative Gasoline Saved (000 lit)**	**Cumulative CO2 avoided (tonnes)**	**Annual Electricity Consumed (MWh)**	**Peak Power Equivalent (MW)**
2015	280	0	821.8	1,175.5	1,173.4	0.4
2020	5503	255	98,273.7	152,212.2	77,207.1	26.4
2025	17328	523	448,454.6	685,152.5	190,573.2	65.3
2030	30990	805	1,096,038.8	1,665,346.7	316,859.5	108.5

1.8.2 Pragmatist Scenario

This scenario is starting with electric vehicles early on across the board and fairly aggressive adoption goals as shown in Table 1-24. Select government fleets are early adopters followed by a car sharing system and some taxis to familiarize the public and prove the concept and operational aspects. Buses and taxis start later and the adoption by private users after that.

Table 1-24 Pragmatist Scenario Input

Total Vehicle fleet	Total ICE fleet size in 2012	% Expected Change of total fleet	% share of EV in new vehicles	Year starting	% of EV in total fleet in 2030	Vehicle Life (years	Utilization (km/day)
Car sharing	0	0.08	100.0%	2015	100%	4.00	120
Rental cars	10150	0.02	1.5%	2019	4%	4.00	120
Government cars	4590	0.01	6.0%	2014	25%	4.00	50
Taxi cars	7148	0.02	4.0%	2016	14%	4.00	190
Private cars	597510	0.03	0.6%	2019	1%	5.00	70
Buses	7579	0.01	1.5%	2016	5%	4.10	350

Expected Battery Cost Drop %	5%
Discount rate	5%
Expected Unsubdized Gasoline Price Ch	1%

The policies that need to be implemented to achieve this level of adoption are essentially the whole policy suite in medium and high intensities.

Suggested Policy	Application Intensity			Desired Effect
	low	medium	high	
Provision for EV-dedicated lane access			√	Shorter travel times for EV drivers
Support for fleet-scale EV adoption		√		Familiarize the public with EVs
EV car sharing and renting programs		√		Familiarize the public with EVs
Availability of electric vehicle supply equipment (EVSE): Availability of charging stations and poles			√	Preliminary step to mainstream EVs
Grants and Tax Subsidies for EV Purchases		√		Lower the cost variance between conventional and EV
Parking Incentives			√	Perk incentive to buy EVs
Demonstration Projects			√	

Such an effort would result in the number of vehicles shown in Figure 1-18, and benefits and costs shown Figure 1-19 and Figure 1-20 respectively.

Figure 1-18 Pragmatist Scenario EV Number
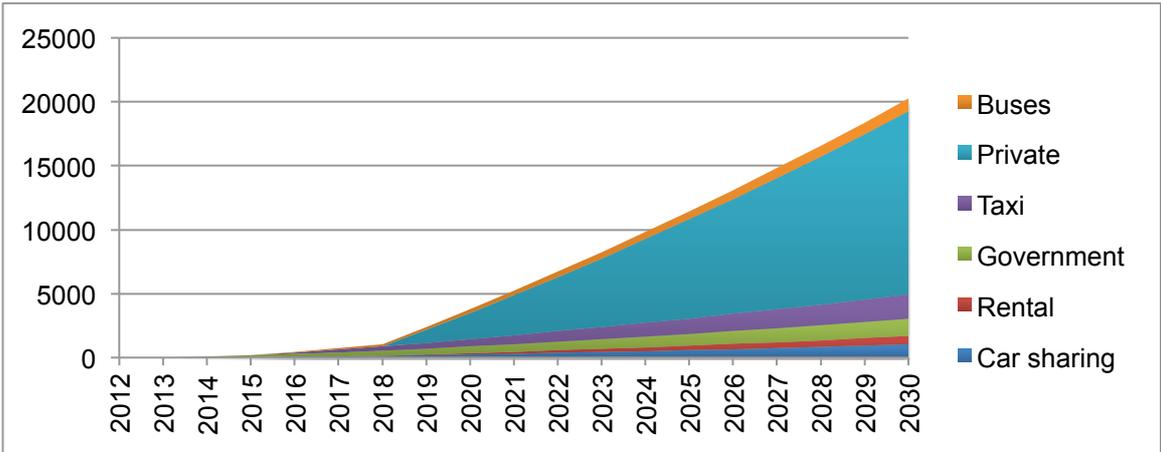
Figure 1-19 Pragmatist Scenario Benefit (Undiscounted 2012$)
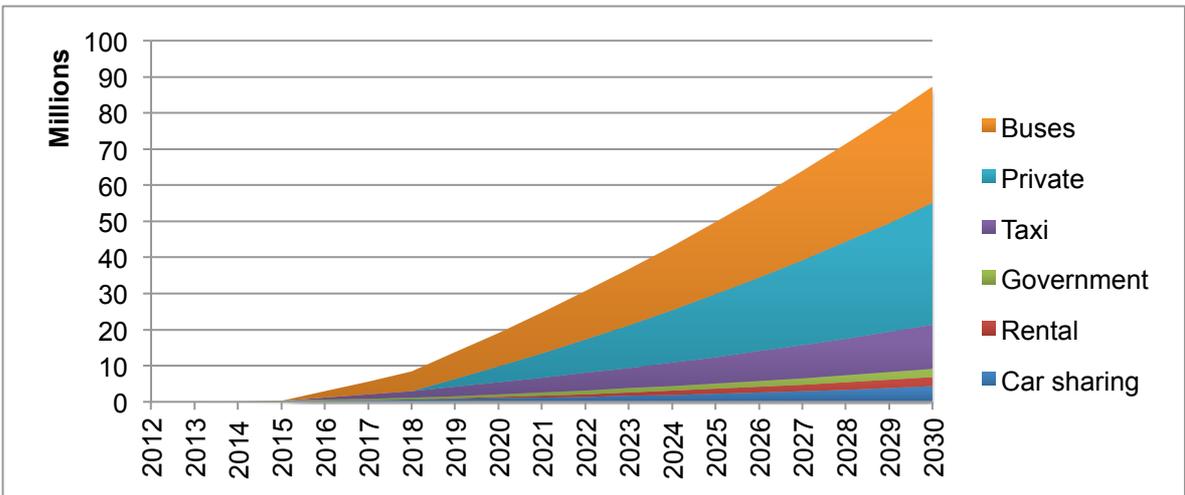
Figure 1-20 Pragmatist Scenario Cost (Undiscounted 2012$)
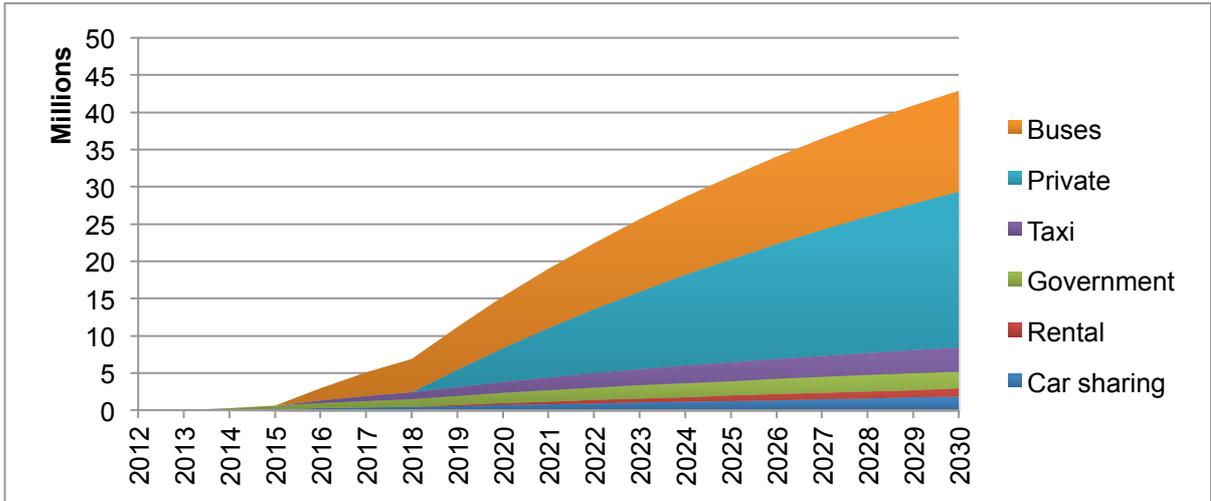
The *cumulative* discounted values and material savings in gasoline/diesel and CO2 tonnes avoided are summarized every five years in Table 1-25.

Table 1-25 Summary Cumulative Values for Pragmatist Scenario

PRAGMATIST						
Year	Cumulative Costs (discounted $2012)		Cumulative Benefits (discounted $2012)		Net Benefit	
	EV Premium	Infrastructure	Fuel Savings	Ancillary		
2015	$ 675,567	$ 78,926	$ 298,459	$ 104,433	$ (351,600)	
2020	$ 22,802,413	$ 2,551,020	$ 32,652,551	$ 15,665,394	$ 22,964,513	
2025	$ 79,352,270	$ 11,716,011	$ 127,607,113	$ 55,880,368	$ 92,419,200	
2030	$ 145,750,663	$ 26,008,324	$ 273,508,213	$ 112,494,729	$ 214,243,955	
Year	# Car EV	# Bus EV	Cumulative Gasoline Saved (000 lit)	Cumulative CO2 avoided (tonnes)	Annual Electricity Consumed (MWh)	Peak Power Equivalent (MW)
2015	182	0	554.4	793.0	824.0	0.3
2020	3364	153	59,726.8	92,295.7	46,746.6	16.0
2025	10514	314	270,992.1	413,372.6	115,120.4	39.4
2030	18820	483	661,968.2	1,004,374.5	191,691.1	65.6

1.8.3 Cautious Scenario

This scenario is starting with electric vehicles in a cautious gradual manner as shown in **Error! Reference source not found.**Table 1-26. All government related entities are early adopters and there is a strong support with both incentives and infrastructure deployment to induce private sector (rentals) and personal vehicles to adopt them widely.

Table 1-26 Cautious Scenario Input

Total Vehicle fleet	Total ICE fleet size in 2012	% Expected Change of total fleet	% share of EV in new vehicles	Year starting	% of EV in total fleet in 2030	Vehicle Life (years	Utilization (km/day)
Car sharing	0	0.08	100.0%	2017	100%	4	120
Rental cars	10150	0.02	0.5%	2020	1%	4	120
Government cars	4590	0.01	3.0%	2016	11%	4	50
Taxi cars	7148	0.02	2.0%	2019	6%	4	190
Private cars	597510	0.03	0.3%	2022	1%	5	70
Buses	7579	0.01	0.9%	2018	3%	4.101204748	350

Expected Battery Cost Drop %	5%
Discount rate	5%
Expected Unsubdized Gasoline Price Ch	1%

The policies that need to be implemented to achieve this level of adoption are essentially the whole policy suite in varying intensities.

Suggested Policy	Application Intensity			Desired Effect
	low	medium	high	
Provision for EV-dedicated lane access		√		Shorter travel times for EV drivers
Support for fleet-scale EV adoption	√			Familiarize the public with EVs
EV car sharing and renting programs	√			Familiarize the public with EVs
Availability of electric vehicle supply equipment (EVSE): Availability of charging stations and poles		√		Preliminary step to mainstream EVs
Grants and Tax Subsidies for EV Purchases	√			Lower the cost variance between conventional and EV
Parking Incentives			√	Perk incentive to buy EVs
Demonstration Projects			√	

Such an effort would result in the number of vehicles shown, benefits and costs shown in Figure 1-21.
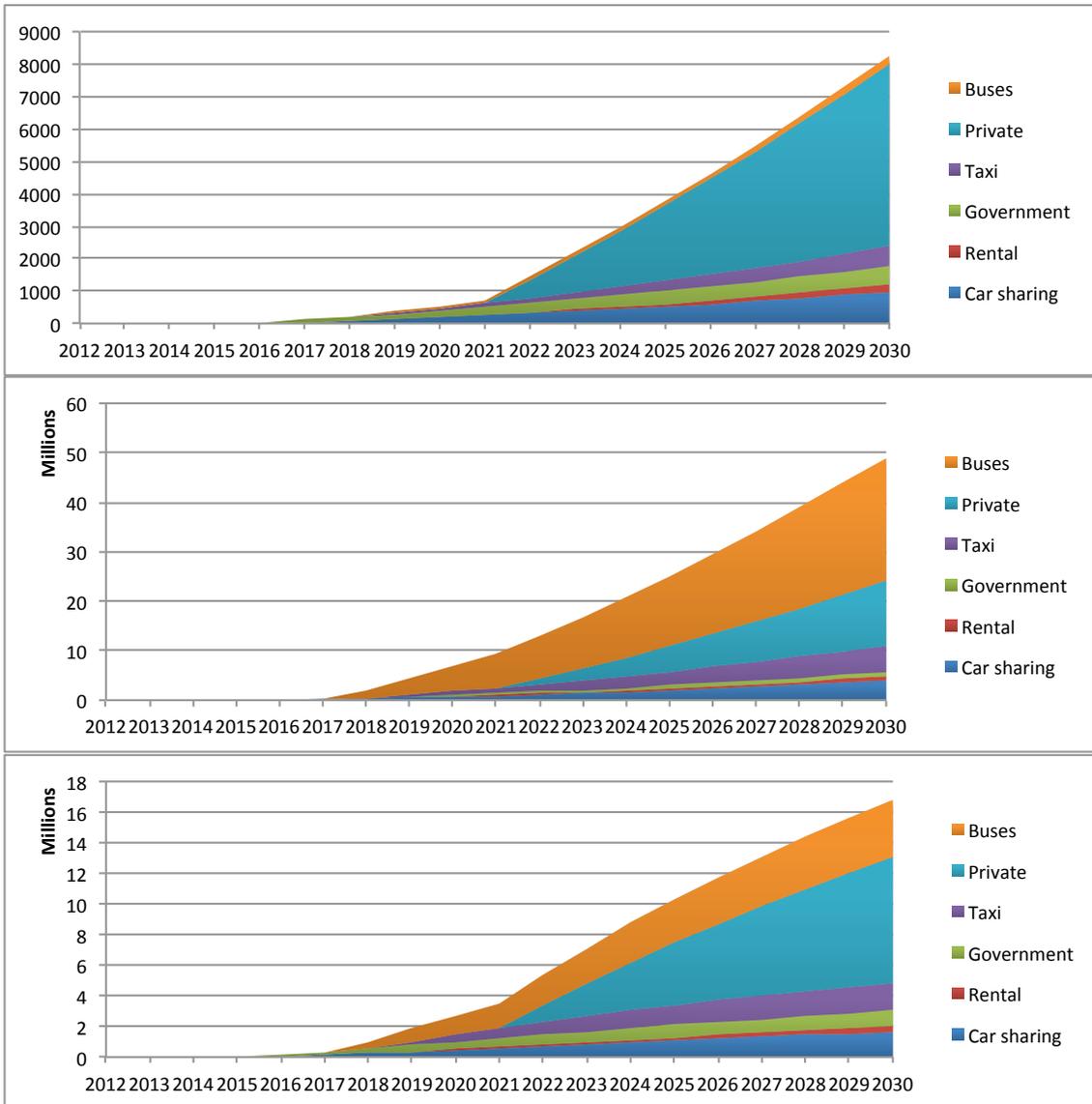
Figure 1-21 Cautious Scenario Vehicle #, Undiscounted Benefit and Costs

The *cumulative* discounted values and material savings in gasoline/diesel and CO_2 tonnes avoided are summarized every five years in Table 1-27.

Table 1-27 Summary Cumulative Values for Cautious Scenario

	CAUTIOUS						
Year	Cumulative Costs (discounted $2012)		Cumulative Benefits (discounted $2012)		Net Benefit		
	EV Premium	Infrastructure	Fuel Savings	Ancillary			
2015	$ -	$ -	$ -	$ -	$ -		
2020	$ 4,090,075	$ 450,531	$ 6,590,028	$ 3,329,931	$ 5,379,353		
2025	$ 22,428,228	$ 3,230,077	$ 41,933,887	$ 19,176,335	$ 35,451,917		
2030	$ 50,752,077	$ 9,170,889	$ 108,435,596	$ 45,805,806	$ 94,318,435		
Year	# Car EV	# Bus EV	Cumulative Gasoline Saved (000 lit)	Cumulative CO2 avoided (tonnes)	Annual Electricity Consumed (MWh)	Peak Power Equivalent (MW)	
2015	0	0	-	-	-	0.0	
2020	479	56	12,057.4	18,575.1	12,951.4	4.4	
2025	3639	152	89,285.4	136,721.4	48,192.4	16.5	
2030	7984	254	265,726.1	404,017.1	90,966.1	31.2	

1.8.4 Section Review and Conclusions

All three of the considered scenarios provide a net benefit by 2030. As the EV premium drops due to battery costs reduction the rate of EV costs is decreasing while the absolute numbers of vehicles (and their benefits) are increasing. Both the Environmentalist and Pragmatist scenarios incur a net cumulative cost by 2020 which is reversed in the following decade reaching a significantly higher benefit level compared to the Cautious scenario (double for the Pragmatist and quadruple for the Environmentalist scenario) with comparative improvements in liquid fuel savings and CO_2 avoided. The cumulative liquid fuel savings on their own in terms of bbl oil equivalent (BOE) are approximately 6.4M, 3.6M, and 1.5M BOE over the period. Although, individually it may not seem to amount to much, approximately 2.5 days of oil production of the Emirate in the best case, the program benefits would accrue much faster once the base and infrastructure is established. In terms of power requirement a conservative assumption for the Environmentalist Scenario is approximately 0.11GW in 2030 which is approximately 0.5% of the expected installed capacity at that time indicating that there should be no problems on the large-scale integration of EVs from the capacity perspective. The study of the localized grid points is conducted in later sections.

1.9 Bibliography

(n.d.). Retrieved 10 2012, from ChargeYourCar:
http://chargeyourcar.org.uk/about/

(n.d.). Retrieved 10 2012, from ChargePoint America:
http://chargepointamerica.com/program-info.php

(n.d.). Retrieved 10 2012, from The EV Project: http://www.theevproject.com/

(n.d.). Retrieved 1 5, 2013, from Coda Automotive:
    http://app.codaautomotive.com/CarConfigurator/View/Specifications

(n.d.). Retrieved 1 5, 2013, from Ford Motors:
    http://www.ford.com/cars/focus/trim/electric/

(n.d.). Retrieved 2 2, 2013, from Plug-in America:
    http://www.pluginamerica.org/accessory-tracker?page=1&type=All&level
    =DCQ&nrtl=All

(n.d.). Retrieved 2 2, 2013, from Nissan QC: http://nissanqc.com/products

(n.d.). Retrieved from Better Place:
    http://www.betterplace.com/press-room/better-place-extends-tokyo-trial-f
    or-additional-three-months

(n.d.). Retrieved from Better Place: www.betterplace.com

(n.d.). Retrieved from ThinkProgress: •
    http://thinkprogress.org/climate/2012/07/03/510344/top-ev-friendly-cities-
    what-are-they-doing-right/?mobile=nc

(n.d.). Retrieved 2012, from Car2Go: http://www.car2go.com

(n.d.). Retrieved 2012, from CarZapp: www.carzapp.com

(n.d.). Retrieved 2012, from ZenCar: http://www.zencar.eu/en

(2011). *Charging Stations Installation Handbook for Electrical Contractors and
    Inspectors.* North Carolina: North Carolina Advanced Energy Corporation.

*Tesla Motors Launches Revolutionary Supercharger Enabling Convenient Long
    Distance Driving.* (2012, September 24). Retrieved February 24, 2013,
    from Tesla Motors:
    http://www.teslamotors.com/about/press/releases/tesla-motors-launches-
    revolutionary-supercharger-enabling-convenient-long-dista

(2002). *Public Transport and Car-Sharing: Together for the Better.* Bremen:
    International Association of Public Transport.

(2008). *Average Annual Emissions and Fuel Consumption for Gasoline-Fueled
    Passenger Cars and Light Trucks.* EPA.

(2009). *Electric Cars: Plugged In 2 : A Mega-Theme Gain Momentum.* Deutsche
    Bank.

(2011, September). Retrieved 2012, from The Economist:
    http://www.economist.com/node/21528681?frsc=dg

Capital Business. (2011). Retrieved from Washington Post:
    http://www.washingtonpost.com/business/capitalbusiness/zipcar-gains-tw

o-competitors-for-washington-drivers/2011/07/29/gIQAsmhSaS_story.ht
ml?tid=pm_business_pop

*Clean State Energy Actions: 2011 Update. Lead By Example. Alternative Fuel
and Vehicle Fleets.* (2011). Retrieved 2012, from National Governors
Association: www.nga.org

Nissan Sumitomo low-cost EV Quick Charger . (2011, 11 12). Retrieved 2 2,
2013, from House of Japan:
http://www.houseofjapan.com/auto-moto/nissan-sumitomo-low-cost-ev-q
uick-charger

Progress Energy. (2011). Retrieved 2012, from
https://www.progress-energy.com

(2011). *Statistical Yearbook of Abu Dhabi 2011.*

(2011). *The China New Energy Vehicles Program: Challenges and
Opportunities.* PRTM.

(2012, 6 6). Retrieved 10 2012, from NYSERDA:
http://www.nyserda.ny.gov/About/Newsroom/2012-Announcements/2012
-06-06-Governor-Cuomo-Announces-Deployment-of-325-Electric-Vehicle
-Charging-Stations.aspx

(2012). Retrieved 02 13, 2013, from ElectroAuto:
http://www.electroauto.com/whybuy.shtml

(2012). Retrieved 02 13, 2013, from ElectricBlue: http://www.ev-blue.com/

ABB and GM: Reusing EV batteries for energy storage works! (2012, 11 16).
Retrieved 01 10, 2013, from SmartGridNews:
http://www.smartgridnews.com/artman/publish/Technologies_Storage/AB
B-and-GM-Reusing-EV-batteries-for-energy-storage-works-5293.html#.U
RtZXqX8_Io

(2012). *Electrical Vehicle Charging Stations: Technical Installation Guide.*
Quebec: Hydro Quebec.

(2012). *EV City Casebook: A Look at the Global Electric Vehicle Movement.*
Organisation for Economic Cooperation and Development/International
Energy Agency.

(2013). Retrieved 02 13, 2013, from Complete Coach Works:
http://www.completecoach.com/services/

(2013). Retrieved 02 13, 2013, from CompleteCoachWorks:
http://www.completecoach.com/zeps-electric-bus-featured-on-jay-lenos-g
arage/

Estonia Is 1st Country In The World To Install Nationwide System Of Fast Chargers For EVs. (2013, 02 23). Retrieved 02 24, 2013, from http://cleantechnica.com/2013/02/23/estonia-is-1st-country-in-the-world-to-install-nationwide-system-of-fast-chargers-for-evs/#AfHEo6RGe4FYcBWj.99

A123 Systems. (n.d.). Retrieved 12 20, 2012, from http://www.a123systems.com/lithium-ion-battery-technology.htm

Abu Dhabi Department of Transport. (n.d.). Retrieved 02 26, 2013, from http://dot.abudhabi.ae/en/info/About_DoT

Abu Dhabi Portal. (n.d.). Retrieved 02 26, 2013, from http://www.abudhabi.ae

ACEA. (2012). *OVERVIEW OF PURCHASE AND TAX INCENTIVES FOR ELECTRIC VEHICLES IN THE EU.* ACEA.

ADNOC Group. (n.d.). Retrieved 02 26, 2013, from http://www.adnoc.ae/Content.aspx?mid=26&newid=26

ADWEA Group. (n.d.). Retrieved 02 26, 2013, from http://www.oldsite.adwea.ae/eng/adweagroup.html

Austin, M. (2010, June). *Reviews: Smart ED*. Retrieved 1 3, 2013, from Car And Driver: http://www.caranddriver.com/reviews/2011-smart-fortwo-electric-drive-first-drive-review

Auto Observer. (n.d.). Retrieved from http://www.autoobserver.com//2010/04/mitsubishi-heavy-industries-to-experiment-with-switchable-battery-electric-buses.html

Autolib'. (n.d.). Retrieved 2012, from https://www.autolib.eu/

Becker, T. A. (2009). *Electric Vehicles in the United States: A New Model with Forecasts to 2030.* Berkley: University of California.

Berman, B. (2011, 1 9). Retrieved 1 5, 2013, from Plug-in Cars: http://www.plugincars.com/exclusive-byd-executive-provides-breakthrough-us-pricing-chinese-electric-car.html

Business Wire. (n.d.). Retrieved from http://www.businesswire.com/news/home/20110725006431/en/BYD-Signs-World%E2%80%99s-Largest-Public-Electric-Vehicle-Fleet

BusinessList.AE. (n.d.). Retrieved 02 26, 2013, from http://www.businesslist.ae/

Cities, C. (2012). *Plug-In Electric Vehicle Handbook for Public Charging Station Hosts.* Alternative Fuels Data Center, U.S. Department of Energy.

DriveClean. (n.d.). Retrieved October 2012, from

http://www.driveclean.ca.gov/incentive_detail.php?incentive_id=36&type
=

Drone, W. (2011, 10 31). *Renault Fluence ZE – the best pure electric car yet?*
Retrieved 15 2013, from The Guardian:
http://www.guardian.co.uk/environment/2011/oct/31/renault-fluence-ze-el
ectric-car

e6. (n.d.). Retrieved 1 2, 2013, from BYD: http://www.byd.com/auto/e6.html#p2

Electromobility in Berlin. (n.d.). Retrieved 11 1, 2012, from eMO:
http://www.emo-berlin.de/en/

eTec. (2010). *Electric Vehicles Charging Infrastructure Deployment Guidelines
for the Oregon I-5 Metro Areas of Portland, Salem, Corvallis and Eugene.*
ELECTRIC TRANSPORTATION ENGINEERING CORPORATION,
Ecotality.

Fabian Kley, C. L. (2011). New business model sfor electric cars— A holistic
approach. *Energy Policy*.

Fit EV. (n.d.). Retrieved 1 5, 2013, from Honda Automobiles:
http://automobiles.honda.com/fit-ev/reviews.aspx

Fluence ZE. (n.d.). Retrieved 1 5, 2013, from Renault Zero Emission Vehicles:
http://www.renault-ze.com/en-gb/z.e.-range/fluence-z.e./fluence-z.e.-193
5.html

Focus Electric. (n.d.). Retrieved 1 5, 2013, from Ford Media:
http://media.ford.com/images/10031/2012_FocusElectric.pdf

General Electric. (n.d.). Retrieved from
http://www.gereports.com/in-largest-single-commitment-ge-to-buy-25000
-electric-vehicles/

IDFC. (September 2010). *Policy Group Quarterly.* Mumbai: IDFC.

iMiEV. (n.d.). Retrieved 1 7, 2013, from
http://www.mitsubishicars.com/MMNA/jsp/imiev/12/specs.do?#engineerin
g

Ishitani, H. (2009, April). Roads Open For Electric Vehicles. *Highlighting Japan
Through Articles*, pp. 11-13.

JAMA. (2012). *The Motor Industry of Japan 2012.* Japan Automobile
Manufacturers Association: JAMA.

James W. May and Matt Mattila. (2009). *Plugging In: A Stakeholder Investment
Guide for Public Electric-Vehicle Charging Infrastructure.* Rocky Mountain
Institute.

Jie Zhenga, S. M. (2011).
StrategicpoliciesanddemonstrationprogramofelectricvehicleinChina. *Transport Policy*, 17-25.

Jordi Perdiguero, J. L. (2012). *Policy Options for the Promotion of Electric Vehicles: A Review.* Barcelona: Research Institute of Applied Economics (IREA).

Kerin Cantwell, I. C. (2012). *US-China Market Review, China Policy: The Road Map for Electric Vehicles.* ACORE, CREA.

Kneeshaw, S. (2012). *Oslo Stockholm Network Meeting and Study Visit May 2012.* Electric Vehicles in Urban Europe.

Koskue, M. (September 2012). Electric Vehicles In Finland. *Electromobility in Europe*, 12-13.

Leaf. (n.d.). Retrieved 1 7, 2013, from NissanUSA: http://www.nissanusa.com/leaf-electric-car/range?next=ev_micro.section _nav

Meyer, G. (2009). *Report on a European Commission Workshop: European Commissions' and Member States' R&D Programmes for the Electric Vehicle.* Berlin: Seventh Framework Programme.

MyCityWay. (2012). *MyCityWay Announces Integration with BMW's DriveNow Car Sharing Fleet at the Content and Apps for Automotive Conference - Yahoo! Finance*. Retrieved 12 15, 2012, from http://finance.yahoo.com/news/mycityway-announces-integration-bmw-dr ivenow-090000790.html

National Council of State Legislatures. (n.d.). Retrieved from http://www.ncsl.org/issues-research/energyhome/state-electric-vehicle-in centives-state-chart.aspx

O'Connor, M. C. (2012, 6 5). *Car2go: a case study for electric carsharing*. Retrieved 11 12, 2012, from http://analysis.evupdate.com/commercialization-evs/car2go-case-study-e lectric-carsharing

Rav4 EV. (n.d.). Retrieved 1 5, 2013, from Toyota: http://www.toyota.com/rav4ev/specs.html

Recharging Infrastructure. (n.d.). Retrieved 10 2012, from Department for Transport. UK: http://www.dft.gov.uk/topics/sustainable/olev/recharging-electric-vehicles

Renault Fluence ZE. (n.d.). Retrieved 1 5, 2013, from Renault Cars:

http://www.renault.com/en/vehicules/aujourd-hui/renault-vehicules-electriques/pages/fluence-ze.aspx

Ridden, P. (2012, June 7). *Honda Fit EV receives highest-ever EPA efficiency rating* . Retrieved 1 6, 2013, from Gizmag: http://www.gizmag.com/honda-fit-ev-highest-epa-fuel-efficiency-rating/22846/

Russell Hensley, John Newman, and Matt Rogers . (2012, 07). *Battery technology charges ahead* . Retrieved 02 02, 2013, from McKensey Quarterly: http://www.mckinseyquarterly.com/Battery_technology_charges_ahead_2997

San Jose Downtown Parking. (n.d.). Retrieved November 2012, from http://www.sjdowntownparking.com/clean_air.html

Smart ED. (n.d.). Retrieved from http://int.smart.com/products-smart-fortwo-electric-drive-product-variants-electric-drive/aaae7c84-981f-5b38-ad55-6d245fe9ffa6

Soylu, S. (2011). *Electric Vehicles -- The Benefits and Barriers.* Croatia: InTech Open.

Stationary Gas Turbines. (n.d.). Retrieved 12 21, 2012, from EPA: http://www.epa.gov/ttnchie1/ap42/ch03/final/c03s01.pdf

Stephen Brown , David Pyke , Paul Steenhof. (2010, March). Electric vehicles: The role and importance of standards in an emerging market. *Energy Policy*.

Tesla Model S. (n.d.). Retrieved from http://www.teslamotors.com/models/options

TransAD. (n.d.). Retrieved 02 25, 2013, from http://www.transad.ae/en/default.aspx

Transport for London. (n.d.). Retrieved from http://www.tfl.gov.uk/corporate/media/newscentre/archive/15017.aspx

Transport, D. o. (2009). *Abu Dhabi Surface Transport Master Plan: A Vision for Connecting Abu Dhabi -- The Plan.* Abu Dhabi: Department of Transport.

Wong, W. (2012, March). Retrieved from Chicago Tribune: http://articles.chicagotribune.com/2012-03-22/classified/ct-biz-0322-zipcar-20120322_1_car-sharing-service-chevrolet-volts-350green-llc

ZipCar. (2012, 9 13). *ZipCar Press Release*. Retrieved 12 1, 2012, from Zipcar San Francisco Fleet Now Includes New Honda Fit EV:

http://ir.zipcar.com/releasedetail.cfm?releaseid=706763

2 Survey of public acceptance of options (Chapter Lead: S. Sgouridis)

2.1   Survey Objective

In order to gauge the current level of understanding and the public's perception of EV's we have conducted a public survey of a representative sample of the UAE population potential users and targeted survey of the fleet operators for their perspective on the use of electric vehicles for their needs. The description and findings from this analysis is provided in the following sub-sections. The survey of public perception for EV adoption consisted of two parts: a focus group discussion (4 mini-groups) and a targeted questionnaire as shown in Appendix I. Both surveys were conducted by YouGov, an agency specializing in market research. An additional survey using online questionnaires is ongoing and will be used to further confirm our findings.

