AMERICAN UNIVERSITY OF BEIRUT

CONSUMER PREFERENCES FOR HYBRID AND ELECTRIC VEHICLES AND DEPLOYMENT OF THE CHARGING INFRASTRUCTURE: A CASE STUDY OF LEBANON

by
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AN ABSTRACT OF THE THESIS OF

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Title: Consumer Preferences for Hybrid and Electric Vehicles and Deployment of the Charging Infrastructure: A Case Study of Lebanon

Market penetration rates of hybrid electric vehicles (HEV) and electric vehicles (EV) remain low in several countries, despite visible efforts from governments and private sector players to promote them. Understanding consumer preferences and stakeholders' interests regarding these cleaner technologies is essential to develop a comprehensive national strategy. Hence, this thesis develops a demand modeling framework incorporating financial and technical attributes of common mid-size Internal Combustion Engines (ICE), HEVs, and EVs, then uses it to compute Willingness to Pay (WTP) measures and evaluate the effectiveness of different monetary incentives. It also sets forth qualitative research methods to capture the perspectives of different stakeholders. An application to the Greater Beirut Area in Lebanon using data from a stated preference survey conducted in 2018 reveals a WTP for a 100-km increase in driving range equal to 705 $ and for a 1 $ reduction in driving costs per 100 km equal to 305 $. The results are lower than several values found in the literature, probably because studied regions differ in terms of electric mobility progress and socio-economic characteristics. A policy testing exercise suggests that doubling fuel taxes could increase the market shares of HEVs and EVs from 9.25% to 9.59% and from 4.98% to 5.84% respectively. The provision of charging incentives to consumers could raise the market share of EVs up to 6.96%. A combination of both policies could further increase the proportion of EVs to 7.22%. In parallel, a stakeholder analysis drew attention to a multitude of challenges regarding the public charging infrastructure rollout as well as HEV and EV uptake, namely excessive delays in establishing the enabling institutional and regulatory environment along with shortcomings in the electricity supply. This research shows that HEVs are better suited than EVs in the short term and that a solid transition to electric mobility in Lebanon necessitates further planning, especially the incentives scheme.

CONTENTS

ILLUSTRATIONS

TABLES

Table Page

CHAPTER 1

INTRODUCTION

This thesis develops a demand modeling framework to determine consumers' preferences and adoption rate of hybrid and electric vehicles. It also investigates strategies for promoting these technologies and the challenges associated with developing the corresponding charging infrastructure. The topic is introduced in this chapter through Section 1.1. Then, Section 1.2 clarifies the objectives and contribution of the research. Finally, Section 1.3 presents the outline of the thesis.

1.1.Motivation

The transportation sector is a main contributor to global greenhouse gas (GHG) emissions. With the ever-rising concerns about climate change, the implementation of sustainable transportation solutions has become necessary. The future of mobility can thus no longer be envisaged without alternative-fuel vehicles (AFV), notably hybrid electric vehicles (HEV) and battery electric vehicles (EV). The former are powered by an internal combustion engine along with one or more electric motors, while the latter rely solely on an electric motor. Contrarily to EVs, HEVs do not need a specific charging infrastructure to recharge their battery, because this is ensured by the internal combustion engine and the kinetic energy generated as the car is in motion (i.e. through slowing down and braking).

Following the 2015 United Nations Climate Change Conference in Paris (COP 21), a multitude of countries committed to electrifying their transportation sector. They set an initial goal of increasing the proportion of EVs up to at least 20% by 2030, with an ultimate goal of banning the production and sale of internal combustion engines (ICE). Car manufacturers are responding to this firm interest in clean vehicles by expanding their product range to include additional electrified models. For instance, Renault will produce eight EV models by 2022, BMW will offer twelve models by 2025, and Volkswagen will invest as much as $84 billion in battery and EV technology so that all 300 of its models can be converted by 2030 (World Economic Forum, 2018).

The acceleration of electrification requires strategic decisions on the regulatory and infrastructural levels. First, policy measures are crucial for promoting the adoption of privately owned EVs (Rietmann and Lieven, 2019). Governments generally choose a combination of monetary and non-monetary incentives that help bridge the cost gap between EVs and vehicles running on ICEs. Financial incentives can be a one-time aid given at the time of vehicle purchase, through a point of sale grant and tax exemptions, or given after the time of purchase, such as post purchase rebates. They can also take the form of a recurrent financial assistance that alleviates ownership costs, such as exemptions/reductions in annual inspection fees or income tax credits (Hardman et al., 2017). Another type is related to use, meaning benefits attained when driving an EV, via discounted or free roadway tolls, charging, and parking. These incentives are often adopted in the early stages of strategies promoting EVs. For example, municipal parking was free and charges on toll roads were removed for EVs until 2017 in Norway (Elbil, n.d.). Moreover, incentives can target the charging infrastructure deployment in the form of a subsidy, tax credit or rebate for installing a station. Non-financial privileges accorded to EV drivers, such as access to restricted lanes and reserved parking, are an additional measure.

Second, the availability of charging stations is essential to eliminate range anxiety besides serving the growing number of users. Indeed, several studies tackle the “range anxiety” issue, which is defined as a psychological barrier developed with regards to the limited range of EVs (Noel et al., 2019). This fear is however founded on inaccurate perceptions as investments in battery manufacturing are growing, notably in China and Europe, enabling higher performance (IEA, 2019). Regardless, charging stations are needed at home, at the workplace, and in public locations. Several studies recognize home charging as paramount to mainstreaming EVs because vehicles are parked there for the longest duration on a daily basis. It is relatively affordable and simple to build, unless a household does not have a dedicated parking spot, or the latter is far from access to electricity. Although it is usually funded by the homeowner, in some cases, electromobility service providers invest in residential charging infrastructure and tax for it in their subscription fees. Next in order is workplace charging, which is reported to be the most effective nonresidential charging investment (NRC, 2015). It is most likely to be financed by the employer. As for public charging, it is widely known for increasing general awareness about the technology and reducing range anxiety. A pilot done in Japan by an electric utility holding company (TEPCO) suggests a correlation between charging availability and electric vehicle miles traveled (eVMT). Following the installation of a fast charger for their own fleet, the average eVMT of the latter increased from 203 km/month to 1,472 km/month (Anegawa, 2010). Among others, public charging includes on-street parking for charging and stations in commercial centers. The installation and operation of public charging stations are open to different business models varying among marketing investments, private investments, and public-private partnerships (World Economic Forum, 2018). In fact, numerous private players have been identified: (1) retailers that could benefit from additional time and money spent in their establishments as well as favorable branding, (2) electric utilities that could earn higher revenues, (3) vehicle manufacturers that wish for an increase in sales and greater market shares, and (4) commercial charging providers that offer subscriptions but still need government support (NRC, 2015).

Third, it is important to address the logistical requirements for equipment installation in existing and new buildings, as well as urban planning implications of on-street charging. In preparation, the European parliament together with EU member states revised their Energy Performance Buildings Directive (EPBD) to ensure the compliance of building codes with the needs of the growing demand for electro-mobility (European Commission, 2016). Accordingly, buildings with more than ten parking spaces that are newly constructed or under renovation must accommodate recharging points (if non-residential) or pre-cabling (if residential).

Lastly, visionary management of the additional demand on the power grid is needed. EV charging is indeed anticipated to impact the distribution system, particularly in the evening. Strategies for smoothing load profiles consist of influencing the charging behavior, namely through setting time-based electricity tariff structures. A research study carried out in California demonstrates that price fluctuations entice EV users to charge during off-peak hours (CPUC 2012a).

1.2.Research Objectives and Contribution

The shift to electric mobility requires major support from governments and well thought-out strategies. This research assesses the market for hybrid and electric vehicles and ways to guide its growth. Hence, it has the following three objectives:

1. Evaluate worldwide progress in the adoption of HEVs and EVs as private vehicles and the deployment of the charging infrastructure.
2. Understand consumer behavior and anticipate the effect of monetary incentives and other policies on the demand for HEVs and EVs as private vehicles.
3. Identify key challenges and successful interventions in the substantial rollout of HEVs and EVs in countries with low market penetration rates from the point of view of different stakeholders.

To achieve the first two objectives, a discrete choice model of vehicle type choice is developed as a function of vehicle attributes. As previous studies have tackled the demand estimation based on stated preferences (SP) surveys (mostly due to low market penetration of clean vehicles), a similar approach is developed and employed for forecasting the market share of gasoline, hybrid and electric vehicles, as well as the willingness to pay for the cleaner options under different suggested policies. The third objective is met by conducting interviews with active and/or potential participants in the establishment of the charging infrastructure.

The proposed framework is then applied to a case study of Lebanon. While studies by Haddad et al. (2015, 2018) investigate the environmental impacts of AFVs in Lebanon, and a study by Irani and Chalak (2015) evaluates the interest of Greater Beirut

Area (GBA) residents in hybrid vehicles and the potential to adopt them, a holistic approach to the mainstreaming of AFVs – in particular EVs – has not been explored yet in Lebanon. This is where this research comes into place. It will contribute to understanding the attitudes and preferences of Lebanese citizens towards HEVs and EVs, and to guiding local authorities in the regulatory and infrastructural planning of electric mobility.

1.3.Thesis Organization

This thesis comprises five chapters of which Chapter 1 is the introduction and Chapter 5 is the conclusion. Each of Chapter 2 and Chapter 3 tackles one of the two topic's dimensions: consumers' preferences and demand for HEVs and EVs, and the deployment of the charging infrastructure. Chapter 4 is a case study. A more detailed overview of the chapters is given below:

- Chapter 2 provides a literature review on the demand and willingness to pay for HEVs and EVs, as well as international and local advancements in the uptake of these vehicles. Then, it describes the methodological approach adopted for modeling, forecasting and testing potential policy scenarios.

- Chapter 3 reports on the means by which the charging infrastructure is being developed and the corresponding status of relevant countries. It then lists the stakeholders and assesses their potential contributions to the development of the charging infrastructure.

- Chapter 4 draws a case study for the Greater Beirut Area in Lebanon. It applies the frameworks established in Chapters 2 and 3, then analyzes the results.

- Chapter 5 reviews the main findings, the contribution, and the limitations of this research. It also offers directions for future research projects related to electric mobility.

CHAPTER 2

CONSUMERS' DEMAND AND PREFERENCES FOR HYBRID AND ELECTRIC VEHICLES

With governments' eagerness to rapidly enlarge the market size of EVs for their energy efficiency and safety benefits, numerous policy measures have been established. This chapter presents a modeling framework for estimating the demand for HEVs and EVs and consumer preferences for their attributes, as well as for testing the effectiveness of relevant policies. It is organized in two main sections: Section 2.1 which provides a literature review and Section 2.2 which describes the research methods.

2.1.Literature Review

This section presents a review of the literature and current situation with regards to the demand for EVs. Section 2.1.1 provides an overview of incentives aimed at boosting EV sales. Section 2.1.2 identifies common types of analyses of consumer preferences for EVs.

2.1.1. Market Penetration

The recent growth in HEV and EV sales is triggered by two events. These are the introduction of the Toyota Prius in 1997, the world's first mass-produced HEV (Toyota, 2015), and the release of the Tesla Roadster in 2008, the world's first luxury EV (Tesla, n.d.). As it happens, the automotive industry is being reshaped. The next few years (2020 – 2030) promise to welcome a multitude of new models, as car manufacturers claim their plans to invest more than 200 billion dollars in the development of electrified vehicles (Levin, 2020).

The increase in supply is naturally a reflection of the rapid growth in sales. In fact, the global stock of passenger EVs exceeded 5 million vehicles in 2018, which represents a 63% increase from the previous year. The top markets are China, Europe, and the US, with 45%, 24%, and 22% of the global stock on their roads, respectively (IEA, 2019). In terms of market share, the statistics are still modest: 2.5% in 2019. Norway is the global leader as HEVs and EVs accounted for more than 50% of new car sales in that year (Norsk elbilforening, n.d.).

Governments have been resorting to an array of policy tools to boost the demand. These include monetary incentives under the form of tax credits, tax reductions, tax exemptions, or purchase subsidies. These tools attempt at bridging the cost gap between ICEs and EVs. Often are economic instruments combined with other policy measures that elevate the value proposition of EVs, notably access to restricted traffic lanes, lower toll fees, and reduced parking fees (IEA, 2019). In some instances, auto manufacturers also benefit from incentives: a reduction in taxes related to CO2 emissions (Zhang et al., 2014) or support in research and development (Matulka, 2014). These aim at reducing development and production costs such that EVs uphold their competitiveness. It is evident that these policies and incentives require monitoring and are thus subject to adjustments once the market grows. For example, Norway reached the last stages of their EV support plan: they have started phasing out.

Electric mobility leaders, identified as China, the US, Japan, Netherlands, Norway, France, the UK, Germany, and Canada, all adopted fuel economy standards, set targets in terms of number of vehicles sold, and provided financial incentives (Hardman et al., 2017; IEA, 2019). Nonetheless, as this thesis builds a case study for Lebanon, two front runner countries (Turkey and Jordan) and one city (Dubai) in the Middle East are further examined. There are large differences between these regions in terms of demographics and car ownership rates. Indeed, the total population in 2018 is 82.319 million and 9.956 million in Turkey and Jordan, respectively (World Bank, 2018) and 3.192 million Dubai (Dubai Statistics Center, 2018). The number of passenger cars per 1,000 individuals is equal to 151 in Turkey in 2018 (Eurostat, 2020), 149 in Jordan in 2015 (OICA, 2015), and 526 in Dubai in 2015 (UITP, 2016). A table illustrating the electric mobility situation in the selected areas is shown below.

Table 1. HEV and EV progress in front-runner countries and cities in the Middle East

	Turkey	**Jordan**	**Dubai, UAE**
Beginning of private EV sales	2013[1]	2014[4]	2016[10]
Approximate total number of EVs	Around 1,300 in 2019[1]	Around 18,000 in 2018[5]	Around 1,000 in 2018[11]
Beginning of private HEV sales	2013[2]	2012[4]	2015[12]
Approximate total number of HEVs	Around 12,000 in 2019[3]	33,400 in 2016[4]	Around 3,000 in 2018[11]
Popular EV model	Renault Zoe[3]	Nissan Leaf[7]	Tesla Model S[13]
Popular HEV model	Toyota C-HR[3]	Toyota Prius[6]	Toyota Prius[13]
Approximate number of public charging stations	582[2]	12[5]	200[10]

	Turkey	Jordan	Dubai, UAE
Market Outlook	HEVs and EVs will make 30% to 65% of sales by 2030 (medium growth – high growth scenario), with an increase in the share of EV sales compared to HEVs[2]	N/A	(1) 10% of all new vehicles will be HEVs or EVs by 2020[10] (2) 2% of all cars will be EVs by 2020 and 10% by 2030[10]
Incentives	2011: reduction in Special Consumption Tax (ÖTV) based on power capacity of the battery[2] 2016: Another round of ÖTV reductions[2] 2018: 75% exemption on the Tax for Engine Vehicles (MTV)[2]	Prior to 2012: reduction of tax for HEVs from 55% to 25% of their price After 2012: customs tax for HEVs is set to 30%, with a gradual increase of 5% every year until 2021[8] 2015: 100% exemption from customs and sales tax and registration fees for EVs 2019: 75% exemption on customs tax for EVs[9]	(1) 15% discount on all registration and renewal fees[10] (2) Free charging at public stations[10] (3) Toll exemption[10] (4) Free parking in designated areas[10] (5) Greenbank loans[10]

Note: Data retrieved from 1: TEHAD, 2019; 2: Saygin et al., 2019; 3: Sandik, 2020; 4: Khalaileh, 2017; 5: Friedrich Ebert Stiftung, 2019; 6: Obeidat, 2014; 7: World Bank and International Association of Public Transport, 2018; 8: Bani Mustafa, 2018; 9: Bani Mustafa, 2019; 10: CMS, 2018; 11: Arabian Business, 2018; 12: Oxford Business Group, 2015; 13: Aji, 2017

While these examples could inspire policies for Lebanon, it is still important to look at other countries that have only recently embarked on the electric mobility journey, like Egypt which included the deployment of EVs in its long term national agenda and began drafting recommendations with respect to tax exemptions and coordination among key stakeholders. The national plan does not stop at financial incentives for private cars, but also aims at introducing vehicle replacement programs, updating public transport fleets, and manufacturing batteries in-house (El-Dorghamy, 2018).

