Analyzing Electric Vehicle Diffusion Scenarios for Istanbul[1]

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Abstract

In this study, a dynamic simulation model for electric vehicle (EV) diffusion is constructed. The objective of this work is to investigate the question; what are the plausible diffusion patterns of electric vehicles for Istanbul under different scenarios developed considering both local and global socio-economic, governmental, technological factors and their interaction with each other? The results show that diffusion of battery electric vehicle (BEV) and hybrid electric vehicle (HEV) would likely reach around 19.76% and 20.77% respectively by 2042 in Istanbul. In addition, CO_2 reduction in the transportation sector would only reach around 17.32% in 2042. Moreover, both gasoline and electricity cost influence EV diffusion. However, their impact on EV diffusion is mainly related with a mobility cost gap between gasoline and electricity. Furthermore, technological improvement would lead BEV sales to increase. Contrary to expectations, even if no technological improvements were progressed, BEVs would still likely succeed to penetrate around 10% of the market with its current technology within the 30 years. Both marketing activities and word of mouth have a remarkable impact on rapid EV diffusion. Subsidies would have a small impact on EV sales. Finally, BEV and HEV inhibit sales of each other.

Keywords: Electric vehicles, Innovation diffusion, CO_2 emission

1. Introduction

Vehicles that are powered by internal combustion engines (ICEs), which transform the chemical energy of fuel to the thermal and mechanical energy, occupy major role in ground transportation industry all over the world (Gupta, 2006). The transportation industry produces high amounts of greenhouse gases and pollutant emissions. For example, CO_2 is one of the major greenhouse gases that is emitted to the atmosphere through burning fossil fuels (EPA, 2011) and Fuglestvedt, Berntsen, Myhre, Rypdal, and Skeie indicate that 20-25% of the global CO_2 emission stems from the transportation sector that is potential cause of global warming (Fuglestvedt et al., 2008). For these reasons, internal combustion engine vehicles (ICEVs) can be seen as one of the major contributors to air pollution and global warming. Apart from

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environmental aspect, 40% of the global energy demand, including almost all of the fuel consumption of transportation system is supplied by conventional oil (Greene, Hopson, & Li, 2006). Heated debates started with the modern oil era in the mid-1800s in relation to the possibility of reaching the peak point of the global conventional oil[2]. This situation is a potential problem for the urban transportation system. Since reaching to peak point of oil means facing with a fuel shortage. In case of reaching to the peak point of oil production, reliance on oil will generate drastic global challenges in petroleum-based transportation sector such as unmet demand, high fuel prices, and oil black-market (Aftabuzzaman & Mazloumi, 2011; Greene et al., 2006).

Emergence of environmental and energy related concerns have given birth to ongoing debates about how world can overcome global warming, air pollution, and limited oil problem. One of the suggestions is to replace fossil-powered internal combustion engine vehicles (ICEVs) with various alternative fuel vehicles (AVFs). Among all alternative fuel vehicle options, the most outstanding one is an electricity-powered one due to its lower fuel cost, availability of the fuel, vehicle technology, and fuel efficiency (Eaves & Eaves, 2004; Hackbarth & Madlener, 2013; van Rijnsoever, Hagen, & Willems, 2013).

Potential advantages of electric vehicles support the suggestion of EV penetration to the automobile market since EVs seem as potential solutions for the environmental and energy related concerns (Shafiei et al., 2012). Many studies in the literature indicate that electric vehicles (EVs) have positive and remarkable impact on the reduction of greenhouse gas emissions, specifically of CO_2 (Kwon, 2012; Lopes et al., 2009; Samaras & Meisterling, 2008; Scott, Kintner-Meyer, Elliott, & Warwick, 2007; Shafiei et al., 2012; Sioshansi & Denholm, 2009). In addition, studies show that electric vehicles are effective options to reduce fuel consumption in transportation sector (Manzie, Watson, & Halgamuge, 2007; von Albrichsfeld & Karner, 2011; Wansart & Schnieder, 2010; L. Zhang, Brown, & Samuelsen, 2011). Additionally, they are regarded as one of the major long-term cost saving remedies with its fuel efficiency feature against the possible high oil prices in the future (Andersson et al., 2010). However, penetration of EVs to the market faces certain technical and social barriers. Immature battery technology, high price, high battery cost, and inadequate refueling infrastructure of EVs are main technical obstacles, while the social barriers can be listed as the lack of public knowledge on EVs, and the hardships of acceptance of new technology. Research and developments about EV technology have been continuing all over the world to reduce the weak aspects of EVs. On the other hand, in order to eliminate the social barriers, regulatory policies to provide subsidies or to lower taxes on electric vehicles and marketing strategies to raise public awareness about EVs are started in the countries that have recognized importance of EVs (Egbue & Long, 2012; Wiedmann, Hennigs, Pankalla, Kassubek, & Seegebarth, 2011).

[2] Peak oil is the term used to describe the point in time at which the global conventional oil production rate will reach its maximum, after which the annual production will begin to decline permanently (Aftabuzzaman & Mazloumi, 2011).

In this study, penetration process of EVs in Istanbul is analyzed considering all advantages and obstacles. Main objective of the study is to answer the broad question of what are the plausible diffusion patterns of electric vehicles for Istanbul under different scenarios developed considering both local and global socio-economic, governmental, technological factors and their interaction with each other. It is important mentioning that Istanbul is the most outstanding city among other cities to analyze EV adoption in Turkey due to two main reasons. Firstly, Istanbul is the most crowded city in Turkey. Number of private and public car is greater than other cities. This means that transportation in Istanbul causes more greenhouse gas emission compared to other cities. Secondly, Istanbul is the central city of automobile market in Turkey due to broad customer profile, being close to manufacturing plant, and high customer number. Thus, it is more reasonable to start planning projects on Istanbul since the decline in gas emission by replacing ICE vehicles with EVs is hand in hand with the number of potential customers that Istanbul could provide this newly emerging sector. Therefore, Istanbul is chosen to study EV penetration process in this work.