2.2   Survey Demographics

The sample of 384 respondents was chosen from long-term UAE residents and its breakdown is shown **Figure 2-1 Overall Survey Demographics**and **Figure 2-2 Income and Residency Survey Sample Breakdown**. It was intended to be representative of the likely car buyers and therefore was skewed towards males, higher incomes (>15,000AED/month mean household income), Emirati nationals, middle-aged professionals, and Abu Dhabi residents.
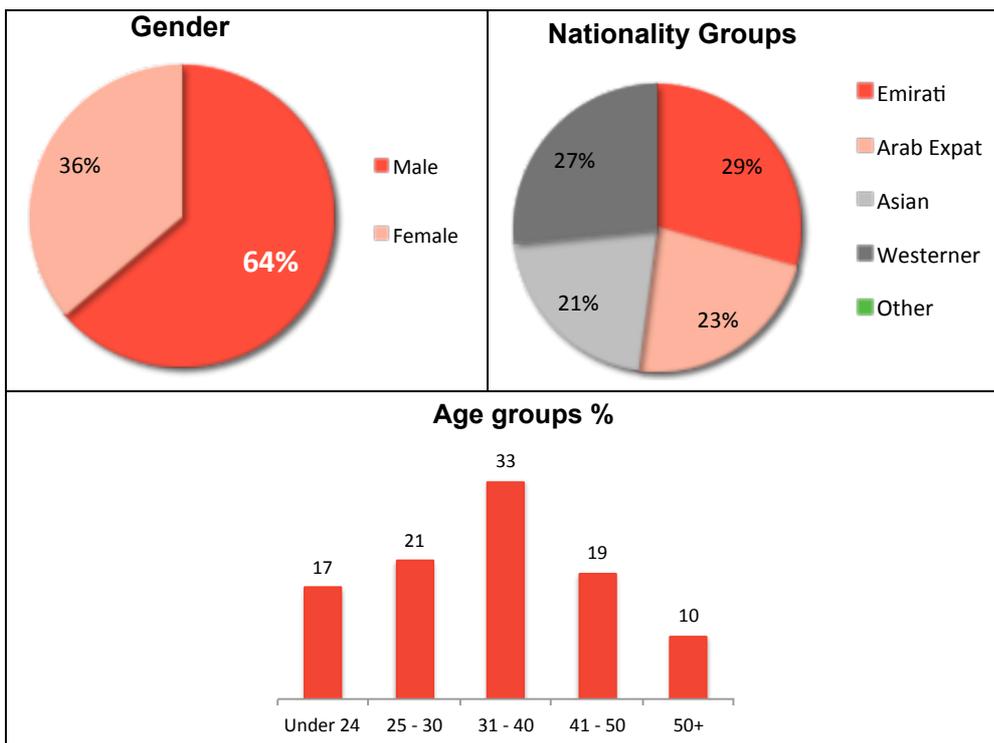
Figure 2-1 Overall Survey Demographics
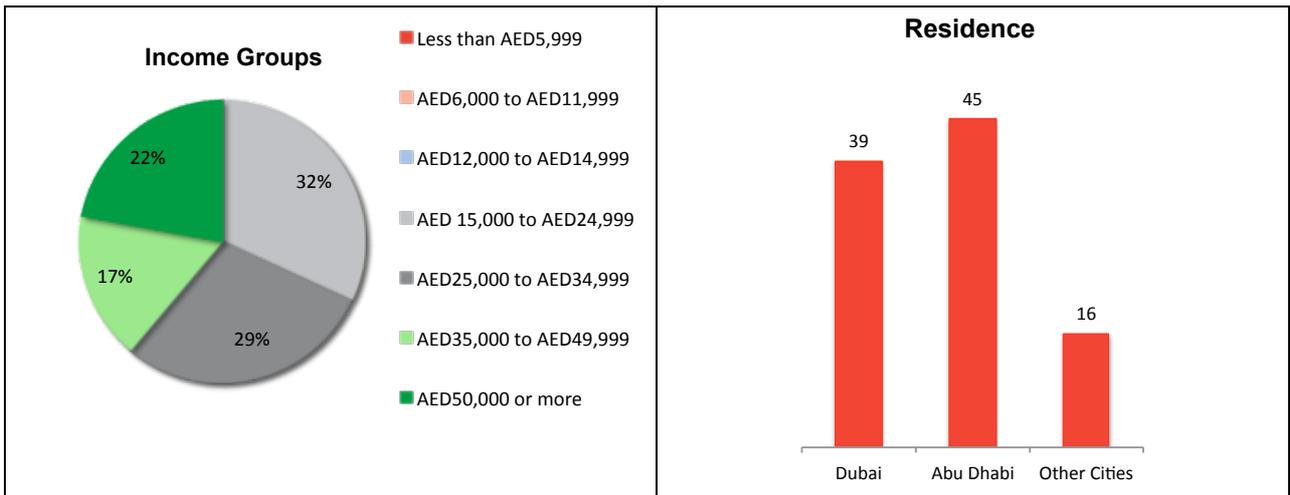
Figure 2-2 Income and Residency Survey Sample Breakdown

2.3 Private Vehicle Transportation Preferences

Our respondents make an average of more than 16 weekly trips broken down in the frequency pattern shown in **Figure 2-3**. On average, they spend approximately 1 hour per day in the car, with only 23% spending more than 90 min. This is indicative that the driving needs of our respondents would overwhelmingly fall under 80km per typical day (average of 56km in a typical day) and therefore be easily within the single-charge range of the current generation of BEVs. On the other hand, approximately 58% make one or more trips of 100+km per week (cf. **Figure 2-4**). This is confirmed in terms of annual distance, as 27% clocks between 30 and 40,000 km per year indicating that there are long-trip distances as well (as the average in this case is 110km per day). This is because Dubai residents are more likely to make multiple 100+ km trips than Abu Dhabi residents.
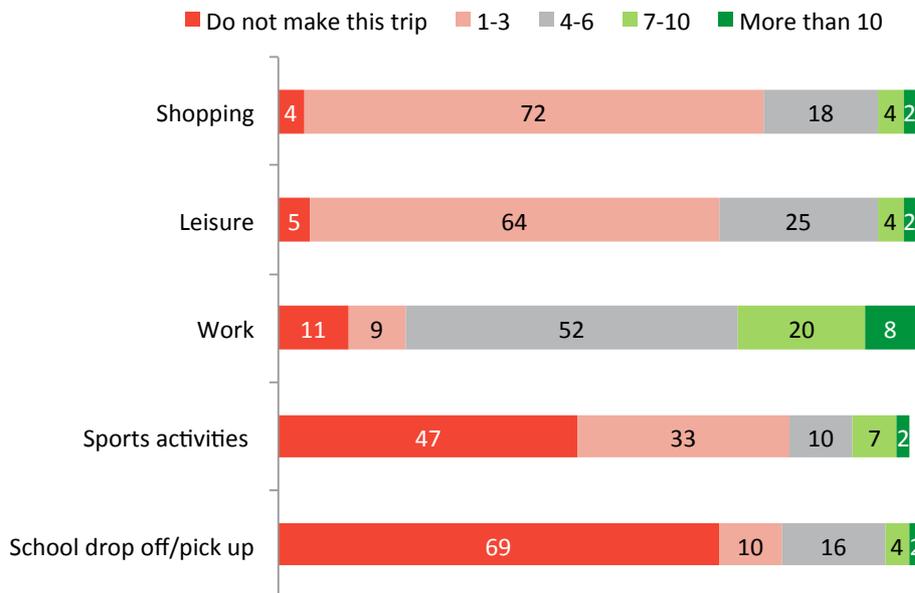
Figure 2-3 Weekly Trip Frequency

Time spent driving per day

Category	Percentage
90 minutes or more	23%
60-89 minutes	28%
30-59 minutes	36%
Less than 30 minutes	10%
Not Applicable	3%

Taking 100km+ trips

Category	Percentage
More than once in a week	24%
Once a week	34%
Once a month	18%
Less than once in a month	19%
Not applicable	5%

Distance per day

Category	Percentage	1 (Only driver)	2	3 or more	Not applicable
Under 10Km	10%	54	22	21	4
10-29Km	19%	40	30	23	7
30-49Km	30%	30	29	33	8
50-100Km	28%	20	28	42	10
More than 100Km	13%	16	20	47	17

Category	Percentage
Less than 5,000Km	3%
5,000Km-9,999Km	8%
10,000Km-19,999Km	13%
20,000Km-29,999Km	23%
30,000Km-40,000Km	**27%**
More than 40,000Km	14%
Don't know	12%

Annual vehicle-km %

Figure 2-4 Trip time, Length, and Passenger Number

Our respondents confirmed the overwhelming preference of this demographic segment

for private car transport as shown in **Table 2-1**. With the exception of school and sports activities, more than 90% of the respondents prefer a private car. For the former two, still 81% and 86% respectively prefer private vehicles.

Table 2-1 Percentage of Transportation Mode Preference

	Work (Base 288)	School drop/pick up (Base 83)	Leisure (Base 316)	Shopping (Base 321)	Sports activities (Base 152)
Private vehicle	92	81	92	93	86
Taxi	1	2	2	1	1
Bus	2	12	2	2	5
Car pooling	2	4	1	2	3
Metro	1	1	1	2	1
Bicycle	0	0	0	0	3
Other	2	0	1	0	1

Car sharing was considered as something that would be interesting to a slight majority of the respondents although 40% tended to react skeptically. Older respondents seemed more amenable to this option than younger ones (32% of the 41+ group responded that they would consider it favorably as opposed to 21% of the younger group 21-30) which, interestingly, is contrary to current trends among youth in US and Europe.
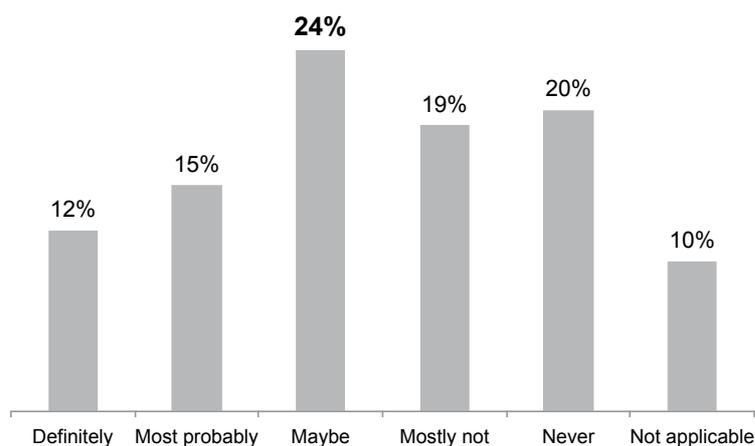
Figure 2-5 Car-sharing preference
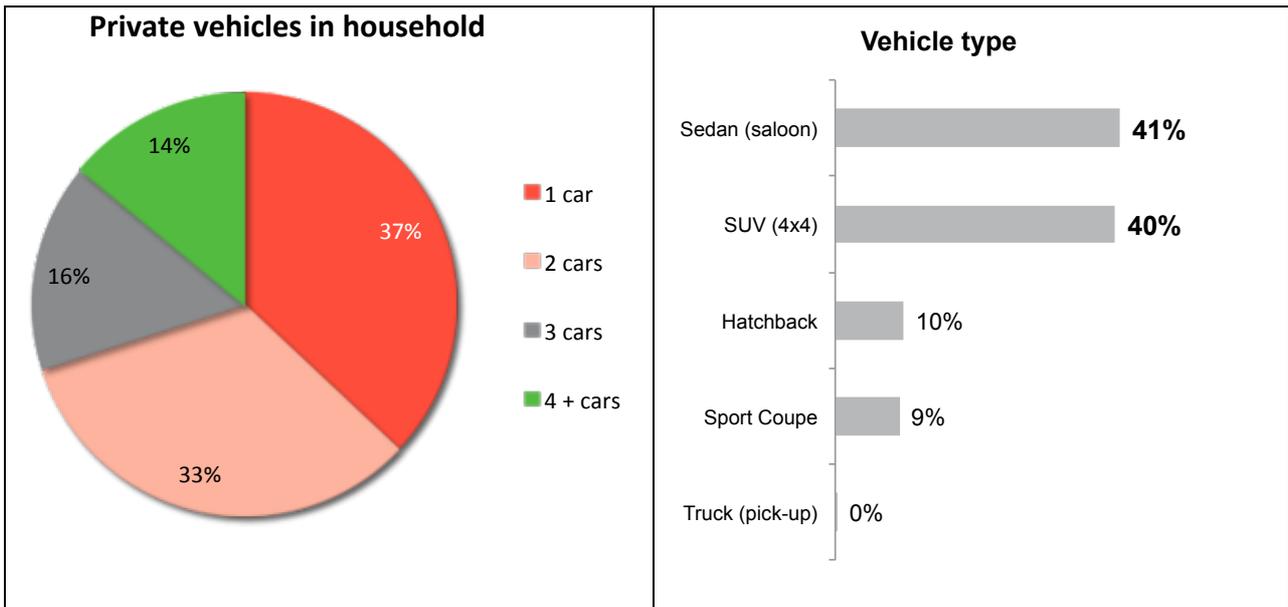
Figure 2-6 Number and Composition of Vehicles by Household

The desire to consider car sharing is even more interesting given that the majority of the households surveyed (63%) already have 2 or more vehicles with 14% having four or more. Of those vehicles, there is an approximately even split between sedans and SUVs which also reflects the engine size.

2.4   Private Vehicle Perceptions and Environmental Awareness

The fact that the UAE maintains a car-oriented culture for the more affluent residents is reaffirmed by the findings of this study. From the focus groups, especially among the UAE males, car was perceived as a status symbol (see **Figure 2-7**). In all groups, the choice of the vehicle is far from being based on economic criteria when it comes to the choice of a large car but becomes much more so when it comes to the choice of a smaller car (see Figure 2-8).

Emirati Males are passionate about their cars: They are an extension of their lifestyle and personality

My second home

Spend a lot of time cruising in their cars

Can't live without it

Passionate about cars

Passionate about driving

Cars represent status and power. A personal sense of accomplishment and outwardly show of success.
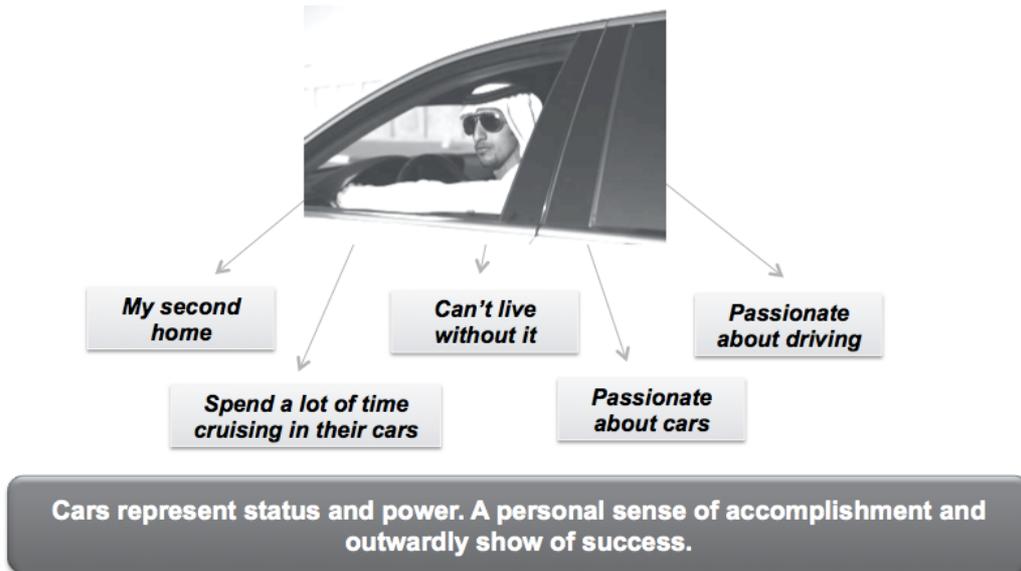
Figure 2-7 Qualitative Perception of Vehicle Ownership

Legend: Very important | Important | Neither important nor unimportant | Not important | Not at all important

Attribute	Very important	Important	Neither	Not important	Not at all
Saftey	69	24	5	0	
Space	66	28	5	0	
Refinement	57	30	11	0	
Off-road Ability	53	27	15	3	1
Fuel Economy	51	38	8	3	1
Speed	51	32	11	4	1
Prestige	48	32	15	4	1
Low Purchase Price	45	41	10	2	0
Environmental Friendliness	28	35	26	3	1

% Large Car

Figure 2-8 Decision Factors for Vehicle Choice

With regard to environmental concerns, the large majority of our respondents indicated that they consider climate change as an important or very important issue (69%) with Emiratis and Asians being the group that was more sensitized to it (75% and 77% respectively) while Europeans indicated the least concern (59%)! Nevertheless, when it comes to vehicle buying, environmental performance alone is not providing a compelling motivation yet.

The lack of awareness on modern BEV development led our focus group participants to consider EVs with the prior experience of small/open golf cart type cars. Their associations were with small, impractical for large families, not rough, not powerful, not fast, basic/no advanced features. EVs lacked emotional and functional appeal. The perceptions changed when shown photographs of currently produced vehicles like the Tesla Model S, Fisker Karma and larger EV platforms.

Among the quotes received after seeing the existing range were:

"They are exactly like normal cars" Arab, Expat, Male

"All our perceptions were based on the idea that EVs are small cars" Emirate Female

"It is not a dream world anymore, it is happening now" Western Female

In the quantitative survey, this was also reflected in the perception of the possibility of buying BEVs. Approximately half of the respondents indicated potential interest in buying an EV (cf. **Figure 2-9**). Despite the fact that nationals considered climate change as extremely important they are the least likely to buy an EV with the Westerner and Asian expats being the more open to do so.
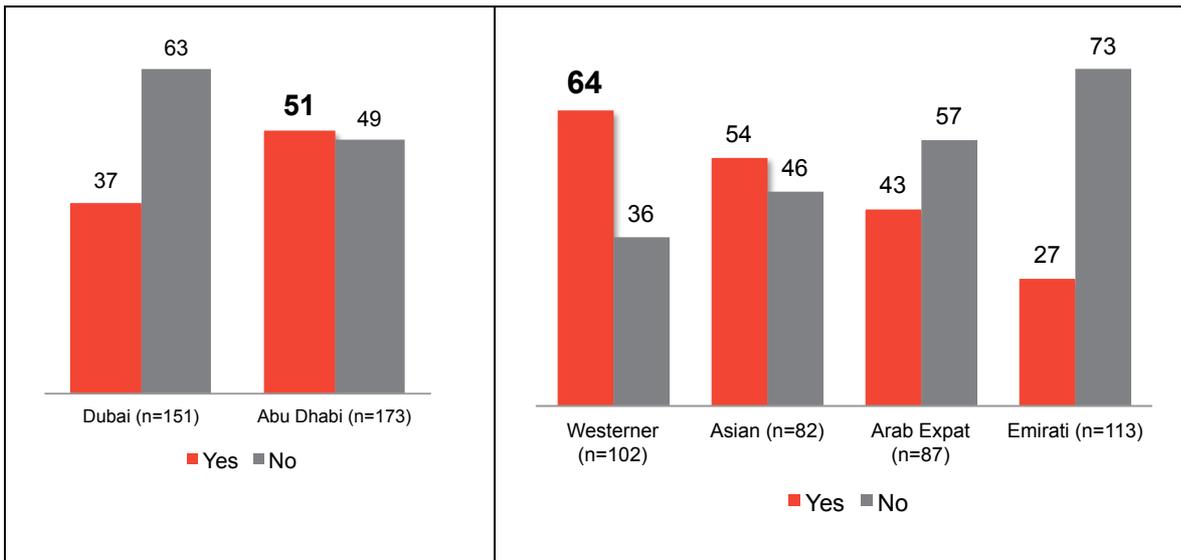
Figure 2-9 Consideration for Buying an EV by Residency and Nationality

The key barriers to EV adoption were ranked by our respondents as shown in **Figure 2-10**. The top five reasons are directly related to battery technology (hassle of charging, battery life) or are derivative (high price, short-range) but clearly the most important is the availability of charging infrastructure. This "range anxiety" was obvious also in the qualitative responses of the focus groups using these characterizations: "confining", "limiting", "anxious", "cannot be spontaneous" to describe their feelings with regard to the need of charging in an environment with no public infrastructure thus requiring a thorough pre-plan of their trips.
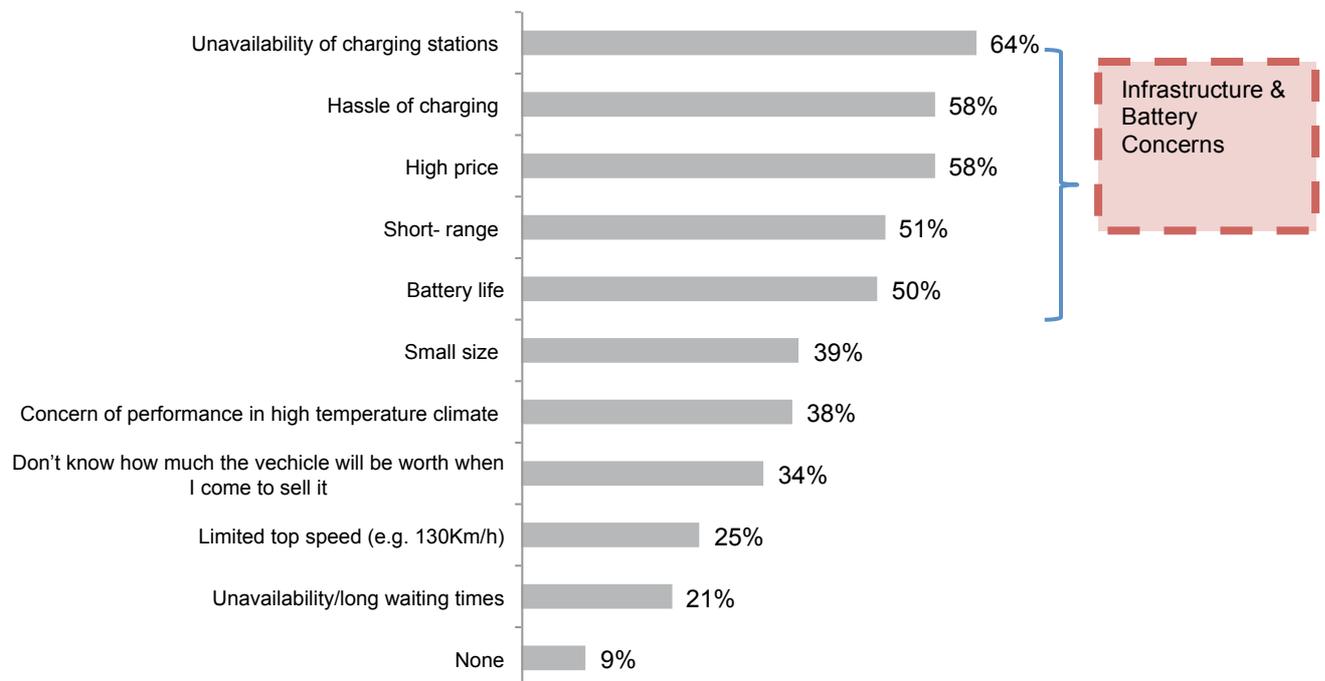
Figure 2-10 Perceived Barriers to EV Adoption

Inversely, availability of infrastructure and lower costs were considered the primary reasons that would decrease the barrier for choosing an EV with registration and toll waiver being the lowest ones (cf. **Figure 2-11**). On the positive side, the novelty and coolness factor could be an attractor for Emirati lead adopters.

■Very important ■Important ■Neither important nor unimportant ■Not important ■Not at all important

	Very important	Important	Neither important nor unimportant	Not important	Not at all important
Availability of charging point at key locations (e.g. parking, malls, workplace etc)	60	23	8	4	3
Equal or lower purchasing costs of EV's compared to conventional vehicles	55	29	9	3	2
Low operating costs (e.g. Ev's require less maintenance as they have less moving mechanical	54	29	9	2	3
Free charging electricity, assuming increasing gasoline prices	53	30	11	2	2
ITS service (Intelligent Transportation System, like electronic signs that facilitate EV maneuverability)	49	27	15	4	2
Guaranteed or free parking at public locations (e.g. roads and malls)	49	32	11	3	2
Avoiding fuel station queues	45	26	9	10	4
Congestion avoidance option through an EV dedicated road or lane	45	35	11	3	3
Registration fee waiver	45	32	12	5	4
Toll road (e.g. SALIK) waiver- Assuming tolls are implemented in the region where you drive	41	27	16	12	3

%

Figure 2-11 Importance of Incentives for Overcoming Barriers

2.5 EV Perceptions Conclusions

Since the car users with the propensity for the luxury/upscale vehicle segment is not sensitive to economic performance, BEVs would need to demonstrate equivalent or better features to ICEV to gain traction in the UAE. In the small car market segment, fuel economy becomes important. Safety is ranked first in all segments.

In any segment, range anxiety is a key barrier for adoption of EVs and the need for concurrent infrastructure development by charger installation would go a long way in allaying those fears. For the respondents in apartments (the majority), the difficulty in installing a charger at home provides an additional barrier. These issues would indicate that plug-in hybrid options may be initially a better option for private users while the government supported push for charging stations takes shape.

Other incentives, like toll waivers are not considered as important with the exception of parking availability in public parking areas.

3 Impacts of EVs on the Abu Dhabi Road Transportation & Electrical

Energy Systems (Chapter Lead: A. Farid)

Electrical vehicles (EV) are fundamentally a part of two physical systems: the road transportation system and the electrical energy system.   In the road transportation system, the EV adds, much like other vehicles, to road and parking congestion; but does so in a modified way due to its constraints on vehicle range and charging patterns.   In the electrical energy system, the charging requirement places an energy demand that can be studied in terms of both energy as well as instantaneous power withdrawals.   Finally, modern day road transportation systems are being upgraded with supporting information technologies called Intelligent Transportation Systems.   Such systems help maintain situational awareness for drivers and traffic control centers alike.   If EV's are to be accepted by everyday consumers, they must interface and interact with these three systems.   This chapter presents a "systems-of-systems" [21][22] approach to studying the impacts of EVs on these three systems in the context of Abu Dhabi island. Section 3.1 addresses traffic congestion by simulation of the Abu Dhabi road network.   Section 3.2 moves on to discuss integration with the Abu Dhabi Department of Transportation Intelligent Transportation System.   Section 3.3 discusses the electrical energy impacts from the perspectives of power and energy in Section 3.3.1 and 3.3.2 respectively. Finally, Section 3.4 gathers the conclusions of the chapter.

3.1. Abu Dhabi Traffic Simulation Base Case

The heart of this study relies on a highly detailed and calibrated simulation of traffic behavior and route patterns on Abu Dhabi Island.   This section describes how such a base case simulation was developed.   Later on in Chapter **Error! Reference source not found.**, this base case will be modified to create a number of simulation experiments or cases to study deeply the technical barriers to EV adoption.   This section proceeds as follows.   First, a number of traffic simulators are reviewed so that Section **Error! Reference source not found.** can identify the functional requirements of a traffic simulator appropriate to EV integration. Next, Section **Error! Reference source not found.** demonstrates a schematic design of the Clean Mobility Simulator (CMS) functionality and explains why it is an appropriate simulator for this study. Finally, Section 3.1.4 explains the development of an Abu Dhabi Island traffic behavior base case.

3.1.1   Review of Traffic Simulation Models

Over the years, many types of traffic simulation models have been developed to address different types of studies into transportation behavior. The various types of simulation models, displayed in **Error! Reference source not found.**, can be effectively used to assess the impact of changes in traffic behavior. Such simulators help evaluate the potential benefits of new real-time traffic control and management functions within the framework of a traffic system [2]. Depending on their application type, traffic simulators can be used when designing, planning or operating a transport system.

Table 3-1 Classification and Application Types of Transportation System Models [1][2]

Name	Classification	Application Type

	Discrete time	Discrete Event	Microscopic	Mesoscopic	Macroscopic	Deterministic	Stochastic	Design	Planning	Operations
CORSIM	X		X				X	X		X
DYNASMART	X			X		X			X	X
NETFLO 1		X		X			X	X		X
PARAMICS	X		X				X	X		X
SYNCRO	X				X	X		X		
VISSIM	X		X				X		X	X
TRANSIMS	X		X				X		X	
TransModeler	X		X				X	X		X
TRANSYT-7F	X				X		X	X		X
CMS	X		X			X		X		X

A common problem in these models is that traffic density has not been linked to energy management. The available traffic simulation models were created under the assumption of an exclusively internal combustion vehicle fleet. EVs, on the other hand, require more data to be simulated in order to calculate changes in the state of charge. For example, battery temperature, battery start state, and weather conditions are all new variables introduced to the simulation model when simulating EV traffic behavior. **Error! Reference source not found.** displays the required input data to calculate the state of charge [1]. Monitoring the state of charge helps determine the travel range of EVs as well as the subsequent charging patterns.
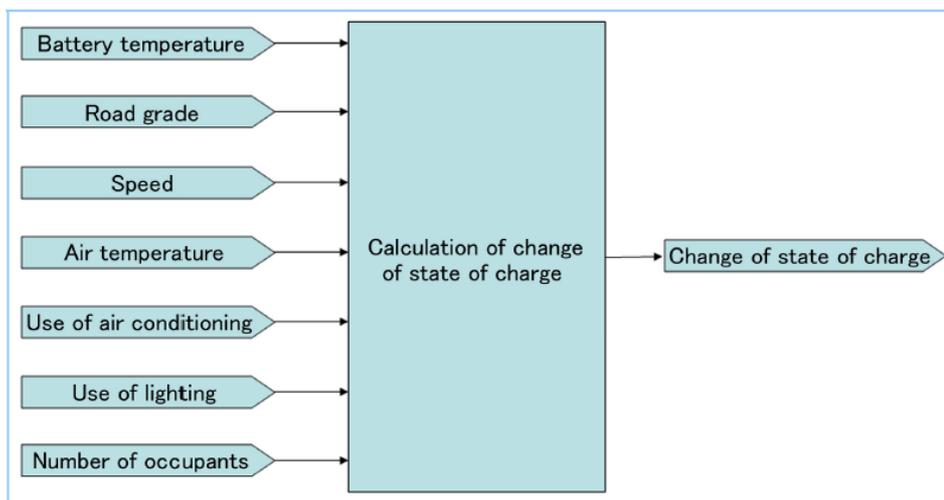
Figure 3-1 Parameters required to calculate state of charge in CMS [1]

3.1.2 Functional Requirements for EV Simulation

One of the main distinguishing features of a traffic simulation appropriate for EVs is that

EVs must be distinguished from the rest of the ICV fleet.   This implies a number of other functional requirements. A traffic simulator is required to be microscopic, discrete-time, deterministic as well as operations-oriented. A microscopic simulator keeps track of each individual vehicle in the simulation, it is able to differentiate between ICV's and EV's. This differentiation allows the simulated motion of ICVs and EV to take into account technical differences in vehicle characteristics. A discrete-time simulator is able to simulate the time dependent location and speed of each vehicle. In an EV traffic simulation, it is necessary to analyze the individual location and speed to determine the charging patters for further analysis of the charging loads. Therefore, a discrete-time simulator is recommended. A deterministic simulator provides predictable results of traffic behavior. In an EV simulation, analyzing the charging loads are determined by the traffic behavior. To study the charging loads, a deterministic simulator will give results that are determined by predictable results based on previously detected parameters of an EV. Finally, an operations-oriented simulator assumes the transportation network is fixed over the simulation duration. For an EV simulation, it is necessary to set have a fixed transportation network to simulate the EV behavior over the simulation time period.

A traffic simulation appropriate for EVs must also recognize the electrical aspect of the vehicle in terms of its electrical charging and discharging.   In terms of charging, various types of chargers are available and each has a set of parameters. For example, a type II charger can charge at an average rate of 19kW while a type III charger can charge at 50kW. The traffic simulator needs to have the ability to distinguish between charging stations to monitor each charging station load separately. In terms of discharging, the user must be able to input a set of parameters that the simulator will use to calculate a vehicle's state of charge over time. To calculate the discharge rate, the user needs to have the ability to input a number of parameters. As shown in **Error! Reference source not found.**, a number of parameters will have the impact on the discharging rate of the vehicle. For example, the EV discharges its battery at a higher rate at higher temperatures. Additionally, EVs require energy for air-conditioner usage which depends on both the driver's attitude as well as the air temperature. The ability to set the parameters shown in **Error! Reference source not found.** result in more faithful simulations of the actual EV discharge.

In summary, the functional requirements for a traffic simulator recommended to simulate EV traffic behavior are the following:

1. Microscopic – Ability to differentiate between ICVs and EVs
2. Discrete-time – Ability to simulate the time dependent location and speed of each vehicle
3. Operations-oriented – Assumes the transportation network is fixed over the simulation duration
4. Deterministic – Provides predictable results of the traffic behavior
5. Monitors state of charge

3.1.3 Clean Mobility Simulator Functionality

As shown in **Error! Reference source not found.**, the CMS has all the required functionalities of an EV simulator and is therefore well suited suited for this study. A discrete-time simulator is required because the sampling of a variable at a finite interval gives the state of charge at any given time. Microscopic simulators give a detailed output of each vehicle. This feature allows the study to understand the behavior of each vehicle and its charging patterns in each geographical location. As a result, the CMS is a tool that has potential to help understand whether EVs, with their technical limitations, meet the needs of transportation behavior in Abu Dhabi. The CMS also has the ability to simulate traffic behavior while determining the energy demand and charging curves of EVs. The results of the simulation will be further extended to understand the impact of EVs on the power network in Section 3.3. A schematic design of the CMS behavior is shown in Figure 3-2.
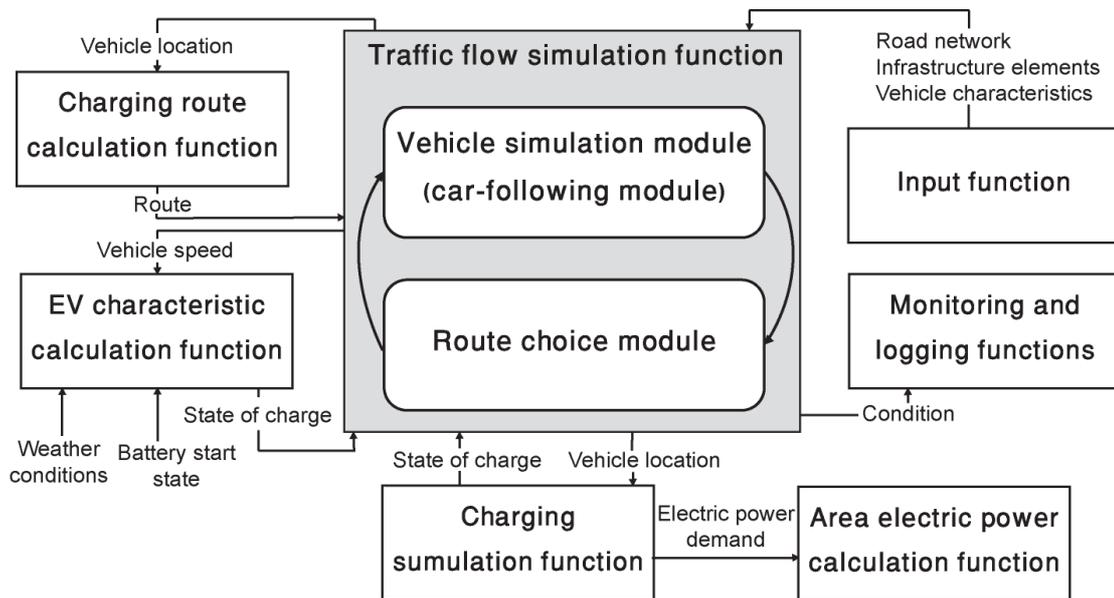
Figure 3-2 Schematic design of the CMS behavior [1]

Monitoring the state of charge determines if the travel distance and battery consumption of EVs that match the route patterns of Abu Dhabi's traffic. EVs have unique challenges as opposed to conventional vehicles. A large number of batteries are required to assure a desired level of power performance in an EV. Also, the travel distance is limited to the level of charge in an EV [C]. These technical barriers can be further studied using the clean mobility simulator (CMS) provided by Mitsubishi Heavy Industries (MHI). The CMS is an appropriate tool to study the electrification of a transportation system as it incorporates energy management. This simulator also helps facilitate the spread of EVs by simulating city traffic flows and quantitatively evaluating traffic-related urban comfort and energy management [1].