2.1.2. Measuring Consumer Preferences

Most studies concerning the demand and preferences for financial, technical and infrastructural attributes of EVs have recourse to discrete choice analyses. In that context, individuals are subject to a choice among a set of vehicle options distinguished by their attributes (i.e. driving range, fuel costs, purchase price, performance measures, charging time, CO_2 emissions). Initial frameworks relied on multinomial logit models, then on nested logit models; however, they were not able to capture taste variations across individuals. Accordingly, mixed logit models became a more common practice (Liao et al., 2015). Often are those studies supported by willingness to pay (WTP) estimations since they can quantify the extent of influence of vehicle attributes on purchase decisions of EVs. As such, they enable better planning of policies.

Table 2 below, which synthesizes the modeling techniques and willingness to pay (WTP) findings of recent academic studies, shows that most of the methodologies adopt the mixed logit model. Another observation is that these studies rely on stated preferences (SP) surveys, due to the ever modest presence of EVs in the market. While the reported results focus on the WTP for reduced operating cost and additional driving range, other measures have been evaluated in the literature. These include the WTP for reduced emissions (Achtnicht et al., 2012) and expansion of refueling infrastructure (Achtnicht, 2012).

Table 2. Summary of past choice studies on alternative fuel vehicles and consumers' willingness to pay for their attributes

Article	Location	Choice Model	Willingness to Pay Findings
Hidrue et al. (2011)	U.S.	Random utility model with latent classes	35 – 75 $ for an additional mile of driving range
Hess et al. (2012)	California	Cross-nested logit model	31 $, 48 $ and 82 $ for an additional mile of driving range, for low, medium and high income households, respectively
Maness and Cirillo (2012)	U.S.	Multinomial and mixed logit models	62 $ and 141 $ for an additional mile of driving range 770 $ and 610 $ per mpg in terms of fuel efficiency (values obtained with the multinomial and mixed logit model, respectively)
Glerum et al. (2013)	Switzerland	Hybrid choice model	111.35 CHF premium on the purchase price of an EV if the monthly cost of leasing the battery is decreased by 1 CHF
Jensen et al. (2013)	Denmark	Joint hybrid choice model	The same WTP for EV costs before and after testing an EV for 3 months, equal to 115 – 310 €/(€cent/km) WTP for an additional km of driving range in a single car household: 34 – 104 € and 91 – 193 €, before and after testing an EV for 3 months, respectively WTP for an additional km of driving range in a multiple car household: 16 – 82 € and 48 – 130 €, before and after testing an EV for 3 months, respectively
Hackbarth and Madlener (2013)	Germany	Mixed logit model	530 – 1,070 € for fuel cost savings of 1 € per 100 km (depending on the purchase price budget) 16 – 33 € for an additional km of driving range 20 – 40 € and 45 – 90 € to abate 1% of the CO2 emissions (depending on budget and environmental awareness)

Article	**Location**	**Choice Model**	**Willingness to Pay Findings**
Daziano (2013)	California	Conditional logit model	141.1 $ and 107.8 $ per mile for a vehicle with a driving range of 75 miles (expected range under unfavorable conditions) and 100 miles (expected range under favorable conditions), respectively
Tanaka et al. (2014)	U.S. (California, Texas, Michigan, and New York) and Japan	Mixed logit model	21.5 $ for 10 additional miles of driving range in both countries
Helveston et al. (2015)	U.S. and China	Mixed logit model	3,000 $ and 1,600 $ per $0.01/mile reduction in operating cost, in China and the U.S., respectively WTP for an EV is 0 $ – 10,000 $ and 10,000 $ – 20,000 $ lower than for an ICE in China and the U.S., respectively
Valeri and Danielis (2015)	Italy	Mixed logit model	50.4 € for an additional km of driving range
Hackbarth and Madlener (2016)	Germany	Discrete choice model with latent classes	1,056 € for a fuel cost reduction of 1 € per 100km 5,925 € for permission to use bus lanes and free parking 12 – 125 € for an additional km of driving range
Ferguson et al. (2017)	Canada	Discrete choice model with latent classes	For households that tend to choose: EV: 29.86 $ for an additional km of driving range / 1,958 $ for free municipal parking / 1,074 $ for toll-fees exemptions HEV: 16.89 $ for an additional km of driving range / 2,987 $ for toll-fees exemption ICE: 13.18 $ for an additional km of driving range / 1,376 $ for free municipal parking / 1,222 $ for toll-fees exemptions

Article	Location	Choice Model	Willingness to Pay Findings
Ščasný et al. (2018)	Poland	Mixed multinomial logit model	317 € for a reduction of 1 € operating and maintenance costs per 100 km Over 1,000 € for 100 additional km of driving range

The following table summarizes the WTP ranges observed across the reviewed papers in Table 2, bearing in mind that these ranges are wide. Indeed, findings suggest large variation in WTP values across studies, notably due to differences in methodologies and population characteristics.

Table 3. Summary of observed WTP ranges

WTP for an additional 100 km of driving range (in $)	**WTP for a fuel cost reduction of 1 $ per 100 km (in $)**
135 – 8,742	115 – 1,865

2.2.Research Methods

This section explains the four steps of the methodological approach adopted in this thesis to determine the demand for HEVs and EVs and consumers' preferences for these vehicles. Section 2.1 covers the modeling framework and formulation. Section 2.2 outlines the criteria considered for selecting the best model. Section 2.3 describes the data used, and Section 2.4 introduces different scenarios for policy analysis.

2.2.1. Modeling Scheme

This section lays out the modeling procedure. It includes providing an overview of the underlying theoretical concepts of discrete choice models and the model formulation.

2.2.1.1. Modeling Framework

A discrete choice modeling approach is adopted to explain the behavioral process that leads to an individual's choice of car type. This is done by relating the factors that govern the individual's choice through a utility function. However, unobserved attributes, unobserved taste variations, measurement errors, and instrumental variables prevent the researcher from constructing a utility with complete certainty (Ben-Akiva and Lerman, 1985). The presence of these random elements results in a stochastic choice. Consequently, researchers model the probability of a particular outcome (Train, 2009). The decision protocol that is typically used in choice modeling is utility maximization which assumes that an individual chooses the alternative with the highest utility.

2.2.1.2. Model Formulation

A mixed logit model is proposed, although the most frequent approaches found in previous choice studies on AFVs are discrete choice models with latent classes (Hidrue et al., 2010, Hackbarth and Madlener, 2016, and Ferguson et al., 2017). However, it is considered to be highly flexible and capable of estimating any random utility model (McFadden and Train, 2000). Moreover, it proved to be the most suitable model according to the selection criteria outlined below.

This sub-section thus expands on the modeling structure and formulation used in this research. It involves defining the utility equations and deriving the likelihood function.

2.2.1.2.1. The Choice Model

A mixed logit model with random coefficients is adopted, which accounts for the panel data that contains repeated choices for every individual over different scenarios. The utility of each vehicle type is defined as a function of vehicle attributes and socio-economic characteristics of the surveyed individual/household. The following equation gives the utility of alternative i, in choice situation t, for respondent n:

$$U_{i,n,t} = \beta'_n X_{i,n,t} + \varepsilon_{i,n,t} \tag{1}$$

In the specification, $X_{i,n,t}$ is a vector of exogenous variables from the survey and β_n is a vector of corresponding coefficients. The coefficients can either be fixed or random, represented by the vectors β_f and β_r, respectively. Random coefficients commonly follow a normal or lognormal distribution. Researchers often have recourse to the lognormal distribution when a coefficient is anticipated to have the same sign across the population, such as price or cost coefficients. Finally, $\varepsilon_{i,n,t}$ is a random disturbance which is independently and identically distributed (iid) as Extreme Value Type I.

2.2.1.2.2. The Likelihood Function

The model is estimated through maximizing the likelihood function, which is the probability of observing the choices of all respondents. Conditional on β, the probability of respondent n choosing alternative i out of J alternatives, in a choice situation t, is expressed as follows, where $y_{i,n,t}$ is a binary choice indicator equal to 1 if alternative *i* is chosen, and 0 otherwise:

$$P(y_{i,n,t}|X_{i,n,t},\beta) = \frac{e^{\beta'_n X_{i,n,t}}}{\sum_{j=1}^{J} e^{\beta'_n X_{j,n,t}}} \tag{2}$$

The conditional choice probability during choice situation t is given by the following equation, where $y_{n,t}$ is a vector of J elements, each of which is a binary choice indicator $y_{i,n,t}$ equal to 1 if alternative *i* is chosen, and 0 otherwise, and $X_{n,t}$ is a matrix of explanatory variables specific to respondent n in a choice situation t:

$$P(y_{n,t}|X_{n,t},\beta) = \prod_{i=1}^{J} \left(P(y_{i,n,t}|X_{i,n,t},\beta)\right)^{y_{i,n,t}} \tag{3}$$

The conditional probability of observing the sequence of choices for respondent n over the T scenarios is the product of logit formulas as expressed below, where X_n is a matrix that combines the explanatory variables, specific to a respondent, across all time periods:

$$P\left(y_n = [y_{n,1}, y_{n,2}, \dots, y_{n,T}]|X_n,\beta\right) = \prod_{t=1}^{T} P(y_{n,t}|X_{n,t},\beta) \tag{4}$$

The unconditional probability is then obtained by integrating Equation 4 over the joint density function of the random parameters $f(\beta_r)$:

$$P_n = \int P\left(y_n = [y_{n,1}, y_{n,2}, \dots, y_{n,T}]|X_n,\beta\right) f(\beta_r) d\beta_r \tag{5}$$

Finally, the likelihood over all N individuals in the sample choosing the sequence of alternatives that they were observed to choose is formulated below:

$$\mathcal{L} = \prod_{n=1}^{N} P_n \tag{6}$$

The probabilities can be approximated through numerical integration if the specification only contains one or two random parameters, or through simulation if it allows for more random components.

2.2.1.3. Selection Criteria

This section establishes the main criteria for evaluating the tested models and ultimately selecting the most suitable one. They include the sign of the parameters and significance of the variables, the tradeoffs and a validation test.

2.2.1.3.1. Signs of the Parameters and Significance of the Variables

A first check is the signs of the parameters to ensure that the model gives sound predictions. For instance, it is expected that individuals be unfavorable towards an increase in the operating costs of a car, which should be manifested through a negative cost coefficient. As for significance of the variables, the standard ‘t-test’ at a significance level of 95% is adopted.

2.2.1.3.2. Tradeoffs

The tradeoffs are a key concept in this research as they enable the comparison of the studied population to others, as well as the confirmation of the reasonableness of the estimated results. Tradeoffs represent the willingness to pay (WTP) for car attributes. For the survey data used in this research, three tradeoffs can be calculated: the WTP for additional kilometers of range, the WTP for a reduction in operating costs, and the WTP for additional horsepower. The equations for each are shown below, where β_{price} is the coefficient of the variable representing the purchase price of the vehicle in thousands of dollars, β_{cost} is the coefficient of the variable representing the vehicle's operating costs in dollars per 100 km, β_{range} is the coefficient of the variable representing the vehicle's driving range in hundreds of kilometers, and $\beta_{horsepower}$ is the coefficient of the variable representing the engine's power in tens of horsepower.

$$WTP_{100\ additional\ kilometers\ of\ range}(in\ \$) = \frac{\beta_{range}}{\beta_{price}} \times 1{,}000 \tag{6}$$

$$WTP_{1\$\ reduction\ in\ operational\ costs}(in\ \$) = \frac{\beta_{cost}}{\beta_{price}} \times 1{,}000 \tag{7}$$

$$WTP_{10\ additional\ horsepower}(in\ \$) = \frac{\beta_{horsepower}}{\beta_{price}} \times 1{,}000 \tag{8}$$

2.2.2. Data Needs

A household or individual traveler survey should be conducted to satisfy the data requirements. It should cover two types of data: the socio-economic status of the household and the respondent's preferences towards different types of cars. As such, the survey used in this thesis enquires about the household size, income, and number of cars owned, as well as the respondent's gender, age, and level of education. Then, a choice experiment and Likert scale questions are included to capture the attitudes and perceptions of the respondents towards gasoline, hybrid and electric vehicles.

2.2.3. Forecasting and Policy Analysis

This section explains the procedure for calibrating the selected model – a prerequisite for forecasting and policy analysis – in addition to a brief methodology for policy analysis.

2.2.3.1. Calibration of the Alternative-Specific Constants

The importance of calibration lies in demonstrating the ability of the model to reproduce the observed patterns in the real market. It is particularly relevant for this research given that SP data is used in the estimation. As it happens, real market shares are not necessarily reproduced when prediction relies on this type of data. Thus, the alternative-specific constants (ASC) or scale must be adjusted (Cherchi and Ortúzar, 2006; Glerum et al., 2013). Nevertheless, in order to maintain the tradeoffs that are well captured by the SP data, the model scale will not be modified. Consequently, calibrating the ASCs, which replicate choice shares across the sample rather than the population, is a better practice (Hensher et al., 2015). It consists of an iterative process and is explained below, as per Train (2009):

- Let α_j^k be the estimated ASC for alternative j, where k indicates the number of the iteration
- Let S_j be the real market share for alternative j
- Apply the model with the estimated ASC values of each alternative to determine the predicted market share, denoted as $\hat{S}_j^k$.

- Modify the ASC of any alternative that has different predicted and real market shares by increasing its value if $S_j > \hat{S}_j^k$ and decreasing it if $S_j < \hat{S}_j^k$. A recommended adjustment takes this form: $\alpha_j^{k+1} = \alpha_j^k + ln\ (S_j/\hat{S}_j^k)$
- Repeat until the forecasts are comparable to the real market share

Once the selected model meets the calibration targets, it can be used for forecasting and policy analysis.

2.2.3.2. Policy Analysis

The policy analysis examines different policies to boost the demand for HEVs and EVs. Depending on the model specification, policies targeting the ownership cost of the available vehicles or charging scheme can be made. Their impact on the demand is assessed by comparing the resulting demand estimates to those of the base case, which approximates the market share of ICEs, HEVs, and EVs, by taking a common/popular vehicle model for each type of vehicle in the study area. Sample enumeration is used to make aggregate inferences about the population. This method estimates the total number of decision makers in a population choosing a given alternative through the weighted sum of individual probabilities. In a case where the sample is not representative of the population, different weights should be applied to different respondents (Train, 2009).

CHAPTER 3

DEPLOYMENT OF THE CHARGING INFRASTRUCTURE

As the realization of electric mobility is not limited to simulating the demand for electric vehicles but also to enabling an initial roll-out of publicly accessible charging stations, the latter is the focus of this chapter. It is divided similarly to Chapter 2, with one section undertaking a review of the literature (Section 3.1), followed by another one presenting the research methods (Section 3.2).

3.1.Literature Review

This section provides an overview about the role, drivers, and rollout strategies of the EV charging infrastructure. Section 3.1.1 explores the relationship between charging infrastructure and EV sales. Section 3.1.2 investigates policy measures adopted to stimulate the expansion of the charging network. Section 3.1.3 identifies the main players in the EV charging network, followed by Section 3.1.4 which determines common business models in that market. Finally, Section 3.1.5 emphasizes the importance of public stations interoperability.