2. Methodology and Model Description

A system dynamics model is developed in order to study EV penetration as well as to analyze the diffusion process for Istanbul comprehensively. The model is constructed regarding conventional vehicle (CV), and two types of electric vehicles that are battery electric vehicle (BEV), and hybrid electric vehicle (HEV). The model boundary includes only middle-size passenger vehicle market in Istanbul (lightweight trucks, compact cars, land vehicles, buses, minibuses are excluded). The model is designed considering two major customer types. They are people/families with middle income (market segment A) and fleet leasing companies (market segment B). People/families with middle income buy a car with the private usage aim and fleet leasing companies buy a car with the aim of renting car to the other companies, or organization.

The whole model is divided into six sectors that are vehicles fleet, vehicle market, customer perception, customer awareness, infrastructure, and environmental impact in order to describe the model eloquently. Simplified causal loop diagram of the model and relationships between sectors are illustrated in Figure 1. It should be noted that although BEV and HEV are separately included in the model; they are represented as 'EV' in the simplified causal loop diagram to provide clear visualization that leads to a better understanding.

2.1. Description of the model sectors

Vehicles Fleet Sector: Vehicles fleet sector covers the variables that are *total number of vehicles* stock, and its inflow and outflow that are *sales*, and *discards of vehicles* in Istanbul for all vehicle types separately. Main stock-flow structure of the vehicle fleet sector is given in Figure 2.

Total number of i represents total number of *i*-type passenger vehicles within the boundaries of Istanbul. Formulation of *total number of i* is given in Equation 1.