3.1.4 Development of Abu Dhabi Island Traffic Behavior Base Case

Once, the CMS was chosen as the traffic behavior simulator a number of steps were taken to develop a detailed and well-calibrated traffic behavior simulation base case of Abu Dhabi Island. Figure 3-3 demonstrates the process of development. First, Abu Dhabi island was chosen as the geographical scope of the traffic simulation as it is the most densely populated geographical location in Abu Dhabi emirate. Abu Dhabi island, also has the highest likelihood of EV adoption. Thirdly, the data for CMS simulator was gathered from different sources which include: traffic counts provided by DOT, GPS loggers measured by MHI and STEAM simulator parameters of the 2015 model from DOT. Next, the road transport network was determined and the CMS input file was generated. Finally, to complete the Abu Dhabi base case, the model was validated and calibrated by being compared to the STEAM model results.

| 1. Determine geographical scope | 2. Acquire data for CMS | 3. Determine road transport network | 4. Generate CMS input file | 5. Validate CMS input file as compared to SOUND |
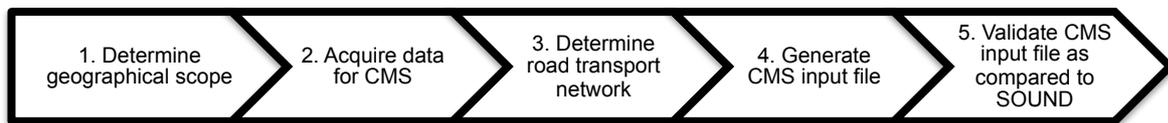
Figure 3-3 Development of traffic simulation base case

3.1.5 Summary of Abu Dhabi Traffic Simulation Base Case

The outcome of this procedure was a detailed and well-calibrated Abu Dhabi Island traffic simulation base case implemented in the CMS for EV penetration study. To determine the traffic behavior of EVs in AD transport, a number of cases will be simulated using the CMS. The hypothetical cases can be imported into the Abu Dhabi base case that represents the AD transport system. However, the outcome of the cases will incorporate EV as new types of modes of transport. In addition, the charging stations and their associated parameters are added to the base case to study the charging curve. By using, the Clean Mobility Simulator, and traffic parameters relevant to AD DOT, the simulation results promise to give a quantitative understanding of the charging behavior and mileage limitations in a model that represents real traffic behavior of Abu Dhabi. Figure 3-4 displays a screen shot of the final Abu Dhabi CMS base case model. Chapter 4 will give a detailed explanation of the development of the cases used to conduct the simulation experiments.
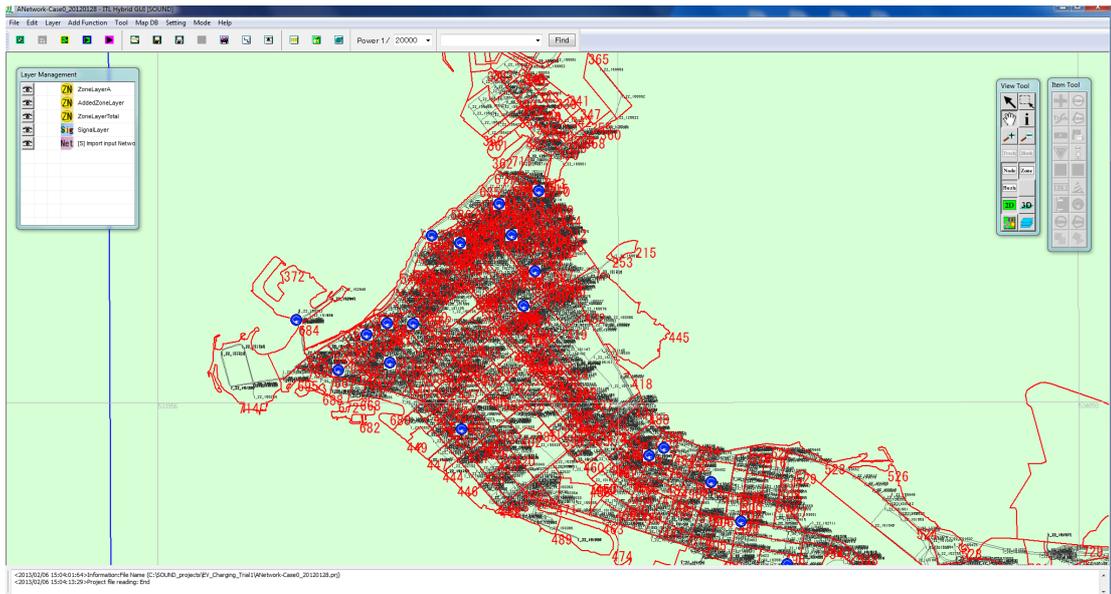
Figure 3-4 Model of Abu Dhabi transportation network in CMS

3.2 Abu Dhabi Department of Transportation Intelligent Transportation System

Over the past decades, an ITS has generally been referred to as a variety of tools that can be applied in an integrated fashion into the transportation system to improve efficiency and safety [4]. This study has identified that the electrification of the transport system requires additional functionalities. Advanced energy management through information systems to support the electrification of a transport system is one example of an added functionality. In any given intelligent transportation system, the functionalities are built in a way to support ICVs. Therefore, the transportation system is mainly built with gas stations distributed in such a way as to support ICVs for re-fueling as opposed to charging stations for charging [5]. As EV penetration increases, an ITS will need to integrate added services through its intelligent system to provide services to EV users.

Section 3.2.1 is a review of the ITS adopted worldwide in the context of EVs. It discusses the possible applicability of typical functionalities adopted worldwide in the integration of EVs. Section 3.2.2 demonstrated the available tools for modeling an ITS. The main tools discussed or modeling an ITS are Unified Markup Language (UML), Design Structure Matrix (DSM) and Multi-domain Matrix (MDM). Section 3.2.3 demonstrates the process of reverse engineering Abu Dhabi's ITS by identifying the system function, stakeholders and form. The following 3.2.4 highlights the possible integration of EVs into Abu Dhabi's ITS. Finally, Section 3.2.5 summarizes the conclusions on the EV readiness of Abu Dhabi's ITS.

3.2.1 Review of ITS Worldwide

According the specific needs of the geographies that they serve, modern traffic systems have benefited from the development of sophisticated ITSs that improve services in transportation system operations. The solutions provided by an ITS typically aim to create additional capacity that will meet the challenges of increasing travel demands. An ITS has the potential to improve traffic flow by reducing congestion, improve air quality by reducing pollution, and improve safety by providing advance warning [4][26]. A first scan of deployed ITS in both the developing as well as developed world shows a tremendous diversity of delivered functionality and form [1] [4] [6] [8] [9] [10] [24] [25]. The function and form of an ITS is tailored to fit the city in which it is located and varies depending on its identified stakeholders. These tailored ITSs reflect a set of functionalities suited for the geography, types of vehicles and level of IT deployment in a city. Abu Dhabi DOT has shown an interest in developing a world-class ITS [10]. **Error! Reference source not found.**, shows a list of examples of the services provided in Abu Dhabi's ITS, and the potential functionalities that may support integration of EVs.

Table 3-2 AD ITS Functionalities and their EV applicability [10]

ITS User Functionalities	EV Applicability
Pre-trip Travel Information	✓
En-route Transit Advisory	✓
Route Guidance	✓
Incident Management	✓
Traffic Control	
Commercial Vehicle Preclearance	
Commercial Vehicle Administrative Services	✓
Commercial Fleet Management	✓
En-route Travel Advisory	✓
Traveler Services Information	✓
Ride Matching and Reservation	✓
Travel Demand Management	✓
Electronic Payment Services	✓
Automated Roadside Safety Inspections	
On-board Safety Monitoring	

While many ITSs worldwide have been developed without EVs specifically in mind, their functionality would benefit from customization to support EVs.

3.2.2 Modeling Tools for ITS

To date, the authors are not aware of any methodologies to assess ITS customized for EVs. Perhaps, this omission is because of the tremendous diversity of ITS implementations, their embedded technologies and the absence of mainstream adoption of EVs [3][20]. Although a methodology of assessing an ITS in terms of social, political, and economic impact was found [11], it does not involve energy management within its framework. Given that an ITS is fundamentally an information technology system, the United States Department of Transportation suggests the usage of the Unified Markup

Language (UML) [12][23] as an appropriate tool for detailed modeling of ITS functionality. Despite its strengths, UML assumes that the systems engineering process of the ITS has proceeded sufficiently so as to map functionality to form [12][23]. To avoid this eventuality, this report also adds the Design Structure Matrix (DSM) and Multi-Domain Matrix (MDM) as additional tools to support the modeling and analysis of an ITS [14].   In order to guide the discussion, these two tools are briefly introduced in the following two subsections.

3.2.2.1 UML

UML is the default tool used for the modeling and assessment of information technology (IT) systems such as ITSs. It evolved to support the field of object-oriented modeling and design and its main concept is to represent systems in terms of its components parts and their respective functions. As such, it represents objects' data and methods in a single visual representation called a class diagram [12].

Figure 3-5 is simple example of a class diagram that categorizes a traveler into 3 categories [13]. Each category of traveler has different behavior and is therefore modeled differently. In this study, an EV driver will be modeled differently than an ICV driver because of the difference in their in behavior.
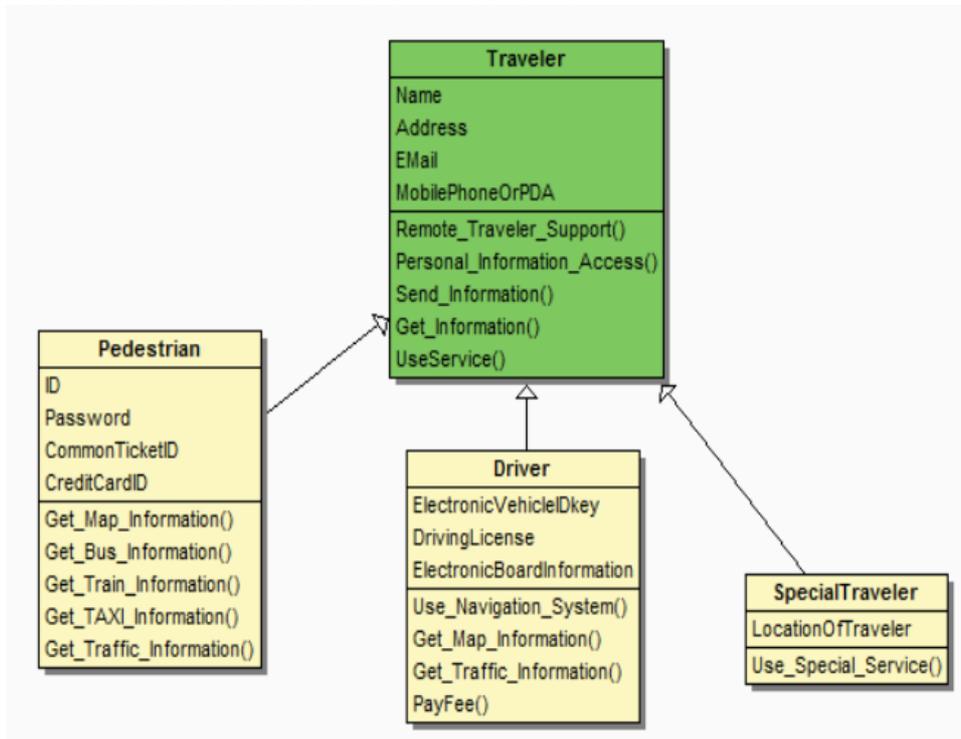
Figure 3-5 UML Traveler Class Diagram [13]

3.2.2.2 DSM/MDM

A Design Structure Matrix (DSM) is a network-modeling tool commonly used to represent elements comprising a system and their interactions [14]. DSM's are essentially N^2 diagrams that are structured in such a way as to facilitate systems-level analysis and process improvement [14]. DSM is suited to applications in the development of complex systems such as the systems modeled in this project. Figure 3-6 demonstrates the three main configurations of a DSM.
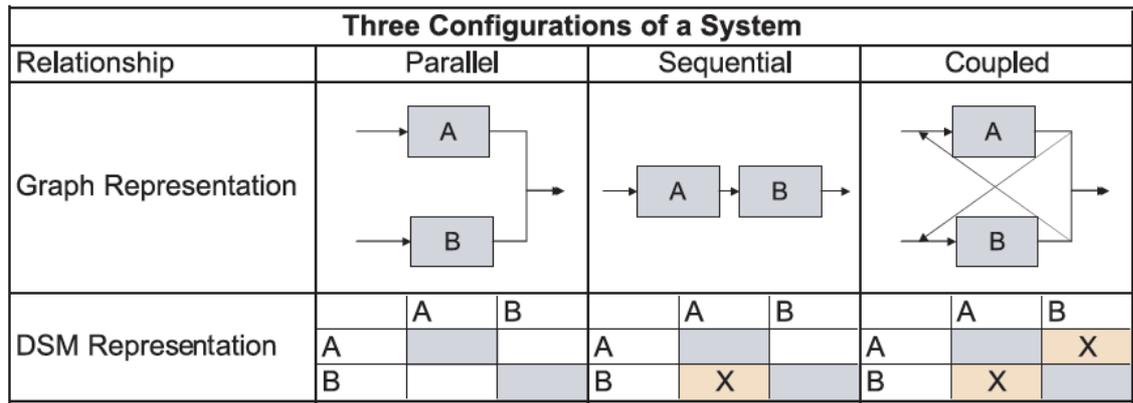
Figure 3-6 Design Structure Matrix Configuration [14]

A multi-domain matrix (MDM) is used to map components, people and activities into one DSM [14].   The graph theoretic approach gives a transparent representation of how the elements of these domains are interrelated and for this reason has been determined as the appropriate tool for the purpose of this study.. Figure 3-7 shows the three types of domains of the MDM used in this study: Functional Requirements, Components, and Stakeholders. These correspond to system function, form and stakeholders respectively.

	Functional Requirements	Components	Stakeholders
Functional Requirements	1		
Components	4	2	
Stakeholders	5	6	3

Figure 3-7 Multi-domain matrix (MDM)

3.2.3 Reverse Engineering the Abu Dhabi DOT ITS

In order to consider the feasibility of EV integration into the Abu Dhabi ITS, it is essential to understand the ITS in its current state of development through a process of reverse engineering.   Such an analysis may not be immediately straightforward as design documentation is relatively scarce and vague at the beginning of the systems engineering process and gains in size and details as the systems engineering process proceeds.   Another main issue identified in the AD ITS document was management of the relationships between stakeholders, components and functional requirement.   A typical ITS will consist in a large number of all three and managing their interrelationships is a particularly challenging task.

The MDM, as a modeling tool, provides an efficient approach to address such issues. For example, in Figure 3-7, submatrices 1, 2 and 3 show the interfaces within a single domain; be it functional requirements, components, or stakeholders.   Furthermore, submatrices 4, 5 and 6 show the relationships between any two of the three domains. Keeping track of these interfaces and relationships can guide later stages of the design

of an ITS especially as it begins to integrate EVs. This reverse engineering analysis will help demonstrate how the objects in the ITS interact.   Later on, Section 3.2.4 will show what types of interactions may be needed to support EV integration. The MDM can also show the potentially missing components in an ITS that can provide EV users with the service required for successful EV integration. First, this section begins by introducing the AD DOT ITS in a high-level view. Next, Sections 3.2.3.1, 3.2.3.2, and 3.2.3.3 will demonstrate the decompositional view of the functional requirements, stakeholders and components respectively.

The DOT ITS document is a strategy, architecture and implementation plan created by the TrafQuest and Iteris consultancy services for their client the Abu Dhabi Department of Transportation. The strategy is built upon the vision of the articulated Plan Abu Dhabi 2030 and the strategic direction provided by its Surface Transport Master Plan (STMP). The document demonstrates program packages as new functional requirements to be implemented within the years 2010 to 2030. The document also focuses on the stakeholders' responsibilities which it refers to as operational concept. Also, the inventory, or system components, has been determined in a high-level view to describe the recommended technology elements that will serve the main functional requirements. The document also highlights the roles and responsibilities of each of the stakeholders that comprise of users, operators and agencies [10]. The structure of the document provided by DOT encouraged the analysis to focus on the relationships of functional requirements, stakeholders and components. The high-level structure of Abu Dhabi's ITS is shown in Figure 3-8.

Figure 3-8 High-level decomposition of Abu Dhabi's ITS [10]

3.2.3.1 System Function

The system's high-level functionalities, referred to as 'Program Packages', were created by numerous workshops and as a response to the major stakeholders. The six high-level functional requirements demonstrated in Figure 3-9, were further decomposed into services. The reason these program packages were separated into six is because they had very similar components and stakeholders. However, the division between each program package does not necessarily mean that each program package is isolated from the rest. Each program package shared a technology element and stakeholders. The most recently introduced program package, called "Integrated Operations" and shown at the bottom of Figure 3-9, comprises of services that integrate the program packages together. For example, the 'ITS Data Warehouse' is a functional requirement in the 'Integrated Operations' program package which gathers data from all other program packages.

Functional Requirements

Regional Active Traffic Management (ATM) and Information
- Highway Network Surveillance
- Highway Traffic Probe Surveillance
- Highway Control
- Highway HOV Lane Management
- Highway Traffic Information Dissemination
- Abu Dhabi Regional Traffic Management
- Abu Dhabi Incident Management System
- Highway Traffic Decision Support and Demand Management
- Abu Dhabi Electronic Toll Collection
- Abu Dhabi Emissions Monitoring and Management
- Highway Roadside Lighting System Control
- Abu Dhabi Regional Parking Management
- Highway Speed Monitoring
- Abu Dhabi Roadway Closure Management
- Highway Traffic Website Broadcast Traveler Information
- Highway Traffic Interactive Traveler Information
- Abu Dhabi Roadway Service Patrols
- Highway Road Weather Data Collection
- Highway Weather Information Processing and Distribution
- Highway Roadway Automated Treatment

Urban Traffic Optimization, Management and Information
- Arterial Network Surveillance
- Arterial Traffic Probe Surveillance
- Arterial Signal Control
- Arterial Traffic Information Dissemination
- Abu Dhabi Regional Traffic Management
- Abu Dhabi Traffic Incidend Management System
- Arterial Traffic Decision Support and Demand Management
- Abu Dhabi Emissions Monitoring and Management
- Arterial Lighting System Control
- Abu Dhabi PArking Facility Management
- Abu Dhabi Regional Parking MAnagement
- Arterial Lighting System Control
- Arterial Traffic Website Interactice Traveler Information
- Abu Dhabi Intersection Safety Warning
- Abu Dhabi Roadway Service Patrols
- Arterial Road Weather Data Collection
- Arterial Weather Information Processing and Distribution
- Arterial Roadway Automated Treatment

Public Transport Management and Information
- Abu Dhabi Public Transport Vehicle Tracking
- Abu Dhabi Public Transport Fixed-Route operations
- Abu Dhabi Public Transport Demand Response Public Transport Operations
- Abu Dhabi Public Transport Fare Collection Management
- Abu Dhabi Public Transport Security
- Abu Dhabi Public Transport Fleet Management
- Abu Dhabi Multi-modal Coordination
- Abu Dhabi Public Transport Traveler Information
- Abu Dhabi Traffic Signal Priority
- Abu Dhabi Public Transport Passenger Counting
- Public Transport Website Broadcast Traveler Information
- Public Transport Website Interactive Traveler Information

Road Works Management and Information
- Maintenance and Construction (M and C) Vehicle Equipment Tracking
- M and C Vehicle Maintenance
- Abu Dhabi Roadway Maintenance and Construction
- Abu Dhabi Work Zone Management
- Abu Dhabi Work Zone Safety Monitoring
- Abu Dhabu Maintenance and Construction Activity Coordination
- Work Zone Speed Monitoring

Freight Management
- Abu Dhabi Electronic Clearance
- Abu Dhabi Boarder Electronic Clearance
- Abu Dhabi Weigh-in-motion
- Abu Dhabi Roadside CVO Safety
- Abu Dhabi On-board CVO and Freight Safety and Security
- Abu DHabi HAZMAT Management
- Abu DHabi Roadside HAZMAT Security Detection and Mitigation

Integrated Operations
- ITS Data Warehouse
- Regional Traffic Management
- Abu Dhabi Multi-modal coordination
- Traveler Information Provided Broadcast Information
- Traveler Information Provider Interactive Traveler Information
- Traveler Information Provider-based Trip Planning and Route Guidance
- Traveler Information Provided Yellow Pages and Reservation
- Emergency Management Call - Talking and dispatch
- Emergency Management Routing
- Road Service Patrols Routing
- Abu Dhabu Mayday and Alarms Support
- Abu Dhabi Transportation Infrastructure PRotection
- Abu Dhabi Wide-Area Alert
- Abu Dhabi Early Warning System
- Abu Dhabi Disaster Traveler Information

Figure 3-9 Functional decomposition of Abu Dhabi's ITS

3.2.3.2 System Stakeholders

The stakeholders involved in operating, managing and using the ITS were also identified in the ITS document. As shown in Figure 3-10, there are three main types of stakeholders: agencies, users, and operators. The users are comprised of the travelers benefiting from the transportation system while the agencies are mainly Abu Dhabi government agencies. It is worthy to note that that the document distinguishes government agencies by the type of role they must play in the ITS development even if such roles are played by different departments within a single agency or by multiple agencies. Finally, the operators are mainly private companies as well as DOT. Each of the stakeholders were later linked to their corresponding functional requirements.
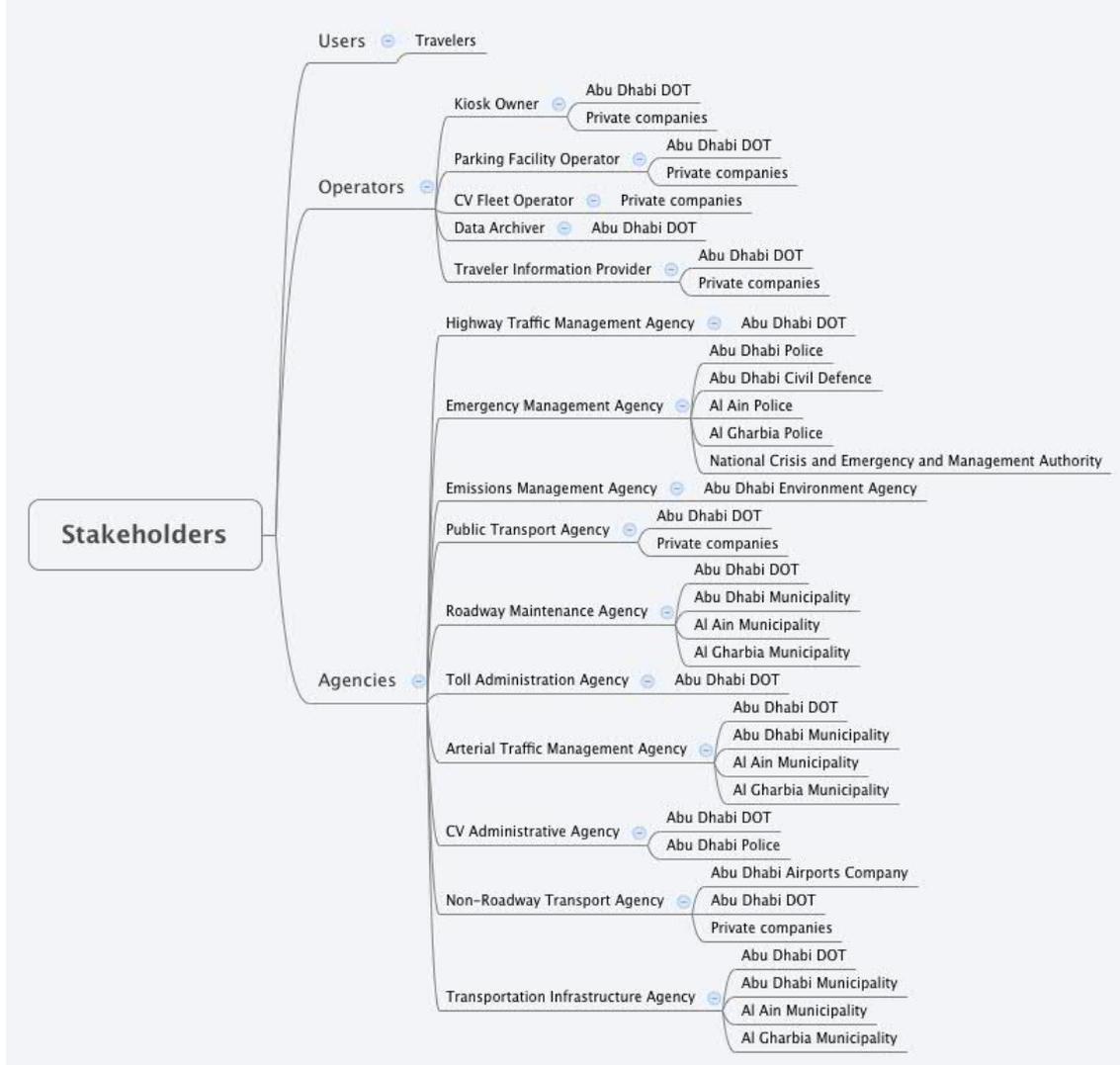
Figure 3-10 Stakeholder decomposition of Abu Dhabi's ITS

3.2.3.3 System Form

The components, or technology elements, are the enabling technologies that will complete the identified functional requirements. Figure 3-11 demonstrates the decomposition of all the listed components within Abu Dhabi's ITS inventory. By decomposing the components, it is easier to determine where EV technology may later

be integrated.
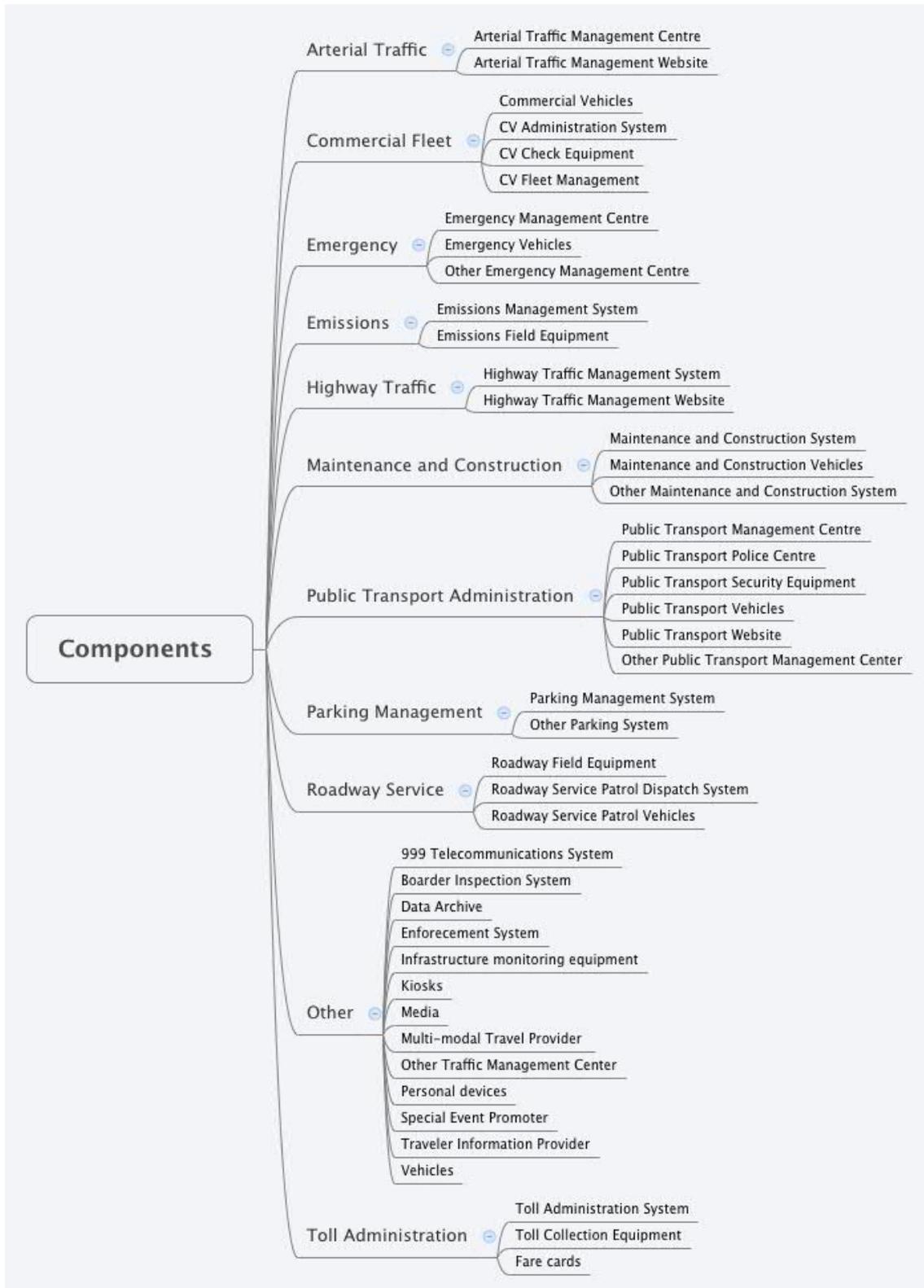
Figure 3-11 Components decomposition of Abu Dhabi's ITS

3.2.3.4 System Concept & Multi-Domain Matrix

The system concept of Abu Dhabi's ITS is demonstrated through a MDM which helps determine the relationship and interfaces between functional requirements, stakeholders and components. This section shows the results of the multi-domain matrix.

Figure 3-12 displays a full MDM of Abu Dhabi's ITS linking functional requirements, components and stakeholders. Each of the six major matrix block is discussed in turn. The first three blocks, which form the matrix diagonal, are hardly addressed within the AD DOT ITS document. This is because the document represents a vision for the future rather than a detailed already complete design. As such, at this early conceptual design stage in the systems engineering process it is very rare that such type of information is provided or detailed. Simply speaking, the ITS design is still fluid enough that detailed interfaces within the functional domain, or the component domain or the stakeholder domain have not yet calcified. The remaining matrix blocks are addressed individually: first a mapping of components to the stakeholders responsible for operation and maintenance, second, a mapping of the functional requirements to components within the inventory, and finally a mapping of stakeholders to functional requirements.
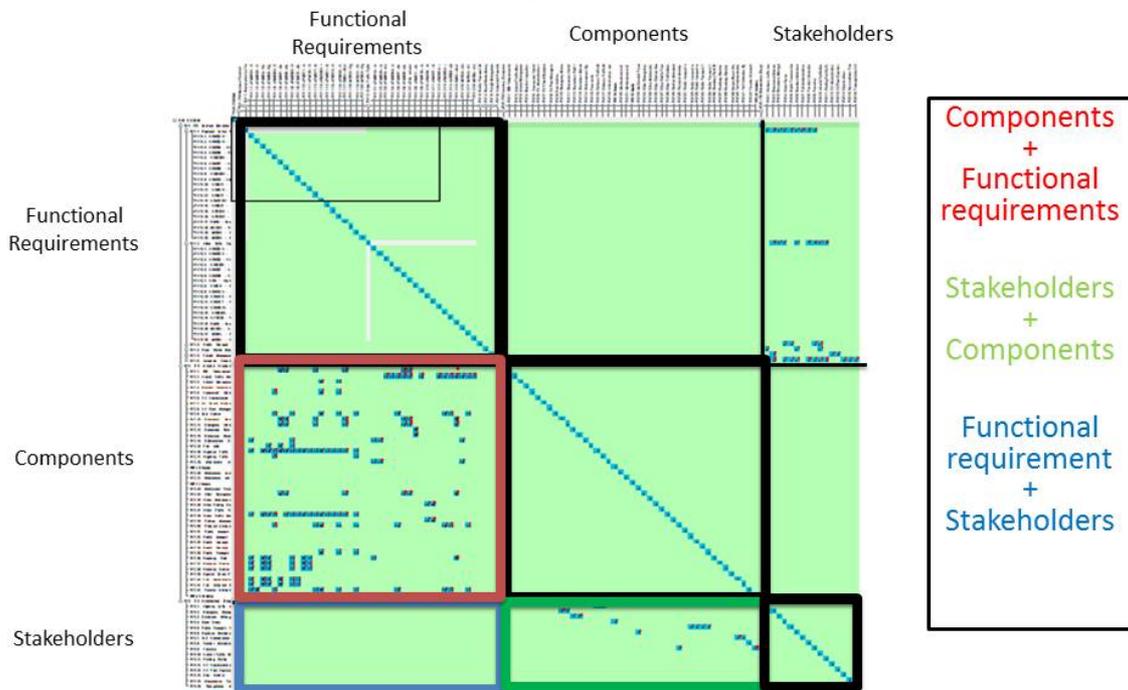
Figure 3-12 MDM of Abu Dhabi's ITS

The AD DOT ITS document has highlighted a number of times that the greatest challenge in Abu Dhabi's ITS is the uncertain roles and responsibilities and the resulting clash in services. As a result, the stakeholders required the proposed plan to be developed in such a way that stakeholders were not only clearly defined but also had clear operations and maintenance responsibilities over each of the identified technologies and services. **Figure 3-13** displays a MDM linking stakeholders to components. Note that some components have relationships with more than one stakeholder; potentially causing confusion in their respective roles and responsibilities. The well-known systems engineering axiomatic design methodology stipulates the independence axiom which encourages a one-to-one mapping between these

stakeholders and components [18][21] .