3.1.1. Relationship between Charging Infrastructure and EV Sales

Access to charging stations (CS) is often regarded as a key component to trigger EV purchase. Potential consumers are still apprehensive of the technology, due to range anxiety, being the fear that the battery runs out while driving. As a consequence, the demand for public CS might exceed the need (Neubauer and Wood, 2014). Determining the optimal number of public CS is thus central to charging infrastructure rollout strategies. It should take into consideration the charging behavior of EV drivers, availability of home and workplace charging, and market share of EVs (Morissey et al., 2015). Studies that have explored the effect of the state of the charging infrastructure on EV uptake (including PHEVs) are summarized in the table below. It is clear that a relationship exists between access to CS and EV sales, and that EV users highly value home charging.

Table 4. Literature review of charging station development and EV uptake

Article	Location	Objective and Method	Key Findings
Plötz et al., 2016	Europe and US	Multiple linear regression to identify controlling factors and policy measures related to EV sales	The number of CS available and the number of EVs per capita in the US are positively linked (ignoring variance at the city or regional levels).
Mersky et al., 2016	Norway	Linear regression to evaluate EV sales on a regional and municipal basis and determine the factors that boost adoption	The number of CS has the highest predictive power for EV sales, at the regional level. The number of CS has more influence on corporate vehicles than on personal vehicles, at the municipal level.
Wang et al., 2017	China	Multiple linear regression to assess EV sales under the provision of incentives	The density of CS is one of the four most important factors to sustain EV market growth. State and local governments are advised to put more weight on the expansion of their charging infrastructure, notably by dedicating construction lands for building CS, or subsidizing CS instead of EVs.
Harrison and Thiel, 2017	Europe	Systems dynamics based agent model to investigate the impact of government policy concerning charging infrastructure on EV uptake	Availability of CS seems to impact EV uptake in Europe when the market share exceeds 5%. In general, the number of EVs on the road as well as the GDP may influence the relationship between charging provision and EV uptake. A ratio larger than one CS per 10 EVs is likely to only lead to little gains, while incurring high costs.
Slowik and Lutsey, 2017	US	Statistical analysis to determine the key activities supporting EV uptake at the metropolitan level	Areas with the highest EV market share have a public charging infrastructure that is 2 to 6 times larger than the average. Public charging, in particular public fast charging, and workplace charging are significantly correlated to EV uptake.

Article	Location	Objective and Method	Key Findings
Sun et al., 2017	China	Chi-square test of independence using data from a questionnaire intended for EV users to study their expectations concerning EV performance and infrastructure	The density of CS is significantly correlated with the satisfaction of EV users.
Narassimhan and Johnson, 2018	US	Regression of vehicle purchase data from 2008-2016	The availability of public CS highly impacts EV purchase decisions. Early investments in charging infrastructure, especially along highways, promise a boost in EV uptake.
Gnann et al., 2018	Germany	Agent based simulation model to study the co-diffusion of EVs and charging infrastructure	Public slow charging does not accelerate EV uptake and is not profitable at the early rollout stages without subsidies because the number of users is still small. Charging at the workplace increases the number of EVs. Home charging is crucial for a wide adoption of EVs.
Hardman et al., 2018	US, Canada and Europe	Literature review of studies that tackle infrastructure needs to support EV uptake	Home charging is the most important location to encourage EV sales, followed by work, then public locations.
Helmus et al., 2018	Netherlands	Introduction of four key performance metrics (number of unique users, connection duration, transaction volume, and ratio of charging and connection time – all defined on a weekly basis) to evaluate two different EV charging infrastructure rollout strategies (demand-driven and strategic rollout)	Demand-driven charging infrastructure is necessary in less mature markets. In mature markets, a combination of demand-driven and strategic rollout (decision made by a local or regional authority to set CSs near a public facility) is favorable.

Article	Location	Objective and Method	Key Findings
Carley et al., 2019	US	Ordinary least squares regression of longitudinal survey results to assess the change in consumers' interest in purchasing or leasing an EV between 2011 and 2017	The correlation between availability of CS and EV purchase decision has increased over the years, as the charging infrastructure is strongly correlated to EV purchase decisions in 2017 after not being correlated in 2011.
Globisch et al., 2019	Germany	Hierarchical linear model to quantify factors that impact the evaluation of (hypothetical) public CS	The density of CS has a significant impact on the assessment of public charging infrastructure by potential EV drivers. Public charging infrastructure is especially valuable for potential buyers that do not fit into the typical early adopters' profile, meaning it could contribute to increasing EV sales.
Clinton and Seinberg, 2019	US	Fixed-effects regression model to evaluate the correlation between charging infrastructure and BEV adoption	Private charging (in residential and business parking facilities) is positively and significantly correlated to BEV sales.

3.1.2. *Policy Measures for Initial Rollout*

The deployment of the charging infrastructure is typically guided by regulations and subsidies. On one hand, governments are revising building codes to accommodate EV charging infrastructure, for new and renovated buildings, as well as parking lots. Indeed, the charging equipment necessitates different electrical wiring and safety gear from those available in most structures, which incur elevated costs for retrofitting (Hall and Lutsey, 2017). On another hand, governments are funding public and private CS (IEA, 2019). An example of public infrastructure support is given by the Norwegian government which introduced a policy in 2009, providing subsidies to local and regional authorities until 2013 (Helmus et al., 2018). In terms of home infrastructure support, there are programs for EV owners who have a private garage, as well as those who share their parking spot in multi-unit dwellings or only have access to off-street parking. For instance, the UK has been funding up to 75% of the CS installation costs at residential places, in addition to operating an on-street residential charge point scheme (OLEV, 2020). Also, Quebec started providing financial aid for the cost and installation of home CS in 2012 and extended it until 2026 (Gouvernement du Quebec, 2019). The government of France, which pays for 50% of the costs of shared CS in multi-unit buildings with the ADVENIR program launched in 2016, is another example (ADVENIR, n.d.). The following table confirms the presence of regulatory and economic instruments established in the leading countries in electric mobility to expand their charging infrastructure.

Table 5. Chargers related policies in front running countries (Source: IEA, 2019)

	Canada	**China**	**Europe**	**India**	**Japan**	**US**
Hardware standards	Yes	Yes	Yes	Yes	Yes	Yes

	Canada	**China**	**Europe**	**India**	**Japan**	**US**
Building regulations	Only at a state/ province/ local level	Only at a state/ province/ local level	Yes	Yes	No	Only at a state/ province/ local level
Fiscal incentives	Yes	Yes	Yes	No	Yes	Only at a state/ province/ local level

In the Middle East, the public charging infrastructure is growing at a slow pace. Recalling from Section 2.1.1 that Jordan is a pioneer in electric mobility in the region since 2014, it only has 12 public charging stations (Friedrich Ebert Stiftung, 2019). The first ten stations were owned by the government, with little to no investment from private players. It turned out that the existing regulatory cap on the electricity retail price for EV public stations ruined any possibility for financial return. To remediate this problem, a policy recommendation was submitted by the end of 2018, which is expected to stimulate private investment in public chargers (GGGI, 2018). As for Dubai, it has an edge over neighboring countries and cities, both in terms of infrastructure size and available incentives. Since it launched the EV Green Charger Initiative to expand the public charging infrastructure in 2015, the Dubai Electricity and Water Authority (DEWA) has deployed 240 stations. The latter are accessible, for free, until the end of 2021, to all the consumers registered in the initiative (DEWA, n.d.).

3.1.3. Main Players in an EV Charging Network

While governments are the main source of capital at the initial stages of the charging infrastructure rollout, other stakeholders become interested in the market as it grows. The transition to commercially sustainable CS can be led by new entrants or established actors under different business models. The two predominant roles that a stakeholder can take on are described in Table 6 below, as per Madina et al. (2016).

Table 6. Roles in a competitive charging infrastructure deployment market

	Electro-Mobility Service Provider (EMSP)	**Charging Point Operator (CPO)**
Role	The legal entity that offers electro-mobility services to the customers (individuals or businesses) at any location, notably charging, search & find, and managing payments	The entity that operates and monitors the physical equipment (i.e. manages the charging session), as well as maintains it. It offers charging services to the EMSP.
Costs	Mainly related to customer management	Mainly related to the operation and maintenance of the infrastructure (e.g. energy and power costs)
Revenues	Service fees (subscription packages or pay-as-you-go)	Services (from the EMSP) as well as other sources (e.g. advertising)

An example of EMSP is Greenlots, a member of a conglomerate of energy and petrochemical companies with projects in 13 countries across the globe. It developed a mobile application that allows EV drivers to locate stations, keep track of their charging status, and pay. In parallel, it serves businesses (e.g. site hosts, grid operators, and network owners) with a cloud-based platform, a grid management software, as well as other software (Greenlots, n.d.).

ChargePoint, a leading EV infrastructure company, can be categorized as a CPO since it operates the largest network of independently owned EV charging stations in 14 countries in North America and Europe. Its products and services range from designing and manufacturing hardware and software solutions, to site planning, installation, set-up and maintenance of the stations (ChargePoint, n.d.).

There are also players that act both as an EMSP and a CPO, namely EVgo. This company owns, operates, and maintains more than 800 public fast charging stations in 34 US states. It also runs an application and a 24/7 customer support center to help users locate and use a charger (EVdo, n.d.).

3.1.4. Business Models

A successful business model considers both the interests of the operator and consumers, being profitability for the first, convenience, affordability and reliability for the second. In the first stages of electric mobility development, investment in public charging infrastructure is challenging but as the industry matures, viable business models stand out. The following table describes some prevailing business models, according to Hall and Lutsey (2017). It is worth noting the list is not mutually exclusive nor collectively exhaustive.

Table 7. Common Charging Infrastructure Business Models

Business Model	Basis	Limitations	Example
Electricity price-based	Sell electricity through a subscription plan or pay-as-you-go option	Financial sustainability relies on the attractiveness of electricity versus gasoline cost	EVgo operates the largest public fast charging network in the US by offering customers monthly subscription plans
Retail sales-based	Attract new customers and increase sales at commercial sites (supermarkets, cinemas, gyms, shopping centers, etc.)	Long dwell times negatively influence a site's revenue-generating capacity (fully charged EVs block the stations)	A major US retailer reported dwell times 50 minutes longer than the average and additional revenues, ensuing the installation of charging stations at one of its locations in California
Advertising revenues-based	Integrate (digital) advertisement on the station	Limited to high-traffic and high-visibility locations (e.g. commercial centers, restaurants, and busy highways)	Volta (California-based company) provides free charging across a nationwide network of CS by diffusing sponsors' advertisements on digital devices installed on each station
Automaker funded	Create a unique customer proposition	Usually targets a specific customer segment only	Tesla's Supercharger network

3.1.5. Interoperability

Past the initial stages of the charging infrastructure deployment, increased difficulty to utilize public CS is expected, due to the presence of a multitude of EMSPs. A customer would thus need several different memberships, accounts, and cards to access all the CS (Hardman et al., 2018). In an attempt to reduce complexity and enhance user experience, policy makers are working towards interoperability. The latter aims at integrating all the key components of the infrastructure, including the stations, the software, and billing methods. It consists of a collaboration between engineering and information technology, under standards and regulations set by policy makers (Schauble et al., 2016). Two examples are selected to illustrate this concept. One of them is the Norwegian EV Association which issued RFID cards for their members to register and benefit from the services of the main EMSPs at any location. The second example is of greater interest and describes the experience of the Netherlands, where every public CS in the country, along with numerous private ones, can be utilized and paid for via a unique radio-frequency identification card. A consortium of grid operators, known as ElaaNL, was behind the establishment of the corresponding standards (the Open Charge Point Protocol (OCPP) and the Open Clearing House Protocol (OCHP)). As a consequence, there is efficient communication between CS, the grid, and back-end offices and interoperability in operation and payment is achieved (Lutsey et al., 2017).

3.2.Research Methods

The methodological approach followed to analyze the stakeholders is described herein. Section 3.2.1 justifies the need for qualitative research, including the data collection method. Section 3.2.2 identifies relevant actors and stakeholders whose interactions are key in the uptake of electric mobility, with a focus on their role in expanding the charging infrastructure.

3.2.1. Qualitative Research

Qualitative research is valuable to endorse information obtained through quantitative research. It is particularly relevant for making decisions about policies which are expected to impact each stakeholder differently. Accordingly, gathering, analysis and interpretation of textual data should be conducted. Popular data collection methods include surveys, interviews, focus groups, conversational analysis, observation, and ethnographies (Olds et al., 2005). This thesis adopts the semi-structured interview type because it is flexible enough to benefit from new insights from the participants while tackling specific dimensions of the research question (Galletta, 2013). The interviews can either be done face-to-face or remotely (by telephone or email correspondence).

3.2.2. Stakeholder Analysis

For a smooth transition to electric mobility, the extent to which strategies align with the interests of stakeholders should be considered. A stakeholder analysis is thus needed to capture the values, standpoint and approach of the players affected by the emerging EV system (Brown and Soni, 2019). It concerns those who are explicitly or implicitly involved in the regulation, provision, operation, and usage of EVs and charging stations. The number of stakeholder groups varies depending on the level of detail sought by the researcher. According to Hardman et al. (2018), an EV charging infrastructure deployment can be led by policy makers, auto manufacturers, utilities, real estate developers, retail companies, fuel stations, or any other stakeholder. In this thesis, five comprehensive categories are targeted: government agencies, car manufacturers and/or importers, energy suppliers, CPOs and/or EMSPs, and end users (a similar classification is adopted in UITP, ESMAP and The World Bank (2018)). The description of each is as follows:

- Governmental institutions represent the policy makers and regulators at a given jurisdiction scale, including inter-governmental bodies, ministries, municipalities, and local authorities. They formulate the policies that help achieve national objectives, as well as share data and regulate the actions of other stakeholders.
- Car manufacturers and/or distributors concern both gasoline and cleaner vehicles (hybrid and electric), as well as auto parts suppliers. They set the pace at which electric mobility moves forward by investing in technologies and charging networks, while keeping financial profitability as a priority.
- Energy suppliers includes power utilities, such as electricity producers, electricity providers, and electric utility grid operators. Beyond accommodating for the power needed by EVs, they can shape charging behaviors with their pricing strategies.
- CPOs and/or EMSPs could be an existing or a new entity, or a combination of both. They operate and/or integrate a network of charging stations.
- End users comprise private vehicle owners, corporates, and public entities.

CHAPTER 4

THE CASE STUDY OF LEBANON

The proposed research frameworks introduced in Chapters 2 and 3 are applied herein to the Greater Beirut Area (GBA) in Lebanon. Section 4.1 evaluates the demand and preferences for hybrid and electric vehicles, while Section 4.2 presents an analysis of stakeholders involved in the deployment of the charging infrastructure.

4.1.Consumers Demand and Preferences for Hybrid and Electric Vehicles

This section is divided into four parts. First, an overview of the transportation sector and progress in the electric mobility field during the period of study is provided. Second, all the steps starting from the data collection to the final model selection are described. Third, the basis for the forecasting and policy analysis exercise are explained. Fourth, the results of model estimation, forecasting, and policy testing are presented then analyzed.

4.1.1. Background Information

The transportation sector in Lebanon is increasingly contributing to harmful emissions, thereby accounting for 23% of GHG emissions in the country in 2013 (MoE/UNDP/GEF, 2016). This results from a combination of factors that make up the land transport conditions in the country. First, the lack of suitable infrastructure for non-motorized modes of travel and the inefficient public transit network result in a peculiarly high average car ownership and usage rate. The number of persons per car was estimated to be 3 in 2002, growing at a positive annual rate of 1.5% until 2012

(MoE et al., 2012). Car ownership rate is believed to remain excessively high up to this day. Second, trips in the GBA are characterized by stop-and-go patterns which exacerbate the operation of ICEs by consuming more fuel (Haddad et al., 2015).