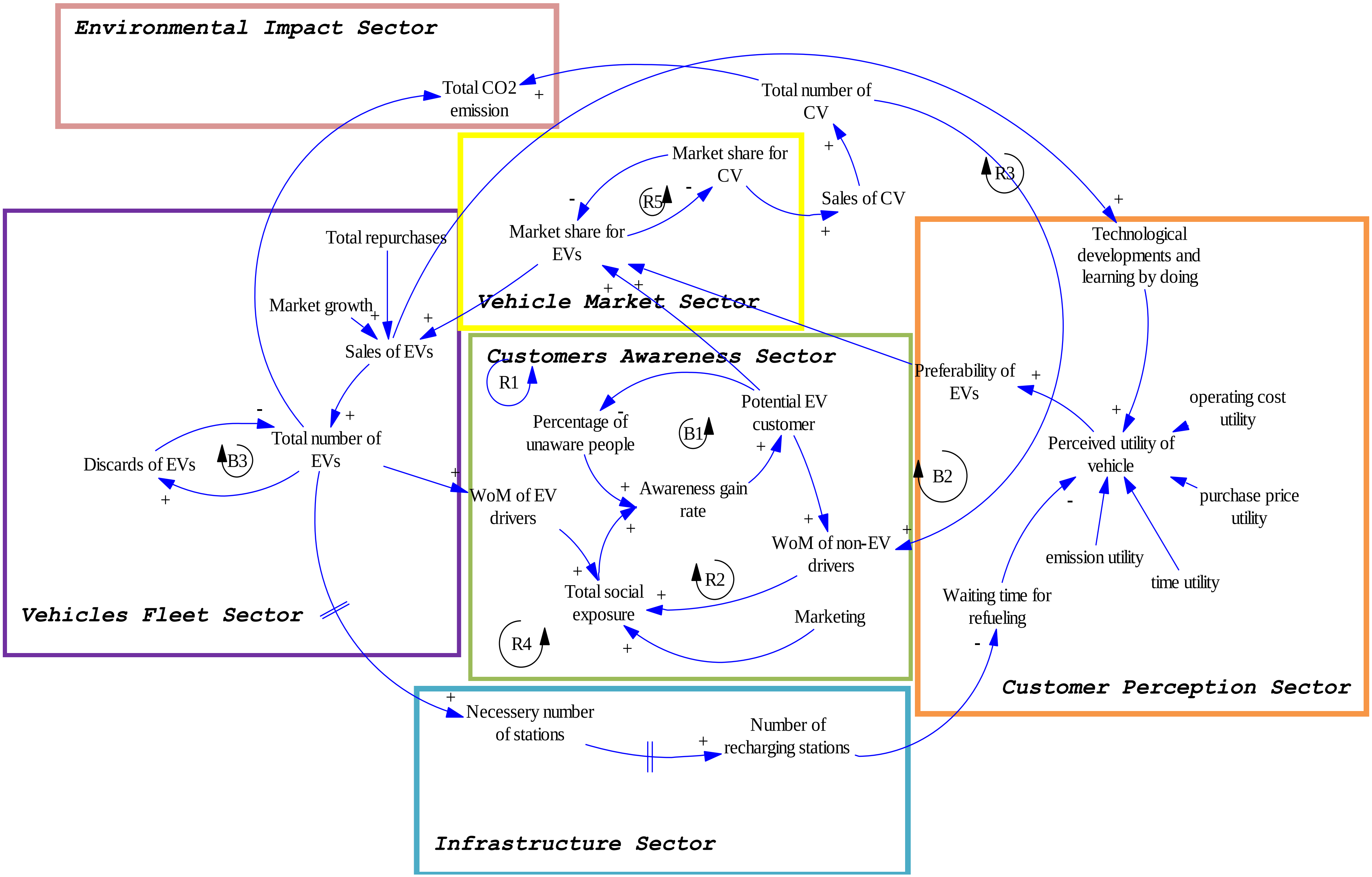

Figure 1. Simplified causal loop diagram of the model

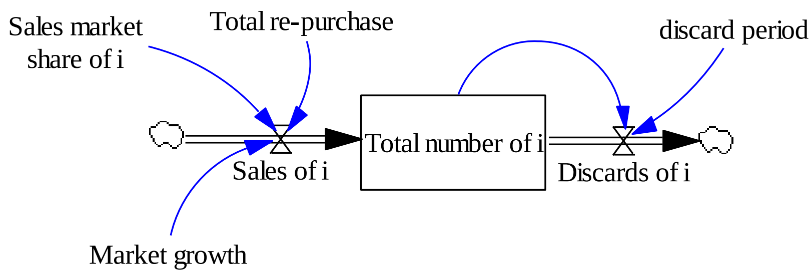

Figure 2. Simplified stock-flow diagram of vehicle fleet sector

$$\text{Total number of i (t)} = \text{Total number of i (t - dt)} + (\text{Sales of i} - \text{Discards of i}) \times \text{dt} \qquad (1)$$

i denotes the vehicle type. *i* = 1, 2, 3 mean conventional vehicles (CV), battery electric vehicles (BEV), and hybrid electric vehicles (HEV), respectively.

Sales for every vehicle type is shaped by market share of each vehicle types, market growth, and total repurchases (Equation 2).

$$\text{Sales of i} = \text{Market share of i} \times (\text{Market growth} + \text{Total re-purchases}) \qquad (2)$$

Market share depends on customer choices about which vehicle type they would purchase. It will be explained in the following sector. *Market growth* is defined as an annual increase in the demand for a vehicle. It is estimated by using motorization rate of Istanbul and 30-years population projection of Turkish Statistical Institute for Istanbul (Turkish Statistical Institute, 2013). *Total re-purchase* is estimated with the sum of each vehicle type's discards. Because once vehicle is discarded, customer begins to need repurchasing. Thus, discards of vehicles would likely have the direct contribution to the repurchases and it is assumed that sum of discarded vehicles produces total repurchases. Besides, *Discards* of vehicles covers vehicles that are retired, broken down and vehicles that are sold out of the city.

Vehicle Market Sector: Customers are assumed to make a multi-criteria decision during purchasing process among all automobile alternatives. They compare certain attributes of every vehicle type such as driving range or purchase price and choose one of the vehicle type. Besides, customer should be aware of any type of vehicle to take it into her/his choice set. Because of this, the customer's awareness along with the customer decisions shape the market share of each vehicle types. Customer awareness will be explained in the following sector but information and formulations for market share of each vehicle type is provided by vehicle market sector.

Priorities and importance level of vehicle attributes differ from one market segment to another because customer profiles of each segment are different. Within this context, firstly, market shares of vehicles in every segment and then overall market share of each vehicle types in Istanbul are formulated. The market share of vehicle in each segment is estimated by using logit decision model given in the work of McFadden (McFadden, 1980). This logit decision model is one of the discrete choice models that are based on probabilistic consumer theory.

j denotes group types (j = 1, 2 mean segment A, segment B respectively).

$\delta_{i,j}$ captures the market share of i-type vehicle in market segment j. Its formula is:

$$\delta_{ij} = \frac{e^{-u_{ij}}}{e^{-u_{ij}}} \times \text{Percentage of potential customers for} \qquad (3)$$

In this equation, $u_{i,j}$ refers to the total perceived utility of i-type vehicle by users in market segment j. $u_{i,j}$ is estimated based on four utility components that are time utility, purchase price utility, operating cost utility, and emission utility. Percentage of potential customers for i captures the customers who are aware of i and who have i in their choice set.

Customer Perception Sector: Customer perception sector provides comprehensive description about relation between vehicle attributes and their value perceived by customer. Important parts of customer perception sector and relations between these parts are given in Figure 3. This relation is determined for each type of vehicle separately in the model.

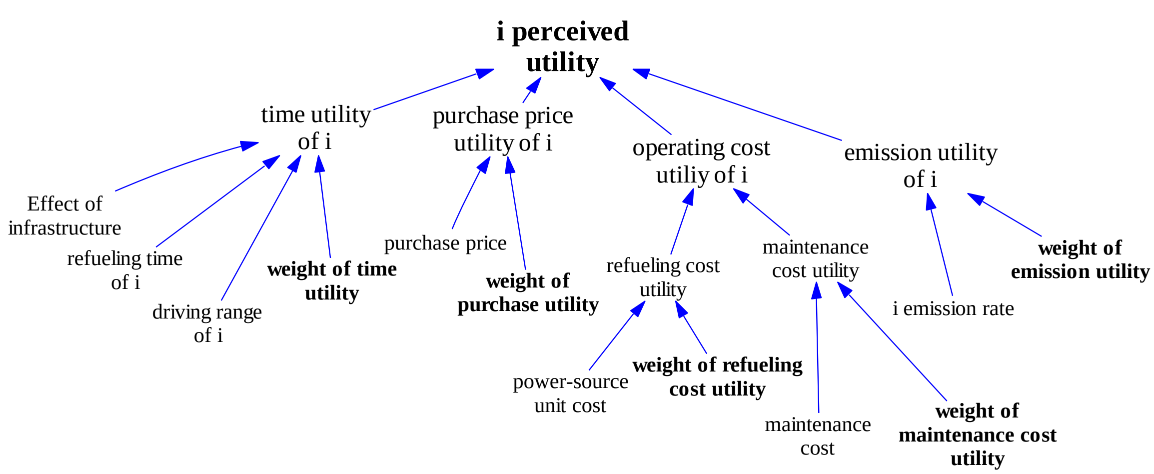

Figure 3. Simplified diagram of customer perception sector

Perceived utility of a vehicle represents the total benefit that vehicle offers from the viewpoint of customers. Utility of a vehicle is firmly related to the vehicle attributes such as driving range, refueling time, and refueling infrastructure (Markel & Simpson, 2006; Shafiei et al., 2012;