Inventory
999 Telecommunications System
Arterial Traffic Management Centre
Arterial Management Website
Boarder Inspection System
Commercial Vehicles
CV Administration System
CV Check Equipment
CV Fleet Management
Data Archive
Emergency Management Centre
Emergency Vehicles
Emissions Field Equipment
Emissions Management System
Enforecement System
Fare cards
Highway Traffic Management System
Highway Traffic Management Website
Infrastructure monitoring equipment
Kiosks
Maintenance and construction system
Maintenance and construction vehicles
Media
Multi-modal Travel Provider
Other Emergency Management Center
Other Maintenance and Construction System
Other Parking System

Figure 3-13 Mapping of Stakeholders to Components

The six main functional requirements are essential to achieve the ITS's main objectives. These objectives cannot be met without the work of multiple stakeholders. Each stakeholder's role and responsibility has been identified and demonstrated in Figure 3-14. This MDM clearly shows that the functional requirements are linked to numerous

stakeholders. For example, 'integrated operations' program package is the functional requirement with the most distributed roles and responsibilities across all agencies and operators.   As in the previous block matrix, the independence axiom should be applied such that this multiple-to-many mapping becomes one-to-one.

Functional Requirements	Highway traffic management	Emergency Management Agency	Emissions MAnagement Agency	Kiosk Owner	Public Transport Agency	Roadway Maintenance Agency	Toll Administration Agency	Traveler Information Provider Organization	Travelers	Arterial Traffic Management Agency	Parking Facility Operator	CV Administration Agency	CV Fleet Operator	Data Archiver	Non-roadway Transport Agency	Transportation Infrastructure Agency	Main Roads Traffic Management Agency
Regional Active Traffic Management (ATM) and Information	X	X	X	X	X	X	X	X	X								X
Urban Traffic Optimization, Management and Information		X	X	X		X			X	X	X	X					
Public Transport Management and Information				X	X				X	X							
Road Works Management and Information	X					X				X							X
Freight Management		X										X	X				
Integrated Operations	X	X		X	X	X		X	X	X	X			X	X	X	X

Figure 3-14 Mapping of functional requirements to stakeholders

Error! Reference source not found. shows the mapping of components to functional requirements. The functionalities of the ITS cannot be met by one type of technology. As a result, these functionalities are met by numerous technologies that can be integrated to deliver the required service. In the case of Abu Dhabi, the basic six functional requirements are clustered into the closest components that work together. This MDM shows how each component is related to the functional requirement and the types of technologies required to meet these functional requirements.   It is expected that as the systems engineering process proceeds normally, these relationships between functional requirements and the corresponding component technologies will become increasingly clear and one-to-one in nature.

Figure 3-15 Mapping of Components to Functional Requirements

3.2.4 Possible Integration of EVs into Abu Dhabi DOT ITS

To incorporate the enabling technologies and functionalities that will support EV

integration, the MDM acts as a guide to develop a decomposition of the stakeholders, components and functional requirements necessary for the electrification of the transport system. This section demonstrates a holistic view for the potential incorporation of EVs into the Abu Dhabi's ITS. The additional functional requirements, stakeholders and components in the electrification of the transportation system are highlighted throughout the section.

The integration of EVs adds new functionalities and technologies into the ITS which are distributed across program packages. As mentioned above, EVs require energy management which is not a part of the proposed ITS. Although the proposed plan highlights the importance of a low carbon economy as one of its top-level functionalities, energy management is not within the scope of the DOT and is therefore not a proposed functional requirement within the ITS.

Figure 3-16 proposes a new set of functional requirements (underlined in green) to be part of the ITS which will help facilitate the management of EVs. It has been considered as a new program package to serve as a set of functionalities that will require the management and operation of charging stations as well as EVs.
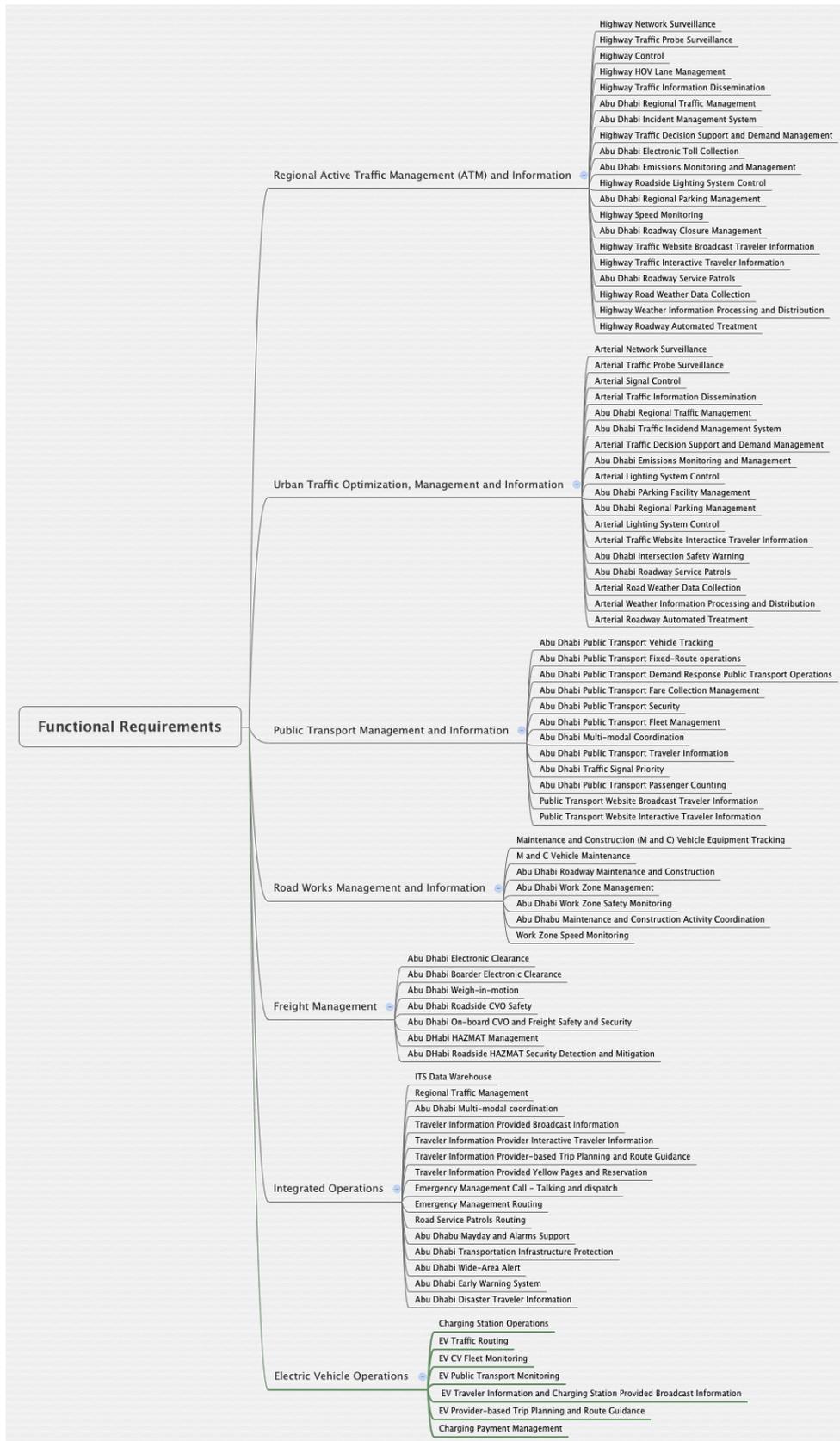
Figure 3-16 Integration of EVs as a functional requirement in Abu Dhabi's ITS

EVs will also add new stakeholders into the system such as: charging station operators and electric vehicle drivers. The following Figure 3-17 demonstrates the additional roles and responsibilities which will require a new group of stakeholders to be part of the operation of Abu Dhabi's ITS. As EVs begin to couple the transportation and the power system, there will be additional responsibilities on Abu Dhabi Distribution Company to operate the required infrastructure such as charging stations that are necessary for EVs.
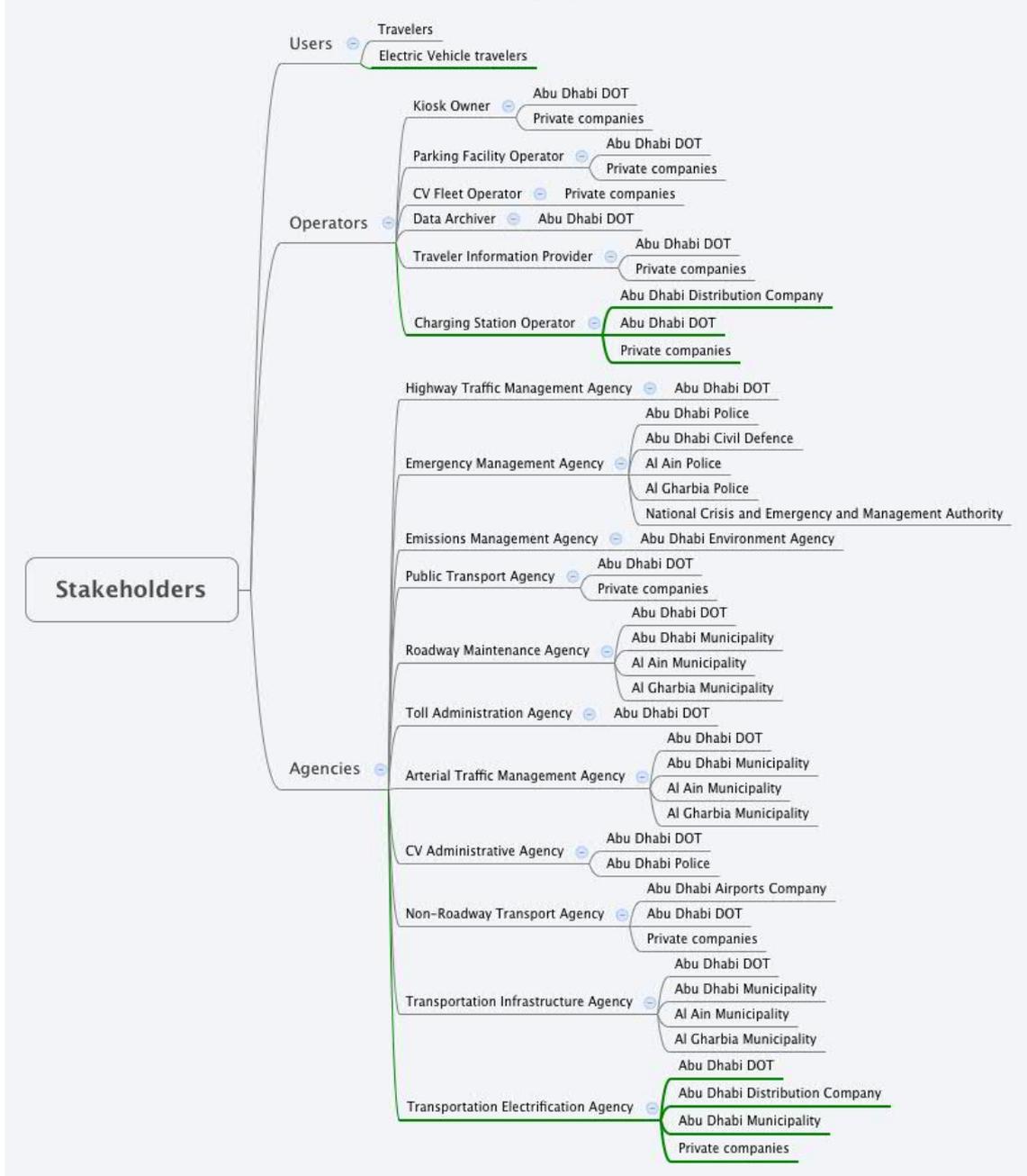
Figure 3-17 Integration of EVs as new stakeholders in Abu Dhabi's ITS

A new set of management systems and technology elements will be required to facilitate the adoption of EVs. As EVs have the potential to be used in corporate fleets, public transportation or private users, the following Figure 3-18 demonstrates the added

components into Abu Dhabi's ITS over a variety of situations. For example, charging stations can be available in taxi stands or parks. Each of these charging stations can be used for public transport or private users. Also, if a corporate vehicle fleet were to decide to switch to electric transportation, an EV management system will be required to do so. Another major change in the inventory list proposed is the classification of ICV and EV drivers. Each of these drivers will require a different set of services and therefore should be classified according to the vehicle type.
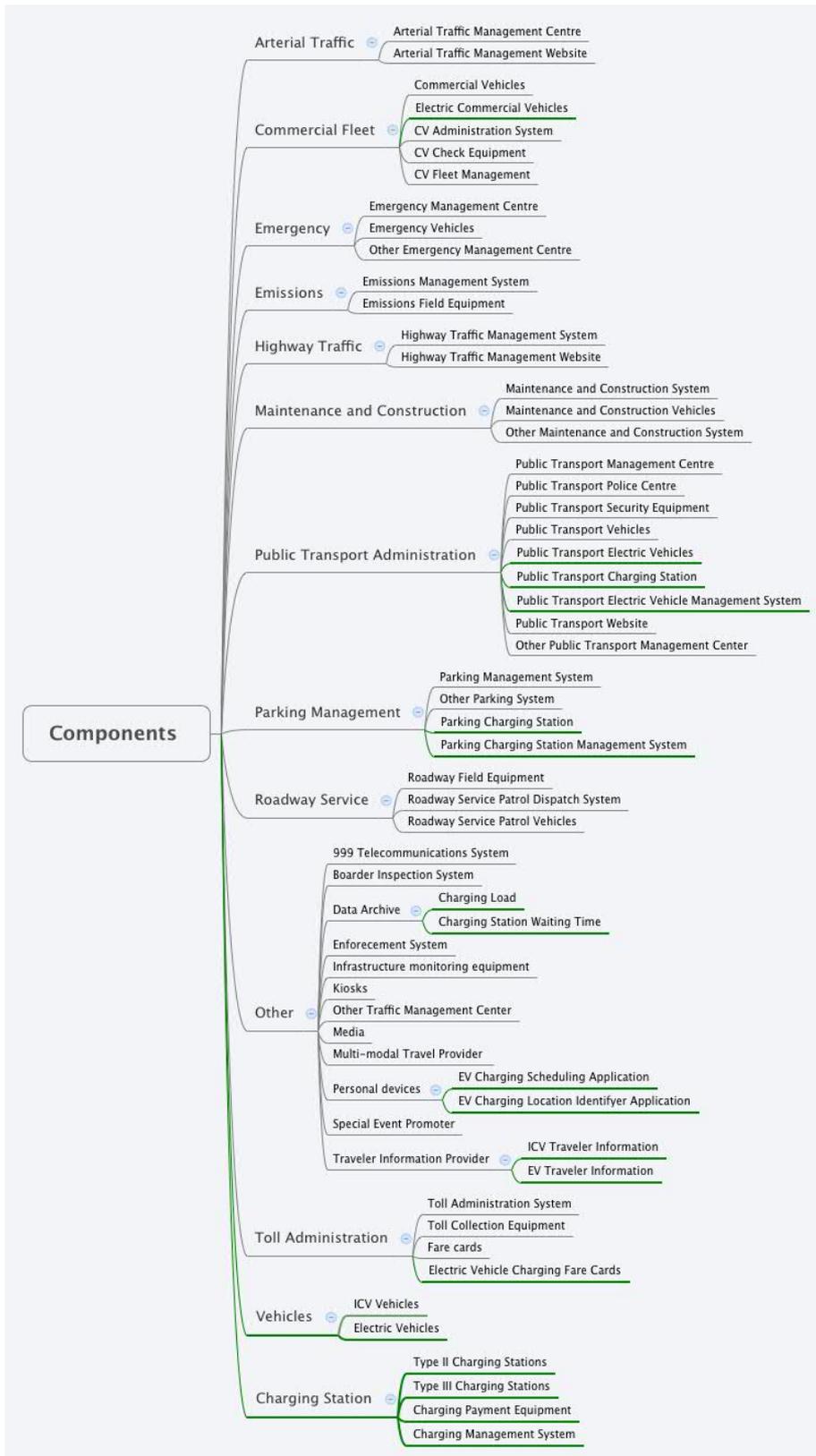
Figure 3-18 Integration of EVs as new components in Abu Dhabi's ITS

3.2.5 Summary of Abu Dhabi DOT ITS Readiness for EVs

Modern intelligent transportation systems are sophisticated IT systems. This section has, therefore, used UML and the DSM appropriate tools for ITS analysis. The AD DOT ITS document represents a strategy, architecture and implementation plan for 2010 to 2030. In this regard, it is a conceptual vision of final implementation rather than a detailed fixed current design. The document demonstrates functional as well as form hierarchies and identifies relevant stakeholders. Nevertheless, at such an early conceptual design stage in the systems engineering process, the document rightly does not contain the detailed component interfaces or functional interactions. This means that the ITS design is still fluid enough that these detailed interfaces and interactions have not yet calcified thus facilitating incorporation of functionality and its associated modules and components. The section then proceeded to highlight what type of EV functionality, component technology and stakeholders can be integrated to support electric vehicles. The document also highlighted areas in the multi-domain design structure matrices where many-to-one type relationships existed between the function, form and stakeholder domains potentially causing unnecessary system coupling and complexity at a later stage in the systems engineering process.

3.3 Impacts on the Abu Dhabi Electrical Energy System

As mentioned at the beginning of the section, EVs are fundamentally a part of the electrical energy system. Specifically, as vehicles charge, they place an energy demand requirement that can be studied in terms of both energy as well as instantaneous power withdrawals. This section treats these two requirements sequentially. First, in Section 3.3.1 the power impacts on the Abu Dhabi distribution system are discussed. Later, in Section 3.3.2, the energy requirements of EV adoption are discussed.

3.3.1 Power Impacts on the Abu Dhabi Electrical Energy System

EVs could have a disruptive impact on the electric grid if not integrated carefully because, unlike ICVs, they will connect to the distribution network to charge [15]. This indicates that the electrical system plays an essential role in the wide adoption of EVs as it represents the main source of energy for charging. It is critical to determine the feasibility of the distribution network to handle the wide adoption of EVs into the transportation system. The supporting infrastructure is therefore essential to be modeled and assessed in the technical feasibility study of EVs in Abu Dhabi. The extent of EVs impact on the local power supply will depend on the degree and density of their penetration, charging requirements as well as time of the day they are charged [15]. Therefore, this study has considered the three aspects impacting the power system by experimenting the ranges of variables through the eight cases demonstrated in the following Chapter 4.

In order to get an intuitive understanding of the relative size of power requirements, EV charging is compared to a home. **Error! Reference source not found.** shows the power requirement of a single home in San Francisco Bay with and without charging [15] and demonstrates the associated power increase with changes in the charger type. In all cases, EV charging represents a significant additional load on the house that does not have EV charging. San Francisco, however, has a very temperate climate and so has neither a high electrical heating or cooling requirement. Abu Dhabi villas, however,

are not only larger in size, but also rely heavily on air conditioning leading to higher electrical loads. According to the Abu Dhabi Regulation & Supervision Bureau, the average power draw of an Abu Dhabi home is approximately 11kW [17].
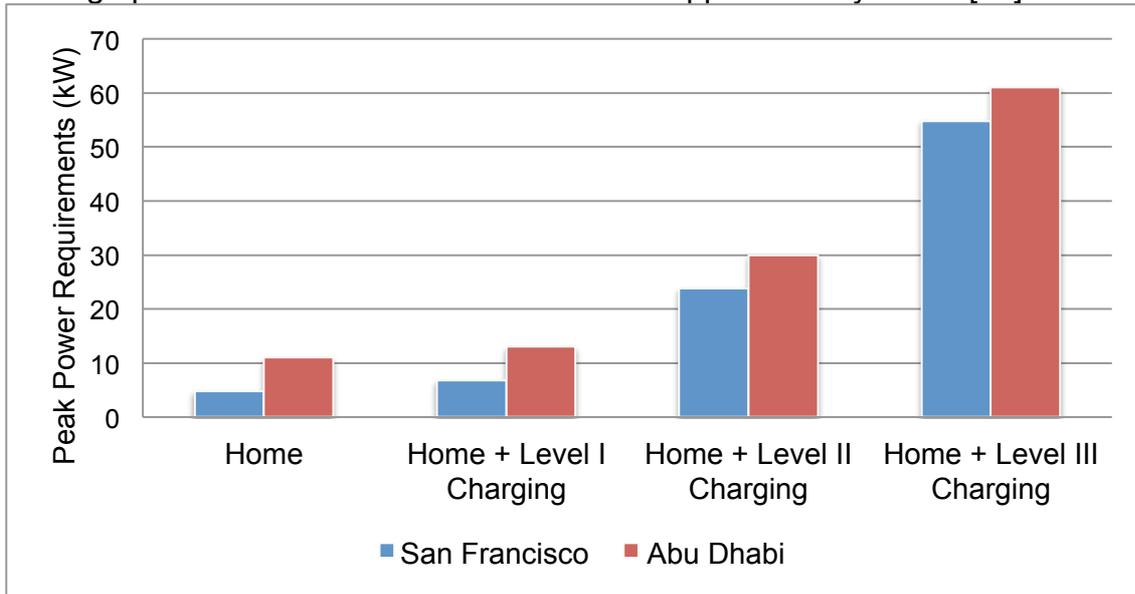
Figure 3-19 Peak Power Requirement of a Single Home in San Francisco Bay and Abu Dhabi With and Without EV Charging [15][16][17]

While average power consumption of a home is useful for gaining an intuitive understanding of the relative size of EV charging, it is not the basis upon which the electrical distribution system is designed, operated and maintained. Rather, because the grid needs to support all possible loads, the peak load consumption of a home is most important.   To that effect, a large Abu Dhabi villa may have a peak load up to as high as 200-250kW [19].   This peak power value is important relative to the ratings of transformers, feeders, and substations in the Abu Dhabi electrical distribution system.

In order to best understand and describe the impact of EV charging consider a hypothetical distribution network as shown in **Figure 3-20**. Loads are represented by the large dark arrows, which may represent Abu Dhabi villas with the peak loads previously specified.   Additionally, the figure shows a radial power grid structure as found in electrical power distributions systems all over the world including in Abu Dhabi.   At each branching of a radial node, the voltage is stepped up to a higher level.   Therefore, the power demand is essentially concentrated from the point of use up to higher voltages and the transmission system.
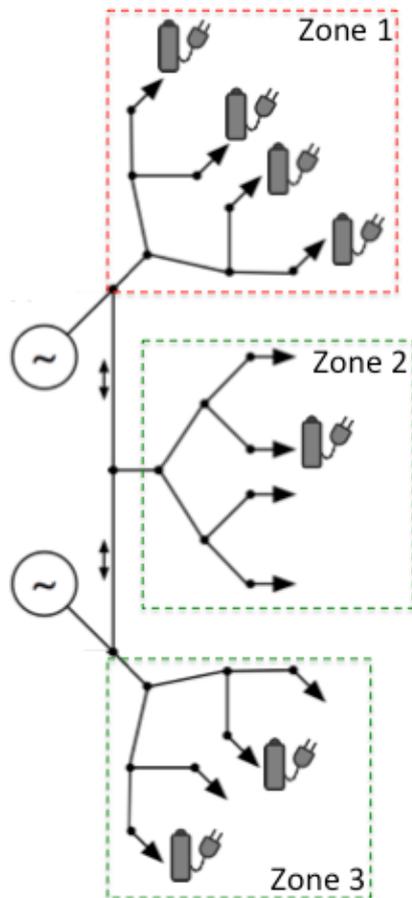
Figure 3-20 Hypothetical example of charging station locations in a radical distribution network

This concentrating effect of the distribution system causes the geographical density of charging stations to be critical in any EV to power grid impact study. Although worldwide projections of EV penetration are highly varied, highly dense regions are expected to experience higher penetrations of EVs than rural areas [15]. In this study, Abu Dhabi Island represents a high-density area that is most likely to adopt EVs. As demonstrated in Section 3.1, this study focuses on Abu Dhabi Island as the main geographical density. Using the calibrated transportation simulation model in CMS, the charging load patterns are examined to determine the possibilities of charging loads exceeding transformer limits. Reconsidering **Figure 3-20**, Zones 1, 2, and 3 show different geographical density penetrations of EV charging stations.   In all cases, the transformers immediately adjacent to the charging stations must have sufficient available power rating capacity to support the introduction of the EV charging station.   However, in Zone 1 the geographical density of the charging stations means that their cumulative effect is additive and hence must be tested at the feeders and substations at higher levels of the distribution system.

To further understand the potential impact of EV charging on the Abu Dhabi power distribution system, it is important to understand Abu Dhabi Distribution Company's load classification system. **Error! Reference source not found.** shows the Abu Dhabi distribution company load classification scheme.   Charging stations of all types

individually fall within Class A.   In this class, if a transformer limit is exceeded, ADDC manually repairs the transformer in the required time.   This repair action is rationalized because the radial network does not have redundancy at this level and the load is sufficiently small value not to merit more timely mitigating steps.   In contrast, Class B and C loads are promised a distribution networking switching action within three hours. Therefore, charging station power requirements need to be very well rationalized against transformer limits as they have the potential to disrupt other loads connected to the same transformer.   Similarly, aggregated groups of charging stations need to be rationalized for their impact on feeders and substations.

Table 3-3 Abu Dhabi Distribution Company Load Classification Scheme [16]

Class of Supply	Range of Demand Group	Potential Cause of Failure	Required Corrective Action
A	0 - 1.5MVA	Transformer, Low Voltage	Manual repair action in the required time
B	1.5 - 6MVA	Transformer or Feeder	Distribution Network switching within 3 hours
C	6 – 30MVA	Transformer, Feeder or Substation	First third of demand: distribution network switching within 30 minutes. Full demand: distribution system network switching within 3 hours.

As expected from **Figure 3-20**, transformer ratings limit depend on the relative location in the distribution system.   **Error! Reference source not found.** shows the transformer limits at different points in the Abu Dhabi power distribution network.   The smallest of these limits is the 500kVA transformer found when a 11/0.4kV substation uses 12 parallel transformer architecture.   While this value seems very large in relation to the EV charging station power ratings, this is not necessarily the case.   A 500kVA transformer is given a 0.6 safety factor in planning.   Therefore, a 500kVA transformer is only meant to accommodate an expected peak load of 300kW.   Considering that an Abu Dhabi villa can consume 200-250k, this leaves only 50-100kW of spare power capacity.   Such a level can be easily reached with one Type III charger or multiple Type II chargers. Therefore, residential EV charging needs to be carefully quantified.   In the case of commercial EV use cases, it is expected that dedicated multiple port charging stations will require either the 1 or 1.5 MVA transformers for perhaps dedicated use.   In the next chapter, the expected charging loads will be calculated using the CMS.

Table 3-4 Transformer Limits at Different Points in the Abu Dhabi Power Distribution Network [16]

Node Type	Architecture	Rating of Single Transformer
132/22 kV Substation	4 Parallel Transformers	80 MVA
132/11 kV Substation	4 Parallel Transformers	40 MVA
33/11 kV Substation	2,3,or 4 Parallel Transformers	20 MVA
11/0.4kV Substation	4,6 or 12 parallel transformers	4 Transformers @ 1.5 mVA 6 Transformers @ 1 MVA 12 Transformers @ 0.5 MVA

3.3.2 Energy Supply Impacts on the Abu Dhabi Electrical Energy System

Let IEEJ take care of this.

3.4 Conclusion

This chapter presents a "systems-of-systems" [21][22] approach to studying the impacts of EVs on the three systems, namely the road transportation system, the Intelligent Transportation Systems and the electrical energy system, in the context of Abu Dhabi island.

To determine the traffic behavior of EVs in AD transport, the procedure was a detailed and well-calibrated Abu Dhabi Island traffic simulation base case implemented in the CMS for EV penetration study. The hypothetical cases were imported into the Abu Dhabi base case that represents the AD transport system. However, the outcome of the cases will incorporate EV as new types of modes of transport. In addition, the charging stations and their associated parameters are added to the base case to study the charging curve. By using the CMS, and traffic parameters relevant to AD DOT, the simulation results promise to give a quantitative understanding of the charging behavior and mileage limitations in a model that represents real traffic behavior of Abu Dhabi.

This chapter has then used UML and the DSM appropriate tools for ITS analysis. The AD DOT ITS is a conceptual vision of final implementation rather than a detailed fixed current design. The ITS design is still fluid enough that these detailed interfaces and interactions have not yet calcified thus facilitating incorporation of functionality and its associated modules and components. The chapter then proceeded to highlight what type of EV functionality, component technology and stakeholders can be integrated to support electric vehicles. The document also highlighted areas in the multi-domain design structure matrices where many-to-one type relationships existed between the function, form and stakeholder domains potentially causing unnecessary system coupling and complexity at a later stage in the systems engineering process.

The final section of this chapter discusses EVs as electrical energy systems- their energy demand requirements and instantaneous power withdrawals during charging. The supporting infrastructure should be modeled and assessed in the technical feasibility study of EVs in Abu Dhabi. The extent of EVs impact on the local power supply will depend on the degree and density of their penetration, charging requirements as well as

time of the day they are charged [15]. The peak load power value is more important relative to the ratings of transformers, feeders, and substations in the Abu Dhabi electrical distribution system. The concentrating effect of the distribution system due to EV charging causes the geographical density of charging stations to be critical in any EV to power grid impact study. Although worldwide projections of EV penetration are highly varied, highly dense regions are expected to experience higher penetrations of EVs than rural areas [15]. In this study, Abu Dhabi Island represents a high-density area that is most likely to adopt EVs. Considering the transformer classifications, charging stations of all types individually fall within Class A. In this class, if a transformer limit is exceeded, ADDC manually repairs the transformer in the required time. This repair action is rationalized because the radial network does not have redundancy at this level and the load is sufficiently small value not to merit more timely mitigating steps. In contrast, Class B and C loads are promised a distribution networking switching action within three hours. Therefore, charging station power requirements need to be very well rationalized against transformer limits as they have the potential to disrupt other loads connected to the same transformer. Similarly, aggregated groups of charging stations need to be rationalized for their impact on feeders and substations. Residential EV charging needs to be carefully quantified as an Abu Dhabi villa can consume 200-250k, which leaves only 50-100kW of spare power capacity. Such a level can be easily reached with one Type III charger or multiple Type II chargers. In the case of commercial EV use cases, it is expected that dedicated multiple port charging stations will require either the 1 or 1.5 MVA transformers for perhaps dedicated use.   In the next chapter, the expected charging loads will be calculated using the CMS.

3.5. Chapter References

[1]   MHI, "Environment-Conscious Urban Design Simulator "Clean Mobility Simulator" - Traffic Simulator that Includes Electric Vehicles," Japan, Tech. Rep. 1, 2012.

[2]   C. D. Alecsandru, "A Stochastic Mesoscopic Cell-Transmission Model for Operational Analysis of Large-Scale Transportation Networks," Department of Civil and Environmental Engineering,

[3]   C. C. C. a. K. T. Chau, "An Overview of Electric Vehicles - Challenges and Opportunities," IEEE, 1996.

[4]   M. A. Chowdhury and A. W. Sadek, Fundamentals of intelligent transportation systems planning. Boston: Artech House, 2003.

[5]   Anonymous, "Systems Engineering for Intelligent Transportation Systems: An Introduction for Transportation Professionals," U.S. Department of Transportation Federal Highway Administration Federal Transit Administration, Washington, DC, Tech. Rep., 2007.

[6]   R. Meier, A. Harrington, and V. Cahill, "A Framework for Inte- grating Existing and Novel Intelligent Transportation Systems," in *IEEE Conference on Intelligent Transportation Systems*, no. Dcc, Vienna, Austria, 2005, pp. 650–655.