However, there are scarcely any legislations that support eco-friendly solutions. One of them is a ban of diesel engines, which passed around mid-year in 2002, under Law 341 (6/08/2001) and Decree no. 7858/2002. As for AFVs, an article aimed at exempting HEVs from customs duties and taxes for three years was proposed by the Ministry of Finance in 2010. The impact of a financial incentive of the like on the potential of GBA residents to purchase HEVs was investigated by Irani and Chalak (2015). They demonstrate that removing the customs and excise taxes is indeed crucial to encourage the switch to these vehicles; nonetheless, the proposed exemption scheme was not implemented at the time. It was not until 2018 that an effective step in that regard was taken via article 55 in the budget Law of 2018 (Law 79/2018), which was then renewed in 2019 (Law 144/2019) under article 25.c. This policy set the customs and excise taxes at 20% and 0% for private (white plate) HEVs and EVs, respectively, and 10% and 0% for HEVs and EVs used in passenger transport (red plate), respectively. It also entitles all red plate owners to a 100% exemption of registration and annual road usage fees (Mécanique) fees for the first year (MoE/UNDP/GEF, 2019). While this exemption is applicable regardless of the vehicle price, other non-HEV and non-EV vehicles are taxed relative to a 20 million LBP (around 13,350 USD) threshold. For a vehicle price below the threshold, the tax consists of 20% of the total price, split between excise tax and customs duties as 15% and 5%, respectively. For a vehicle price above the threshold, the tax includes 20% of the threshold amount, with an additional

50% of the price above the threshold, the latter being divided into 45% excise tax and 5% customs duties.

This tax incentive comes after the commitment that Lebanon made in the 2015 United Nations Climate Change Conference (COP 21), which consists of cutting its GHG emissions by 15% by 2030. Moreover, it set a target conditional on financial, technical and capacity building support, of boosting the proportion of AFVs to 20%, by 2030. It is believed that this tax incentive scheme has encouraged car importers to expand their product range to include AFVs. In fact, the first full-sized EV was introduced in January 2019. Moreover, the E-Motorshow held in April 2019 was the first of its kind in Beirut, where 18 models were displayed and available for a test drive. This trend can be associated with a change in customer behavior, as the senior sales consultant at Porsche Center Lebanon claimed that 40% of their clients are switching to PHEVs (Kanaan, 2019).

With the discovery of offshore natural gas, higher levels of environmental benefits could be achieved by transitioning to electric mobility. Mansour and Haddad (2017) claimed that natural gas vehicles infrastructure and EV infrastructure have comparable costs, while the latter provides superior GHG emission savings. Moreover, Mansour et al. (2018) showed that HEVs and EVs offer considerable emissions reduction opportunities on a tank-to-wheel level in the GBA but fail on a well-to-tank level because of the country’s dirty electricity mix. If the power sector turns to natural gas for electricity generation, the attractiveness of EVs would become indisputable.

4.1.2. Modeling the Demand for Hybrid and Electric Vehicles in Greater Beirut Area

This section is an application of the modeling framework presented in Section 2.2. using data collected in the Greater Beirut Area (GBA). It is divided into four sections that present the data, describe basic features of the sample studied, focus on model estimation, and propose a list of scenarios for policy analysis.

4.1.2.1. Data Used

This section presents the data used in the modeling framework. It was obtained from a survey designed by a research group at the American University of Beirut (Otary, 2019). The survey was a household survey conducted in the Greater Beirut Area (GBA) and two additional zones to its north and south, being Jounieh and Jiyeh, respectively, in July 2018. It comprised two parts: revealed preferences (RP) and stated preferences (SP). From the first part, only the socio-economic characteristics of the respondents are relevant to this research. They include gender, age, and level of education for every member of the household as well as household size and car ownership. As for the SP part, its objective was to capture the potential of cleaner vehicles to be picked by the studied households, in the event of buying a new car in the next 12 months. Therefore, respondents were given four scenarios and were asked to choose, in each, among a mid-size gasoline, hybrid and electric car. Besides, the SP survey elicited the perceptions and attitudes of respondents towards HEVs and EVs. They expressed their level of agreement with attitudinal statements such as “Electric cars don’t offer enough performance” or “I am concerned that the electric car might run out of electricity while on the road” using a 5-point scale.

The three car options differed in their purchase price (in $), driving costs (in $/100km), driving range (in km), and horsepower (in hp). These constitute four of the fundamental characteristics in studies about consumer preferences for EVs, as shown by Liao et al. (2015) who reviewed 26 papers on this matter. Multiple levels for each attribute were determined, then randomly combined in order to present different scenarios to each respondent (refer to Appendix A for the details about the experimental design). The operating costs were estimated for each car in terms of energy cost, which is a common approach (Musti and Kockelman, 2011). The cost for the gasoline option was calculated using car fuel efficiency and the prevailing price of fuel in 2018. The cost for the hybrid option was assumed to be 40% to 70% less than that of a gasoline car. As for the electric option, cost was computed based on the battery efficiency of the corresponding mid-size car and the rate of electricity given by Electricité du Liban. In parallel, the purchase price, the range and the horsepower were based on the attributes of popular mid-size car brands in 2014 (Otary, 2019).

Moreover, two of the four scenarios introduced governmental incentives on environmentally friendly vehicles, in line with article 55 in the budget Law of 2018 (discussed in Section 4.1.1).

An experienced Lebanese survey company conducted the survey as a personal interview with people in their residences using a tablet. Examples of the choice experiment generated for a given respondent by randomly combining the attribute levels defined in Appendix A are illustrated in Tables 8 and 9 below.

Table 8. Example of a scenario given in the choice experiment without financial incentives

Characteristic	Option 1	Option 2	Option 3
Car Type	Gasoline	Hybrid Electric Car	Electric Car
Price ($)	16,660	22,491	25,823
Range (km)	760	570	228
Horsepower (hp)	160	216	115
Cost ($/100km)	6.00	3.30	1.80

Table 9. Example of a scenario given in the choice experiment where financial incentives are introduced

Characteristic	Option 1	Option 2	Option 3
Car Type	Gasoline	Hybrid Electric Car	Electric Car
Price ($)	16,660	24,157 – 437 = 23,720	27,656 – 1,866 = 25,790
Range (km)	880	950	264
Horsepower (hp)	130	228	107
Cost ($/100km)	12.00	5.89	2.85

4.1.2.2. Descriptive Statistics

This section describes demographics and socio-economics for the collected sample which consists of 400 households in the GBA. Then, it highlights interesting characteristics among categories in the sample.

4.1.2.2.1. Sample Demographics and Socio-Economics

The sample demographics fairly represent the population of the GBA, apart from the distribution of household size and respondent gender. The following Table 10 categorizes the responses with respect to household size, monthly income and car ownership, and respondents' level of education and gender.

Table 10. Distribution of sample demographics (Sample size = 400)

Survey Question	Category	Percentage of Households
Household size	1	4.25
	2	29.75
	3	27.00
	4 or more	39.00
Monthly household income	0 - 1,999,000 L.L.*	28.00
	2,000,000 L.L. - 3,999,000 L.L.	25.00
	4,000,000 - 5,999,000 L.L.	20.25
	6,000,000 - 7,999,000 L.L.	9.25
	8,000,000 - 9,999,000 L.L.	3.75
	10,000,000 - 14,999,000 L.L.	3.50
	I don't know / No response	10.25
Education of respondent	No formal education	1.50
	Less than secondary / high school diploma	34.25
	Secondary / high school diploma (12 years of schooling)	24.00
	Some college / university	11.25
	Technical or vocational school	9.75
	University undergraduate / bachelor's degree or equivalent	16.00
	Postgraduate, master's degree, doctorate	3.25
Gender of respondent	Male	87.75
	Female	12.25
Car ownership	0	8.25
	1	51.00
	2 or more	40.75

*1 US dollar is equivalent to 1,500 L.L. at the time the survey was conducted

First, the majority of surveyed households is composed of at least two individuals (95.75%) and the biggest sub-category is the one with a size superior or equal to 4 members (39%). The average size observed is 3, which is lower than the population household size of 4.23 estimated by the Central Administration of Statistics (CAS) in 2007. Hence, adjustments will be made by applying weights at the model forecasting stage. Second, the average household income is almost 4,000,000 L.L. Those who earn more than this are only 17.5% of the sample, while the remaining 10.25% abstained from giving information about their financial status. Third, the variation in the educational background of the respondents is broad: more than a third of them haven't accomplished the lowest levels (up to high school diploma), in contrast to another third who hold at least a college degree. Fourth, the majority of respondents are men (87.75%) which does not accurately represent Lebanon's demographics: the sex ratio is in fact around 1. The high proportion of men in the sample is probably because the interviewer asked to speak to a member of the household that was knowledgeable about car use for every car in the household, and men seemed to know more about the mileage of each car than women. Fifth, 51% of the households own one car, and 40.75% own at least two. These numbers can only be compared to a 25-year old study conducted by TEAM International (1995) due to lack of more recent data: whereas the percentage of households that own one car is comparable (around 50%), the percentage of households with more than two cars is lower (25%) in the general population.

4.1.2.2.2. Socio-economic Variable Variation Between EV Choosers and non-EV Choosers

The characteristics of the people who showed interest in the EV option are investigated herein. To that end, the socio-economic variables are categorized, when applicable, into three levels (low, medium and high, with these ranges specified in the table below), and the sample is divided into two groups: respondents who choose the

EV option at least once (Group 1) and those that don't choose the EV option in any of the scenarios (Group 2). The results are shown in the following Table 11.

Table 11. Comparison of demographic and socio-economic characteristics between respondents that are favorable towards EVs (Group 1) and those that are not (Group 2)

Socio-economic Characteristic	**Category**	**Group 1**	**Group 2**
Household size	1	5%	4%
	2 – 3	42%	59%
	4+	53%	37%
Monthly Household Income	Low (0 – 1,999,999 L.L.)	27%	32%
	Medium (2,000,000 – 5,999,999 L.L.)	49%	50%
	High (above 6,000,000 L.L.)	24%	17%
Education Level	Low (No formal education, Less than secondary / high school diploma)	30%	38%
	Medium (Secondary / high school diploma (12 years of schooling), Technical or vocational school)	28%	35%
	High (Some college / university, University undergraduate / bachelor's degree or equivalent, Postgraduate, master's degree, doctorate)	42%	26%
Gender	Male	96%	95%
	Female	4%	5%
Car Ownership	0	4%	9%
	1	45%	52%
	2+	51%	39%

There are no flagrant differences between the two groups; however, respondents with a favorable attitude towards EVs tend to have a higher household size, monthly income, educational level, and car ownership level compared to the other group. Indeed, the majority of Group 2 is composed of households of 2 to 3 members, whereas Group 1 comprises more households with 4+ members. While both groups contain a similar number of medium income level households, there are more high income level ones in Group 1 than in Group 2 (24% and 17%, respectively). Moreover, the proportion of high educational level respondents in Group 1 is considerably larger than that detected in Group 2 (42% and 26%, respectively). Finally, the number of households in Group 1 that doesn't own cars is half of that in Group 2, and there are 51% of them who own at least two cars, compared to 39% in Group 2.

These observations are similar to those found in the literature. It seems that choosing the EV option is associated with middle and upper classes, which is not a singular observation, as the question of EVs being reserved for the wealthy has been in the headlines of several newspapers and magazines. It has also been addressed in a multitude of studies: high incomes have been linked with lower price sensitivity in the adoption of EVs (Achtnicht et al., 2012; Hackbarth and Madlener, 2013; Hess et al., 2012; Valeri and Danielis, 2015). Moreover, research studies have found that early adopters are highly educated (Campbell et al., 2012; Carley et al., 2013; Hidrue et al., 2011; Higgins et al., 2017) and have multiple cars (Kurani et al., 1996; Khan and Kockelman, 2012; Peters Dütschke, 2014; Tamor and Milacic, 2015).

4.1.2.3. Model Development

Several specifications were examined and assessed according to the selection criteria. At first, a model with fixed parameters was estimated, but all the variables with the exception of price were insignificant. Non-linear transformations such as piecewise linear (for the range and/or horsepower) were thus tested, but the estimation results were also not satisfactory. The presence of a random error component did not improve the estimation results either: the cost, range and horsepower variables were not significant.

Next, mixed logit specifications were studied. All the combinations of random parameters including the alternative-specific constants were tested. However, any model with more than one random parameter did not stabilize, even after taking the number of draws above 50,000. As the model with the random cost parameter met all the selection criteria, it was further developed by adding socio-economic variables in the hybrid and electric utility equations. These included, among others, household income and size, as well as the gender, education level and age of the respondent. Only one of them was significant (household car ownership level equal to or exceeding two) and was thus retained.

In parallel, a latent class choice model (LCCM) was investigated. Neither the resulting parameter signs were correct, nor did the model converge. Finally, models with one or two latent variables were explored. However, all the trials had estimation issues, possibly due to the small size of the sample.

4.1.2.4. Final Model Specification

Respondents were faced with four choice experiments. Since three alternatives were given in each scenario, there are 12 utility equations in total. The systematic utilities of the gasoline, hybrid and electric options, represented by Gas, HEV and EV, respectively, are presented below, where n represents the respondent and t the scenario.

$$V_{Gas,n,t} = \beta_{Cost,n} \times Cost_{Gas,n,t} + \beta_{Price} \times Price_{Gas,n,t} + \beta_{Range} \times Range_{Gas,n,t} \tag{9}$$

$$V_{HEV,n,t} = ASC_{HEV} + \beta_{Cost,n} \times Cost_{HEV,n,t} + \beta_{Price} \times Price_{HEV,n,t} + \beta_{Range} \times Range_{HEV,n,t} + \beta_{TwoPlus\_Cars\_HEV} \times TwoPlus\_Cars_n \tag{10}$$

$$V_{EV,n,t} = ASC_{EV} + \beta_{Cost,n} \times Cost_{EV,n,t} + \beta_{Price} \times Price_{EV,n,t} + \beta_{Range} \times Range_{EV,n,t} + \beta_{TwoPlus\_Cars\_EV} \times TwoPlus\_Cars_n \tag{11}$$

The cost coefficient follows a log-normal distribution. On one hand, it accounts for unobserved taste variation across respondents. On the other hand, it enables fixing its sign as negative, which is preferred over the normal distribution (Train, 2009). In the following equation, $\mu_{\beta cost}$ and $\sigma_{\beta cost}$ are the mean and standard deviation of the underlying normal distribution, to be estimated as unknown parameters.

$$\beta_{cost,n} = -e^{(\mu_{\beta cost} + \sigma_{\beta cost} \times \omega_n)} \qquad \text{where } \omega_n \sim N(0,1) \tag{12}$$

The explanatory variables appearing in the utility functions are explained in the following table.

Table 12. Explanatory variables used in the final model

Variable	Type	Description
$\boldsymbol{Cost_{i,n,t}}$	Continuous variable	Cost of driving 100km of alternative i, presented to respondent n, in scenario t (in $/100km)
$\boldsymbol{Price_{i,n,t}}$	Continuous variable	Purchase price of alternative i – including customs and excise, VAT, and registration fees – presented to respondent n, in scenario t (in thousands of $)
$\boldsymbol{Range_{i,n,t}}$	Continuous variable	Driving range of alternative i, representing the distance the car can travel before refueling or recharging, presented to respondent n, in scenario t (in 100 km)
$\boldsymbol{TwoPlus\_Cars_n}$	Dummy variable	A binary variable equal to 1 if the household owns two or more cars, and 0 otherwise

The horsepower variable was not even significant at a 60% confidence level in any of the tested specifications. A plausible explanation is that the type of car presented in the choice experiment (mid-size) reduced the importance of engine power among respondents. Indeed, high horsepower is commonly associated with sports vehicles and bigger size vehicles. It might also simply mean that the sample prioritizes other attributes over engine power.

4.1.3. Forecasting and Policy Analysis

This sub-section covers the assumptions taken to perform the calibration and the forecasting, then, three suggested policies for analysis.