Wansart & Schnieder, 2010). Moreover, purchase price of a vehicle is one of the crucial criteria that customers care while buying a car (Struben & Sterman, 2008; T. Zhang, Gensler, & Garcia, 2011). In addition, emission rate and operating costs are also effective factors on consumer's preference (Egbue & Long, 2012). Perceived utility is equal to sum of these four utilities. It is assumed that customers compare perceived utilities of vehicles and make decisions about which type they will purchase.

It should be noted that importance level of each feature may likely vary in relation to the viewpoint of customers. For example, purchase price criteria may have more priority than emission level criteria for most people. Besides, priorities and importance level of vehicle attributes differ from one market segment to another because customer profiles of each segment are different. Therefore, each attribute in every segment has different importance level that is called as *weight*. It is important to point out that the larger absolute value of a weight means a higher importance level. Weights used in the study are estimated considering the revealed-preference multinomial logit model of alternative fuel vehicle preferences estimated by Brownstone, Bunch, and Train (Brownstone et al., 2000).

Four major utilities are included in the model. They can be listed as time utility, purchase price utility, operation cost utility, and lastly emission utility. In all utility types, two major factors, which are vehicle attributes and weight of these attributes, help to estimate the utility.

Time utility: Time utility is related to driving range and refueling time features of vehicle, as well as availability of refueling stations on account of being forceful factors on consumer decision. Driving range of vehicle corresponds to how much a conventional car and a hybrid car can drive with one tank gasoline (50 lt-tank), and the total range of km, which a BEV can drive with one full battery. Refueling time of vehicle is the duration of refueling of gasoline tank/battery fully. In this respect, time utility formula is developed considering average time loss stemming from driving range, refueling time, and refueling infrastructure in a certain distance.

Driving range and refueling time are not constant. Thus, these two parameters change due to learning curve effects for BEV. Learning curve effects provide a mean to count improvements about battery technology in the model since improvements about battery technology would likely continue gradually due to cumulative research and development studies. Formulation of learning curve effect is given in the following equation (Yücel, 2013).

$$\alpha(t) = \alpha(0) \times (E(t) / E(0))^{\alpha} \tag{4}$$

$\alpha \quad t$ denotes value of the attribute at time t

$E(t)$ denotes value of cumulative experience at time t

$\propto$ denotes learning factor

In the study, learning curve effect is regarded for only battery technology. In other words, HEV technology or CV technology is not improved by learning curve effects in the study

Purchase Price Utility: Purchase price is a substantially influential factor in the course of choosing a car. In addition to price, costumer budget is also crucial while estimating the purchase price utility. This utility is developed considering these two factors.

Operating Cost Utility: Operating cost is constituted of fuel cost and maintenance cost in the model. Refueling cost is defined as the cost of fuel that vehicle uses in order to travel one km distance. Maintenance cost is formulated considering monthly maintenance cost of vehicle. Monthly maintenance cost consists of both battery renting cost (if portable battery is available) and routine monthly maintenance cost. BEVs need portable battery, which can be purchased or rented to operate. It is assumed that battery is rented monthly due to high purchase prices of batteries. Routine monthly maintenance cost refers to cost of maintenance that every vehicle should have in every month.

Emission Utility: Emission is defined as total CO_2 released from conventional and hybrid vehicles during their trip. However, there is no tailpipe emission coming from battery electric vehicles. Therefore, emission of BEV is specified as CO_2 that is released to the atmosphere from electricity plant during electricity generation.

Customer awareness sector: This sector includes social exposure coming from marketing and word of mouth as well as impact of social exposure on customer familiarity with a vehicle. Any vehicle type can enter choice set of consumer, if and only if consumer is aware of that vehicle type. Therefore, awareness of people about vehicles is a substantial factor for purchasing decisions (Struben & Sterman, 2008; Wansart & Schnieder, 2010). Every potential driver in Istanbul is aware of conventional vehicles. On the other hand, EVs are new technology and Turkish customers are not completely familiar with the EV concept. Main stock flow diagram of the customer awareness sector is given in Figure 4.