[7] J.-C. Thill, G. Rogova, and J. Yan, "Evaluating Benefits and Costs of Intelligent Transportation Systems Elements From a Planning Perspective," *Research in Transportation Economics*, vol. 8, no. 04, pp. 571–603, Jan. 2004. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0739885904080254

[8] S. Skippon and M. Garwood, "Responses to battery electric vehi- cles: UK consumer attitudes and attributions of symbolic meaning following direct experience to reduce psychological distance," *Transportation Research Part D: Transport and Environment*, vol. 16, no. 7, pp. 525–531, Oct. 2011. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S1361920911000654

[9] F. Milano, *Power system modelling and scripting*, 1st ed. New York: Springer, 2010.

[10] Anonymous. (2011). Abu Dhabi Intelligent Transportation Systems: Strategy Architecture and Implementation Action Plan 2010- 2030. (D. of Transport, Ed.). Abu Dhabi.

[11] A. Garcia-Ortiz, "Intelligent Transportation Systems Enabling Technologies," Math. Comput. Modelling, vol. 22, pp. 11-81, 1995.

[12] M. Blaha and J. Rumbaugh, "Object-oriented modeling and design with UML," p. xvii, 477 p., 2005.

[13] Arrayangkool, A., & Apinetr Unakul. (2009). A Flexible Intelligent Transportation System Architecture Model with Object Oriented Methodology and UML. IEEE, 741–746.

[14] S. D. Eppinger and T. R. Browning, *Design structure matrix methods and applications*. Cambridge, Mass.: MIT Press, 2012, p. xii, 334 p.

[15] J. G. Kassakian, R. Schmalensee, G. Desgroseilliers, T. D. Heidel, K. Afridi, A. M. Farid, J. M. Grochow, W. W. Hogan, H. D. Jacoby, J. L. Kirtley, H. G. Michaels, I. Peŕez-Arriaga, D. J. Perreault, N. L. Rose, G. L. Wilson, N. Abudaldah, M. Chen, P. E. Donohoo, S. J. Gunter, P. J. Kwok, V. A. Sakhrani, J. Wang, A. Whitaker, X. L. Yap, R. Y. Zhang, and M. I. of Technology, "The Future of the Electric Grid: An Interdisciplinary MIT Study," Cambridge, MA, Tech. Rep., 2011. [Online]. Available: http://web.mit.edu/mitei/research/studies/documents/electric- grid-2011/Electric Grid Full Report.pdf

[16] Anonymous. (2007). *Power Distribution Network Planning Criteria and Design Philosophy* (pp. 1–37). Abu Dhabi, UAE.

[17] Anonymous. (2007). *Report Consumption Water and Electricity* (pp. 1–2). Abu Dhabi, UAE.

[18] Buede, D. M. (2009). *The engineering design of systems : models and methods. Wiley series in systems engineering and management* (2nd ed., p. xiv, 516 p.). Hoboken, N.J.: John Wiley & Sons.

[19] Lazazi, N. (2012, 01 30). Electrical Engineer. Project Delivery - Masdar City. (A. Farid, Interviewer)

[20] J. Zheng, S. Mehndiratta, J. Y. Guo, and Z. Liu, "Strategic policies and demonstration program of electric vehicle in China," Transport Policy, vol. 19, pp. 17-25, 2012.

[21] O. L. De Weck, D. Roos, and C. L. Magee, *Engineering systems : meeting human needs in a complex technological world*. Cambridge, Mass.: MIT Press, 2011, p. xvi, 213 p.

[22] A. Kossiakoff, W. N. Sweet, and Knovel (Firm), "Systems engineering principles and practice." Wiley-Interscience, Hoboken, N.J., 2003.

[23] D. W. Oliver, T. P. Kelliher, and J. G. Keegan, "Engineering complex systems with models and objects," p. xix, 325 p., 1997.

[24] D. L. Patrick, T. P. Murray, and R. A. Davey, "Regional ITS Architecture for Metropolitan Boston," Massachusetts Department of Transportation, Boston, MA, USA, Tech. Rep. December, 2011.

[25] IBI-Group, "Puget Sound Regional ITS Architecture," Puget Sound Regional Council, Seattle, WA, United states, Tech. Rep. June, 2001.

[26] T. Yokota, "ITS Applications Around the World," World Bank, Tech. Rep., 2004.

4 Technical Assessments of EV integration on the Abu Dhabi Road Transportation & Electrical Energy Systems (Chapter Lead: A. Farid)

The previous chapter identified the tools of assessment in regards to power and transportation systems. This chapter applies these assessment tools to assess the technical feasibility of EVs with respect to their supporting infrastructure. For the physical transportation system, a microscopic discrete-time traffic operations simulator, or clean mobility simulator is used to study the kinematic state of the EV fleet over the duration of one day [1]. For the impact on the electric power system, the EV traffic flow patterns from the CMS are used to calculate the timing and magnitude of charging loads. In order to integrate the two systems into one technical feasibility assessment, Section 4.1 provides an overview of a technical assessment methodology that includes quantitative quality measures. Next, Section 4.2 gives an intuitive explanation of the variables that impact the two infrastructure systems. This facilitates the development of the simulation experimental design in Section 4.3; a set of case studies which can be objectively compared. The results and discussion of these simulations are discussed in Section 4.4. Section 4.5 concludes the chapter with the major findings.

4.1. Overview of Technical Assessment methodology

Given the modeling methodologies presented in Chapter 3, this section provides an integrated method for the technical feasibility assessment of EV integration into the power and transportation systems. Figure 4-1 provides a schematic of the assessment as a whole.
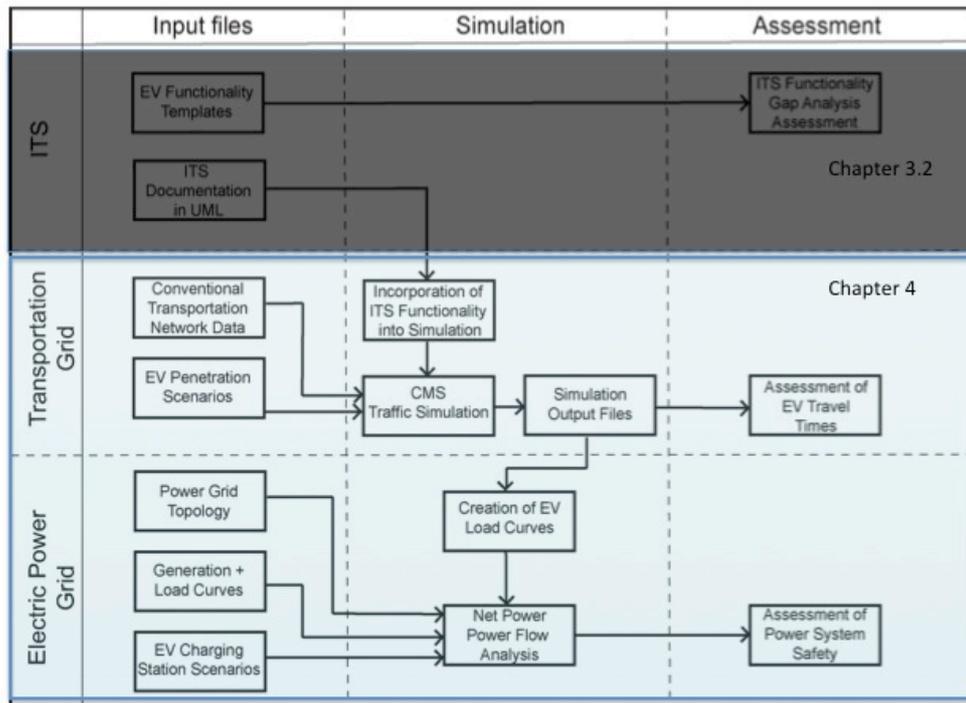
Figure 4-1 Integrated method for the assessment of technical feasibility

As shown, Figure 4-1 shows a three stage integrated method for the assessment of technical feasibility.   It includes: 1.) the process of transforming input files into the respective modeling tool, 2.)the simulation of the respective systems and finally 3.) the assessment of the results of the two interconnected systems. Intuitively, transportation and power systems are coupled due to EV's reliance on the grid for charging. Therefore, the CMS traffic simulator is required to generate the times and locations of charging behavior.   Conventional transportation network data is combined with EV penetration cases and are fed to the CMS to generate such output files.   This data is combined with power grid safety ratings, generation & load behavior, and a description of the set of EV charging stations to analyze the impact on the power grid.   Special attention is given such that no charging station exceeds upstream power ratings. These include circuit breakers, protection systems as well as transformers. In the transportation system, a quality of service (QoS) measure has also been defined to assess the impact of EV charging on travel times. Each of these is now addressed in turn.

4.1.1 Assessment of Traffic System: Quality of Service (QoS)

The charging times of electric vehicles present a major concern to many potential EV users.   Specifically, users wish that EVs are available when required and do not require excessive charging time in the middle of their journeys.   To this end, the assessment of EV integration for the transportation system focuses on the measurement of EV 'quality of service' (QoS) as a ratio of the trip's travel time over its total trip time including charging and searching for chargers. Here, the travel time T_i of the ith EV trip is specifically defined as the difference between the time an EV is requested for travel service t_{r_i} and the moment of arrival t_{a_i}, and tci is the time required to charge during the trip.   The idea behind such a ratio is that ideally charging time be minimized or deferred to a time that is not part of the travel duration. Hence, the quality of service measure becomes:

$$QoS = \frac{\left[\sum_i^{trips}[t_{a_i} - t_{r_i}] - \sum_i t_{c_i}\right]}{\sum_i^{trips}[t_{a_i} - t_{r_i}]}$$

Note that this quality of service measure should ideally tend towards unity.

4.1.2 Assessment of Power System

On the power system side, EV charging represents a time and location dependent electrical load that requires assessment.   As described in Chapter 3, the challenge here is that the EVs do not draw so much electrical power as to exceed the ratings of the lines and transformers to which they are connected. Subsequently, the impact of EV charging on power system line and transformers can be assessed with a safety criterion that represents the average amount of excess energy required in all the lines connected to the charging stations. Given a set of N_i lines, a given line i will have a line/transformer limit P_i ,the safety criterion SC can be calculated as

$$SC_1 = \frac{1}{N_l T_s} \sum_i^{N_l} \left[\frac{1}{P_i^*} \int_0^{T_s} f_i(t)dt \right]$$

where

$$f(i) = \begin{cases} P_i(t) - P_i^* & if P_i > P_i^* \\ 0 & otherwise \end{cases}$$

Note that this safety criterion should ideally tend towards zero kWhs as it is measured above the critical available power, Pi*, in the line or transformer rating.

4.2   Variables Impacting Road Transport Electrification in Abu Dhabi

Any effort to understand the impact of an addition to the road transport system must begin with traffic simulation. As demonstrated in Section 3.1, the Clean Mobility Simulator is an appropriate tool to simulate the impact of EVs in Abu Dhabi. This section gives an intuitive explanation of the variables that impact the road transport electrification in Abu Dhabi.   They are electric vehicle penetration rate, charging system design, and simultaneity of EV charging. These variables are defined followed by an explanation of their potential impacts in the technical feasibility assessment.

4.2.1 Penetration Rate of Electric Vehicles

The electric vehicle penetration is taken to be percentage of the total road traffic vehicle fleet without increasing its overall size.   In other words, a 1% EV penetration replaces the same number of vehicles from the ICV fleet.   Impacts can be expected on both the transportation and the power systems.

Given the definition of vehicle replacement embedded within the EV penetration rate, there is no expected change in the aggregate road traffic transport or congestion.   Nevertheless at a micro-simulation level, the EV penetration rate can have an impact.   ICV route patterns assume that the vehicle is available whenever the driver would like to travel.   In EVs, charging times and the availability of charging stations may cause user route patterns to be affected. Therefore, holding all other vehicles constant, as the EV penetration rate increases, the charging station capacity may become constrained causing EV users to queue for nearby charging stations or drive to more distant charging stations known to be less heavily used.   As a result, one can expect the quality of service to deteriorate because of an increase in the total trip time and the potential need for queuing at charging stations.   In Abu Dhabi, the similar behavior of ICV queuing at gas stations can already be observed at peak travel times in highly congested areas of the city.

The impact of EV penetration rate on the power system is comparatively straightforward. As demonstrated in Figure 4-2, as the penetration of EVs increases, the charging load increases accordingly. Said differently, the charging load of 1 electric vehicle every 100 vehicles will have a lower curve than a

penetration of 20 electric vehicles every 100 vehicles.
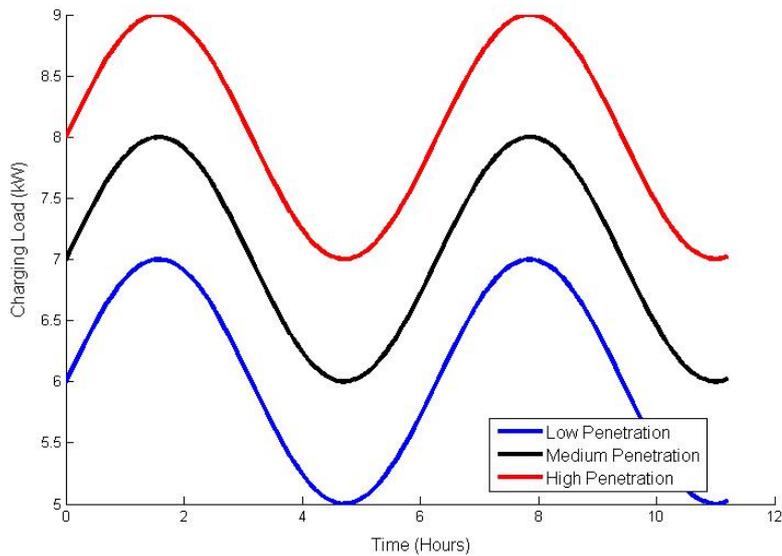
Figure 4-2 Impact of EV Penetration on Charging Load

4.2.2 Charging Station Type

From the discussion on EV penetration rate, one can expect that charging station types have an impact on both the transportation as well as the power system.   In this report, charging station type refers to their maximum power consumption.   From the perspective of the transportation system, the installation of fast chargers reduces charging times, any potential charging queues, and as a result reduce deteriorations in the quality of service. From the perspective of the power system, charging station types cause a change in the amplitudes of charging load but not the duty cycle or frequency. As shown in Figure 4-3, an EV would reach a charging station at a specific time.   At that point, if presented with a Type III charger a relatively large charging load would be required relative to a slower Type II charger.   Note that in either condition the area under the curve is the same as it represents the vehicle's battery capacity.
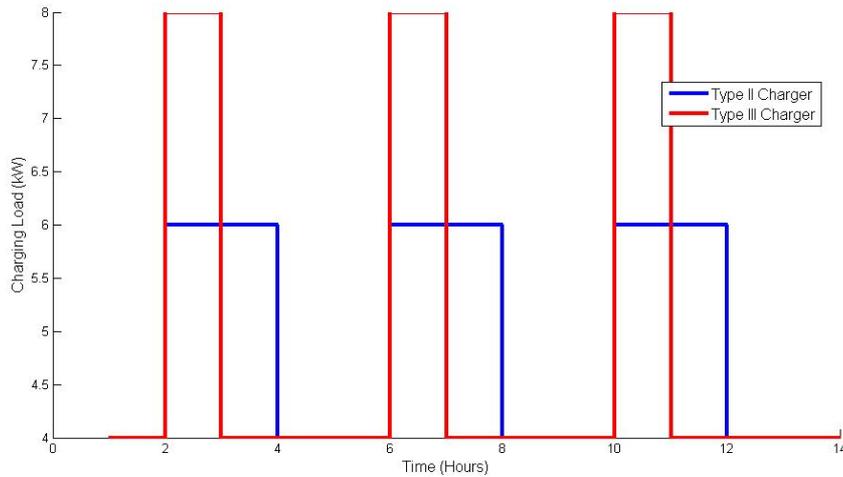
Figure 4-3 Impact of Type of Charger on Charging Load

4.2.3 Geographical Density of Charging

Similar to the charging station types, geographical density of charging stations will impact both traffic as well as power systems. In regards to the traffic system, geographically sparse or well-distributed charging stations means that in general EV users have greater accessibility to charging. Therefore, less extra travel time is required to reach a charging station. In regards to the power system, as shown in Figure 4-4, areas where the charging stations are dense, the amplitude of charging load is higher than an area with relatively sparse charging stations. This is because in the dense case a number of vehicles can charge simultaneously within the same vicinity causing that portion of the distribution system to aggregate charging loads together.
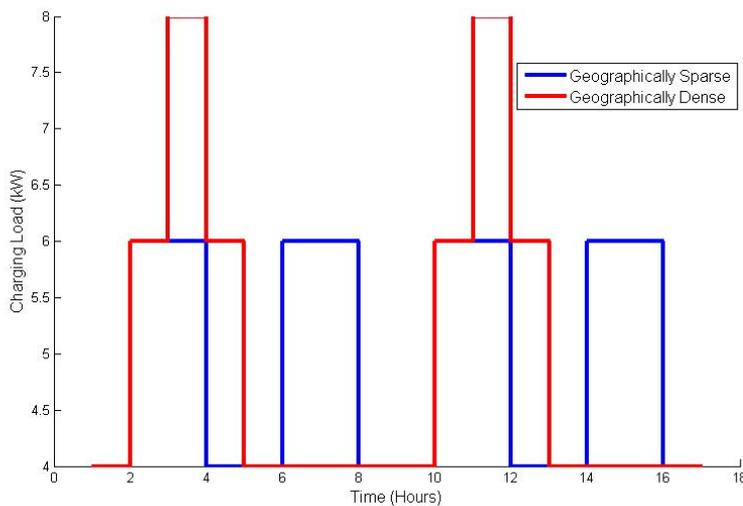
Figure 4-4 Impact of Geographical Density of Charging Stations on Charging Load

4.2.4 Simultaneity of Electric Vehicle Charging

Simultaneous charging can create high charging load amplitudes. Coordinated charging as opposed to uncoordinated charging can be optimized in a way so as to not exceed a certain level of charging load as demonstrated in Figure 4-5. For example, a neighborhood can have a number of EV drivers who arrive home after work at the same time and plug in their vehicles to charge. In that case, the amplitude will be high and that could have an impact on the power system.
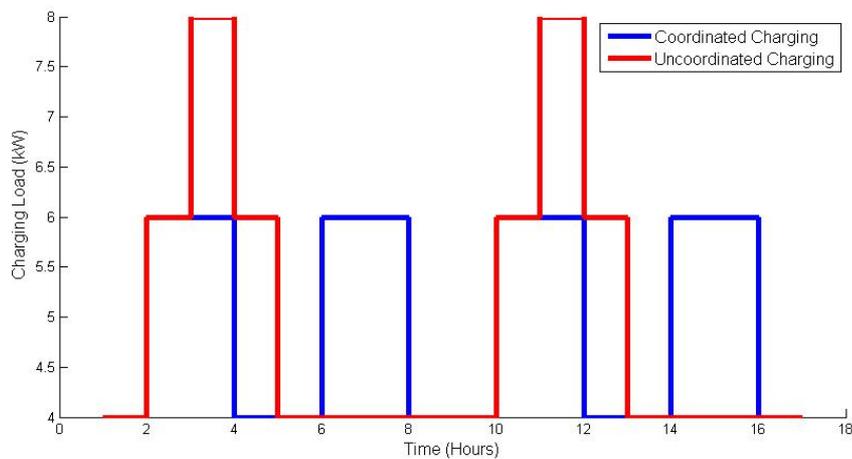
Figure 4-5 Impact of Charging Coordination on Charging Load

4.3 Cases for the Study of Impacts of Road Transport Electrification in Abu Dhabi

In this section, the variables described in the previous section are translated into a simulation experimental design for study in Section 4.4.   As shown in Table 4-1, the study as a whole is composed of 12 simulation cases.   The variable of penetration rate was studied faithfully at 3,5, and 10%.   The variable of charging station type and density was combined into four charging system designs as characterized by their location, and maximum charging power requirement.   The final variable of simultaneity of charging was not addressed in this study as it would require significant manipulation of the clean mobility simulator functionality. The simulation experiment is explained further in the following subsections.

Table 4-1 Cases for EV Simulation

Case #	Penetration	Charging System Design
1	3%	Full
2	5%	Full
3	10%	Full
4	3%	Limited Sparse
5	5%	Limited Sparse
6	10%	Limited Sparse
7	3%	Limited Dense
8	5%	Limited Dense
9	10%	Limited Dense
10	3%	Limited Dense Mixed
11	5%	Limited Dense Mixed
12	10%	Limited Dense Mixed

4.3.1   Cases: Study of Penetration Rate of Electric Vehicles

First, the study of penetration rate of electric vehicles was conducted at 3, 5 and 10%. Table 4-2, shows the corresponding simulation cases for each of the three levels of EV penetration.

Table 4-2 Ranges for EV Penetration

Case #	Penetration
1, 4, 7 and 10	3%
2, 5, 8 and 11	5%
3, 6, 9 and 12	10%

4.3.2 Cases: Study of Charging System Design -- Type & Location

Second, the study of charging system design was conducted for four designs called "Full", "Limited Sparse", "Limited Dense", and "Limited Dense Mixed". Table 4-3 shows the corresponding simulation cases for each of the four charging system designs.

Table 4-3 Set of Charging System Designs

Case #	Design Number	Charging System Design	Description
1, 2 and 3	D_1	Full	One charging station for every mall, park and petrol station.
4, 5 and 6	D_2	Limited sparse	One type II charging station for every mall and park
7, 8 and 9	D_3	Limited dense	Six type II charging stations in one neighborhood.
10, 11 and 12	D_4	Limited dense mixed	Three type II and three type III in the same neighborhood.

For all four charging system designs mentioned above, each individual charging station was set to have 5 charging station bays on each side of the road. Additionally, those charging stations marked as Type II were set to draw 19 kW per EV while Type III chargers were set to draw 50 kW per EV. The remainder of the section describes the differences between each of these charging system designs in the necessary detail.

The "full" charging system design consists of Type II charging stations for every mall and park on Abu Dhabi Island as well as Type III charging stations at petrol stations. In the full design, the geographical density of the chargers is distributed around the island and the types of chargers are diverse. This charging system design is meant to reflect a wide adoption of electric vehicles. The design is depicted in Figure 4-6.
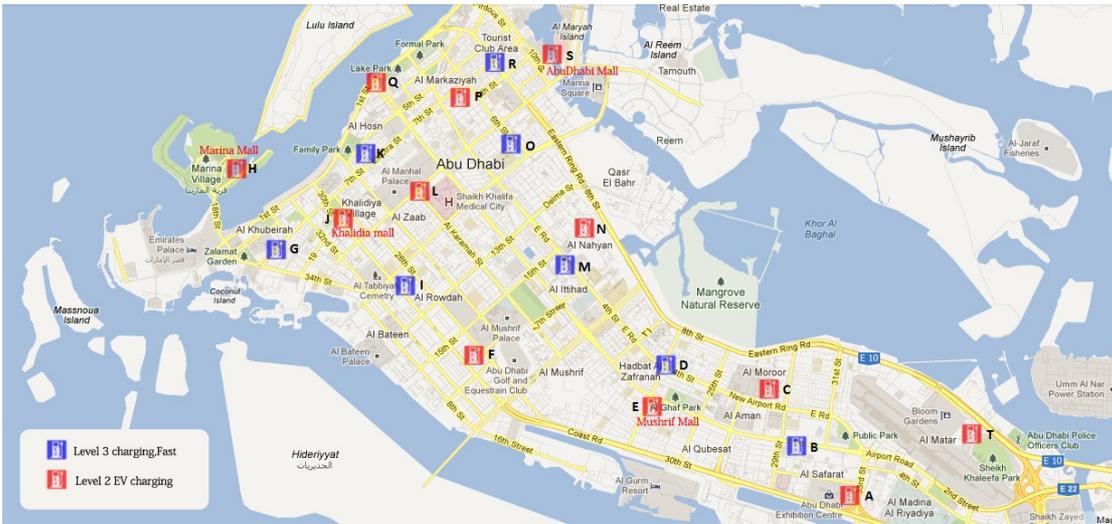
Figure 4-6 Full Charging System Design

The "limited sparse" consists of one Type II charging system for every mall and park on Abu Dhabi Island but differs from the "full" design in that it does not include the Type III chargers at the petrol stations. In this design, the geographical density of the chargers is distributed around the island but the types of chargers are only Type II. This charging system design is meant to reflect a wide adoption of electric vehicles with only Type II chargers. The design is depicted in Figure 4-7.

Figure 4-7 Limited Sparse Charging System Design

The "limited dense" consists of six Type II charging stations in the same neighborhood. In this design, the geographical density of the chargers is dense and the charger types are limited to Type II. This charging system design is meant to reflect a limited adoption of electric vehicles with only Type II chargers. The design is depicted in Figure 4-8.
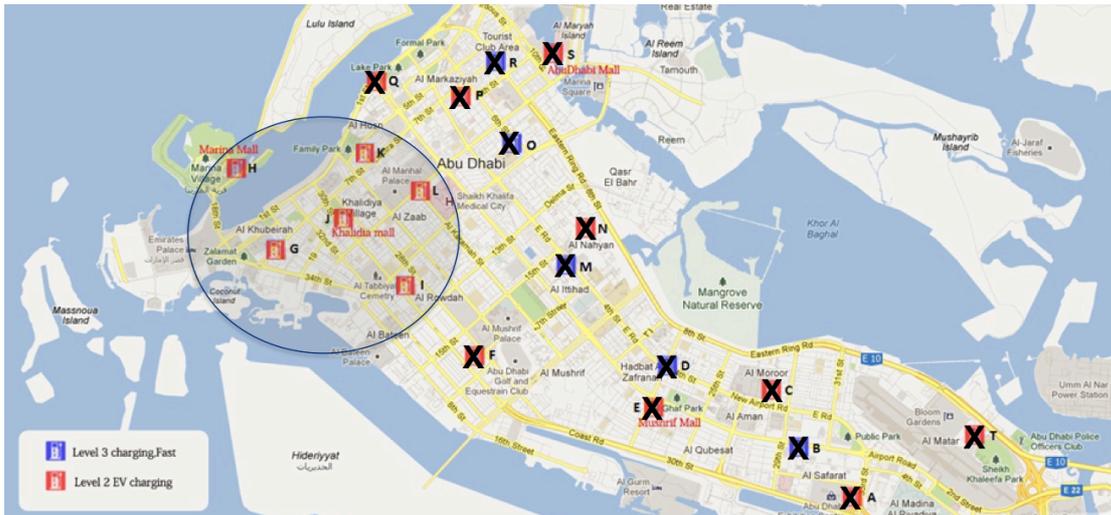
Figure 4-8 Limited Dense Charging System Design

The "limited dense mixed" design consists of three Type II charging stations and three Type III charging stations in the same neighborhood. In this design, the geographical density of the chargers is dense and the charger types are a mixture of type II and type III. This charging system design is meant to reflect a limited adoption of electric vehicles with different types of charging stations. The design is depicted in Figure 4-9.

Figure 4-9 Limited Dense Mixed Charging System Design

4.4   Results & Discussion

The previous section discussed the 12 cases constructed for simulation using the Clean Mobility Simulator. This section discusses the results of these simulation cases. The transportation system assessment utilizes the Quality of Service measure discussed in Section 4.1.1. The power system assessment

begins investigates the total load curve as a function of time, the value of the associated safety criterion and where it is illustrative the load curves of individual charging stations.

4.4.1 Transportation System Assessment

This section discusses the impact of both the penetration level and the charging system design on the Quality of Service.

4.4.1.1 Impact of EV Penetration on QoS

The QoS measure in each case changes with the penetration and charging system design. As the penetration increases, the QoS generally decreases, as shown in Figure 4-10. The corresponding numerical values are compiled in Table 4-4. This degradation effect is likely due to longer charging queues. For example, the lowest QoS is shown in all 10% penetration levels. With a fixed set of charging stations and an increasing number of EVs, the waiting time of each vehicle to charge increases. This demonstrates the importance of number of charging stations in a high penetration ratio. To maintain a high QoS, it is essential to increase the number of charging stations as the penetration of electric vehicle increases.
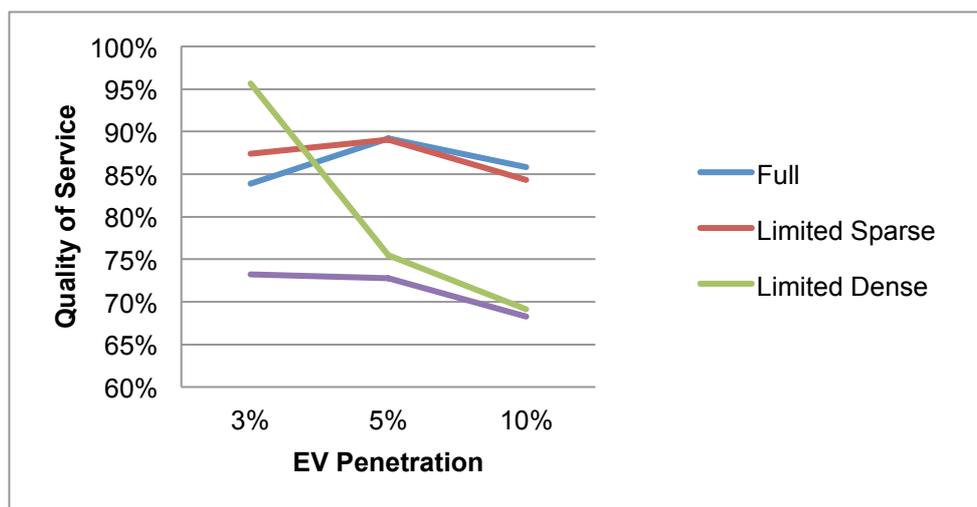
Figure 4-10 Changes in QoS in All Charging System Designs as Penetration Increases

Table 4-4 Quality of Service for All Cases

Case #	Charging System Design	Penetration	QoS
1	Full	3%	83.89%
2	Full	5%	89.21%
3	Full	10%	85.84%
4	Limited Sparse	3%	87.40%
5	Limited Sparse	5%	89.08%
6	Limited Sparse	10%	84.31%
7	Limited Dense	3%	95.64%
8	Limited Dense	5%	75.49%
9	Limited Dense	10%	69.13%
10	Limited Dense Mixed	3%	73.25%
11	Limited Dense Mixed	5%	72.79%
12	Limited Dense Mixed	10%	68.27%

Interestingly, the Limited Dense at 3% penetration case shows an odd result as it demonstrates a very high QoS with a decrease of 20% as the penetration increases fromto 5%. This result is likely due to the nature of the clean mobility simulator as a stochastic discrete-time simulation. Fundamentally speaking, the simulator controls how many ICVs and EVs leave in a specified duration but the exact departure time of these vehicles is a stochastic variable. Therefore, it is possible for waves of traffic density to develop that subsequently create charging queues even for the same set of simulation variables. This effect also explains the slight increase in QoS in both the Full and Limited Sparse cases at 5%.

4.4.1.2 Impact of Charging System Design on QoS

The modification of charging system design also demonstrates an impact on QoS. The geographic density of chargers in Abu Dhabi Island and its suburbs appeared to have a greater impact on trip times than charging station type. Both the "Full" and "Limited Sparse" not only had the higher levels of QoS but were also less susceptible to growth in the EV penetration. The "Limited Dense" and "Limited Dense Mixed", in contrast, had significantly lower QoS values. These simulations suggest that the introduction of charging stations

geographically spread throughout the city can help avoid the undesirable situation of EV users driving long distances to charging stations while facing low battery charge.   Meanwhile, the addition of Type III chargers had a relatively small impact on the QoS.   In all, the results seem to suggest that QoS can be best maintained by first the location, second the number and then the type of the charging station.

4.4.1.3 Transportation System Assessment Conclusions

The preceding paragraphs have demonstrated that the integration of electric vehicles in to the transportation system can have a significant detrimental impact on the quality of service provided by the electric vehicles.   The implications of this are profound depending upon the EV use case.   Left unmitigated in public sector or commercial applications, such a degradation of quality of service can result in either direct or indirect loss of revenue.   For example, EV taxi or EV bus passengers may decide to use other modes of transport as they experience delays in their travel itineraries.   Government commercial fleets may find that the use of EV results in an impaired ability to execute their daily tasks.   Such impacts can ultimately have negative word-of-mouth knock-on effect in the adoption rate of private users.   Therefore, the ultimate viability of electric vehicles depends on technical efforts to mitigate the actual and perceived degradations in quality of service.   One can frame the cost of these technical efforts within an ROI decision framework given an understanding between the relationship of quality of service and lost revenue.

The technical efforts to mitigate the degradation of quality of service ultimately requires that charging stations are geographically spread out across the city or the area of service.   This is equally true for relatively small EV penetration rates. Technically speaking, a large number of charging stations geographically spread throughout the city may lead to acceptable quality of service in such circumstances.   However, the aggregate value of charging stations per EV would be relatively high and potentially cost prohibitive on the supply side.   EV users, coming from the conventional mentality of ICV transport, probably have a limited willingness to subsidize charging station infrastructure despite potentially demanding QoS requirements.   An alternate solution would be target use cases where the EV routes are well known and quantified.   In such cases, charging station placement can be concentrated along these routes.   Regardless of

whether the EV adoption scenario is geographically broad or limited, significant future research is required in optimal placement methods that maintain QoS at minimal cost. Such work must be done in conjunction with nascent work on the coordinated charging of electric vehicles.