4.1.3.1. Calibration of the Alternative-Specific Constants

The actual market shares for hybrid and electric vehicles are negligible in Lebanon, considering that their uptake started in 2019 after the introduction of government incentives and the import of different models of these cars into the Lebanese market. Indeed, out of all the new white plate cars registered in 2019 (approximately 22,000 vehicles), only 315 are hybrid, 69 are plug-in hybrid electric, and 12 are battery electric (S. Saad, personal communication, 2020). Taking BEVs and PHEVs together, their proportion is barely 0.37%, whereas that of HEVs is 1.43%. Demand for HEVs and EVs is expected to rise in the next decade, particularly because the year 2030 is the deadline adopted by the Ministry of Environment at the UNFCCC 2015 to attain an appreciable penetration rate of environmentally friendly vehicles. In addition, neighboring countries are already moving forward with the deployment of EVs. Recalling the success of Jordan documented in Section 2.1.1, the market shares they attained today, five years after the introduction of HEVs and EVs, could be taken as an example. Accordingly, for the purpose of calibrating the alternative-specific constants, the calibration target market shares are assumed to range between 7% and 10% for HEVs, and 2% to 5% for EVs, by 2025. However, the escalating economic crisis in Lebanon does not enable more than the formulation of speculations for the time being. It is for instance highly likely that the government abandons incentives on HEVs and EVs (along with other privileges) to increase its revenues.

4.1.3.2. Forecasting Procedure

The market shares are first predicted for the base case. The latter consists of a scenario in which all respondents are confronted with the same vehicle alternatives to which the governmental incentives defined in Law 79/2018 are applied. To match common market products and apply the model which was developed for mid-size cars, mid-size cars are selected. Forecasting is then performed for the suggested policy scenarios for the year 2025, in the hope of attaining higher market shares for HEVs and EVs.

4.1.3.2.1. Base Case Scenario

In the absence of a brand that concurrently markets the three types of vehicles in Lebanon and is a top seller, the purchase price, driving costs and range are determined for the base case scenario using specifications from multiple brands of the same tier. The table below contains the base case scenario characteristics.

Table 13. Base case scenario

Characteristic	**Option 1**	**Option 2**	**Option 3**
Car Type	Gasoline	Hybrid Electric Car	Electric Car
Price ($)	18,815	28,305	49,950
Range (km)	850	945	520
Cost ($/100km)	7.83	4.48	1.53

Option 1 is the Toyota Corolla 2019. The choice is based on the fact that it is one of the best-selling cars in the world (Toyota, n.d.). Moreover, Toyota demonstrated consistent sales growth throughout the years in Lebanon (Bankmed, 2016), where this model is extremely popular (G. Bejjani, personal communication, 2020). While the range shown in Table 8 corresponds to the one mentioned in the company specifications, operating cost are rather calculated using the approximate number of kilometers completed with a 20 L refuel given by BUMC, based on experience (around 200 km). The reason is that fuel efficiency varies depending on traffic and road conditions. This assumption would thus enable a more accurate representation of real conditions.

Option 2 is the Toyota Prius 2019. The Prius is the first mass-produced hybrid vehicle in the world, and the only mid-size one in Lebanon. The range and cost shown in Table 8 are determined as per the approach discussed for Option 1, using an approximate number of kilometers completed with a 20 L refuel equal to 350 km. Although Toyota has been selling more Camry and RAV4 hybrid models in 2019, the former falls a bit on the more luxurious end of the spectrum of mid-size cars and the latter is an SUV.

Option 3 is the Chevrolet Bolt 2019. This fully electric crossover has the longest range among its competitors and achieved the highest number of sales in 2019 in Lebanon. Four other car distributors experimented with EV’s between 2018 and 2019: Hyundai, Renault, BYD and Changan (S. Saad, personal communication, 2020). The last two were not very popular as Chinese brands have not earned a solid reputation in Lebanon yet, notably due to the scarcity of their spare parts. As such, the Yuan which is the compact SUV offered by BYD at 34,310$ including VAT, was removed from the market (Khoury, 2019). The Twizy model and the Kona model offered by Renault and Hyundai are not suitable for this study because of their size (a compact two-seater and an SUV, respectively). As for the Renault Zoe, three units were brought in 2018. This vehicle’s range is 250 km and it was showroomed at a starting price of 39,000$; however, it was no longer in stock in 2019 (I. Kfoury, Email correspondence, 2020).

4.1.3.2.2. Sample Enumeration Method

The sample enumeration method is employed to calculate the market shares under the base case and suggested policy scenarios. However, due to the unrepresentativeness of the sample, adjustments are made prior to obtaining the market segments. These are made at the household size distribution level because it is one of the few variables for which population level data is available and that does not vary considerably over the years. Weights are thus assigned to each household depending on its location in either of two regions: Municipal Beirut (MB) or outside Municipal Beirut (OMB), using the household size distribution determined by the Central Administration of Statistics (2007) in the Living Conditions Survey. Assuming that each household's decision is equivalent to that of the member who answered the interview, the probability of a respondent choosing a certain alternative is multiplied by its corresponding weight, and the estimated number of individuals in favor of a given alternative is the weighted sum of individual probabilities. The equation below gives the weight corresponding to any observation, with r representing the region and g the household size category:

$$W_{r,g} = \frac{Number\ of\ households\ in\ r\ from\ category\ g}{Number\ of\ sampled\ households\ in\ r\ from\ category\ g} \tag{13}$$

The estimated market share of alternative i, denoted as $\widehat{W_T}_i$, is equal to the ratio of the number of households in the population predicted to choose alternative i and the number of households in the population, designated by $\widehat{N_T}_i$ and N_T, respectively. The numerator is defined by Equation 14 below, where $P(i|\mathrm{X}_n;\beta)$ is the probability that household n chooses alternative i, N_T is the number of households in the sample, and w_n is calculated using Equation 15. In the latter, $I_{n,MB,\mathrm{g}}$ and $I_{n,OMB,g}$ are binary choice indicators equal to 1 if household n is in the corresponding region and belongs to household category g, and 0 otherwise.

$$\widehat{N_T}_i = \sum_{n=1}^{N_T} P(i|X_n; \beta)\, w_n \tag{14}$$

$$w_n = \sum_{g} W_{MB,g} I_{n,MB,g} + \sum_{g} W_{OMB,g} I_{n,OMB,g} \tag{15}$$

4.1.3.3. Policy Analysis

Three policies that aim to increase the attractiveness of environmentally-friendly vehicles, in particular EVs, are suggested. With the collected data, this can only be done by varying the purchase price and/or the operating cost of the vehicles. The rationale behind the strategies and the means for including them in the simulation are discussed in this sub-section.

4.1.3.3.1. Policy 1: Increase the Fuel Tax

This policy increases the cost associated with options operating on fuel. With fuel taxes being usually a policy tool for mitigating greenhouse gas emissions from transport, they can influence the decision to purchase a car. Indeed, higher operating costs negatively affect this choice (Mock and Yang, 2014). Since the cost for gasoline and hybrid cars was calculated based on car fuel efficiency and the price of fuel, it is proportional to variations in the latter. Forecasting will be conducted for a range of 10% to 100% increase in the tax on fuel, with increments of 10%. It is worth noting that although this policy affects the cost of HEVs, there is evidence in the literature that higher fuel prices result in higher demand for these vehicles (Beresteanu and Li, 2011; Gallagher and Muehlegger, 2011; Whitehead et al., 2019).

4.1.3.3.2. Policy 2: Provide Charging Incentives

This policy reduces the operating cost associated with EVs. One way of implementing it is through free public charging. A similar initiative is implemented in Dubai, where free charging at all the public stations owned by the government, for privately owned EVs, is available until the end of 2021 (DEWA, 2020). Although Hardman et al. (2018) show that the bulk of charging takes place at home and only around 10% at public stations, it is expected that such a policy encourages charging more at public stations. As such, the policy is tested for different probabilities of charging events taking place at public locations starting at 10% up until 80%. It is forecasted by reducing the operating costs associated with EVs in a similar manner. The upper limit is restricted to 80% because a complete reliance on public charging seems unrealistic.

4.1.3.3.3. Policy 3: Introduce a Purchase Credit

This policy encourages the choice of EVs by lowering their up-front price. The USA has this type of plan: EV and PHEV buyers are entitled a credit up to 7,500$. The amount decreases for a car brand after the corresponding manufacturer sells more than 200,000 vehicles (EVAdoption, 2020). Similarly, in Germany, the United Kingdom, and several other European countries, EVs receive attractive purchase incentives.

Accordingly, this policy will be tested by removing up to 5,000$ of the price of EVs, using increments of 1,000$.

4.1.4. Results

This section summarizes and analyzes the outcome of the mixed logit model application to the Greater Beirut Area in Lebanon. To that end, Section 4.1.4.1 presents the estimation results and compares them to those reported in the literature. Section 4.1.4.2 studies the effect of the policy scenarios suggested in Section 4.1.3.3 on increasing the demand for hybrid and electric vehicles.

4.1.4.1. Model Estimation Results

Model estimation was carried out using PythonBiogeme (Bierlaire, 2016) and the likelihood function was maximized through Monte-Carlo integration. The MLHS type of draws was selected since Bierlaire (2015) commends its suitability for discrete choice models.

Stability of the model was verified by increasing the number of draws until the absolute value of the variation in the parameters' values between two consecutive estimations became less than 10%. Furthermore, the estimation exercise was repeated from different starting points to ensure that the same solution was reached from different starting points. As such, the results of the stable model, achieved at 9,000 draws, are presented in Table 14 below.

Table 14. Estimation results of the final model

Variable/ Parameter	Parameter Estimate	Robust Std err	Robust t-test	p-value
ASC_{HEV}	-4.40	0.415	-10.61	0
ASC_{EV}	-11.5	1.17	-9.83	0
$\mu_{\beta cost}$	-3.77	0.468	-8.04	0
$\sigma_{\beta cost}$	4.06	0.501	8.10	0
$Price(\$/1000)$	-0.0768	0.0320	-2.40	0
$Range(km/100)$	0.0542	0.0408	1.33	0.18
$TwoPlus\_Cars_{HEV}$	2.23	0.166	5.80	0
$TwoPlus\_Cars_{EV}$	0.966	0.250	8.93	0
Null Log-Likelihood $L(0)$: -8,343.508 **Final Log-Likelihood $L(\hat{\beta})$: -699.663** **Rho-Squared ρ^2: 0.916** **Adjusted Rho-Squared $\bar{\rho}^2$: 0.915** **Akaike Information Criterion: 1,415.327** **Bayesian Information Criterion: 1,447.258** **Final Gradient Norm: +7.829E-04**				

The median, the mean and the variance, equal to -0.0234, -0.176 and 1.76, respectively, are derived from the estimates of the mean and variance of the log of the coefficient as per Train (2009).

4.1.4.1.1. Signs of the Parameters and Significance of the Variables

The sign of the $Cost$ parameter was set as negative through the lognormal specification, in order to match the common negative attitude towards an increase in driving costs. Despite its standard deviation being relatively large, which could be attributed to the small sample size, its statistical significance at the 95% level of confidence indicates the presence of unobserved taste heterogeneity for the variable.

The $Price$ parameter is negative and significant at the 95% level of confidence. This result, implying that an increase in the purchase price decreases the utility of any alternative, is expected.

The $Range$ coefficient has a positive sign, as reported in a vast majority of studies (Liao et al., 2015), meaning that people prefer to purchase a vehicle characterized by a larger driving range. Despite it being only significant at the 80% level of confidence, it was kept in the model since range anxiety still widely influences the choice of EVs.

The $TwoPlus\_Cars$ variable is significant in both the HEV and EV utility equations at the 95% level of confidence. The positive sign of its coefficient suggests that households with at least two cars would prefer the purchase of an HEV or an EV over a gasoline vehicle if everything else was the same. This could reflect a higher flexibility in vehicle purchase decisions, unlike the remaining households who favor established technologies.

Both alternative-specific constants are significant and negative. Their magnitude is relatively large, which considerably reduces the value of the HEV and EV utility equations. It is expected since Lebanese people still favor ICEs over HEVs or EVs by a long shot (S. Saad, personal communication, 2020).

4.1.4.1.2. Tradeoffs

The willingness to pay (WTP) for additional kilometers of range and the WTP for a reduction in operating costs are calculated using the final model results. The latter was obtained after performing a Monte Carlo simulation for 1,000 observations, since the cost coefficient is random and log-normally distributed. Because this type of distribution is characterized by a long right-hand tail, which eventually affects WTP calculations, the median value is reported herein. A similar assumption was taken in the technical report for the U.S. Environmental Protection Agency (2018) which summarizes 52 US papers published in the past 25 years about consumers WTP for vehicle attributes. Indeed, the median was preferred for determining the central estimates of lognormally distributed coefficients, while mean values were used when dealing with normally distributed random coefficients.

The WTP for an increase in driving range of 100km is equal to 705$. The value is lower than all the ones reported in Table 2, except for the one estimated by Tanaka et al. (2014). There are two points that could justify this result, and two others that contradict it. On one hand, the country's geography makes most travel distances short, thus within the battery range, and a good proportion of households own at least one car, meaning they are less sensitive to the range of their second purchased vehicle. On another hand, the high levels of traffic congestion increase travel time significantly and the underdeveloped charging infrastructure is expected to exacerbate range anxiety among consumers.

The median WTP for a reduction of 1$ in driving costs per 100 km is equal to 305$. This value turns out to be lower than the ones reported by Hackbarth and Madlener (2013, 2016) and Helveston et al. (2015), but similar to the one reported by Ščasný et al. (2018). Although recurrent sudden increases in fuel prices were witnessed over the past few years in Lebanon and bad traffic conditions elicit higher fuel consumption, it seems that the Lebanese put less weight on a reduction in operating costs of a vehicle compared to its purchase price. Indeed, according to the sales manager at Toyota in Lebanon, customers seem truly convinced about the benefits of HEVs and EVs but end up disregarding them as soon as they realize they are more expensive than the ICE alternative.

While these results clearly do not conform for the most part with the ranges found in the reviewed literature (Table 2), it should not be forgotten that the latter discuss the situation in developed countries where electric mobility has somehow taken off. As such, they cannot accurately represent the situation in Lebanon. Moreover, palpable differences in consumer preferences exist even in the same context: for example, the EPA document (2018) highlighted the presence of large variations in WTP within and across studies.

4.1.4.2. Forecasting and Policy Analysis

This section presents the calibrated model and explores three policies that have the potential of influencing the market size of hybrid and electric vehicles.

4.1.4.2.1. Model Calibration

The calibration targets were achieved, using the base case scenario, following the iterative process defined in Section 2.2.3. Recalling that the targets range between 7% and 10% for HEVs, and 2% and 5% for EVs, the table below shows the changes between the non-calibrated and the calibrated model. The latter suggests that 14.23% of the total demand will be for hybrid and electric cars under the base case scenario.