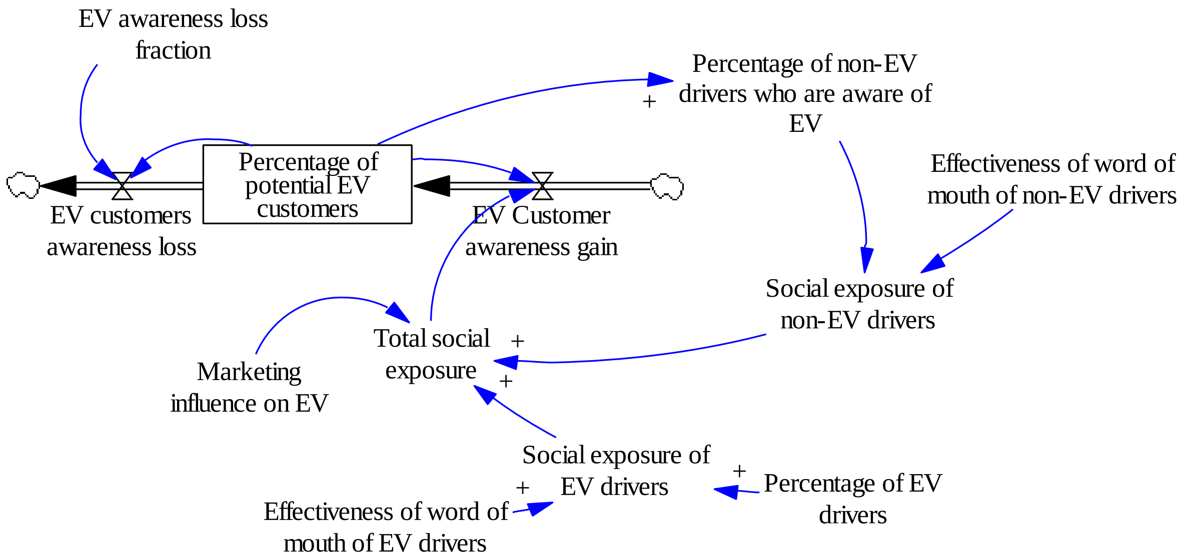

Figure 4. Stock-flow diagram of customer awareness sector sector

Percentage of potential EV customers is a term that is used to represent portion of customers who accept EV technology emotionally and cognitively in the model. These people are percentage of customers who are willing to take EVs into their choice set during purchasing. It is assumed that if customers gain awareness of the EVs via social exposure, they become potential EV customers and take EVs their choice set during purchasing a car. *Customer awareness gain* is shaped by multiplication of total social exposure and percentage of customer, who are not aware of EVs. In other words, unfamiliar people with EVs learn about EVs through social exposure.

$$\begin{aligned}\text{Customer awareness gain} = {} & \text{Total social exposure} \\ & \times (1 - \text{Percentage of potential EV customers})\end{aligned} \tag{5}$$

Total social exposure is provided by marketing activities and word-of-mouth (WoM) of people about EVs in this work. Marketing activities cover all marketing channels such as TV advertisements, newspapers, journals, magazines, and internet. Moreover, word-of-mouth includes all ways that drivers can spread information about EVs on their own such as conversation, driving EVs on the road, internet, or social media. These drivers can be both EV driver and non-EV driver. Thus, *Total social exposure* is equal to the sum of marketing, social exposure of EV drivers, and social exposure coming from non-EV drivers.

$$\begin{aligned}\text{Total social exposure} = {} & \text{Marketing influence} + \text{Social exposure of EV drivers} \\ & + \text{Social exposure of non - EV drivers}\end{aligned} \tag{6}$$

It should be noted that percentage of potential EV customers is formulated using familiarity model of (Struben & Sterman, 2008). It is assumed that customers are equally familiar with HEV and BEV and potential EV customers have all information and understanding about EVs. Finally, it is assumed that certain percentage of potential EV customers losses their awareness about EVs.

Infrastructure Sector: Refueling infrastructure sufficiency means that number of refueling stations adequately meets the refueling demand of all vehicles. Infrastructure sufficiency is an important criterion for customers (Shafiei et al., 2012; Wansart & Schnieder, 2010). Gasoline stations are currently adequate for CVs and HEVs in Istanbul. However, BEVs use electricity to be recharged externally and inadequate recharging infrastructure is one of the substantial concerns about BEVs (Egbue & Long, 2012). There are currently thirteen charging points in Istanbul. This number appears to be notably inadequate value when potential, and growing demand for BEV is considered. However, new constructions would be implemented in parallel with beginning of EV penetration. Total station number is a dynamic variable and one of the main stocks in the model. Stock flow diagram of infrastructure sector and relations between these parts are given in Figure 5.