In summary, technical efforts are required to mitigate the potential degradation of transportation QoS. The technical solution itself requires yet-to-be developed optimal placement algorithms and is a subject for future research. This work must be done in conjunction with coordinated charging methods. Such methods will ultimately show that certain adoption scenarios or pilot projects have infeasible combinations of cost and QoS. Feasible, technical solutions can be further rationalized in a return on investment framework assuming a relationship between lost revenue and quality of service.

4.4.2 Power System Assessment

As discussed in Section 0, twelve simulation cases were studied; the full combinations of four charging system designs: "Full", "Limited Sparse", "Limited Dense" and "Limited Dense Mixed" and three penetration rates: 3, 5, and 10%. These cases are now assessed from three power system perspectives. First, the total charging system load curve for each case is quantified and compared. Next, the line/transformer safety criterion is measured and compared. Finally, where it is illustrative, the individual charging station load curves in a given case is shown. For completeness, the remaining individual load curves for this charging system design may be found in the Appendix. To organize the discussion, and better discuss the results, the simulations are grouped on the basis of charging system design in order of most limited to most widespread. Throughout the section, the discussion draws extensively on Figure 4-11 and Figure 4-12.

Prior to proceeding, it is important to recognize that the Clean Mobility Simulator, like other traffic simulation tools, simulates traffic evolution from origin to destination and so does not capture any activity including charging before an origin or after a destination. In order to overcome this challenge, the simulations were implemented as two sets of sets of electric vehicles. The first set leaves in the morning with a full charge while the second set leaves in the afternoon with a 50% initial state of charge. As a result, the simulations assume

that the vehicles that had travelled in the morning had done so and expended 50% of their charge in the process without drawing on the grid for power. As the simulation results show, none of the morning trips expended sufficient battery charge so as to require morning charging. Subsequently, all charging occurred in the latter half of the day. As expected, in all cases, as EV penetration increases, so too does the total power demanded. The remainder of the section interprets and differentiates the results of the twelve simulation cases.
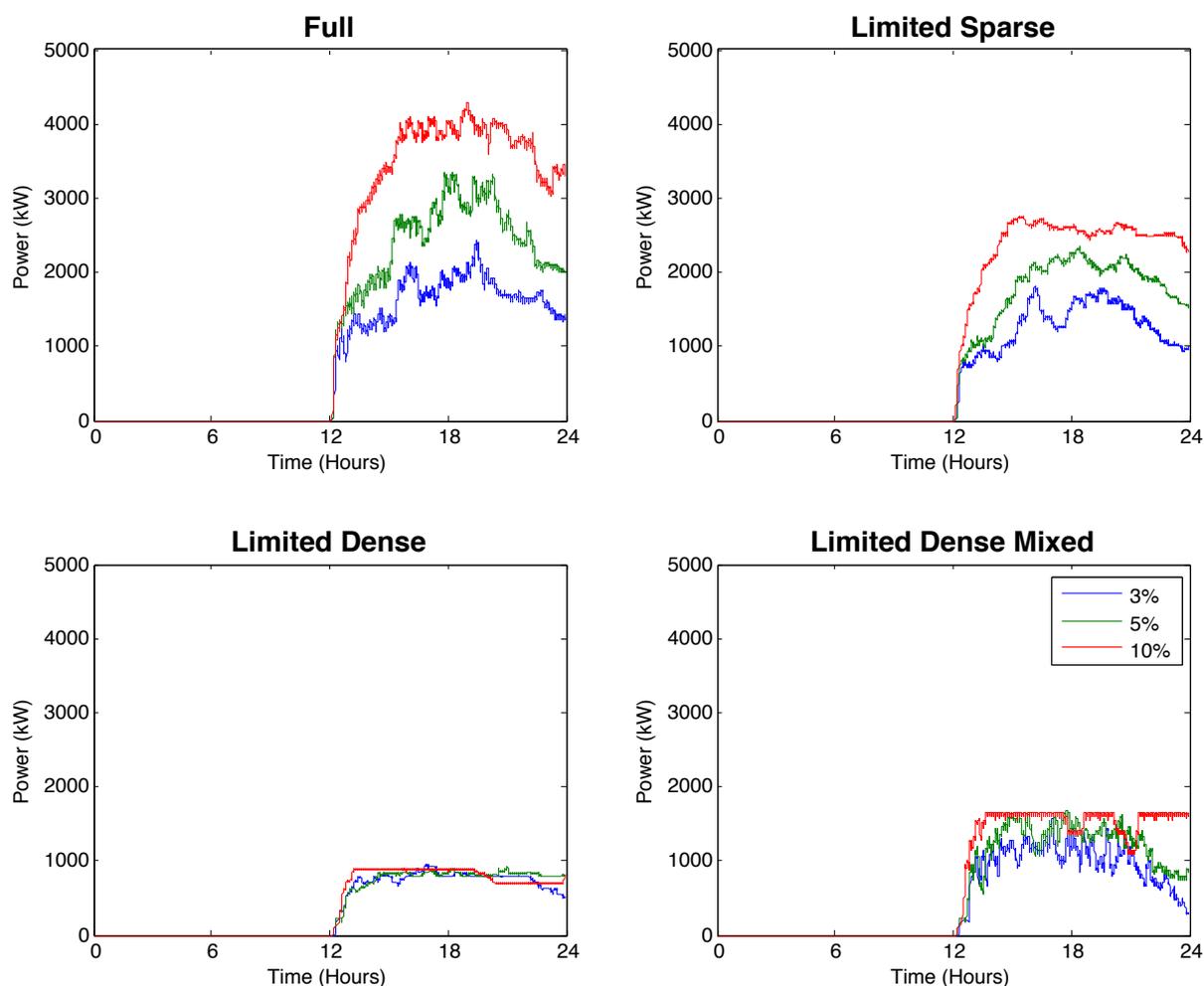
Figure 4-11 Total Charging System Load Curves for all 12 Simulation Cases
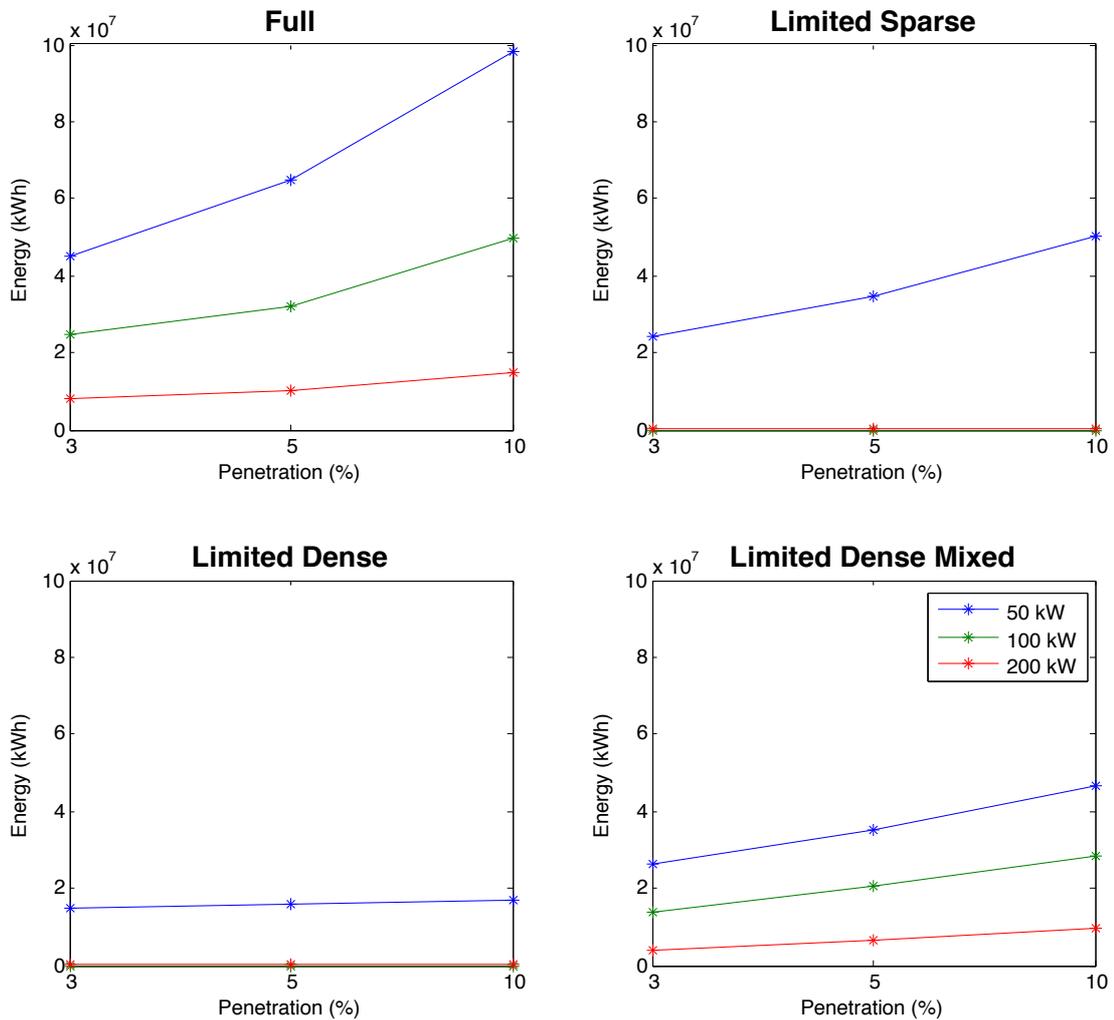
Figure 4-12 Safety Criterion Analysis of All Charging Station Designs

4.4.2.1 Limited Dense Charging System Design

The Limited Dense charging system design has the smallest charging system load curve at around 1MW for all three penetration rates. In absolute terms, 1MW comprises a very small portion the Abu Dhabi generation capacity of X GWs. Therefore, from an energy perspective, EVs do not present a major challenge. More interestingly, this charging system's load curve is characterized by saturation, which only becomes more prevalent with penetration rate. This saturation is due to the limitations in the number of chargers and their type and is best illustrated with a simple capacity calculation. Six charging stations, each with 10 charging slots which consume at the Type II

charger power of 19kW yields 1.14MW. Therefore, the charging station capacity becomes a type of system "bottleneck" where the impact on the power grid is the maximum possible but also generally decoupled from the vehicle dynamics in the transportation system. Although, this saturated and highly predictable load curve is desirable from a power utility perspective, it is entirely undesirable from a transportation system perspective in that it causes charging station queues and degraded quality of service. Recall from Section 4.4.1.2 that the limited dense charging station design resulted in some of the lowest QoS values.

The corresponding line/transformer safety criterion values provide a similar understanding. As shown in Figure 4-12, the limited dense charging station design does not exceed transformer safety limits when 100 or 200kW of available capacity are assumed. Only in the case of 50kW of available power capacity does this charging station exceed the safety criterion; although it does so at the same level irrespective of penetration rate. Once again, the saturation of the charging station limits the power drawn to a highly predictable value.

While the aggregate charging system load curve is relatively well behaved, the underlying load curves for each of the charging stations is quite different. While it is graphically impractical to show the load curves for all charging stations, it is most interesting to pick out the charging stations with the following five statistics:

- Maximum value of power consumption.
- Maximum energy consumption
- Minimum energy consumption
- Maximum variability in power consumption
- Minimum variability in power consumption.

Figure 4-13 shows the individual load curves for the limited dense charging system load curve at 5% penetration rate.

In this case, Station 1 demonstrated the maximum power of 100kW consistently and so also had the minimum variability. Very similarly, Station 10 consumed the most energy over time. Provided that significant EV charging queues do not develop at these stations and that the charging load does not exceed line/transformer limits, these highly utilized charging stations represent very well rationalized parts of the charging system design because of their consistent but

bounded load to the grid. In contrast, Station 4 consumed the least energy calling into question its need in the total charging system design. Meanwhile, Station 13 exhibited the greatest variability in its load curve. These statistics have further operational significance for power system operators. The maximum and minimum energy statistics reflect the amount of consistent generation that is required to meet the demand. Meanwhile, the maximum power gives a sense of how much ramping capability may be quickly required for balancing. The maximum power also gives a sense of how much a frequency deviation occurs as this charging load swings in and out of operation. Finally, the minimum and maximum variability places bounds on the required regulation capacity to balance the power system via automatic generation control. In this limited dense charging system design, the individual charging station load curves are significantly different from charging station to charging but fairly well behaved in comparison to later cases described in the later subsections.
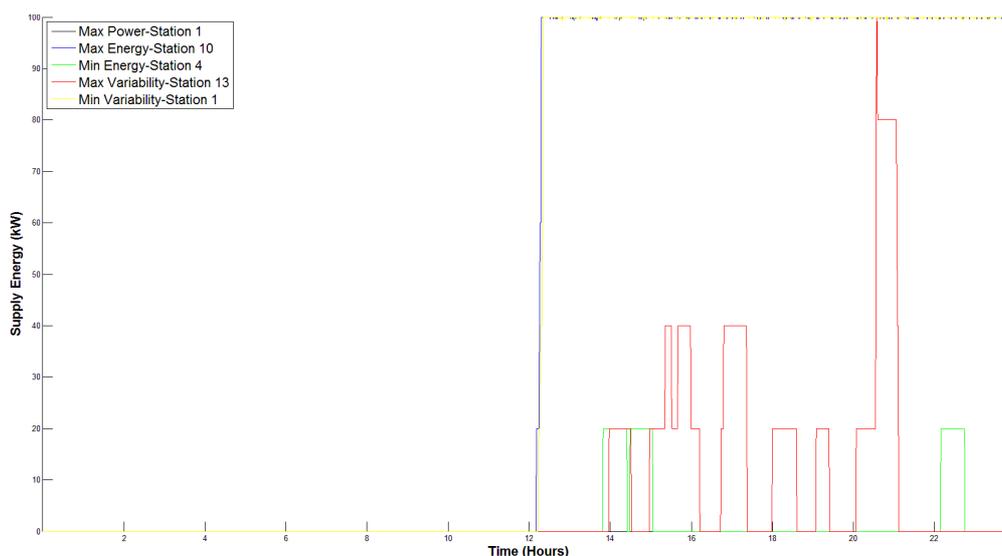
Figure 4-13 Individual Charging Station Load Curves for the Limited Dense Charging System at 5% Penetration

In summary, these results suggest that from a practical perspective the maximum power and energy impacts can be calculated a priori and incorporated within power utility planning activities. Nevertheless, operating the EV fleet at these maximum values results in degraded quality of service.

4.4.2.2 Limited Dense Charging System Design

The Limited Dense Mixed charging station design has similar load curves to the limited dense case but with higher limits and greater variability.   Although, the charging slots available are the same, the types of chargers differ.   These results follow the developed intuition in Section 4.2.2. The Level III chargers are able to more quickly process any charging station queues and so the aggregate load curve is more variable than the limited dense charging station design. The replacement of three Level II chargers with Level III chargers also increased the saturated maximum power from 1MW to 1.5 MW.   As before, the saturation of chargers and the limiting maximum power gives an advantage to the power utilities because of the ease of predictability. However, as with the limited dense case, a degradation in the QoS follows.

The saturation and variability behavior in the aggregate load curve becomes more pronounced when looking at individual charging station load curves. Figure 4-14 shows the considerable differences between the individual load curves for the limited dense mixed charging system load curve at 5% penetration rate. Station 2, for example, exhibits a minimum energy load curve; calling into question its necessity in the design.   Meanwhile, Station 1 shows minimum variability as the result of a Type II charger being required at nearly full capacity. Meanwhile Stations 6, 8, and 9 all demonstrated aggravated amplitudes as Type III charging stations
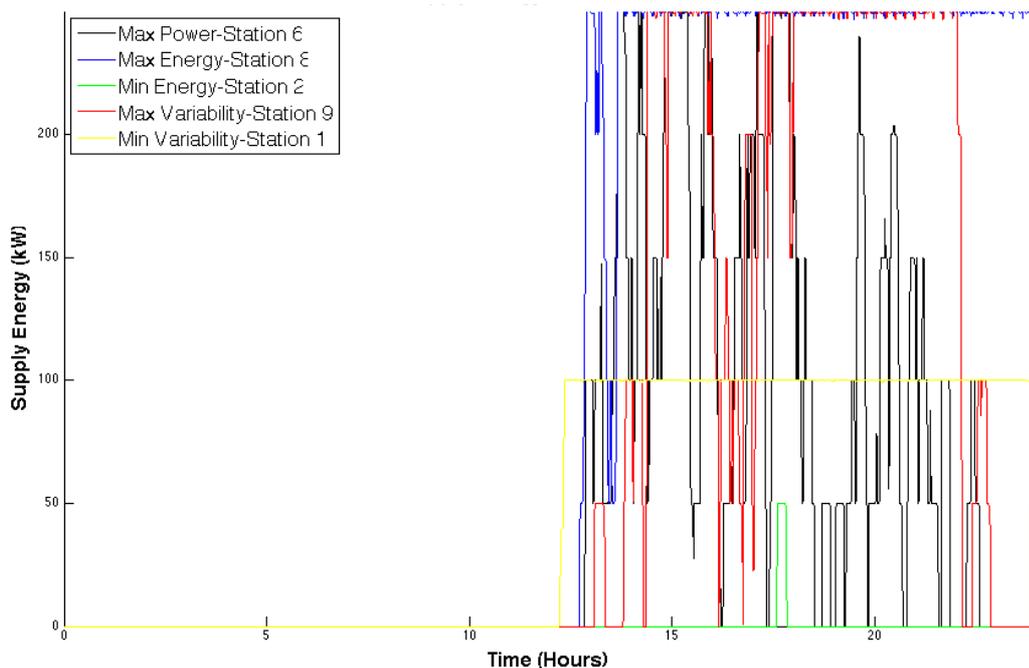
Figure 4-14 Individual Charging Station Load Curves for the Limited Dense Mixed Charging System at 5% Penetration

The charging power variability in the limited dense mixed charging system provides a new operational challenge to power system utilities.   Power utilities' main operational challenge is to maintain the balance of power consumed and generated.   This task is easiest for well quantified, predictable, and slowly evolving loads.   In contrast, the power drawn in this case is highly variable. Such a result suggests that power system utilities would have to use the power system's regulation services to automatically control generation in response. Such a solution is technically viable provided that the degree of variability is within the saturation limits of the planned regulation service.   The few hundred kWs of variability shown above is not likely to exceed any major technical limits. Nevertheless, regulation services are the most expensive form of power and their additional use can add an extra marginal cost for power utilities and their consumers.

As shown in Figure 4-12, the line safety criterion provides similar information for the limited dense mixed charging system design. In comparison to the limited dense charging system design, the inclusion of Type III chargers in the limited dense mixed charging system now requires lines and transformers to have

greater available power capacity to avoid exceeding the safety limits regardless of whether there was 50, 100, or 200kW of available power capacity. As shown in Figure 4-12, the total energy exceeding the power limit has a positive slope with the EV penetration rate. This suggests that the EVs are not just consuming more power but they are also doing so at times when other vehicles are charging; adding to the times in which the lines are over their safety limits.

The implications of such results are significant. Installation of such a charging station design would naturally require careful thought as they are integrated into the power grid. One solution would be to upgrade the lines/transformers to which the charging station is connected. Another would be to connect the charging station to a higher distribution system voltage. This would require a dedicated charging station transformer. Both solutions require significant capital expenditure, which may affect the ultimate viability of the envisioned EV adoption scenario.

4.4.2.3 Limited Sparse Charging System Design

Continuing to a more widespread charging station design, the limited sparse design shows an interesting interplay between the power drawn, the geographical sparsity and the variability. At 3% penetration, the power drawn varies between 1-2MW with some variability but no saturation. Relative to the previous charging system designs, the addition of charging stations and their geographical distribution has allowed EVs to charge as is necessary with significantly reduced wait times. However, the relatively unconstrained charging has led to greater amplitudes in the charging power variability. Interestingly, this increase in charging power variability is not significantly greater than the previous charging station design to due to the complete reliance on Type II charging stations. At 10%, the number of EVs begins to push the capacity limits of the limited sparse charging system design. The charging power evolves from 1-2 MW to a more consistent 2.5 MW; the size of a typical gas turbine generator. The power variability experienced at the lower penetration levels is replaced with near saturation as charging vehicles are quickly replaced from the oncoming traffic.

At the individual load curve level, the limited sparse charging system design provides insights not apparent at the aggregate level. Figure 4-15 shows the

individual charging station load curves for the limited sparse charging system at 5% penetration. While not immediately apparent, the results show a strong resemblance to the individual curves in the limited dense 5% case shown in Figure 4-13. The maximum power, maximum energy, minimum energy and minimum variability charging station statistics all have similar features. The exclusive use of Type II charging stations in both cases has also lead to the maximum individual load of 95kW. The main difference between the two cases is the growth in the maximum variability; perhaps due to the expansion of the charging system and its subsequent underutilization in some areas. It is expected that as the charging system is expanded and charging station saturates is alleviated, the charging station power variability will grow. Nevertheless, the similarity of the two figures outweigh the differences and so the exclusive usage of Type II chargers in geographically spread out locations represent a sort of extensible design solution in both the transportation and power systems.
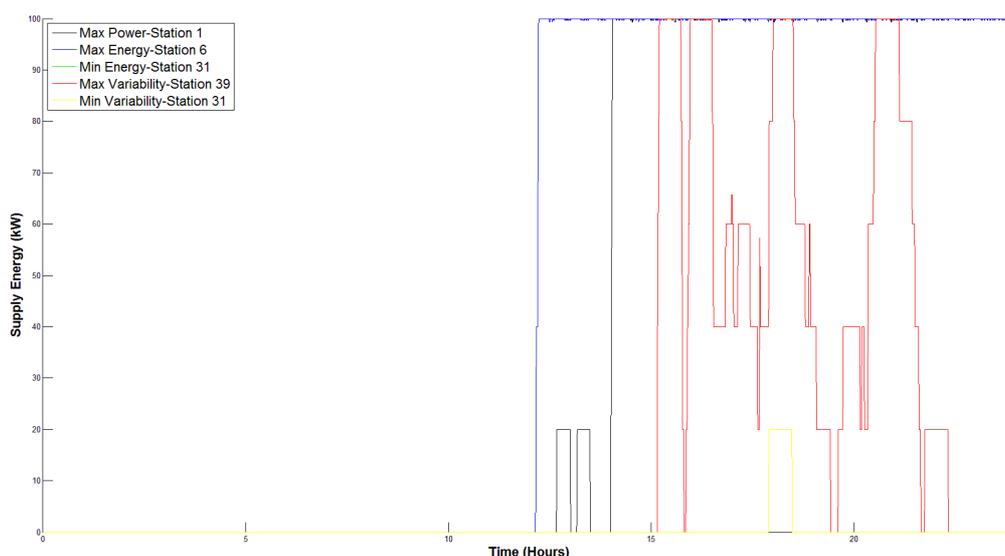
Figure 4-15 Individual Charging Station Load Curves for the Limited Sparse Charging System at 5% Penetration.

Despite the aggregate growth in the maximum charging power for this charging station design, a similar evolution in the safety criteria did not occur. At all penetration levels, the safety limits were not exceeded assuming 100kW and

200kW of available line/transformer capacity. It is only when the available line/transformer capacity was limited to 50kW that the safety criterion was exceeded. In this regard, the limited sparse charging system design followed the behavior of the limited dense design because of their exclusive use of Type II chargers.   The main difference between the two charging station designs appears in the conservative case of 50kW availability capacity.   In the limited dense case, the safety criterion values remain constant for all values while in the limited sparse case it grows from 3% up to 10%.   In the former case, the near full charging power station saturation limits the power transferred through the lines/transformers.   In the latter case, the number and geographical distribution of charging stations allows the value of the safety criterion to be not only relatively larger but also grow to accommodate the increasing demand for EV charging.   These results suggest that instead of upgrading line and transformer capacities, the impact on lines and transformers can be most reliably mitigated in the planning phase by ensuring that the lines and transformers have enough available capacity at all times to accommodate the maximum charging station power.   Alternatively, a more complex yet cost-effective technical solution would be to implement an automated coordinated charging strategy which actively limits the charging station power to the currently available line/transformer power capacity.

4.4.2.4 Full Charging System Design

The full charging system design presents the most aggravated impact on the power grid in regard to both the maximum charging power and the charging power variability.   In this case, the charging system has sufficient capacity to bring its power impact onto the grid.   Depending on the EV penetration rate, this maximum power could range from 2-4 MW.   While these values are not large in relation to the total generation capacity, in absolute terms they are equivalent to a significantly size gas turbine.   Additionally, given that the charging system has sufficient capacity, the number of simultaneously charging EVs and the associated charging power can vary substantially.   Relative to the limited sparse charging system, the effect is exacerbated by the presence of the Type III chargers.

As the charging system grows the EV penetration rate, the integration of EVs tends to appear more and more like a variable demand side energy resource.

Its mitigation on the power system requires similar measures. Regulation services can do their part to eliminate some of the variability, but ultimately this solution is the costliest in terms of marginal price and is limited within market and regulatory limits. Some of the variability must be mitigated in the power system dispatching. Such a solution requires that high fidelity charging system power forecasts be developed with good accuracy. Research in this space can evolve along a number of directions. In this case that limited information can be passed between the transportation and power systems, forecasting methods can be developed on the basis of statistical data mining methods. In more transparent and cooperating circumstances, traffic simulation technology integrated within intelligent transportation systems can be used to deliver reliable forecasts. Finally, coordinated charging techniques can be combined with a demand side response framework to actively manage the grid to the impact. Ultimately, these challenges suggest a future convergence and collision of the intelligent transportation systems and smart grid disciplines and represent open directions for future research.

At the individual load curve level, these effects become even more pronounced. Figure 4-16 shows the individual charging station load curves at 10% penetration and is best understood as an aggravation of both the limited sparse case shown in Figure 4-15 and the limited dense mixed case shown in Figure 4-14. The maximum power has expanded from 95kW to 250kW. Meanwhile, the highly utilized Type II charging station 23 provides the minimum variability over the course of the day. The greatest concern in this simulation case is the exaggerated variability shown in Station 8. Here, the usage of Type III charging stations has combined with a generally underutilized charging system to cause significant disruptions to the grid operations. Left unmitigated, power system operators would have to deploy significant regulation services as well as optimized dispatch schedule. Nevertheless, could have been minimized by placing the Type III chargers only in the most utilized locations.

The full charging station design also presents a challenge to line and transformer power limits. As shown, the total power exceeding all three critical lines is the highest. The mixture of charger types resulted in power exceeding the limit of 50kW, 100kW and 200kW. As with the limited dense mixed charging system, the full charging system design has a mixture of Level II and Level III. In the

Level III chargers, there are 5 charging slots which means that a single charging location can reach up to 250 kW of power when 5 vehicles are charged at the same time. As the penetration increases, the likelihood of having 5 vehicles plugged in at the same time increases; resulting in a positive slope with penetration rate. In such aggravated conditions, upgrading line and transformer limits are likely the only technical solution and would require the associated capital expenditures.
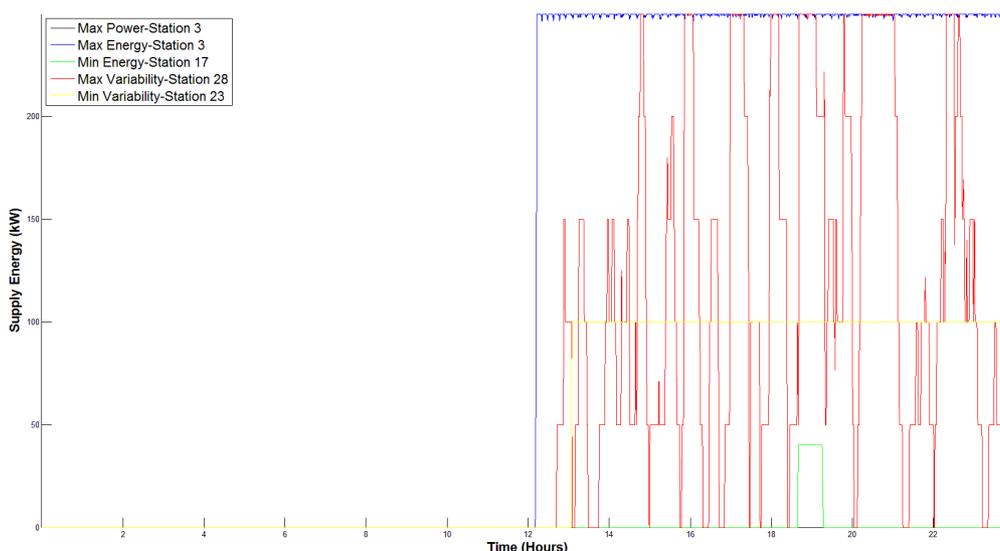
Figure 4-16 Individual Charging Station Load Curves for the Full Charging System at 10% Penetration

4.4.2.5 Power System Assessment Conclusions: Heuristics for Charging System Design

This section has provided a thorough assessment of twelve EV penetration cases based upon three penetration rates and four charging system designs. It showed clearly that the EV brings about a transportation-energy nexus in which negative impacts can be shifted fluidly from the transportation system to the power system and vice versa. The mitigation of these averse impacts could have significant economic impacts outside the scope of the EV manufacturer that can ultimately impair the EV adoption trajectory. The impacts described throughout this section are compiled systematically in the chapter's conclusion.

4.5 Conclusion: Heuristics for Charging System Design & Future Work

This chapter has applied the assessment tools described in the previous chapter to assess the technical feasibility of EVs with respect to their supporting infrastructure. For the physical transportation system, a microscopic discrete-time traffic operations simulator, the clean mobility simulator, was used to study the kinematic state of the EV fleet over the duration of one day [1]. For the impact on the electric power system, the EV traffic flow patterns from the CMS were used to calculate the timing and magnitude of charging loads. In order to integrate the two systems into one technical feasibility assessment, Section **Error! Reference source not found.** provided an overview of a technical assessment methodology that included quantitative quality measures. Next, Section 4.2 gave an intuitive explanation of the variables that impact the two infrastructure systems. This facilitated the development of the simulation experimental design in Section 4.3; a set of case studies which were objectively compared in Section 4.4.

The technical feasibility assessment brought into the spotlight that the introduction of the electric vehicle brings about a transportation-energy nexus. Moreover, the need to charge the electric vehicle brought about impacts on the three supporting infrastructure systems: the intelligent transportation system, the physical transportation system, and the physical power grid. The first of these was well addressed in the previous chapter. This chapter showed that the negative impacts can be shifted fluidly from the transportation system to the power system and vice versa. Impacts on the transportation system were measured in terms of "Quality of Service" – a relative measure of how available EVs; or how delayed they are by the need for charging. Impacts on the power system were measured in aggregate as well as for individual charging stations. Here, five statistics
- Maximum value of power consumption.
- Maximum energy consumption
- Minimum energy consumption
- Maximum variability in power consumption
- Minimum variability in power consumption.

were associated with different types of power grid impacts.

The results showed that the design of the charging system itself is highly influential in either amplifying or mitigating the impacts of the EV integration. This is a multi-variable design space and irrationalized decisions can easily have unintended consequences on the combined transportation-energy infrastructure nexus. Table 4-5 compiles the technical implications on the power system and transportation system for the five previously mentioned statistics. On the transportation side, low QoS which is also evidenced by low power variability and high maximum energy of load curves, can significantly impair long term EV adoption and reduce the revenue of the transportation services that choose to use electric vehicles. On the power system side, high max power could cause significant capital expenditures in upgrading lines and transformers. Meanwhile, high power variability will require the use of generation with significant ramping capabilities: flexible generation, synchronized reserves, and automatically controlled regulation services. All of these lead to a system wide increase in the marginal price of electricity. If there is insufficient flexibility in the generation fleet, then EV integration could potentially require further capital expenditures.

Table 4-5 also provides charging system design heuristics to mitigate impacts to the transportation-energy nexus. Here, the two main problems are 1.) insufficient charging capacity 2.) inappropriate use of under-utilized Type III chargers. Simply speaking, a significant number of charging station distributed over the service area is required to avoid reduced quality of service and overloaded power lines and transformers. Meanwhile, Type III chargers should be systematically avoided unless there is a clear rationale that they will be utilized at near full capacity.

While these design heuristics are useful, ultimately the operation of the transportation-energy nexus presents an example of complex engineering system dynamics that cannot be addressed purely with simple design rules.

Significant capital and operating costs within the infrastructure systems can be avoided with the planning & design decision support tools such as charging station optimal placement & sizing algorithms. Furthermore, coordinated charging strategies need to become integral parts of not just the intelligent transportation system functionality but also part of the quickly developing suite of smart grid applications. In both of these cases, research is still quite nascent and further rigorous and quantified efforts are required.