Table 15. Calibration results for the base model

	Non-calibrated Model	**Calibrated Model**
Estimated ASC for the EV alternative, α_{EV}	-11.538	-46.318
Estimated ASC for the HEV alternative, α_{HEV}	-4.399	-5.691
Predicted market share for the EV alternative, $\hat{S}_{EV}$	11.22%	4.98%
Predicted market share for the HEV alternative, $\hat{S}_{HEV}$	5.33%	9.25%
Predicted market share for the Gasoline alternative, $\hat{S}_{GAS}$	83.45%	85.77%

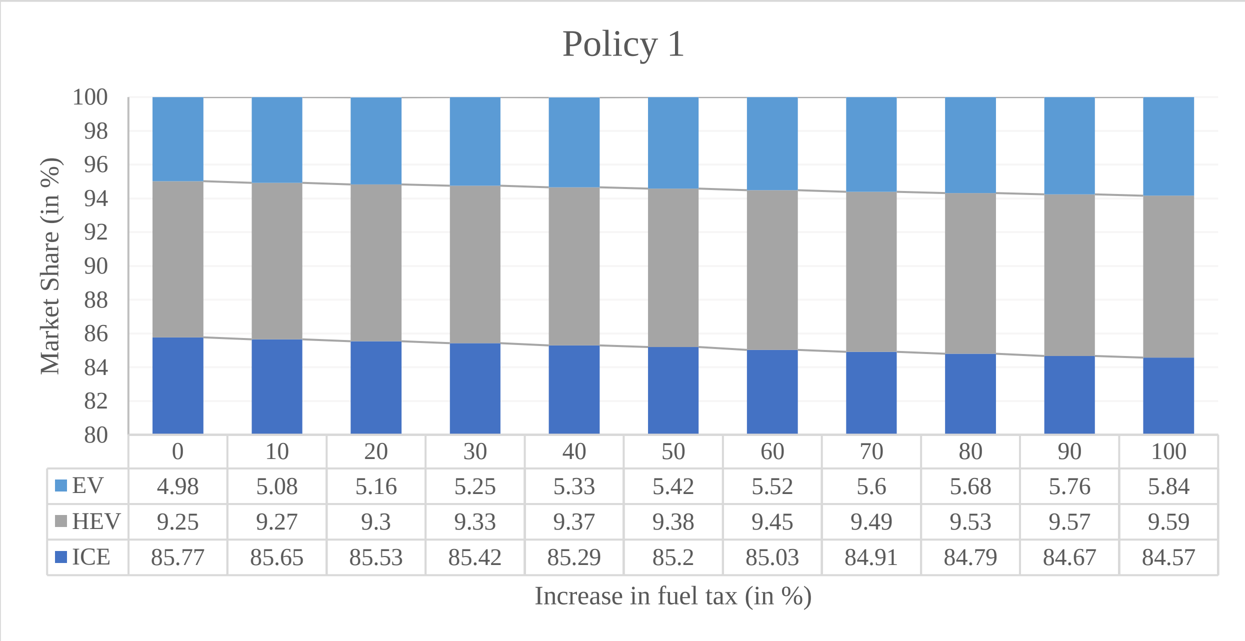
4.1.4.2.2. Policy 1: Increase the Fuel Tax

This policy considers an increase in the tax on fuel to give an edge to EVs. The table below shows the change in operating cost per 100 km of ICEs and HEVs upon the implementation of this policy.

Table 16. Changes in the cost of ICEs and HEVs under Policy 1

Scenario	**Fuel Tax Amount (in $/20L)**	**Cost of ICEs (in $/100km)**	**Cost of HEVs (in $/100km)**
Base Case	3.33	7.83	4.48
10% increase	3.66	8.01	4.58
20% increase	4	8.18	4.68
30% increase	4.33	8.36	4.77
40% increase	4.66	8.53	4.87
50% increase	5	8.71	4.97
60% increase	5.33	8.88	5.07
70% increase	5.66	9.06	5.17
80% increase	5.99	9.23	5.26
90% increase	6.33	9.41	5.36
100% increase	6.66	9.58	5.46

The figure below shows the effect of the policy on the market shares of the three alternatives studied.



	0	10	20	30	40	50	60	70	80	90	100
EV	4.98	5.08	5.16	5.25	5.33	5.42	5.52	5.6	5.68	5.76	5.84
HEV	9.25	9.27	9.3	9.33	9.37	9.38	9.45	9.49	9.53	9.57	9.59
ICE	85.77	85.65	85.53	85.42	85.29	85.2	85.03	84.91	84.79	84.67	84.57

Figure 1. Forecasting results with an increase in fuel tax (Policy 1)

Despite succeeding in lowering the market share of ICEs in favor of EVs, this policy does not seem to be very impactful: the absolute value of the reduction is almost negligible, at 1.20%. A possible explanation is that the tax increase, resulting in up to 1.75$ increase in operating cost for ICEs, is accepted by the Lebanese population, especially since no other adequate public transportation alternative is available. Accordingly, the Lebanese population could have developed a low sensitivity to variations in fuel prices. Moreover, there are some individuals who do not consider non-gasoline options, regardless of their benefits. This is effectively observed in the sample, where 67% of the respondents chose ICE under every scenario. This group of people is thus unlikely to switch to EVs simply because this option's costs are further reduced. Finally, the results could be influenced by households with higher incomes (which constitute a sizeable proportion of the population), as they were suspected by Helveston et al. (2015) and Valeri and Danielis (2015) to only be slightly affected by higher fuel costs.

In parallel, the market share of HEVs increased despite a rise in the operating cost of this option. This result complies with the findings of Beresteanu and Li (2011) and Gallagher and Muehlegger (2011) that fuel prices drive HEV adoption. The non-negative direction of change is likely associated with more individuals switching from ICE to HEV than those switching from ICE or HEV to EV. Indeed, out of the sample respondents who selected ICE in two or three of the scenarios, 6.75% and 0.75% included HEV and EV in the remaining choices, respectively. Moreover, the cost of HEV is impacted by this policy less than that of an ICE: the increase ranges between 0.10$ and 0.98$ for the former, and between 0.18$ and 1.75$ for the latter. Additionally, individuals who initially opted for an ICE could have reversed their decision after the implementation of this policy, considering the value proposition of HEV is still higher than that of an EV. All these reasons make the switch from an ICE to HEV conceivable, resulting in an increase in the market share of HEVs.

Finally, the market share of EVs increased by 0.86%. Although the influence of fuel prices on the EV market share has not been tackled extensively in the literature and the one study that was found claimed no significant relationship between the two (Sierzchula et al., 2014), the forecasting results seem logical. Indeed, the cost of EVs is considerably lower than that of the other options and is unaffected by this policy. Nevertheless, it is a relatively small increase since the change in ICE and HEV costs was not excessive and a respondent’s decision is impacted by factors other than cost.

Although there are no major obstacles to the implementation of this policy from the government side, there is a potential resistance from the population, knowing that it would substantially increase operating cost while the public transportation system is not an attractive option (it is highly unregulated and unreliable).

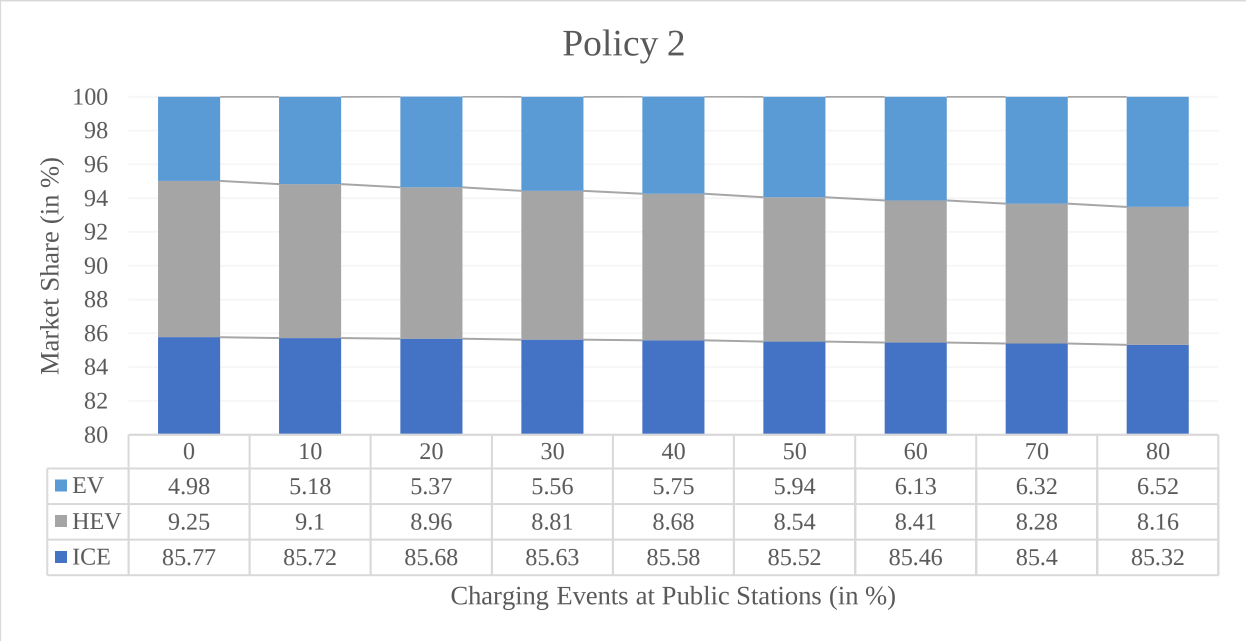
4.1.4.2.3. Policy 2: Provide Charging Incentives

A charging incentive enhances the utility of EVs by alleviating its operating cost, which are already minimal compared to ICEs and HEVs. The table below shows the change in operating cost per 100 km of EVs upon the implementation of this policy.

Table 17. Changes in the cost of EVs under Policy 2

Percentage of Charging Events at Public Stations	**Cost of EVs (in $/100km)**
0% (Base Case)	1.53
10%	1.377
20%	1.224
30%	1.071
40%	0.918
50%	0.765
60%	0.612
70%	0.459
80%	0.306

Figure 2 below shows the effect of a charging incentive on the market shares of the three alternatives studied up to the scenario where 80% of charging events take place at public stations.



	0	10	20	30	40	50	60	70	80
EV	4.98	5.18	5.37	5.56	5.75	5.94	6.13	6.32	6.52
HEV	9.25	9.1	8.96	8.81	8.68	8.54	8.41	8.28	8.16
ICE	85.77	85.72	85.68	85.63	85.58	85.52	85.46	85.4	85.32

Figure 2. Forecasting results with the provision of a charging incentive (Policy 2)

It seems that no previous research considered the effect of such a policy on EV adoption yet, but it effectively boosted the market share by 1.54% in absolute value, which is equivalent to a 31% increase. This results from a 0.45% and 1.09% decrease in the ICE and HEV market shares, respectively. It seems that the change is mainly driven by individuals with a favorable attitude towards clean vehicles and who would pick either HEV or EV, depending on the most attractive offer. Indeed, 21% of the sample consistently opted for an HEV or EV across the choice experiment. Conversely, only 1.5% of the sample considered both ICE and EV options in the experiment. As such, a higher decrease in the HEV market share is logical. Nonetheless, this policy fails to significantly expand the total proportion of AFVs in the Lebanese market, which went from 14.23% to 14.68%.

Under the event of adopting this policy, the government would have to allocate a budget for it. Considering the EV operating costs computed previously (1.53 $), the range of the EV used in the base case scenario (520 km), the average annual household mileage (12,500 km), and the policy scenario (80% of charging events taking place at public locations), subsidizing the charging of one car would only cost around 30 $ annually. If the total number of newly registered white plate vehicles in 2025 remains close to 22,000 vehicles and the EV share grows linearly from 0.37% to reach 6.52% (i.e. 1.23% increase in absolute value per year), Policy 2 would require an approximate cumulative funding amount of 335,370 $.

4.1.4.2.4. Policy 3: Introduce a Purchase Credit

The purchase credit is expected to improve the utility of EVs. It can be seen as complementary to the existing incentive of exempting EVs from customs and excise taxes since it aims at further reducing the price of this type of car. The figure below shows the effect of the purchase incentive for EVs on the market shares of the three alternatives studied.

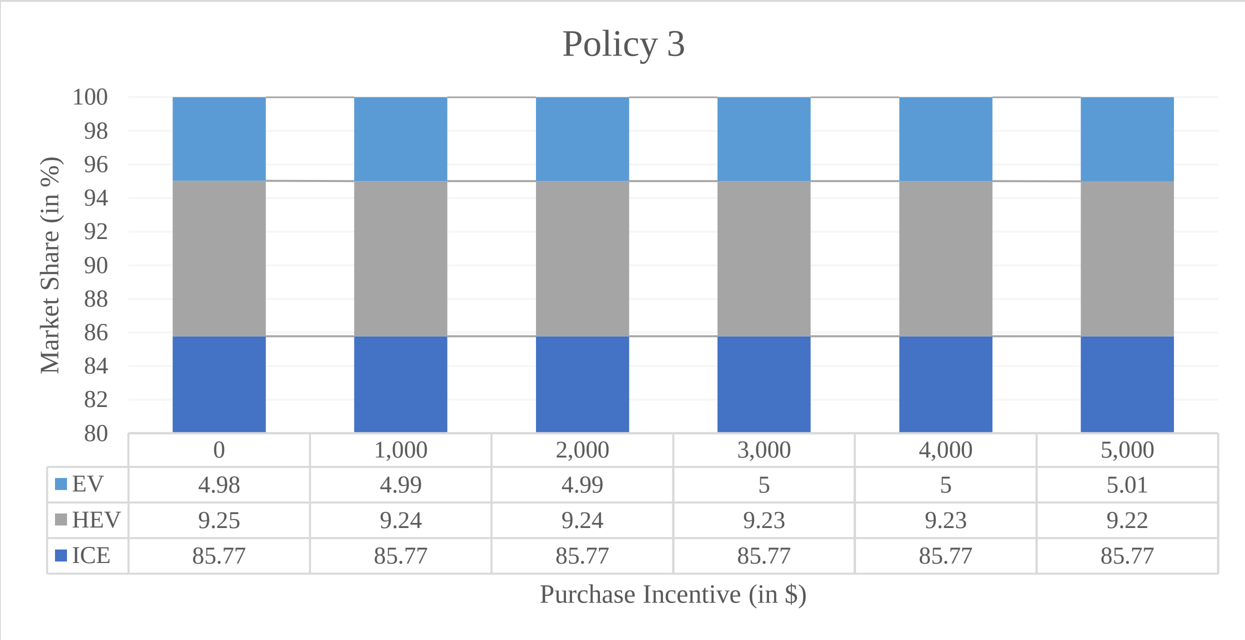


Figure 3. Forecasting results with the introduction of a purchase incentive (Policy 3)

The one-time price reduction policy has a minimal impact on the choice of individuals as expected. This result does not diverge from other findings. In fact, Liao et al. (2015) observed that the effect of a reduction in purchase price is significant 50% of the time. It can be argued that the purchase price of EVs is still remarkably higher than that of ICEs and HEVs. Hence, the reduction suggested is not enough from the buyers' perspective to go with the EV option.

4.1.4.2.5. <u>Discussion of the Policy Analysis Results</u>

A table summarizing the range of increase or decrease in the market share of each alternative (with respect to the base case scenario) under the policies tested is shown below.

Table 18. Summary of the changes in market shares under each policy

	Market Share of ICEs	**Market Share of HEVs**	**Market Share of EVs**
Policy 1	0.12% to 1.20% decrease	0.02% to 0.34% increase	0.10% to 0.86% increase
Policy 2	0.05% to 0.45% decrease	0.15% to 1.09% decrease	0.20% to 1.54% increase
Policy 3	Unchanged	0 to 0.03% decrease	0 to 0.03% increase

Policy 1 is the best at boosting the market share of HEVs and EVs altogether. As for the biggest change in terms of EV market share only, it is induced by Policy 2. This result conforms with the general observation that EV uptake is encouraged by monetary incentives. While Policy 3 follows the same mindset, it is less effective because it cannot bring the purchase price of the EV to the level of the other vehicle alternatives. Indeed, under the extreme case of offering a 5,000$ purchase incentive, the EV purchase price remains approximately 165% and 75% higher than that of the ICE and HEV alternatives, respectively.

Based on the promising results of Policy 1 and Policy 2, a merging of the two is attempted. To that end, nine combinations are formed between a low (20%), middle (50%) or high (80%) scenario from one policy with the other. The results are shown in the Figure below.