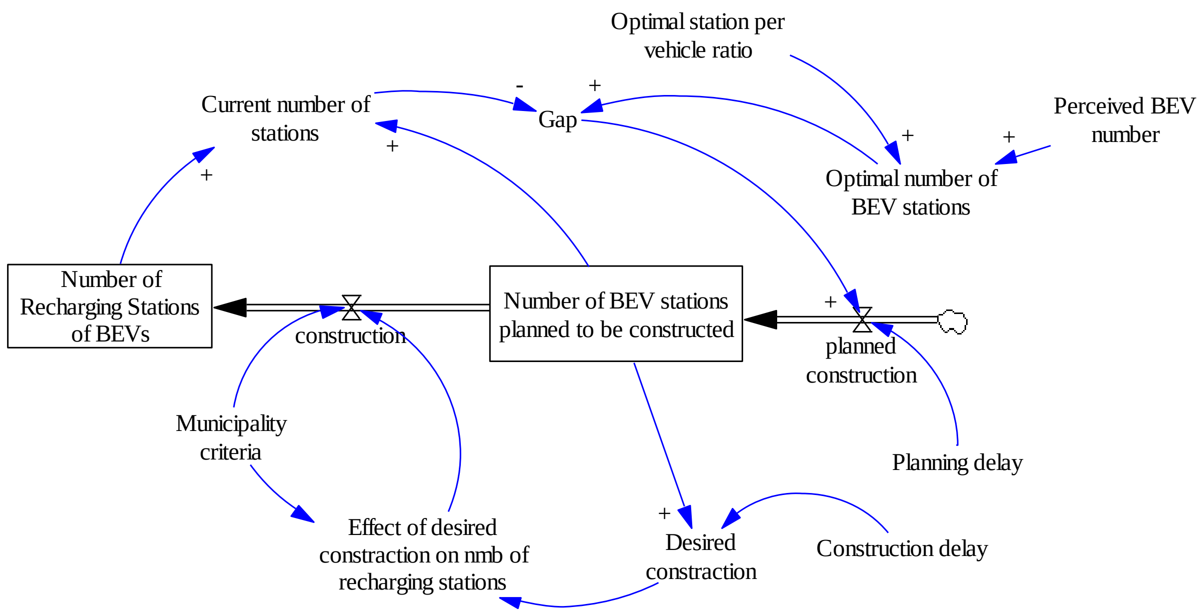

Figure 5. Stock-flow diagram of infrastructure sector

Number of Recharging Stations of BEVs is a stock variable and it is changed by construction. New charging points are constructed in the case of current ones begin insufficient to cover the total demand. *Optimal number of BEV stations* refers to a necessary station number in Istanbul for drivers to find recharging points easily and not to wait in a queue for a long time. It is equal to multiplication of perceived BEVs number in Istanbul and optimal station per vehicle ratio. *Perceived BEV number* in Istanbul is a smoothed version of the total number of BEVs in Istanbul. Besides, *optimal station per vehicle ratio* is a ratio that is formulated regarding how many station points per vehicle should be available in Istanbul to sustain adequate infrastructure. If there is a gap between *optimal station number* and *current station number* in Istanbul, new stations are constructed after certain planning and construction delays. Lastly, the gap between optimal number of stations and current ones may such a huge that it may be hard to cover due to limited budget or feasibility studies. Therefore, it is assumed that there is an upper municipality criterion, which restricts construction of stations.

Environmental Impact Sector: Environmental impact sector includes CO_2 reduction coming from EV penetration. As mentioned earlier, most of researches claim that EVs may likely be an effective solution for CO_2 emissions. However, this substantially depends on both number of EVs that replace CVs, and means of electricity generation. For these reasons, once diffusion rate of EV is observed, its effect on CO_2 will be analyzed in order to estimate ultimate environmental impact of EVs.

2.2.Parameter Estimation and Critical Assumptions

The time unit of the model is taken as a year. The time horizon of the simulation is set to three decades, from 2012 to 2042 in order to be long enough to capture direct, indirect, and delayed effects of the variables and feedbacks.

Total number of vehicle in Istanbul is a stock variable that is initialized based on the actual data taken from Turkish Statistical Institute (Turkish Statistical Institute, 2012). Motorization rate is assumed as a constant value and it is calculated according to the current ratio of number of passenger vehicles and inhabitant in Istanbul. In this regard, it is obtained as 0.145 vehicle /person. Population in Istanbul changes over time and its three decades future is estimated based on population projection of Turkish Statistical Institute (Turkish Statistical Institute, 2013). Moreover, available battery technology currently provides 165 km range (Granovskii, Dincer, & Rosen, 2006) and 1-hour refueling time with quick charging on average (Barut, 2013) for BEVs. Long charging (3-6 hours and usable at night at home, or parking area of shopping malls) (Barut, 2013) is commonly used when vehicle is idle whereas quick charging is mostly used during trips if vehicle runs out of the fuel. In the model, time utility of a vehicle that is during operation is estimated. Thus, only quick recharging stations are considered in the model. It is assumed that recharging points are distributed evenly across Istanbul.

Refueling cost is estimated regarding current prices of gasoline and electricity. According to Tran, Banister, Bishop, & McCulloch, gasoline vehicles consume about 8 lt/100 km on average (2012). Current price of gasoline is about 4.8 TL/lt in Turkey. Thus, cost per km is estimated to be 0.384 TL. This value is 25% less for hybrid cars due to efficiency of HEV (Christidis, Hernandez, & Georgakaki, 2005). Besides, BEV uses 0.2 kWh per km on average (Lemoine & Kammen, 2009; Tran et al., 2012). Electricity cost for households is 0.0563 TL/ 0.2 kWh (0.0563 TL/ km) on average. However, the model includes only commercial refueling and in this sense, electricity cost is determined considering a profit margin.

Tailpipe CO_2 emissions of conventional vehicle is about 188 g/km (United States Enviormental Protection Agency, 2011). Emission rate of a hybrid car is about 25% less than a conventional car (Geyer, Koehn, & Olsen, 2005). As it is stated earlier, although BEVs release zero tailpipe emission, certain amount of CO_2 is created during the electricity generation process. Amount of CO_2 depends on energy sources. Emission level stemming from BEV varies among countries because of the using different energy sources. For example, in Turkey, around 362.8 tons CO_2 is released to the atmosphere for one GWh electrical energy production (TEİAŞ, 2004). As it is said before, BEV uses 0.2 kWh per km on average (Helms, Pehnt, Lambrecht, & Liebich, 2010; Lemoine & Kammen, 2009). Therefore, emission arisen from electricity generation process for one BEV to drive one km is estimated to be 72.56 g/km in Turkey based on actual data taken from Turkish Electricity Transmission Company (TEİAŞ, 2004). Optimal station per vehicle ratio is determined to be 0.05 station/vehicle regarding refueling time, and accessibility of stations.

Percentage of the first market segment and the second market segment are estimated to be 88%, and 12% respectively based on the real data (TEB ARVAL & Corporate Vehicle Observatory, 2012).

It is worth pointing out that sensitivity tests are applied to all parameters that do not have exact values taken from their real counterparts.