Table 4-5 Charging System Design Heuristics for Mitigation of Impacts to Transportation-Energy Nexus

Technical Challenge	High Max. Energy	High Max. Power	High Power Variability	Low Min. Energy	Low Power Variability
Technical Implications on Power System	-- None. Small in comparison to generation capacity	-- Overloaded lines & transformers	-- System wide need for generator ramping capabilities. Appears as flexible generation, synchronized reserves, and regulation services -- System wide need for improved charging load forecasting	-- None	-- None.
Technical Implications on Trans. System	-- Suggests long charging queues and reduced QoS.	-- None	-- None	-- Under-utilized charging station.	-- Suggests long charging queues and reduced QoS.
Economic Implications	-- Impaired EV adoption. -- Reduced transportation service revenues	-- Significant capital expenditure on line & transformer upgrades	-- System wide increase in the marginal cost of electricity. -- Potential need for capital investments into flexible	-- Poor ROI. -- Weak financial rationale for charging station	-- Impaired EV adoption. -- Reduced transportation service revenues

			generation and automatic generation control		
Mitigating Charging System Design Heuristic	-- Optimize the scope of the EV use case -- Expand # of charging stations w/ optimal placement algorithms - Balance increased costs with potential revenue losses	-- Coordinated charging strategy -- Optimal placement algorithms -- Systematic preference for Type II chargers -- Reduce # of charging station slots	-- Coordinated charging strategy -- Type III chargers as chargers of last resort. -- Optimal placement of Type III chargers for high utilization	-- Optimal placement algorithms for charging stations	-- Expand # of charging stations w/ optimal placement algorithms - Balance increased costs with potential revenue losses

4.6   Chapter References

[1]   MHI, "Environment-Conscious Urban Design Simulator "Clean Mobility Simulator" - Traffic Simulator that Includes Electric Vehicles," Japan, Tech. Rep. 1, 2012.

5 Interaction with AD DOT

AD DOT has participated in the present study in the form of data provision (STEAM model output and traffic count data) to support the calibration of the SOUND traffic simulator and through workshops at the beginning and the end of the study period. In the last workshop on February 5th 2013, participants from all DOT departments – ITS, Strategy and Planning, Transit, TRANS AD had the chance to be presented intermediate findings and discuss them with the researchers and the MHI team. The workshop agenda is provided in Appendix 2.

One of the participants indicated about the workshop in a follow-up email:

"*Thank you very much for hosting the informative and interesting workshop on Tuesday. As discussed I would like to maintain a close liaison between ourselves during the completion of your study into electric cars and ours into the feasibility of introducing a low emissions zone in Abu Dhabi Metropolitan area and the introduction of charging stations for EVs into building codes.*" A. Clarke.

The main areas of feedback that were received from the workshop were:

- Develop the bus component as the Transit department is actively considering the establishment of a trial Electric Bus option.
- Add the non-CO_2 pollutant valuation in the parametric analysis as the reduction of local air pollution is an important component of the AD DOT strategy.
- Introduce net present valuation of the cash flows for the scenarios
- The development of the grid compatibility component and specifically how the requirement for charging infrastructure compatibility could be integrated in the building code
- Carefully consider the taxi operations for EV compatibility

The DOT team felt that providing dedicated parking for buildings, which would have charging outlets, is a doable task with minimal costs by introducing the provisions into building codes. So, from the technical aspects of EV adoption in AD, the DOT was very interested in knowing the electrical demands of the EV, both in residential and commercial buildings. The MI research team could provide detailed explanations to these queries through presentations of their research as is shown in Appendix 2. They were also impressed with demonstrations of the CMS simulations.

Follow up meetings with TRANSAD (taxi) and the Transit (bus) operators

allowed us to obtain further information and enriched the data used to better represent the taxi and bus EV options and the respective benefits and costs.

The MI research team has addressed these requests in the current revised version of the report and reflects all up to date information. Any additional comments received on the circulation of the draft to DOT will be noted here and addressed to the extent possible.

6 Conclusions – Result Consolidation (1st Draft SS, 2nd Draft AF)

Vehicle electrification is a necessary component of an ultimate transition to a sustainable transportation system. This study showed that EVs are a viable option for meeting a portion of the UAE resident's mobility needs with today's technologies. The effect of the hot, arid climate on range and battery longevity is manageable with the appropriate strategies. The potential users of EVs from the UAE public demonstrate significant concerns over range, cost, safety and comfort based on the survey that we conducted as part of the study but these concerns can be alleviated by charging infrastructure deployment. Notably, once the current EV models that are equivalent in terms of safety and comfort levels were shown to the respondents their attitude towards EVs changed drastically. Given the high numbers of potential EV users living in apartments, a useful proactive regulatory effort would be to include charger-installation readiness for new building construction by the municipality.

On the economics of EV adoption, UAE's subsidization of both liquid fuels and electricity create a particular environment. The UAE government that implicitly supports the subsidy and foregoes opportunity of selling the oil at market prices internationally stands to gain significantly with the adoption of EVs and therefore has an additional incentive to support their deployment if it does not intend to reduce the level of subsidy and move to cost-reflective pricing. Local air pollutants and CO_2 are significantly reduced with the use of EVs in the operational parameters of the UAE. For realized net benefits though, the EVs at the current level of battery prices would need to be utilized at a higher utilization rate than what government fleets and private vehicles do in typical urban driving. As a result, car sharing, bus and taxi fleet applications are a particularly interesting niche although they would require some operational adjustments for the latter two and a willingness on the part of the government to share the benefit from liquid fuel consumption reduction with the operators to make their adoption commercially viable.

On the electricity side, the total power consumption of the ambitious EV adoption scenario called "Environmentalist" (cf. Section 1.8.1) amounts to a conservatively rated 0.11GW in 2030, which is approximately 0.5% of the total planned capacity for the Emirate by that year.

We review the barriers, benefits, transition strategy recommendations and technical feasibility in the following sections.

6.1. Benefits of EV adoption in UAE

EV adoption in the UAE context can provide the following benefits:
- Reduction in local liquid fuel consumption
- Local air pollutant reduction
- CO_2 emissions reduction
- Increased efficiency of the transportation system and better integration with renewable energy generation

All benefit categories are consistent with the goals of the ADSTMP (Strategies 6 & 7) and the vision set by Abu Dhabi 2030 Economic Plan. In the latter case, the increased efficiency of the transportation includes not only the inherent efficiency of the electric propulsion but also operational changes that would need to be placed in order to accommodate some of the limitations of the EVs (especially range). For example, taxi operations could utilize more call-on-demand services rather than the roaming model currently in operation reducing significantly unnecessary vehicle miles and resultant congestion without any loss of customer service if the allocation of the taxi stands/charging stations is done with appropriate coverage.

We have quantified the benefits in the form of parametric analysis in Section 1.7 for typical electric car and bus configurations. The breakdown of these benefits is shown Figure 6-1.
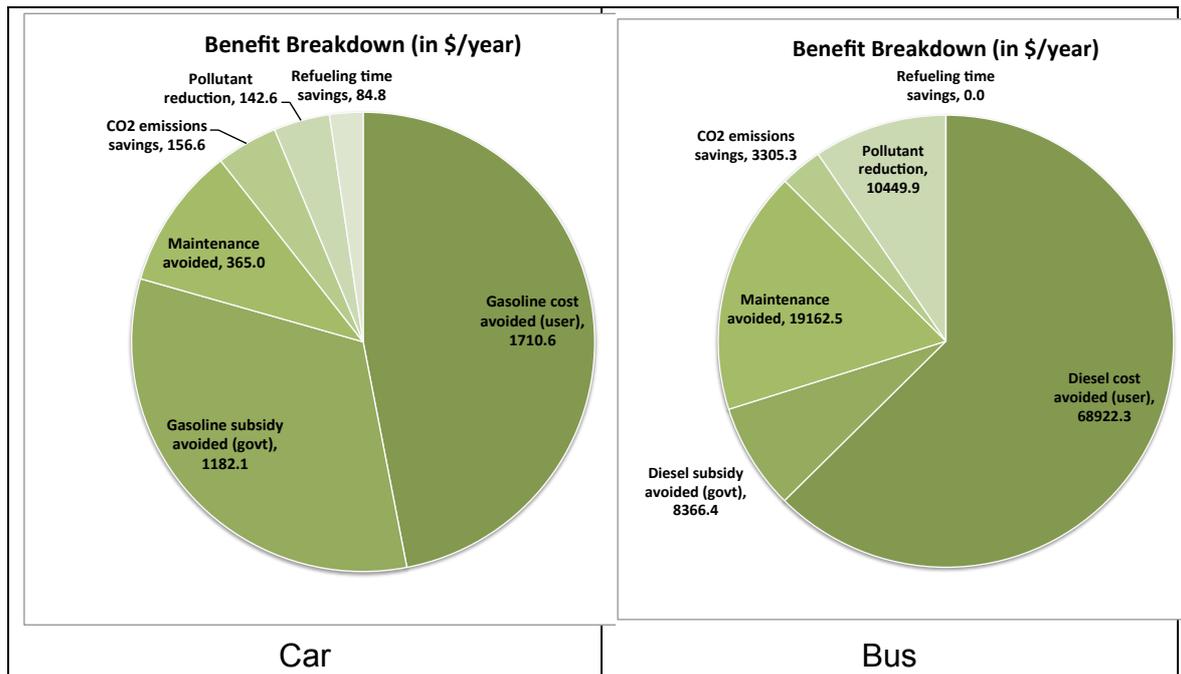
Figure 6-1 Annual Benefit Breakdown in 2012$ for Car (100km/d) and Bus (200km/d) in Abu Dhabi

The relative significance of the subsidy reduction for the government side in the case of Electric Car replacing an equivalent gasoline ICEV is clearly demonstrated as it comprises more than 30% of the benefits.

6.2. Barriers to EV Adoption in UAE

We categorize the barriers to EV adoption in the UAE in six main areas:

- Technical
- Social,
- Infrastructure,
- Regulatory, and
- Commercial

We overview each area individually and indicate where there is overlap and interaction across categories.

6.2.1. Technical Barriers

Technical barriers include range limitation aggravated by AC use, reduced lifetime of batteries due to high operating temperatures, and reduced power at charging (longer charging time) to avoid battery overheating. As Section 1.1 indicated all of the technical limitations are currently addressed. The range limitation is more serious as to be addressed on the vehicle would require

larger battery capacity with the attendant commercial costs. The currently available EVs though are capable of ranges >80km during hot weather driving which falls well within the needs of the majority of commuters in UAE (cf. Section 2).

6.2.2. Social Barriers

The UAE, partly due to fossil fuel subsidies, has developed a car-based culture and an urban planning development that is not easily amenable to public transportation. Efforts to increase public transit availability are under way but will take several years to yield results. In the meantime, reliance on automobile and the social identity it entails create a perception barrier for EVs. This barrier is evident both the national and expat population to varying degrees. But it can work both ways, if EVs can be shown to be both viable and symbols of a progressive, state-of-the-art attitude. Their environmental credentials and higher initial prices but lower operating expenses are likely to be neither booster nor impediments in the luxury vehicle sector but maybe more interesting levers for the entry level smaller vehicles. The fact that most families have more than one vehicle is also providing the option to have a second or third vehicle as all electric. This in combination with the limited parking availability makes the development of EV based car-sharing systems a very promising market niche both the introduction of EVs in the general public.

6.2.3. Infrastructure Barriers

The documented phenomenon of 'range-anxiety' was clearly also exhibited by the respondents of our survey in the UAE. A well-developed charging infrastructure with widespread and adequate availability of Level 2 and Level 3 charging stations in public (malls, on-street parking) and private – especially in apartment buildings – areas is a necessary aspect of widespread high utilization of EVs. This creates an upfront cost for the government/municipality, and the utility which there are many ways to address. Given the ancillary benefits of EV adoption to government, carrying that initial cost remains a cost-effective policy – as shown in the next subsection.

6.2.4. Commercial Barriers

Although it is known that private car buyers do not account properly for the long-term financial impact of their choices, vehicle economics plays a critical

aspect in the social momentum for the adoption of any technology. When looking at the cost breakdown of EV choices in **Figure 6-2** and compare it with the benefits for these parameters, we come to the conclusion that the market distortion from the fuel subsidy allows the government to fully cover the charging infrastructure costs and the subsidized electricity costs and still create a net benefit (including pollution avoidance).
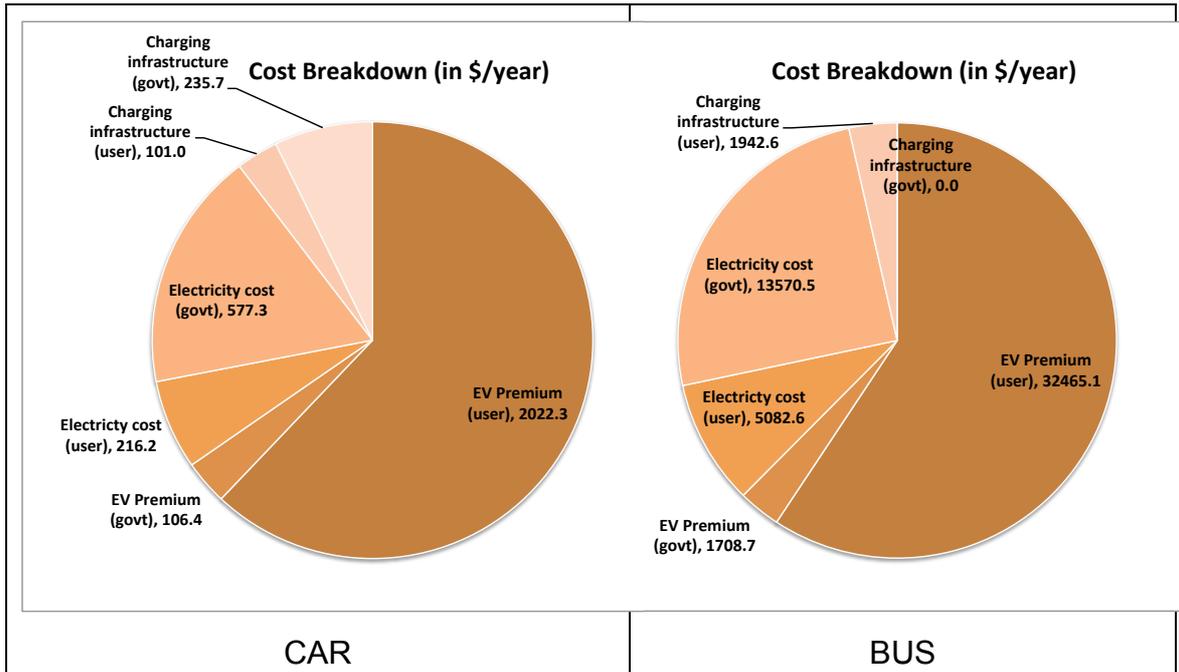
Figure 6-2 Cost Breakdown for Car (100km/d) and Bus (200km/d) EV

Given that the results are sensitive to vehicle utilization and vehicle premium, our sensitivity analysis (shown for the combined net benefit for cars and buses in **Table 6-1**) indicates that today's battery costs (ranging from 400 to 600 $/kWh) require vehicles to be operated at a high utilization rate. This is easier for a bus that is operated commercially and breaks even at a utilization of >140km/d at the $400/kWh battery level, than a private vehicle that would need to be operated >90km/d which exceeds the stated average trip distance for more than half the UAE residents. As a result, fleet operators with high utilization (taxis, car-sharing) are the ones that could make a clear financial case if they can assimilate EVs in their operations.

Table 6-1 Electric Car (Top) and Electric Bus Sensitivity Analysis of Net Annual Combined Benefits

Car Combined Benefit/Cost

$/Year	\$/kWh of Battery Cost					
	100	200	300	400	500	600
40	376.8	-48.9	-474.7	-900.4	-1326.2	-1752.0
50	661.6	235.9	-189.9	-615.6	-1041.4	-1467.1
60	946.5	520.7	94.9	-330.8	-756.6	-1182.3
70	1231.3	805.5	379.8	-46.0	-471.7	-897.5
80	1516.1	1090.3	664.6	238.8	-186.9	-612.7
90	1800.9	1375.2	949.4	523.7	97.9	-327.9
100	2085.7	1660.0	1234.2	808.5	382.7	-43.0
110	2370.6	1944.8	1519.1	1093.3	667.5	241.8
120	2634.1	2187.0	1740.0	1292.9	845.8	398.8

Vehicle Utilization (km/day) (row label axis)

Bus Combined Benefit/Cost

$/Year	\$/kWh of Battery Cost					
	100	200	300	400	500	600
100	19399.4	14583.3	9767.1	4951.0	134.9	-4681.3
200	45557.5	40741.4	35925.3	31109.1	26293.0	21476.8
300	69897.7	63263.6	56629.5	49995.3	43361.2	36727.1
400	94134.7	85579.5	77024.4	68469.2	59914.0	51358.8
500	118369.1	107890.3	97411.4	86932.5	76453.7	65974.8
600	142602.2	130198.4	117794.5	105390.7	92986.8	80582.9
700	166834.6	152505.0	138175.4	123845.8	109516.2	95186.6
800	191066.5	174810.7	158554.9	142299.0	126043.2	109787.4
900	215298.1	197115.7	178933.4	160751.0	142568.7	124386.3

Vehicle Utilization (km/day) (row label axis)

6.2.5. Regulatory Barriers

We have already extensively referenced the liquid fuel subsidy. To this we add the lack of a fleet fuel consumption target, and the lack of externality pricing for pollutant and GHG emissions. The pollutant reduction advantage is especially prominent for the bus EV replacement. Since, it is unlikely that the current social contract will change substantially, it is largely a governmental decision to support EV adoption in other ways to receive the benefits of gasoline consumption reduction.

To address this we have investigated a series of scenarios and policies that are summarized in the following section.

6.3. Transition Strategy Recommendations

In the two sections above we have established that there is a strong case for government intervention to spearhead the adoption of EVs – in some ways greater than the incentives of other national or regional governments that have

done considerable effort towards this direction (cf. Section 1.2). We have investigated three scenarios of options for supporting EV adoption which we called Environmentalist, Pragmatist, and Cautious (cf. Section 1.7) and which are summarized in **Table 6-2**.

Table 6-2 Scenario Comparison in Terms of Cumulative Results by Year

ENVIRONMENTALIST					
Year	**Cumulative Costs** (discounted $2012)		**Cumulative Benefits** (discounted $2012)		**Net Benefit**
	EV Premium	**Infrastructure**	**Fuel Savings**	**Ancillary**	
2015	$ 1,065,558	$ 124,417	$ 442,881	$ 155,032	$ (592,061)
2020	$ 37,412,927	$ 4,145,313	$ 53,848,764	$ 25,902,597	$ 38,193,121
2025	$ 131,112,242	$ 19,263,921	$ 211,423,259	$ 92,683,464	$ 153,730,560
2030	$ 241,087,201	$ 42,847,698	$ 453,360,773	$ 186,641,946	$ 356,067,820

Year	**# Car EV**	**# Bus EV**	**Cumulative Gasoline Saved (000 lit)**	**Cumulative CO2 avoided (tonnes)**	**Annual Electricity Consumed (MWh)**	**Peak Power Equivalent (MW)**
2015	280	0	821.8	1,175.5	1,173.4	0.4
2020	5503	255	98,273.7	152,212.2	77,207.1	26.4
2025	17328	523	448,454.6	685,152.5	190,573.2	65.3
2030	30990	805	1,096,038.8	1,665,346.7	316,859.5	108.5

PRAGMATIST					
Year	**Cumulative Costs** (discounted $2012)		**Cumulative Benefits** (discounted $2012)		**Net Benefit**
	EV Premium	**Infrastructure**	**Fuel Savings**	**Ancillary**	
2015	$ 675,567	$ 78,926	$ 298,459	$ 104,433	$ (351,600)
2020	$ 22,802,413	$ 2,551,020	$ 32,652,551	$ 15,665,394	$ 22,964,513
2025	$ 79,352,270	$ 11,716,011	$ 127,607,113	$ 55,880,368	$ 92,419,200
2030	$ 145,750,663	$ 26,008,324	$ 273,508,213	$ 112,494,729	$ 214,243,955

Year	**# Car EV**	**# Bus EV**	**Cumulative Gasoline Saved (000 lit)**	**Cumulative CO2 avoided (tonnes)**	**Annual Electricity Consumed (MWh)**	**Peak Power Equivalent (MW)**
2015	182	0	554.4	793.0	824.0	0.3
2020	3364	153	59,726.8	92,295.7	46,746.6	16.0
2025	10514	314	270,992.1	413,372.6	115,120.4	39.4
2030	18820	483	661,968.2	1,004,374.5	191,691.1	65.6

CAUTIOUS					
Year	**Cumulative Costs** (discounted $2012)		**Cumulative Benefits** (discounted $2012)		**Net Benefit**
	EV Premium	**Infrastructure**	**Fuel Savings**	**Ancillary**	
2015	$ -	$ -	$ -	$ -	$ -
2020	$ 4,090,075	$ 450,531	$ 6,590,028	$ 3,329,931	$ 5,379,353
2025	$ 22,428,228	$ 3,230,077	$ 41,933,887	$ 19,176,335	$ 35,451,917
2030	$ 50,752,077	$ 9,170,889	$ 108,435,596	$ 45,805,806	$ 94,318,435

Year	**# Car EV**	**# Bus EV**	**Cumulative Gasoline Saved (000 lit)**	**Cumulative CO2 avoided (tonnes)**	**Annual Electricity Consumed (MWh)**	**Peak Power Equivalent (MW)**
2015	0	0	-	-	-	0.0
2020	479	56	12,057.4	18,575.1	12,951.4	4.4
2025	3639	152	89,285.4	136,721.4	48,192.4	16.5
2030	7984	254	265,726.1	404,017.1	90,966.1	31.2

All three have a net cost in the initial phases of implementation. This is primarily driven by the expectation that low utilization government fleets will be converted to EV which as we showed has an impact on economics. Nevertheless in all scenarios, the cumulative result in net present valuation is overwhelmingly positive while the gasoline savings reach 6.4 million BOE in the Environmentalist case.

There are risks though associated with a very aggressive initial adoption of EVs. If there are failures due to technology kinks, it may result in a backfire

effect where the public (which in the end, even with very limited adoption rates in the Cautious scenario still operates more than 50% of the EV fleet by 2030) may opt against EV delaying significantly widespread adoption.

Rather the staged timing of the Pragmatist scenario will allow both a greater potential for resolving issues, putting up the infrastructure and, crucially, allowing the learning curve of battery technology to bring costs down for the widespread adoption. On the other hand, the Cautious scenario, although seemingly the one with the least risk, hides the danger of underperformance as neither infrastructure nor fleet uptake can be undertaken so quickly. If no effort is done early on, then Abu Dhabi essentially locks-in the existing mobility paradigm and opts out of the upside which translates in both significant improvements in energy efficiency and utilization and reductions in both pollutants and greenhouse gas emissions.

The set of policies that could support this Pragmatist scenario are shown below.

Suggested Policy	Application Intensity			Desired Effect
	low	medium	high	
Provision for EV-dedicated lane access			√	Shorter travel times for EV drivers
Support for fleet-scale EV adoption		√		Familiarize the public with EVs
EV car sharing and renting programs		√		Familiarize the public with EVs
Availability of electric vehicle supply equipment (EVSE): Availability of charging stations and poles			√	Preliminary step to mainstream EVs
Grants and Tax Subsidies for EV Purchases		√		Lower the cost variance between conventional and EV
Parking Incentives			√	Perk incentive to buy EVs
Demonstration Projects			√	

6.4. Technical Feasibility of EVs

The technical feasibility assessment brought into the spotlight that the introduction of the electric vehicle brings about a transportation-energy nexus. Moreover, the need to charge the electric vehicle brought about impacts on the three supporting infrastructure systems: the intelligent transportation system, the

physical transportation system, and the physical power grid. Chapter 4 showed that the negative impacts can be shifted fluidly from the transportation system to the power system and vice versa. Impacts on the transportation system were measured in terms of "Quality of Service" a relative measure of how available EVs; or how delayed they are by the need for charging. Impacts on the power system were measured in aggregate as well as for individual charging stations. Here, five statistics

- Maximum value of power consumption.
- Maximum energy consumption
- Minimum energy consumption
- Maximum variability in power consumption
- Minimum variability in power consumption.

were associated with different types of power grid impacts.

The results showed that the design of the charging system itself is highly influential in either amplifying or mitigating the impacts of the EV integration. This is a multi-variable design space and irrationalized decisions can easily have unintended consequences on the combined transportation-energy infrastructure nexus. Table 6.3 compiles the technical implications on the power system and transportation system for the five previously mentioned statistics. On the transportation side, low QoS which is also evidenced by low power variability and high maximum energy of load curves, can significantly impair long term EV adoption and reduce the revenue of the transportation services that choose to use electric vehicles. On the power system side, high max power could cause significant capital expenditures in upgrading lines and transformers. Meanwhile, high power variability will require the use of generation with significant ramping capabilities: flexible generation, synchronized reserves, and automatically controlled regulation services. All of these lead to a system wide increase in the marginal price of electricity. If there is insufficient flexibility in the generation fleet, then EV integration could potentially require further capital expenditures.

Table 6-3 also provides charging system design heuristics to mitigate impacts to the transportation-energy nexus. Here, the two main problems are 1.) insufficient charging capacity 2.) inappropriate use of under-utilized Type III chargers. Simply speaking, a significant number of charging station distributed over the service area is required to avoid reduced quality of service and

overloaded power lines and transformers. Meanwhile, Type III chargers should be systematically avoided unless there is a clear rationale that they will be utilized at near full capacity.

While these design heuristics are useful, ultimately the operation of the transportation-energy nexus presents an example of complex engineering system dynamics that cannot be addressed purely with simple design rules. New design approaches are in the process of research in this area. Significant capital and operating costs within the infrastructure systems can be avoided with the planning and design decision support tools such as charging station optimal placement and sizing algorithms. Furthermore, coordinated charging strategies need to become integral parts of not just the intelligent transportation system functionality but also part of the quickly developing suite of smart grid applications. In both of these cases, research is still quite nascent and further rigorous and quantified efforts are required.

Table 6-3 Charging System Design Heuristics for Mitigation of Impacts to Transportation-Energy Nexus

Technical Challenge	High Max. Energy	High Max. Power	High Power Variability	Low Min. Energy	Low Power Variability
Technical Implications on Power System	-- None. Small in comparison to generation capacity	-- Overloaded lines & transformers	-- System wide need for generator ramping capabilities. Appears as flexible generation, synchronized reserves, and regulation services -- System wide need for improved charging load forecasting	-- None	-- None.
Technical Implications on Trans. System	-- Suggests long charging queues and reduced QoS.	-- None	-- None	-- Under-utilized charging station.	-- Suggests long charging queues and reduced QoS.
Economic Implications	-- Impaired EV adoption. -- Reduced	-- Significant capital expenditure	-- System wide increase in the marginal cost of electricity. -- Potential	-- Poor ROI. -- Weak financial rationale for	-- Impaired EV adoption. -- Reduced

	transportation service revenues	on line & transformer upgrades	need for capital investments into flexible generation and automatic generation control	charging station	transportation service revenues
Mitigating Charging System Design Heuristic	-- Optimize the scope of the EV use case -- Expand # of charging stations w/ optimal placement algorithms -- Balance increased costs with potential revenue losses	-- Coordinated charging strategy -- Optimal placement algorithms -- Systematic preference for Type II chargers -- Reduce # of charging station slots	-- Coordinated charging strategy -- Type III chargers as chargers of last resort. -- Optimal placement of Type III chargers for high utilization	-- Optimal placement algorithms for charging stations	-- Expand # of charging stations w/ optimal placement algorithms - Balance increased costs with potential revenue losses

Appendix 1 Public Survey Questionnaire

YG Masdar
Electric Vehicle Adoption
Questionnaire v2

	SCREENER	

	EN	AR
Topic	**Vehicles**	
S1	**Gender**	الجنس
	[DO NOT ASK, SIMPLY RECORD UPON OBSERVATION]	**[لا تسأل، دوِّن بالملاحظة فقط]**
	Male	ذكر
	Female	أنثى
S2	**Are you a UAE Resident or an International Visitor? (By International Visitor, we mean that you are temporarily visiting the UAE and have not been in the country for longer than 90 days so far)**	هل أنت مقيم في دولة الإمارات أم زائر من الخارج؟ (المقصود بزائر من الخارج أنَّك تزور الدولة مؤقتا ولم تُقِم بها أكثر من **90** يوما حتى الآن)
	UAE Resident	مقيم في دولة الإمارات
	International Visitor	زائر من الخارج
	TERMINATE IF INTERNATIONAL VISITOR	
S3	**Do you currently drive a car?**	هل تقود سيارة حاليا؟
	Yes	نعم
	No	كلا
	TERMINATE IF DO NOT DRIVE A CAR	
S4	**Which of the following age do you fall into?**	ما هي الفئة العمرية التي تنتمي إليها؟
	Under 21	تحت سن الـ21

	21 - 24	24 21
	25 - 30	30 25
	31 - 40	40 31
	41 - 50	50 41
	50+	أكثر من 50
	TERMINATE IF UNDER 21	
S5	**If you add up the income from all sources, what is your average NET household income per month? (Net income means amounts as you receive it, which is normally after tax or Zakat and contributions to social insurance and pension)**	**إن جمعت الدخل من جميع المصادر، ما هو متوسط الدخل الصافي لأسرتك شهريًا؟ (الدخل الصافي يعني المبالغ التي تتلقاها عادةً بعد حسم الضريبة والزكاة والمساهمات المتعلقة بالضمان الاجتماعي والنفقة)**
	Less than AED5,999	أقل من 5،999 درهم إماراتي
	AED6,000 to AED11,999	بين 6،000 و 11،999 درهم إماراتي
	AED12,000 to AED14,999	بين 12،000 و14،999 درهم إماراتي
	AED 15,000 to AED24,999	بين 15،000 و24،999 درهم إماراتي
	AED25,000 to AED34,999	بين 25،000 و34،999 درهم إماراتي
	AED35,000 to AED49,999	بين 35،000 و49،999 درهم إماراتي
	AED50,000 or more	50،000 درهم إماراتي أو أكثر
	Don't know/rather not say	لا أعرف/أفضل عدم الإجابة
	TERMINATE IF UNDER 15,000 (UNLESS EMIRATI)	
S6	**Where do you live in the UAE?**	**ما اسم المنطقة التي تقيم فيها في الإمارات العربية المتحدة؟**
	Dubai	دبي
	Abu Dhabi	أبوظبي
	Sharjah	الشارقة
	IF ABU DHABI RESIDENT	
S7a	**Where do you live in Abu Dhabi?**	**ما اسم المنطقة التي تقيم فيها في أبوظبي؟**
	Abu Dhabi Gate	بوابة أبوظبي
	Al Aman	الأمان

	Al Baladia	البلدية
	Al Bateen	البطين
	Al Bateen Airport	مطار البطين
	Al Dhafrah	الظفرة
	Al Hosn	الحصن
	Al Ittihad	الاتحاد
	Al Karama	الكرامة
	Al Khalidiya	الخالدية
	Al Khubeirah	الخبيرة
	Al Madina Al Riyadiyah	المدينة الرياضية
	Al Manhal	المنهل
	Al Maqta	المقطع
	Al Markaziya East	المركزية الشرقية
	Al Markaziya West	المركزية الغربية
	Al Nahyan	النهيان
	Al Qubeisat	القبيسات
	Al Rawdah	الروضة
	Al Reehan	الريحان
	Al Saadiyat	السعديات
	Al Safarat	السفارات
	Al Wehda	الوحدة
	Al Zahra	الزهرة
	Grand Mosque	الجامع الكبير
	Hadabat Al Zafarana	هضبة الزعفرانة
	Khalifa City A	مدينة خليفة أ
	Khalifa City B	مدينة خليفة ب
	Madinat Zayed	مدينة زايد
	Mohamed Bin Zayed City	مدينة محمد بن زايد
	Mushrif	مشرف
	Reem Island	جزيرة الريم
	Tourist Club	النادي السياحي
	Yas Island	جزيرة ياس
	Other area	منطقة أخرى

	IF DUBAI RESIDENT	
S7b	Where do you live in Dubai?	ما اسم المنطقة التي تقيم فيها في دبي؟
	Al Barsha	البرشاء
	Bur Dubai	بر دبي
	Deira	الديرة
	Discovery Gardens	حدائق ديسكفري
	Downtown	وسط المدينة
	Dubai Marina	مرسى دبي
	Emirates Hills	تلال الإمارات
	Gardens	الحدائق
	Greens / Views	الروضة
	International City	المدينة العالمية
	Jebel Ali	جبل علي
	Jumeirah	الجميرا
	Jumeirah Lakes Towers (JLT)	أبراج بحيرات الجميرا
	Karama	الكرامة
	Al Khail Gate	بوابة الخيل
	Mirdif	مردف
	Al Nahda	النهدة
	Al Qusais	القصيص
	Satwa	السطوة
	Sheikh Zayed Road	شارع الشيخ زايد
	Silicon Oasis	واحة السيليكون
	Springs	الينابيع
	Tecom	تيكوم
	Umm Suqeim	أم سقيم
	Other area	منطقة أخرى
S8	Which of the following best describes your nationality?	أي من الخيارات التالية يصف جنسيتك بشكل أفضل؟
	UAE National / Emirati	إماراتي/ مواطن
	Australian	أسترالي
	Austrian	نمساوي
	Bahraini	بحريني
	British	بريطاني

	Central/South American	أمريكا الجنوبية / الوسطى
	Chinese	صيني
	Dutch	هولندي
	Egyptian	مصري
	French	فرنسي
	German	ألماني
	Indian	هندي
	Indonesian	إندونيسي
	Iranian	إيراني
	Jordanian	أردني
	Kazakhstani	كازاخستاني
	Kuwaiti	كويتي
	Lebanese	لبناني
	New Zealander	نيوزيلندي
	North American	أمريكا الشمالية
	Omani	عُماني
	Pakistani	باكستاني
	Palestinian	فلسطيني
	Filipino	فيلبيني
	Qatari	قطري
	Russian	روسي
	Saudi Arabian	سعودي
	South African	جنوب أفريقي
	Syrian	سوري
	Tunisian	تونسي
	Other (please specify)	غير ذلك (يرجى التحديد)
S9	**Which of the following best describes your marital status? (Please select one only)**	أي مما يلي يصف وضعك الاجتماعي بشكل أفضل؟ (يرجى اختيار إجابة واحدة فقط)
	Single (no children)	أعزب (من دون أبناء)
	Married without children	متزوج من دون أبناء
	Married with children	متزوج ولدي أبناء
	Divorced/ separated/ widowed (without children)	مطلق/ منفصل/ أرمل (من دون أبناء)
	Divorced/ separated/ widowed (with children)	مطلق/ منفصل/ أرمل (لدي أبناء)