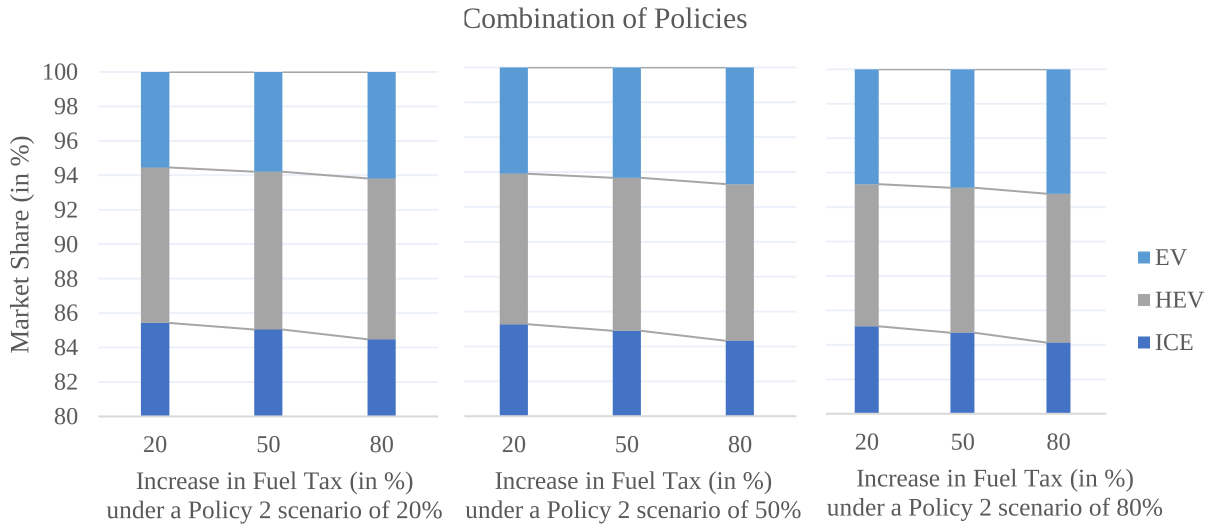


Figure 4. Forecasting results with the introduction of a purchase incentive (Policy 1 & 2)

Under the lowest levels tested (20% increase in fuel taxes and 20% of charging events at public stations), the market shares of ICEs, HEVs, and EVs are equal to 85.43%, 9.03%, and 5.54%, respectively. At the other end of the spectrum (80% increase in fuel taxes and 80% of charging events at public stations), the market shares of ICEs, HEVs, and EVs are equal to 84.13%, 8.64%, and 7.22%, respectively. This combination has thus a higher potential to influence car purchasing decisions than each of Policy 1 and Policy 2 on their own. Indeed, it reduces the market share of ICEs (0.34% up to 1.64%) and enlarges that of EVs (0.56% to 2.24%). It also has a less pronounced effect on the decrease in the market share of HEVs than Policy 2 (0.22% to 0.61%).

In terms of implementation, this combination of policies could be the most promising as the government's expenses dispensed for Policy 2 can be compensated for by the additional revenues coming from Policy 1.

4.2. Deployment of the Charging Infrastructure

This section is divided into three parts. First, the state of the charging infrastructure is described by covering the regulatory context and main obstacles. The relevant stakeholders are then identified. Finally, the outcomes of the interviews are interpreted.

4.2.1. Background Information

Currently, Lebanon does not have an enabling environment for sustainable transport, hardly even for electric mobility. For example, there are no environmental taxes on vehicles. Instead, the annual road use taxes (Mécanique) are such that the older the car model is (which means more polluting), the lower the amount to be paid is. Additionally, due to a weak institutional framework, technical challenges, and limited financial resources, several projects were abandoned. One of these initiatives is the Nationally Appropriate Mitigation Action (NAMA) developed in 2017 by the Ministry of Environment and the UNDP to remediate the country's traffic and air quality issues. It consisted of a plan for car scrappage of old vehicles and replacement into fuel efficient vehicles. Despite being approved by the Council of Ministers, no funds were allocated to the project. It was thus not pursued, neither did negotiations for that matter in the subsequent years.

Another barrier is the management of electricity production and supply. The electricity sector is monopolized by Electricite du Liban (EDL), a public institution under the Ministry of Energy and Water (MoEW). It has been experiencing considerable generation shortages and grid losses, which lead to a heavy reliance on private generators among the population (Fardoun et al., 2012). In this context, the impacts of a significant market penetration of AFVs on the power grid could possibly not be sustained. In addition, both sources (EDL and private generators) resort to fossil fuel, which impairs the expected positive impact of AFVs. An environmental assessment of AFVs in Lebanon shows that EVs generate up to 45 times the amount of CO_2 emissions yielded by an ICE, when taking into account energy production. Consequently, despite being among the cleanest technologies, their holistic contribution to reducing harmful emissions is significantly scaled down due to the dirty electricity mix (Mansour et al., 2018).

Finally, there are neither a set of targets and charging standards, nor a solid charging infrastructure rollout strategy. As no intervention from the government and only few from the private sector have been made, the number of public charging stations remains extremely low. The first chargers entered the picture in 2018 with MEDCO, an importer and distributer of oil products and gas station operator. The company installed EVSE in four gas stations around Beirut and in the parking of three commercial centers. Their next step is importing seven new stations and placing them along major corridors outside Beirut. In parallel, a solar-powered EV charging unit was built by another oil importing company, IPT, in late 2019. However, the company is still investigating its rollout strategy because it is not profitable yet (Schellen, 2019).

4.2.2. Stakeholder Analysis

Five semi-structured interviews were conducted between March and May 2020 with representatives of stakeholders belonging to the groups identified in Section 3.2.2., except for the end users group and energy suppliers. The perspective of the former can be inferred from the qualitative part of the SP survey, while that of the latter can be obtained from one of the governmental authorities interviewed (MoEW) as it oversees the sole company in charge of electricity production and supply in Lebanon. There are also interviews with two governmental bodies that could not be conducted. The first is the Ministry of Finance (MoF), which controls fiscal policies and thus the incentives on the vehicles and the EV charging infrastructure. The second is the Ministry of Interior and Municipalities (MoIM) which carries out most development projects (e.g. demonstrational charging infrastructure projects) and manages vehicle registration.

Although the questionnaires differed from one respondent to another to accurately match their organization's role, it was ensured that they all report on expectations, plans/activities and expected challenges for the large-scale adoption of EVs. One of the interviews was conducted by telephone and the rest in person. A narrative describing the findings is provided in the following Section 3.4. The selected stakeholder group representatives along with their role in addressing the main challenges of the Lebanese electric mobility system are provided in the table below.

Table 19. Interviewed stakeholder groups

Stakeholder Group	Selected Organization	Description	Role
Governmental institutions	Ministry of Environment (MoE)	The national authority who is entitled to preserve and sustainably develop the environment. It contributed to the passing of the incentive law on HEV and EV purchase in 2018.	Establish the enabling environment for electric mobility, through updating emissions standards, introducing environmental taxes, maintaining/increasing incentives, etc.
	Ministry of Energy and Water (MoEW)	The national authority that, among other responsibilities, regulates the production, transmission, and distribution of electricity, as well as sets safety, environmental, and technical specifications for construction and electrical equipment. It contributed to the passing of the incentive law on HEV and EV purchase in 2018.	Establish the enabling environment for electric mobility, notably through updating building codes Address the electricity shortage, dirty generation mix, and charging tariffs
Car manufacturers and/or distributors	Boustany United Machineries Company s.a.l. (BUMC)	The exclusive distributor of Toyota and Lexus. It is heavily marketing HEVs since 2018.	Encourage the uptake of HEVs by expanding the product line
	IMPEX	The exclusive dealer for General Motors brands Chevrolet, Cadillac, and Hummer, and for the Isuzu Japanese brand. It is marketing EVs under the Chevrolet line-up since 2019.	Encourage the uptake of EVs by expanding the product line and potentially contributing to the expansion of the charging infrastructure
CPOs and/or EMSPs	MEDCO	The oldest importer and distributor of refined petroleum products. It started investing in electric mobility in 2019.	Address the EV infrastructure barrier by developing a vast and accessible charging network

4.2.3. Results

All the findings included in this section are based on the interviews. The few references to the literature are either a back up to statements made by the respondents or a reference to studies they conducted.

4.2.3.1. Governmental Institutions

The MoE is currently working towards a decrease in national greenhouse gas emissions through upgrading vehicular emission standards from Euro 3 to Euro 6, rather than through electrification. Despite the MoE participating in the legislation for reducing customs and excise taxes on HEVs and EVs in 2018 (Law 79/2018), the severe financial crisis hitting the country at the end of 2019 is limiting the extent of their support to electric mobility. Indeed, the ministry fears that this incentive may get removed from the budget law in the upcoming years and is not pushing for any project regarding the charging infrastructure rollout. The latter is also a result of not having a study identifying the number and location of charging stations needed per region, leaving the MoE without a basis for regulating the development of charging stations.

The MoEW reiterated that the topic of electric mobility lost priority over the past few months. Charging incentives are thus not on their agenda until at least a reform of the country's financial plan occurs, which restricts their strategy to theoretical preparations. To date, they conducted a cost-benefit analysis for the use of HEVs and EVs, in collaboration with the UNDP, which led to two main conclusions: (1) HEVs are the top pick in the short term as they realize close to the highest GHG savings without incurring any infrastructure investment costs nor excessive foregone earnings to the government (2) EVs are preferred in the medium and long term as they necessitate moderate infrastructure investment costs while resulting in high government foregone revenues (MoEW/UNDP/SODEL, 2017). Moreover, they received approval on funding for another project with the UNDP, expected to take effect in 2020. It aims at investigating all the aspects of electricity tariffs restructuring and the impact of subsidies on the electricity sector. It will analyze the feasibility of offering special prices for public charging stations and smart charging at residential locations.

Concerning the regulatory aspect of the charging infrastructure deployment, the MoEW believes it is too early for modifying building codes or regulating the distribution and legalization of permits among EMSPs and CPOs. This step is anticipated to take place in the long-term (around 2030), such that a significant number of EVs would have entered the market and their impacts would have been assessed.

4.2.3.2. Car Manufacturers and/or Distributors

Toyota, which has no direct competitor in the small/medium car category in Lebanon, asserted the importance of incentives in increasing HEV sales. An overview of the journey of introducing hybrid models to the Lebanese market is provided to illustrate the challenges and opportunities. The Toyota Prius was first introduced in 2007, when the technology itself was still expensive worldwide and no financial support on import taxes was available in Lebanon. The model was thus extremely expensive (52,000$ before VAT compared to a similar ICE costing16,000$) and impossible to sell. Only few units were acquired by expats who valued the hybrid technology. The project regained attractiveness in 2018, after HEVs were entitled to lower customs and excise taxes. As the price of the Prius became more appealing (25,500$ before VAT) and the customers' feedback was extremely positive, BUMC expanded their product line with the Camry and the RAV4. Owing to the governmental incentive, both models were cheaper than their gasoline alternative: the hybrid and gasoline Camry models cost 30,550$ and 31,250$ before VAT, respectively; the hybrid and gasoline RAV4 models cost 34,300$ and 34,900$ before VAT, respectively. Consequently, the demand for these vehicles surged, and BUMC decided to only sell the hybrid models in 2019. In that year, 31 Camry, 235 RAV4, and 19 Prius were sold, bringing the share of hybrid sales to 9%. This is a milestone, considering that there are only three HEVs in a lineup of 26 models. As a next step, Toyota's distributor set a target for their hybrid sales equal to 20 to 25% of their total sales by 2022. Nonetheless, it is conditional on having the governmental incentives still in effect by then. Quoting Mr. Bejjani (2020): "if the incentives are removed, we go back to zero", BUMC's response is clear: HEVs will have to be put aside and ICEs will dominate the market again.

The Chevrolet distributor formulated their need for governmental support beyond just an exemption of customs and excise taxes, for example, via eliminating the registration fees as well. Fully electric cars remain considerably more expensive than other options available in the market and are hard to sell. Increasing the product line or number of units in the showrooms is thus not likely to take place in the short term. In terms of charging, the company does not consider building a network, as it is expensive and EV Bolt buyers already benefit from a complementary Level 1 charger. This type of equipment enables the plugging of the vehicles into any electric outlet at home. Using 6, 10 or 16 amperes, it can fully recharge the battery in 25 to 30 hours. A Level 2 charger, which can charge the battery in 9 hours, can be purchased for 2,000$; however, it would require a subscription to 32 amperes (uncommon and expensive). As such, customers prefer residential charging using a Level 1 charger or superfast charging at available public locations.

4.2.3.3. CPOs and/or EMSPs

As the EV market is still not mature, the separation between CPOs and EMSPs does not exist. For instance, MEDCO provides both before and after-sale services for public locations, including bringing the equipment, installing it, operating it, and performing maintenance and repair. They have thus created the largest EV charging network in the country. In parallel, they also supply small chargers for residential use; however, consumers prefer charging at their stations.

To date, the main barriers to entering the market are the need to obtain international approvals for high quality equipment, irregular electricity supply, and low demand. The last two are the most critical because they are not within the control of a CPO or EMSP. On one hand, the equipment is at a high risk of damage because of daily disruptions in electricity. Consequently, the company must resort to private generators throughout the day. On another hand, it is unprofitable to develop a chargers' network before significant EV ownership levels are realized. MEDCO moved with early adopters and implemented two initiatives. First, they sponsored the MEDCO e-MotorShow Middle East for Electric and Hybrid Cars in April 2019, a first of its kind event where free test drives, an exhibition, and tech-talks with local and international speakers took place. Second, they deployed seven charging stations in Beirut and its suburbs where they provide a pay-as-you-go charging service at a rate of 1,000

LBP/kWh (equivalent to 0.67$/kWh). However, they are waiting for the demand to take off to proceed with a second wave of initiatives, consisting of installing additional stations along the major axes leading to the capital.

4.2.3.4. End Users

Home charging does not seem to be essential to the Lebanese population. Based on the sample used in this research, 48% of respondents do not value home charging and 31% are neutral about it. This is surprising at first glance, knowing that the residential electricity tariffs are lower than those imposed at the available public locations: they range between 0.02$/kWh to 0.13$/kWh (excluding the fixed elements of the bill, such as the monthly tax, stamp tax, and rehabilitation tax), depending on the subscription (Electricity of Lebanon, n.d.). Although this is contradictory to the reviewed literature, it could be associated with the deficient electricity supply in the country and high costs incurred from using private generators, along with the numerous installation difficulties such as low parking garage availability.

4.3. Recommendations

The literature review, policy testing, and stakeholder analysis conducted shed light on weaknesses and challenges in the electric mobility sector in Lebanon. Consequently, few recommendations are suggested in the table below.

The short term recommendations are those that could be implemented within a one to two year timeframe, as they rely mainly on conducting studies and disseminating information. The medium term recommendations require more time (two to five years) because they depend on lengthy government decision making processes. Recommendations that are likely to be considered when the electric mobility sector matures, probably by the year 2030, are described as long-term.