3. Validation of the Model

Model validity is tested both in structural and behavioral aspects (Barlas, 2002). Significant portion of structural validation has been done during the model construction process. Moreover, the structure of the model is tested via indirect structure tests via extreme condition and sensitivity tests. Extreme condition tests help to evaluate validity of the model equations because if model is robust under extreme conditions, then it should behave in appropriate fashion no matter how extreme policies and inputs are applied (Sterman, 2000). Different extreme condition tests are applied to the model. The results show that the model is robust under extreme conditions. One of the tests will be explained to exemplify. For example, BEV attributes are modified and they are set to unprofitable values. Its refueling time is set to 20 hours, and its driving range is set to 5 km. In addition, its price is increased exponentially. In these conditions, it would be expected that there would be no BEV sales due to insufficient attributes of BEV. The result of this test is given in Figure 6.

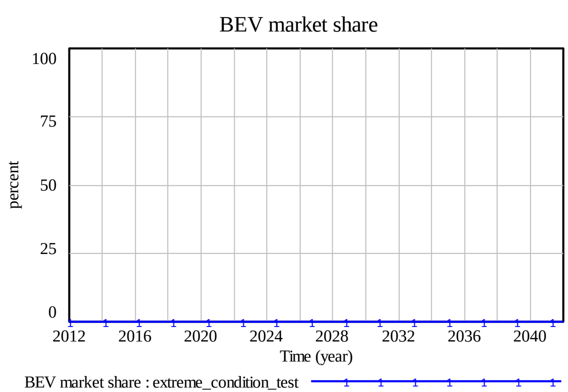

Figure 6. Extreme condition test

As it can be seen from the Figure 6, nobody buys BEV in this case. The results that were reached are matching with the expected outcomes because in this extreme situation, battery electric vehicle attributes become not satisfactory for consumers due to both extremely low value of time utility and high value of purchase price. Thus, it is logical that nobody prefers BEV and market share becomes zero. As a result, the model is valid under extreme condition test.

According to Barlas, 'Behavior sensitivity tests consist of determining those parameters to which the model is highly sensitive, and asking if the real system would exhibit similar high sensitivity to the corresponding parameters' (1996). In the study, most of the parameters are tested to understand whether there are parameters, to which the model is highly sensitive or not In this regard, sensitivity tests are applied to all parameters that do not have exact values taken from their real counterparts. To give an sensitivity test example, *optimal station per vehicle ratio* is assumed to be 0.05 station/vehicle in the model. The value is changed between the range of 0.02 and 0.07 (station/vehicle). The impact of this adjustment on the BEV diffusion is given in Figure 7.

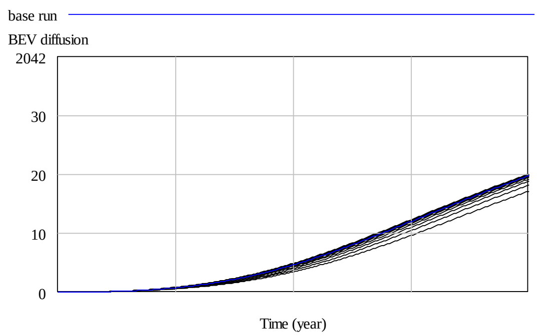

Figure 7. Sensitivity result for motorization rate

As it can be seen from the Figure 7, BEV diffusion is not strongly sensitive to *optimal station per vehicle ratio*. Similarly, it is observed that the model is insensitive or not strongly sensitive to different parameters such as motorization rate, weights of different utilities, or time delays. It must be noted that there may be sensitivity in numerical results. However, the model has low sensitivity in terms of pattern dynamics. This means that long-term behavior of the model strongly depends on structure of the model rather than some uncertain variables.

When it comes to behavior validity, Istanbul or Turkey has no historical data about battery electric vehicles or hybrid vehicles to compare with behavior patterns of the simulation result of the model. However, the model generates patterns that resemble the ones perceived in other mobility systems given in the literature.

4. Simulation experiments

4.1. Base Behavior

In the base case, it is assumed that the recent trends would likely continue with no major changes. In other words, all technological improvements, prices, costs, and regulations given in the beginning of the analysis would be progressed gradually according to broadly accepted trajectories. Driving range, refueling time, and maintenance cost of BEV improve gradually over time. Purchase prices of BEVs, HEVs and CVs decrease gradually over time. It is assumed that both electricity and gasoline prices would show similar trend to their historical data. Market share represents percentage of total sales volume captured by each vehicle in the market. Diffusion represents the ratio of number of each vehicle type to the total number of vehicle available on the road of Istanbul. It is a share in the active stock. Results of the base run are given in Figure 8, Figure 9, Figure 10, and Figure 11.

The simulation results show that sales volumes of both BEV and HEV are always lower than CV sales throughout the simulation period in the base case (Figure 8). After three decades, each of BEV and HEV shares in the sales reaches only around 30% while CV sales manage to capture 40% of the market at 2042. Furthermore, diffusions of BEVs and HEVs reach respectively 19.76% and 20.77% in Istanbul by 2042.