	Other		غير ذلك
S10	**What is the <u>highest level</u> of education you have completed? (Please select one only)**		ما هو <u>أعلى مستوى</u> علمي قد أتممته؟ (يرجى اختيار إجابة واحدة فقط)
	Elementary school		المدرسة الابتدائية
	Secondary school		المدرسة الثانوية
	Vocational college education (to qualify as an electrician, nurse, etc)		كلية تدريب مهني (للعمل ككهربائي، ممرض/ممرضة، الخ...)
	University first degree (BA, BSc, etc)		شهادة جامعية (بكالوريوس)
	University higher degree (Masters, MBA, PhD, etc)		شهادة جامعية عليا (ماجستير، دكتوراه، الخ...)
	Professional higher education (to qualify as lawyer, accountant, etc)		تعليم عالي مهني (للعمل كمحامي، محاسب، الخ..)
	None of the above		لا شيء مما سبق

MAIN QUESTIONNAIRE

Q1	**What is your house type?**		ما هو نوع منزلك؟
	Shared Apartment		شقة مشتركة
	Apartment		شقة
	Villa		فيلا
	Other		غير ذلك
Q2	**How many people are there in your household?**		كم عدد الأفراد في أسرتك؟
	Less than 3 members		أقل من ثلاثة أفراد
	3-5		3 5
	6-10		6 10
	More than 10		أكثر من 10
Q3	**To what extent is climate change an important issue to you?**		ما مدى أهمية مسألة تغير المناخ بالنسبة لك؟
	Not at all important		ليست مهمة على الإطلاق
	Not important		ليست مهمة
	Neither important nor unimportant		ليست مهمة ولا غير مهمة

	Important	مهمة
	Very important	مهمة جدًا
	Don't know	لا أعرف
Q4	**How much do you think road transportation contributes to the total CO2 emissions in this country?**	**كم، برأيك، يساهم النقل البري في مجمل انبعاثات ثاني أكسيد الكربون في هذا البلد؟**
	5%	5%
	10%	10%
	20%	20%
	30%	30%
	Don't know	لا أعرف
Q5	**Have you ever heard about alternative fuel vehicles? (E.g. Electrical Vehicles, Hydrogen fuel cell vehicles, etc.)**	**هل سبق لك أن سمعت عن سيارات الوقود البديل؟ (على سبيل المثال، السيارات الكهربائية والسيارات التي تعمل بواسطة خلايا الوقود الهيدروجينية، الخ.)**
	Yes	نعم
	No	لا
Q6	**In 2003 the CO2 emissions per capita in the USA were 19.5kg and 9.8kg in Japan. What do you think are the CO2 emissions per capita in the UAE?**	**في عام 2003 بلغت انبعاثات ثاني أكسيد الكربون بالنسبة للفرد في الولايات المتحدة الأميركية 19.5 كلغ و9.8 كلغ في اليابان. برأيك، كم تبلغ انبعاثات ثاني أكسيد الكربون بالنسبة للفرد في الإمارات العربية المتحدة؟**
	0.0- 4.9 kg	0.0 4.9 كلغ
	5.0- 9.9 kg	5.0 9.9 كلغ
	10.0-19.9 kg	10.0 19.9 كلغ
	More than 20 kg	أكثر من 20 كلغ
	Don't know	لا أعرف
Q7	**How many private vehicles are there in your household?**	**كم عدد السيارات الخاصة لدى أسرتك؟**
	OPEN INTEGER RESPONSE, MAX 10	
	ASK IF 1 OR MORE VEHICELS IN HH	

Q8	What type is each vehicle that you have?	ما هو نوع كل سيارة لديكم؟
	ONLY DISPLAY ROWS EQUAL TO NUMBER OF VEHICLES OWNED AT Q7	
	Vehicle 1	1 السيارة
	Vehicle 2	2 السيارة
	Vehicle 3	3 السيارة
	Vehicle 4	4 السيارة
	Vehicle 5	5 السيارة
	Vehicle 6	6 السيارة
	Vehicle 7	7 السيارة
	Vehicle 8	8 السيارة
	Vehicle 9	9 السيارة
	Vehicle 10	10 السيارة
	Hatchback	هاتشباك
	Sport Coupe	رياضية كوبيه
	Sedan (saloon)	سيدان (صالون)
	SUV (4x4)	إس يو في (4×4)
	Truck (pick-up)	شاحنة (بيك أب)
	ASK IF 1 OR MORE VEHICELS IN HH	
Q9	Please tell us the size of engine of each of these vehicles. • By small engine we mean 4-cylinders or less and usually up to 2.4 litres size. • By large engine we mean more than 4 cylinders and usually over 2.4 litres size.	أخبرنا من فضلك عن حجم محرك كل من هذه السيارات • نعني بالمحرك الصغير ذو الـ4 اسطوانات أو أقل حتى سعة 2.4 ليتر. • نعني بالمحرك الكبير الأكثر من 4 اسطوانات وعادة يتسع لأكثر من 2.4 ليتر.
	ONLY DISPLAY ROWS EQUAL TO NUMBER OF VEHICLES OWNED AT Q7	
	Vehicle 1	1 السيارة
	Vehicle 2	2 السيارة
	Vehicle 3	3 السيارة
	Vehicle 4	4 السيارة

English	Arabic
Vehicle 5	السيارة 5
Vehicle 6	السيارة 6
Vehicle 7	السيارة 7
Vehicle 8	السيارة 8
Vehicle 9	السيارة 9
Vehicle 10	السيارة 10
Small	صغيرة
Large	كبيرة
ASK ONLY IF HAVE A SMALL ENGINE CAR	

	English	Arabic
Q10	**How important were the following factors to you when choosing a car with a small engine? (4-cylinder)**	**ما مدى أهمية العوامل التالية بالنسبة لك عند اختيار سيارة بمحرك صغير؟ (4 اسطوانات)**
	Speed	السرعة
	Fuel Economy	التوفير في الوقود
	Space	المساحة
	Safety	الأمان
	Refinement	الدقة
	Off-road Ability	القدرة على الطريق الوعرة
	Prestige	المكانة
	Environmental Friendliness	الحفاظ على البيئة
	Low Purchase Price	سعر شراء منخفض
	Not at all important	ليست مهمة على الإطلاق
	Not important	ليست مهمة
	Neither important nor unimportant	ليست مهمة ولا غير مهم
	Important	مهمة
	Very important	مهمة جدًا
	Not applicable	لا تنطبق
	ASK ONLY IF HAVE A LARGE ENGINE CAR	
Q11	**How important were the following factors to you when choosing a car with a bigger engine? (more than 4-cylinder)**	**ما مدى أهمية العوامل التالية بالنسبة لك عند اختيار سيارة بمحرك أكبر؟ (أكثر من4 اسطوانات)**

	Speed	السرعة
	Fuel Economy	التوفير في الوقود
	Space	المساحة
	Safety	الأمان
	Refinement	الدقة
	Off-road Ability	القدرة على الطريق الوعرة
	Prestige	المكانة
	Environmental Friendliness	الحفاظ على البيئة
	Low Purchase Price	سعر شراء منخفض
	Not at all important	ليست مهمة على الإطلاق
	Not important	ليست مهمة
	Neutral	متعادلة
	Important	مهمة
	Very important	مهمة جدًا
	Not applicable	لا تنطبق
Q12	**How many trips do you usually make per week of each type?**	**ما هو عدد الرحلات التي تقوم بها عادةً أسبوعيا لكل نوع؟**
	Do not make this trip	لا أقوم بهذه الرحلة
	1-3	1 3
	4 - 6	4 6
	7 – 10	7 10
	More than 10	أكثر من 10
	Work	عمل
	School drop off/pick up	اصطحاب/نقل إلى ومن المدرسة
	Leisure	ترفيه
	Shopping	تسوّق
	Sports activities	نشاطات رياضية
	Other	غير ذلك
	IF MAKE WORK TRIP	
Q13a	**What is the origin and destination of your usual work trip?**	**ما هي نقطة الانطلاق ووجهة رحلة عملك المعتادة؟**

	From	من
	To	إلى
	OPEN RESPONSE (CODE AFTER)	
	IF RESPONDENT SAYS 'HOME', CODE AS PER S7	
	Home	المنزل
	Sharjah	الشارقة
	Ajman	عجمان
	UAQ	أم القيوين
	RAK	رأس الخيمة
	Fujairah	الفجيرة
	Western region	المنطقة الغربية
	Al Ain	العين
	ABU DHABI: Abu Dhabi Gate	أبوظبي: بوابة أبوظبي
	ABU DHABI: Al Aman	أبوظبي: الأمان
	ABU DHABI: Al Baladia	أبوظبي: البلدية
	ABU DHABI: Al Bateen	أبوظبي: البطين
	ABU DHABI: Al Bateen Airport	أبوظبي: مطار البطين
	ABU DHABI: Al Dhafrah	أبوظبي: الظفرة
	ABU DHABI: Al Hosn	أبوظبي: الحصن
	ABU DHABI: Al Ittihad	أبوظبي: الاتحاد
	ABU DHABI: Al Karama	أبوظبي: الكرامة
	ABU DHABI: Al Khalidiya	أبوظبي: الخالدية
	ABU DHABI: Al Khubeirah	أبوظبي: الخبيرة
	ABU DHABI: Al Madina Al Riyadiyah	أبوظبي: المدينة الرياضية
	ABU DHABI: Al Manhal	أبوظبي: المنهل
	ABU DHABI: Al Maqta	أبوظبي: المقطع
	ABU DHABI: Al Markaziya East	أبوظبي: المركزية الشرقية
	ABU DHABI: Al Markaziya West	أبوظبي: المركزية الغربية
	ABU DHABI: Al Nahyan	أبوظبي: النهيان
	ABU DHABI: Al Qubeisat	أبوظبي: القبيسات
	ABU DHABI: Al Rawdah	أبوظبي: الروضة
	ABU DHABI: Al Reehan	أبوظبي: الريحان
	ABU DHABI: Al Saadiyat	أبوظبي: السعديات

	ABU DHABI: Al Safarat	أبوظبي: السفارات
	ABU DHABI: Al Wehda	أبوظبي: الوحدة
	ABU DHABI: Al Zahra	أبوظبي: الزهرة
	ABU DHABI: Grand Mosque	أبوظبي: الجامع الكبير
	ABU DHABI: Hadabat Al Zafarana	أبوظبي: هضبة الزعفرانة
	ABU DHABI: Khalifa City A	أبوظبي: مدينة خليفة أ
	ABU DHABI: Khalifa City B	أبوظبي: مدينة خليفة ب
	ABU DHABI: Madinat Zayed	أبوظبي: مدينة زايد
	ABU DHABI: Mohamed Bin Zayed City	أبوظبي: مدينة محمد بن زايد
	ABU DHABI: Mushrif	أبوظبي: مشرف
	ABU DHABI: Reem Island	أبوظبي: جزيرة الريم
	ABU DHABI: Tourist Club	أبوظبي: النادي السياحي
	ABU DHABI: Yas Island	أبوظبي: جزيرة ياس
	ABU DHABI: Other area	أبوظبي: منطقة أخرى
	DUBAI: Al Barsha	دبي: البرشاء
	DUBAI: Bur Dubai	دبي: بر دبي
	DUBAI: Deira	دبي: ديرة
	DUBAI: Discovery Gardens	دبي: حدائق ديسكفري
	DUBAI: Downtown	دبي: وسط المدينة
	DUBAI: Dubai Marina	دبي: مرسى دبي
	DUBAI: Emirates Hills	دبي: تلال الإمارات
	DUBAI: Gardens	دبي: الحدائق
	DUBAI: Greens / Views	دبي: الروضة
	DUBAI: International City	دبي: المدينة العالمية
	DUBAI: Jebel Ali	دبي: جبل علي
	DUBAI: Jumeirah	دبي: الجميرا
	DUBAI: Jumeirah Lakes Towers (JLT)	دبي: أبراج بحيرات الجميرا
	DUBAI: Karama	دبي: الكرامة
	DUBAI: Al Khail Gate	دبي: بوابة الخيل
	DUBAI: Mirdif	دبي: مردف
	DUBAI: Al Nahda	دبي: النهدة
	DUBAI: Al Qusais	دبي: القصيص
	DUBAI: Satwa	دبي: السطوة
	DUBAI: Sheikh Zayed Road	دبي: شارع الشيخ زايد
	DUBAI: Silicon Oasis	دبي: واحة السيليكون

	DUBAI: Springs	دبي: الينابيع
	DUBAI: Tecom	دبي: تيكوم
	DUBAI: Umm Suqeim	دبي: أم سقيم
	DUBAI: Other area	دبي: منطقة أخرى
	IF MAKE SCHOOL TRIP	
Q13b	**What is the origin and destination of your usual school drop off/pick up trip?**	ما هي نقطة الانطلاق ووجهة الاصطحاب / النقل إلى ومن المدرسة المعتادة؟
	From	من
	To	إلى
	OPEN RESPONSE (CODE AFTER)	
	IF RESPONDENT SAYS 'HOME', CODE AS PER S7	
	IF MAKE LEISURE TRIP	
Q13c	**What is the origin and destination of your usual leisure trip?**	ما هي نقطة الانطلاق ووجهة رحلتك الترفيهية المعتادة؟
	From	من
	To	إلى
	OPEN RESPONSE (CODE AFTER)	
	IF RESPONDENT SAYS 'HOME', CODE AS PER S7	
	IF MAKE SHOPPING TRIP	
Q13d	**What is the origin and destination of your usual shopping trip?**	ما هي نقطة الانطلاق ووجهة رحلة تسوقك المعتادة؟
	From	من
	To	إلى
	OPEN RESPONSE (CODE AFTER)	
	IF RESPONDENT SAYS 'HOME', CODE AS PER S7	

		IF MAKE SPORTS TRIP	
Q13e	What is the origin and destination of your usual sports activities trip?		ما هي نقطة الانطلاق ووجهة رحلة نشاطاتك الرياضية المعتادة؟
	From		من
	To		إلى
	OPEN RESPONSE (CODE AFTER)		
	IF RESPONDENT SAYS 'HOME', CODE AS PER S7		
Q14	What mode of transportation do you normally use for each trip?		ما هي وسيلة النقل التي تستعملها عادةً لكل رحلة؟
	Private vehicle		سيارة خاصة
	Taxi		سيارة أجرة (تاكسي)
	Bus		حافلة
	Car-pooling		قطار
	Metro		مترو
	Bicycle		دراجة
	Other		غير ذلك
	COLS: ONLY SHOW EACH TRIP TYPE MADE AT Q12		
	Work		عمل
	School drop off/pick up		اصطحاب/نقل إلى ومن المدرسة
	Leisure		ترفيه
	Shopping		تسوّق
	Sports activities		نشاطات رياضية
Q15	At what times do you make each trip? Select all that apply.		في اي وقت تقوم بكل رحلة؟ حدّد كل ما ينطبق
	6am-8.59am		6 صباحا 8.59 صباحا
	9am-11.59am		9 صباحا 11.59 صباحا
	12noon-2.59pm		12 ظهرا 2.59 ظهرا
	3pm-5.59pm		3 عصرا 5.59 مساء
	6pm-8.59pm		6 مساء 8.59 مساء

	9pm-11.59pm	9 مساء 11.59 مساء
	12am-2.59am	12 ظهرا 2.59 ظهرا
	3am-5.59am	3 صباحًا 5.59 صباحًا
	COLS: ONLY SHOW EACH TRIP TYPE MADE AT Q12	
	Work	عمل
	School drop off/pick up	اصطحاب/نقل إلى ومن المدرسة
	Leisure	ترفيه
	Shopping	تسوّق
	Sports activities	نشاطات رياضية
Q16	**How much time do you spend driving on average per day?**	**ما هو معدل الوقت الذي تمضيه في القيادة يوميا؟**
	Less than 30 minutes	أقل من 30 دقيقة
	30 – 59 minutes	30 59 دقيقة
	60 – 89 minutes	60 89 دقيقة
	90 minutes or more	90 دقيقة أو أكثر
	Not Applicable	لا ينطبق
Q17	**Approximately, how far do you travel per day?**	**تقريبا، ما هي المسافة التي تقطعها في اليوم؟**
	Less than 10km	أقل من 10 كلم
	10 - 29 km	10 29 كلم
	30 - 49 km	30 49 كلم
	50 – 100 km	50 100 كلم
	More than 100 km	أكثر من 100 كلم
Q18	**How often do you make trips that are longer than 100km?**	**كم مرة تقوم برحلات أطول من 100 كلم؟**
	More than once in a week	أكثر من مرة في الأسبوع
	Once in a week	مرة في الأسبوع
	Once in a month	مرّة في الشهر
	Less than once in a month	أقل من مرة في الشهر
	Not Applicable	لا ينطبق

Q19	How many passengers (including the driver) are usually present on trips that are less than 10km?	ما هو عدد الركاب (بما فيهم السائق) الذين يرافقونك في الرحلات التي لا يتعدى طولها الـ10 كلم؟
	1 (Only driver)	1 (السائق فقط)
	2	2
	3 or more	3 أو أكثر
	Not Applicable	لا ينطبق
Q20	How many passengers (including the driver) are usually present on each of these trip lengths?	ما هو عدد الركاب (بما فيهم السائق) الذين يرافقونك في كل من هذه الرحلات التي يبلغ طولها؟
	Under 10km	أقل من 10 كلم
	10-29 km	10 29 كلم
	30-49 km	30 49 كلم
	50-100 km	50 100 كلم
	More than 100 km	أكثر من 100 كلم
	1 (Only driver)	1 (السائق فقط)
	2	2
	3 or more	3 أو أكثر
	Not Applicable	لا ينطبق
Q21	What is your average yearly mileage? (A good estimate is dividing the total mileage by the age of the car)	ما هو متوسط عدد الكيلومترات التي تقطعها في السنة؟ (يعتمد التقدير الجيد على قسمة العدد الإجمالي للكيلومترات على عمر السيارة)
	Less than 5,000km	أقل من 5،000 كلم
	5,000km-9,999km	5،000 كلم 9،999 كلم
	10,000km-19,999km	10،000 كلم 19،999 كلم
	20,000km-29,999km	20،000 كلم 29،999 كلم
	30,000km-40,000km	30،000 كلم 40،000 كلم
	More than 40,000km	أكثر من 40،000 كلم
	Don't know	لا أعرف
Q22	On average, how many times per week do	كمعدل، كم مرة في الأسبوع تشتري صفيحة وقود

		you purchase a full tank of fuel?	كاملة؟
		Less than once	أقل من مرة واحدة
		1	1
		2	2
		3	3
		4	4
		More than 4 times	أكثر من أربع مرات
	Q23	**Usually, on what fuel level do you refuel?**	**عادةً، عند أي مستوى من الوقود تعيد التعبئة؟**
		Above 50%	فوق الـ50%
		Between 25 to 50%	بين 25 و50%
		At 25%	عند الـ25%
		Below 25%	تحت الـ25%
		Don't know	لا أعرف
		Electric Vehicles • Electric vehicles (EVs) are powered by a battery that must be charged from an external electricity supply . • Modern EVs have a range of 150km and can charge over 3-5 hours. • They are generally small in size but comfortably seat four adults, and have a full-suite of safety equipment. • Currently, EVs are more expensive to purchase. However they are environmentally friendly and have a good rate of acceleration.	**السيارات الكهربائية** • تعمل السيارات الكهربائية بواسطة بطارية يجب شحنها من مزوّد كهرباء خارجي. • تقطع السيارات الكهربائية الحديثة مسافة 150 كلم ويمكن شحنها لمدة تتراوح بين 3 5 ساعات. • إنها صغيرة الحجم عموما لكن مقاعدها مريحة للراشدين، ولديها مجموعة كاملة من معدات السلامة. • حاليا، إن السيارات الكهربائية هي أكثر كلفة للشراء. مع ذلك، فإنها تحافظ على البيئة ولديها نسبة جيدة من السرعة.
	Q24	**Would you consider buying an Electric vehicle?**	**هل يخطر في بالك أن تشتري سيارة كهربائية؟**
		Yes	نعم
		No	لا
	Q25	**How important are the following factors if**	**ما مدى أهمية العوامل التالية إن قررت شراء سيارة**

	you were to buy an Electric vehicle?	كهربائية؟
	Cool/fashionable	رائعة/عصرية
	Environmentally friendly	للحفاظ على البيئة
	Government incentives	حوافز الحكومة
	Low operating costs	تكاليف تشغيل منخفضة
	Not at all important	ليست مهمة على الإطلاق
	Not important	ليست مهمة
	Neither important nor unimportant	ليست مهمة ولا غير مهمة
	Important	مهمة
	Very important	مهمة جدًا
	Not applicable	لا تنطبق
Q26	**How important are these incentives that might persuade you to buy an Electric vehicle (EV) over a conventional car?**	**ما مدى أهمية هذه الحوافز التي قد تقنعك بشراء سيارة كهربائية أكثر من سيارة تقليدية؟**
	Registration fee waiver	إعفاء من رسوم التسجيل
	Lower operating costs (e.g. EV's requires less maintenance as they have less moving mechanical parts)	تكاليف تشغيل منخفضة (على سبيل المثال، تتطلب السيارة الكهربائية صيانة أقل بما أنها تحتوي على قطع تحريك ميكانيكية أقل)
	Toll road (e.g. SALIK) waiver - Assuming tolls are implemented in the region where you drive	إعفاء من ضريبة الطريق (على سبيل المثال، رسوم سالك) على افتراض أنه يتم تطبيق قانون الضرائب في المنطقة التي تقود فيها)
	Free charging electricity, assuming increasing gasoline prices	شحن مجاني للكهرباء، على افتراض زيادة أسعار البنزين
	Equal or lower purchasing cost of EV's compared to conventional vehicles	كلفة شراء معادلة أو أقل للسيارة الكهربائية مقارنة بالسيارة التقليدية
	Congestion avoidance option through an EV dedicated road or lane	خيار تجنب الازدحام عبر طريق أو ممر مخصص للسيارت الكهربائية
	Guaranteed or free parking at public locations (e.g. Roads and malls)	موقف مؤمّن أو مجاني في المواقع العامة (على سبيل المثال، الطرقات ومراكز التسوق)
	ITS service (Intelligent Transportation System, like electronic signs that facilitate EV maneuverability)	خدمة نظام نقل ذكي، كالإشارات الإلكترونية التي تسهل الاستدارة في شتى الاتجاهات لدى السيارات الكهربائية)

	Availability of charging point at key locations (e.g. Parking, malls, workplace, ... etc)	توفر نقطة الشحن عند المواقع الرئيسية (على سبيل المثال، الموقف، مراكز التسوق، مكان العمل، ...إلخ)
	Avoiding fuel station queues	تجنب طوابير محطة الوقود
	Not at all important	ليست مهمة على الإطلاق
	Not important	ليست مهمة
	Neither important nor unimportant	ليسن مهمة ولا غير مهمة
	Important	مهمة
	Very important	مهمة جدًا
	Not applicable	لا تنطبق
Q27	**What are the reasons that might discourage you to consider an Electric vehicle? Select all that apply.**	**ما هي الأسباب التي قد تثنيك عن التفكير في شراء سيارة كهربائية؟ حدد كل ما ينطبق.**
	Short-range	قصر المدى
	Unavailability of charging stations	عدم توفر محطات الشحن
	Hassle of charging	مشاكل الشحن
	Small size	الحجم الصغير
	Limited top speed (e.g. 130 km/h)	السرعة القصوى المحدودة (على سبيل المثال، 130 كلم/ساعة)
	Unavailability / long waiting times	عدم التوفر/فترات الانتظار الطويلة
	High price	السعر الباهظ
	Concern of performance in high temperature climate	قلق من الأداء في مناخ مرتفع الحرارة
	Battery life	حياة البطارية
	Don't know how much the vehicle will be worth when I come to sell it	لا أعرف كم ستكون قيمة السيارة حين أقرر بيعها
	None	لا شيء مما سبق
Q28	**In your opinion, how important are the following charging facilities to an Electric vehicle owner?**	**برأيك، ما مدى أهمية تسهيلات الشحن التالية بالنسبة إلى مالك سيارة كهربائية؟**
	Public chargers at parking lots	أجهزة شحن عامة في مواقف السيارات
	Chargers at work	أجهزة شحن في العمل
	Chargers at home	أجهزة شحن في المنزل

	Battery swap services (Swapping your drained battery with a fully-charged one)	خدمات استبدال البطارية (استبدال بطاريتك المستنفدة ببطارية مشحونة)
	Not at all important	ليست مهمة على الإطلاق
	Not important	ليست مهمة
	Neutral	متعادلة
	Important	مهمة
	Very important	مهمة جدًا
	Not applicable	لا تنطبق
	Public Transport • Public transportation options include; buses, metro, subway, tram, water-taxi, rapid transit, etc. • The goal of public transport is to provide an effective, easy to use, and popular alternative to the private car.	**النقل العام** • تتضمن خيارات النقل العام؛ الحافلات، والمترو، ومترو الأنفاق، والترام، وسيارة الأجرة المائية، والنقل السريع، إلخ.) • يهدف النقل العام إلى توفير بديلا فعالا، وسهل الاستخدام، وشعبيا للسيارة الخاصة.
Q29	**How often do you use public transportation in your city of residence?**	**ما هو عدد المرات التي تستعمل فيها النقل العام في المدينة التي تقيم فيها؟**
	Never	أبدا
	Rarely	نادرا
	Sometimes	أحيانا
	Often	غالبا
	Always	دائما
Q30	**How satisfied are you with the public transportation system in your city of residence?**	**ما مدى رضاك عن نظام النقل العام في المدينة التي تقيم فيها؟**
	Very Dissatisfied	غير راض أبدا
	Dissatisfied	غير راض
	Somewhat Dissatisfied	غير راض إلى حد ما
	Somewhat Satisfied	راض إلى حد ما
	Satisfied	راض
	Very Satisfied	راض جدا

	Not Applicable	لا ينطبق
Q31	**What type of alternative modes of transportation do you use in your city of residence?**	**ما هو نوع وسائل النقل البديلة التي تستخدمها في المدينة التي تقيم فيها؟**
	Buses	الحافلات
	Taxi	سيارة الأجرة (التاكسي)
	Bicycle	الدراجة
	Motor bike	الدراجة النارية
	Car sharing	السيارة المشتركة
	Walking	السير
	None	لا شيء مما سبق
Q32	**How satisfied are you with each alternative mode of transport that you use?**	**ما مدى رضاك عن كل وسيلة نقل بديلة تستخدمها؟**
	ROWS: SHOW ONLY MODES USED AT Q31	
	Buses	الحافلات
	Taxi	سيارة الأجرة (التاكسي)
	Bicycle	الدراجة
	Motor bike	الدراجة النارية
	Car sharing	السيارة المشتركة
	Walking	السير
	Very Dissatisfied	غير راض أبدا
	Dissatisfied	غير راض
	Neither satisfied nor dissatisfied	لست راضيا أو غير راض
	Satisfied	راض
	Very Satisfied	راض جدا
	Don't know	لا أعرف
Q33	**How important are each of the following reasons that discourage people from using public transport?**	**ما مدى أهمية كل الأسباب التالية التي تثني الناس عن استخدام النقل العام؟**
	Limited accessibility	إمكانية الوصول إليه محدودة
	Too slow	بطيء جدا

	Cultural reasons/ No privacy	أسباب ثقافية/ليس هناك من مكان للخصوصية
	Poor services	سوء الخدمات
	High prices	الأسعار المرتفعة
	Unavailability / long waiting times	عدم التوفر/فترات الانتظار الطويلة
	Do not feel informed enough to use	ليست لدي معلومات كافية لاستخدامه
	Want to spend as little time as possible outside in the summer	أريد أن أمضي وقت أقل ممكن في الخارج خلال فصل الصيف
	No access close to where I live	لا يوجد نقطة وصول قريبة من المكان الذي أقيم فيه
	Not at all important	ليست مهمة على الإطلاق
	Not important	ليست مهمة
	Neither important not unimportant	ليست مهمة ولا غير مهمة
	Important	مهمة
	Very important	مهمة جدًا
	Don't know	لا أعرف
Q34	**If public transportation is accessible from every major area in the city, would you consider using it?**	**إن كان بالإمكان الوصول إلى نقطة النقل العام من كل منطقة رئيسية في المدينة، هل تفكر باستخدامه؟**
	Yes	نعم
	No	لا
	IF YES AT Q34	
Q35	**Which mode of public transportation would you prefer to use?** **(Choose all applicable)**	**أية وسيلة نقل عام تفضل استخدامها؟ (حدد كل ما يطبق)**
	Buses	الحافلات
	Metro	المترو
	Taxi	سيارة الأجرة (التاكسي)
	Water Taxi	سيارات الأجرة المائية
	Tram	الترام
	Light Rapid Transit	النقل الخفيف السريع
Q36	**How important are each of the following factors in encouraging you to use public**	**ما مدى أهمية كل العوامل التالية في تشجيعك على استخدام النقل العام في كثير من الأحيان؟**

	transport more often?	
	Cheap prices compared to high operating costs of private vehicles	الأسعار الرخيصة مقارنة بتكاليف التشغيل الباهظة للسيارات الخاصة
	Safety	السلامة
	Avoid congestion	تجنب الازدحام
	Care toward the Environment	الاهتمام بالبيئة
	Punctuality	الدقة في الوقت
	Avoid driving tension	تجنب توتر القيادة
	If it got me to my destination more quickly	إن كانت تنقلني إلى الوجهة التي أقصدها بسرعة أكبر
	Not at all important	ليست مهمة على الإطلاق
	Not important	ليست مهمة
	Neither important nor unimportant	ليست مهمة ولا غير مهمة
	Important	مهمة
	Very important	مهمة جدًا
	Don't know	لا أعرف
Q37	**How important would each of the following policies be in encouraging you to use public transport more often?**	**ما مدى أهمية كل من السياسات التالية في تشجيعك على استخدام النقل العام في كثير من الأحيان؟**
	Higher cars' registration and insurance fees	ارتفاع رسوم تأمين وتسجيل السيارات
	Toll gates	بوابات الرسوم
	Increase in fuel prices	ارتفاع أسعار الوقود
	Not at all important	ليست مهمة على الإطلاق
	Not important	ليست مهمة
	Neither important nor unimportant	ليست مهمة ولا غير مهمة
	Important	مهمة
	Very important	مهمة جدًا
	Don't know	لا أعرف
Q38	**How important would each of the following incentives be in encouraging you to use public transport more often?**	**ما مدى أهمية كل من الحوافز التالية في تشجيعك على استخدام النقل العام في كثير من الأحيان؟**
	Accessibility to different areas in the city	إمكانية الوصول إلى مناطق مختلفة في المدينة

	Affordable prices	أسعار معقولة
	Special packages (e.g. for Students, Elderly …etc.)	عروض خاصة (على سبيل المثال، للطلبة، المسنين... الخ.)
	Not at all important	ليست مهمة على الإطلاق
	Not important	ليست مهمة
	Neither important nor unimportant	ليست مهمة ولا غير مهمة
	Important	مهمة
	Very important	مهمة جدًا
	Don't know	لا أعرف
Q39	**Car rental sharing is a model of car rental where people rent cars for short periods of time, often by the hour (i.e. AED1/ minute), and usually do not need to return the car to the place of collection. Will you consider using car sharing service if it was available?**	**المشاركة في استئجار سيارة هي نموذج لاستئجار السيارات بحيث يستأجر الناس سيارات لفترات قصيرة من الوقت، غالبًا في الساعة (أي درهم إماراتي واحد / الدقيقة)، وعادةً لا يحتاجون إلى إعادة السيارة إلى المكان الذي استأجروها منه. هل يمكن أن تفكر باستخدام خدمة السيارة المشتركة إن كانت متوفرة؟**
	Definitely	بالتأكيد
	Most probably	على الأرجح
	Maybe	ربما
	Mostly not	على الأرجح لا
	Never	أبدا
	Not Applicable	لا ينطبق

Appendix 2 DOT Workshop Agenda

Topic: Feasibility Assessment of Electric Vehicle Adoption in Abu Dhabi
DOT Feedback Workshop

Invitees: DOT (including TRANSAD and Public Transit), METI/MHI
Location: Masdar Institute – President's Boardroom (Third Floor)

<u>Agenda</u>

Tuesday 05/02/2013

9-915: Project and Team Members Introduction

915-945: Review of Policies and Case Studies for Adoption of EV -

945-1015: Interview and Survey Interim Results on EV Perception in Abu Dhabi

1015-1030: Break

1030-11: Economics of EV Adoption in Abu Dhabi & Policy Options Scenarios

11-1130: Cases for EV integration in Transportation System Simulation Modeling

1130-1230: Discussion of Scenarios and Results

1230-1315: Lunch

1315-1345: AD ITS Architecture and EV Adoption

14-1500: Adoption of EV and AD Grid Integration

15-1600: Conclusions: Barriers and Opportunities from EV adoption in AD Discussion with TRANSAD and Bus on EV potential - Next Steps

16: Adjourn