Table 20. Recommendations based on the literature review, policy testing and stakeholder analysis

Objective	Recommendations	Current Status	Key Stakeholders	Timeframe
Develop a clear national plan	Set HEV and EV market penetration targets[1]	The only target is the one set at the UNFCCC in 2015 but it does not set a target for HEVs and EVs	MoE	Short term
	Study the number and location of stations in a preliminary charging infrastructure network to encourage uptake[2]	No in-depth study has been done in this regard yet	MoE and/or MoEW, Universities and/or other R&D centers	Short term
	Raise awareness among the public regarding the benefits of owning an HEV or EV and the available financial support[3]	No major efforts have been done in this regard yet	MoIM and Car importers	Short term
	Exchange experience with countries/cities that have similar (e.g. Egypt) or more advanced levels of progress (e.g. Jordan)[4]	Mainly local events were held, such as conferences by universities and the MEDCO E-motor show	Government of Lebanon, Car importers, CPOs and/or EMSPs, Universities and/or other R&D centers	Short term
	Reconsider a scrappage scheme and old vehicle replacement program	NAMA for the transport sector was abandoned in 2017	MoE	Medium term

Objective	Recommendations	Current Status	Key Stakeholders	Timeframe
	Integrate HEVs and EVs into public transport and governmental fleets[5]	Apart from the Lebanese army, which is considering clean vehicle options, no other governmental entities are planning a similar integration Potential for introduction in the Greater Beirut Bus Rapid Transit (BRT) project	Ministry of Public Works and Transportation (MoPWT)	Medium/Long term
Establish an enabling regulatory environment	Determine standards for recording, evaluating and monitoring progress[6]	The statistics department of the Traffic, Trucks and Vehicles Management Authority as well as the Association des Importeurs d'Automobiles au Liban have data about the number registered and newly registered vehicles, respectively, but they are not completely similar	MoIM and MoE	Short/Medium term
	Update annual road tax fees and other taxes on vehicles (e.g. exempt HEVs and EVs from Mécanique, impose environmental taxes on ICEs)	Only red plate cars are exempted from Mécanique for the first year	MoE	Medium term
	Establish charging infrastructure standards to ensure quality and interoperability	There are no permits or approvals to be acquired locally for the charging equipment	MoEW	Medium term

Objective	Recommendations	Current Status	Key Stakeholders	Timeframe
	Regulate the distribution and provide permits for charging services	Current players are selling charging services by buying electricity from the grid or their generators	MoEW	Medium term
	Draft new building codes[7]	Last update to building codes was regarding the solar water heaters, which waited until the technology is well established in the market before integrating it at the building level	MoEW, Director General of Urban Planning, and Municipalities	Long term
Provide adequate incentives	Maintain existing customs and excise tax reductions for HEVs and EVs[8]	The corresponding article was renewed in 2019	Council of Ministers	Short term
	Expand the purchase incentive scheme (e.g. exempt HEVs and EVs from registration taxes)[8]	This option is not currently under discussion	Council of Ministers	Short/Medium term
	Provide additional incentives such as free parking, free charging, and rebates for Level 2 residential chargers[9]	This option is not currently under discussion	Council of Ministers	Short/Medium term
	Offer lower interest rates or longer periods to pay loans on HEVs and EVs	This option is not currently under discussion	Council of Ministers, the banking sector	Medium term

Objective	Recommendations	Current Status	Key Stakeholders	Timeframe
Address shortcomings of the power grid	Increase the share of renewable energy in the production[10]	The progress towards using 12% by 2020 and 30% by 2030 renewable energy in electricity production is very slow	MoEW	Medium/Long term
	Overcome the supply shortage	A new electricity policy paper aiming at reforming the sector was released in 2019 but it does not consider the financial impacts, leaving the country again in a deadlock situation	Council of Ministers	Medium/Long term
	Set dynamic pricing	Residential charging relies on a fixed rate	MoEW	Medium/Long term
Encourage private sector initiatives	Support service providers willing to convert their vehicle fleet or invest in charging networks, notably through customs reductions and income tax breaks	A decree issued in 2017 provided customs reductions and income tax breaks over a 10+ year period for companies and environmental service providers, excluding the transport sector	Council of Ministers	Medium term

Note: Recommendations are made considering the status in Lebanon or based on:
1: IEA, 2019
2: Stakeholder analysis (Section 4.2.3) and abundance of papers determining appropriate EV charging stations locations
3: Observed differences in WTP values reported before and after driving EVs for few months (Jensen et al., 2013)
4: Recommendations given to the Jordanian and Egyptian delegations in Germany (Friedrich Ebert Stiftung, 2019)
5: Initiatives in Turkey, Egypt, and Dubai
6: Open database for charging stations in Norway: NOBIL (Kvisle, 2012) and availability of Norwegian EV fleet information (Norsk elbilforening, n.d.)
7: Revision of the building codes by the European parliament and EU member states (European Commission, 2016)
8: Stakeholder analysis (Section 4.2.3)
9: International literature (Sections 2.1.1 and 3.1.2) and results of Policy 2 (Section 4.1.4.2.3)
10: Proven losses in EVs environmental benefits due to the dirty electricity generation (Mansour et al., 2018)

CHAPTER 5

CONCLUSION

This chapter concludes the thesis with four sections. The first summarizes the findings, the second points out the research contributions, the third states the research limitations, and the fourth formulates recommendations for future research.

5.1.Summary of Findings

This research provides primarily a framework to estimate the demand for electric and hybrid vehicles and the willingness to pay for these vehicles' attributes. Accordingly, it develops a mixed logit model using financial and technical attributes for mid-size gasoline, hybrid, and electric vehicle alternatives. The proposed framework was applied to the Greater Beirut Area in Lebanon using data collected from a stated preference survey. The model incorporates three main variables: purchase price, operating cost, and driving range. Results suggest that HEVs and EVs are not attractive options yet as respondents displayed a strong pro-gasoline attitude and relatively low willingness to pay for the cleaner technologies. Indeed, the WTP for a 100-km increase in driving range is equal to 705$, which is lower than the values reported by all the reviewed studies (except for one). This can be associated with the country's geography characterized by short distance trips, as well as the high car ownership rate which makes multi-car households less sensitive to the range of a new vehicle. Regarding the WTP for a 1$ reduction in driving costs per 100 km, it is equal to 305$. This finding also falls below the range of WTP values observed across the reviewed literature (except for one).

The reason is suspected to be a high tolerance for increases in fuel prices among the Lebanese population.

Forecasting was performed on the calibrated model in order to evaluate three policies that aim at augmenting HEV and EV market shares in the next five years. Policy 1 considered increasing fuel taxes, Policy 2 consisted of providing charging incentives, and Policy 3 looked at offering a purchase credit to EV buyers. The analysis revealed that Policy 1 can raise the share of clean vehicle options from 14.23% to 15.04%, with the proportion of HEVs going from 9.25% up to 9.59% and that of EVs from 4.98% up to 5.84% as an increase in fuel taxes up to twice its current value consistently deters individuals from purchasing an ICE. However, the biggest impact on the market share of EVs can be accomplished through Policy 2, under the scenario where 80% of charging events take place at public stations for free (the market share reaches 6.96%). A combination of these two policies succeeds in further boosting the proportion of EVs (the market share reaches 7.22%). As for Policy 3, it fails to influence the predicted market shares since it is unable to bridge the gap between the purchase price of the other alternatives and that of an EV. These results reaffirm the idea that monetary incentives are efficient policy instruments for promoting EVs.

Additionally, this research investigates the challenges of a public charging infrastructure rollout as well as HEVs and EVs wide adoption from different stakeholders' points of view. Based on the five semi-structured interviews that were conducted, there is clearly an interest in electric mobility from the private sector. On one side, car distributors are resolutely experimenting with the integration of HEVs and EVs in their product line and targeting bigger market shares over the next few years. On another side, CPOs and EMSPs are building charging stations to meet the needs of the early adopters. However, the rollout of a wide public charging infrastructure is slowed down by limited financial resources, competing priorities on the national development agenda, and immature policy and regulatory frameworks. Most importantly, the deficient electricity production and supply poses a barrier to private sector investments. As such, the preparations for the electrification of the transport sector are yet largely insufficient, meaning a wide EV penetration rate is more foreseeable for the medium to long term. Prioritizing HEVs in the short term is advised and feasible.

In pursuance of a long term vision and plan to scale up the number of HEVs and EVs in Lebanon as well as in another country with similar market penetration rates, the following recommendations can be made: (1) develop a clear national strategy including a set of targets for vehicles and charging infrastructure deployment rates, (2) establish the enabling institutional environment for electric mobility (3) expand the scope of incentives to other economic and non-economic policy instruments targeting both users and charging network developers, and (4) address the environmental and technical shortcomings of the electricity production and supply.

5.2.Research Contributions

This thesis advances the existing literature by delivering a holistic approach to the deployment of HEVs and EVs in a country with minimal adoption rates. It takes into consideration both the demand and supply sides of the market by analyzing consumers' preferences and reporting stakeholders' vision.

The suggested mixed logit model can accommodate other vehicle attributes (e.g. performance) as well as another vehicle alternative (e.g. plug-in-hybrid vehicles).

The policy and stakeholder analyses lay the ground for better planning as they point out the opportunities and challenges to the wide adoption of cleaner vehicle technologies. Besides, the results confirm that financial incentives are essential for EV market uptake.

5.3.Research Limitations

The main limitation of this research is the sample size. The latter is suspected to be the reason behind the statistical insignificance of some variables, which prompted their exclusion from the model. Moreover, the forecasting results may be sensitive to the calibration targets and the car models selected in the base case scenario. They also depend on people's current preferences towards HEVs and EVs which may change in the future as people become more familiar with these vehicle types. Another shortcoming is the exclusion of charging infrastructure attributes from the survey, which prevented modeling the impact of increased charging availability on the decision to purchase a vehicle. Finally, the list of interviewed stakeholders is not exhaustive. Some governmental entities were not approached and only major car distributors and CPOs/EMSPs were interviewed.

5.4.Recommendations for Future Research

Future research ought to tackle the limitations of this research and further advance knowledge in the electric mobility field. Accordingly, a larger sample can be examined and additional technical and infrastructure attributes (performance, recharging time, availability of charging stations, etc.) can be included in the survey. This would probably enable the detection of interesting interactions between pertinent attributes (e.g. between driving range and charging station availability), as well as the enrichment of the available set of willingness-to-pay measures. Moreover, a revealed preference survey targeting EV users or a two-wave stated preference survey with individuals who tested an EV for a certain period of time could be considered. This would reduce hypothetical bias. Lastly, it would be interesting to investigate business models for charging networks that would appeal to EMSPs and eventually boost the demand for EVs in countries with low EV market penetration rates.

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APPENDIX A: ATTRIBUTE LEVELS

The experimental design of the choice experiment is explained here based on Otary (2019). The methodology concerns the obtention of the cost levels; however, the same steps are followed to find the other attribute levels.

First, the vehicles market was segmented by brand in order to list the different models (along with their price, range and horsepower attributes) provided by those with the highest number of sales and hybrid and/or electric vehicles in their product line. Second, the operating cost was calculated for each of the selected cars. It was determined using car fuel efficiency and prevailing fuel prices for ICEs and using battery efficiency and prevailing electricity tariffs for EVs. For HEVs, a value smaller by 40% to 70% to that of the ICE available under the same brand was adopted. Third, a range of attributes for the ICE alternative was set, where the lower and upper boundaries are slightly below and above the minimum and maximum values observed in the market, respectively. Fourth, multiplication factors for HEVs and EVs were determined to obtain the range of HEV and EV prices that correspond to the fixed ICE levels. The factors are equal to the ratio of a given vehicle price to that of the ICE. This means that the attribute levels of HEVs and EVs are conditional on those of ICEs.

The scenarios presented to each respondent are a random combination of the levels presented in Tables A1, A2, A3 and A4 below.

Table A1. Purchase price attribute levels (in $)

Gasoline Car	**Hybrid Car**			**Electric Car**		
16,660	22,491	24,157	27,489	23,324	25,823	27,656
22,800	30,096	31,464	34,200	30,552	31,920	34,656
29,000	37,700	39,150	40,600	37,700	39,440	41,180

Gasoline Car	**Hybrid Car**			**Electric Car**		
36,220	44,188	45,637	47,086	43,464	47,086	47,810
47,600	49,028	52,360	57,120	49,980	52,360	58,072

Table A2. Cost attribute levels (in $/100 km)

Gasoline Car	**Hybrid Car**			**Electric Car**		
6	2.4	3.3	4.1	1.8	2.0	2.2
9	3.1	4.4	5.4	2.3	2.5	2.6
11	5.2	6.4	6.8	2.8	3.2	3.8
14	5.9	6.2	6.9	2.6	4.3	4.5

Table A3. Range attribute levels (in km)

Gasoline Car	**Hybrid Car**				**Electric Car**			
500	425	610	650	875	150	200	215	550
650	520	735	878	1,105	228	241	286	553
760	570	874	912	1,178	228	243	266	562
880	616	950	1,012	1,188	220	264	299	572
1,000	650	1,000	1,100	1,250	210	360	400	580

Table A4. Horsepower attribute levels (in Hp)

Gasoline Car	**Hybrid Car**				**Electric Car**			
130	114	130	189	228	98	107	111	113
160	128	131	216	272	102	107	115	120
185	130	148	228	300	102	109	117	122
230	131	150	255	354	115	120	123	128
270	149	176	297	405	132	138	142	147
320	176	192	352	480	141	147	160	170

APPENDIX B: STAKEHOLDERS QUESTIONNAIRES

Governmental Entity: Ministry of Environment

Part 1: Incentives

1. What was the target for HEV and EV sales behind article 55 in the budget Law of 2018? How do you compare actual HEV and EV sales to that target?

2. Is there a certain period during which the reduction of customs and excise taxes on HEVs and EVs will be applicable or a predefined number of cars or budget or other underlying rationale?

3. Are there other types of monetary or non-monetary incentives being considered (free public charging, free/priority parking, etc.)?

Part 2: Pilots

4. Are you considering any scrappage scheme?

5. Do you have any pilot project for public transportation (e.g. electric buses in Turkey)?

6. Do you include governmental fleets in the future sustainability plans (e.g. Dubai converting their governmental/police fleets to electric)?

Part 3: Standards

7. What are the air quality standards and how did they change over the past ten years (before and after the 2015 UNFCCC)?

8. Are there any limits on fuel consumption or emissions on old/new/used/imported cars?

9. Are there any new/in progress studies in this sector?

Part 4: Priorities

10. How do you see the progress and outlook of electric mobility in Lebanon?

11. Are you aware or involved in the implementation of any (pilot) projects for the charging infrastructure?

Governmental Entity: Ministry of Energy and Water

<u>Part 1:</u> Renewable Energy

1. What is the progress in terms of increasing the share of renewable energy in the mix?
2. How will the availability of natural gas change the situation?

<u>Part 2:</u> Perspective

3. What is your outlook on EVs in Lebanon?
4. What has been done by the MoEW until now in the field of electric mobility?

<u>Part 3:</u> Electricity

5. Is there a plan for tariff restructuring that could encourage the deployment of EVs?
6. Is there a possibility to provide charging incentives?
7. How will you provide/control residential charging?
8. How is the new load on the grid infrastructure going to be accounted for?

<u>Part 4:</u> Policies

9. Are there any standards for real estate developers in preparation (e.g. making a minimal number of outlets mandatory and proposing technical specifications to be met in installation of electrical equipment)? Would they differ between residential, commercial, and public places?

Car Manufacturers/Distributors: BUMC

1. When did you get the first model of HEV to Lebanon?
2. When did the sales start to take off?
3. What share of sales do HEV represent in 2019 out of all your sales? How are they divided between the Toyota Prius and other HEV models available?
4. Do you have any target sales for HEVs in the next few years?
5. How do you expect sales to change if the incentive is removed?
6. Who do you believe are your major competitors in medium-sized HEVs?
7. What is the customer feedback on HEVs?
8. What is your opinion on the EV outlook in Lebanon?

Car Manufacturers/Distributors: IMPEX

1. When did you get the first model of EV to Lebanon?
2. What share of sales do EVs represent in 2019 out of all your sales?
3. Do you consider expanding the EV product line on the short term?
4. What is your opinion on the EV outlook in Lebanon?
5. Do you have any target sales for EVs in the next few years?
6. How do you expect sales to change if the incentive is removed?
7. Who do you believe are your major competitors in medium-sized EVs?
8. What is the customer feedback on EVs?
9. Would you consider building charging stations for your customers or general EV users?

CPOs and/or EMSPs: MEDCO

Part 1: Installation Process

1. What kind of difficulties were faced when importing the stations (order time, delays, taxes…)?
2. What type of permits were needed (insights about the procedure: time, cost, delays…) (e.g. permit from local jurisdiction)?
3. Were there any existing design guidelines or requirements to follow?
4. What is the source for the electric installation?
5. Who is installing stations in residential buildings?

Part 2: Operation

6. How are the electricity rates set?
7. Is the business profitable?
8. What is the business model for running these stations (is there an external party providing the service to the clients – if not, is it an option for the future)?

Part 3: Deployment of the Charging Infrastructure

9. Would it be easy to replicate for public access stations (additional requirements: permits, safety, maintenance, funding…)?
10. Do you believe an increase in the number of charging stations would result in an increase in the demand for EVs?

11. Nicolas Abou Halka (general manager of lubricants and bunkering business unit) said in an interview (reported in the Executive Magazine in July 2019) that there will be 15 units spread all over the country by the end of 2019. When is this going to happen or what hindered the process?

Part 4: The Market

12. Who do you consider as your main competitors?

13. Who else do you expect to try to enter the market?

14. What were (and are) the difficulties for entering this market?