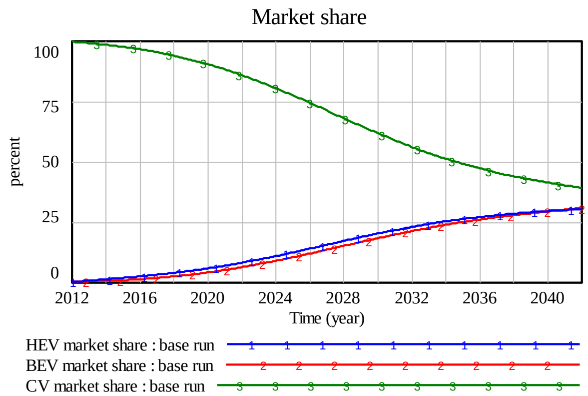

Figure 8. Market shares of vehicle types

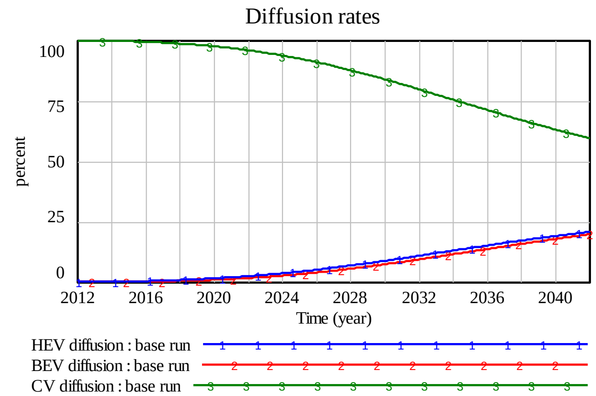

Figure 9. Diffusion rates of vehicle types

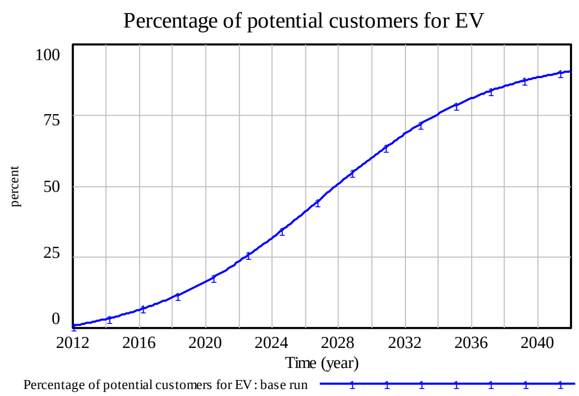

Figure 10. Potential EV customers percent

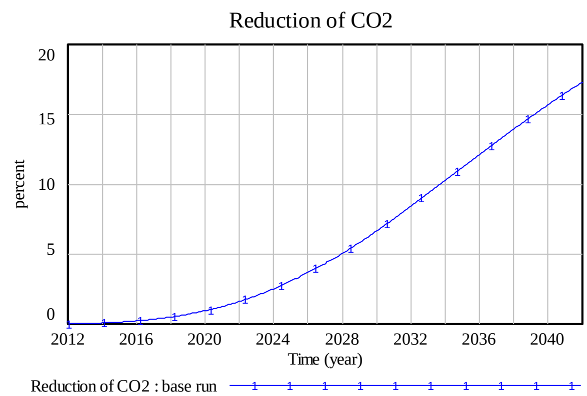

Figure 11. Reduction of CO2 under base run

There are two main reasons why EV sales are lower than CV's even after 3 decades. Firstly, although the percentage of potential customers increases gradually, there are still people who do not recognize EVs (Figure 6). These unaware customers buy CVs due to the perception of the unavailability of other choices. The number of unaware people is substantially high in the first years of the simulation. Therefore, EV sales are also relatively lower at the beginning of the simulation. As to the second reason, although BEVs and HEVs may display advantages compared to CVs, some of attributes still remain less efficient than CVs'. For example, BEVs and HEVs are profitable in terms of operating cost, and emissions. However, the driving range of BEVs is lower, and the refueling time of BEVs is longer than CV. Also, the maintenance cost of BEVs is markedly higher compared to the CVs throughout the simulation period. In addition, the purchase price of HEV is also higher than both BEV and CV. So, even after familiarity with EVs greatly increases in the public, the market shares of BEVs and HEVs still fail to reach the market share held by CVs due to the perception that conventional vehicles have more preferable properties. Apart from these, the market share of HEVs is slightly higher than the BEVs market share in throughout majority of the simulation period. This means that certain attributes of HEV, which are maintenance cost utility and time utility, are seen as more preferable than BEVs' from the viewpoint of the customers. However, in the last years of simulation, the BEV finally begins to be more preferable compared to the HEV due to improvements about battery technology.

The percentage of potential EV customers has an S-shaped behavioral pattern. It begins with a 1% potential EV customer among all drivers in Istanbul, and converges to 100% near the end of the simulation. It grows slowly in the beginning of the diffusion due to the low number of adopters compared to high number of non-adopters. Moreover, the majority of the population among the non-adopters does not have adequate knowledge about EVs in the beginning of the penetration process. Therefore, information about EVs spreads very slowly during the first few years. After a while, the percentage of potential EV customers grows faster because of the increase of non-adopters who become familiar with EVs, and the adopters. This portion of aware people who drive EVs on the road, talk about them, or mention them on the internet and in conversation, then leads to a positive rise of further potential EV customers.

Another important point about EVs is the reduction level of greenhouse gas emissions, which is one of the major reasons of why EVs are proposed as a necessary replacement for CVs. When diffusion rates of BEV and HEV coming from simulation results are regarded, CO_2 reduction in the transportation sector reaches around 17.32% in 2042. Moreover, cumulative CO_2 reduction reaches 17.07×10^6 tons by 2042.

4.2. Scenario Analysis

In scenario analysis section, different scenarios are examined to capture plausible changes in the context. Topics of these scenarios are basically future costs of electricity and gasoline, BEV technology, launching only BEV into the market, and customer awareness. The results of these scenarios will mostly be presented comparing them with the base run to provide better understanding for analysis.

4.2.1. Rapid Increase in Gasoline Cost (Scenario 1)

Battery electric vehicles are electricity-powered vehicles whereas their conventional and hybrid counterparts use gasoline as a power source. Because of this reason, costs of electricity and gasoline may be effective factors on customer decisions about vehicle types. However, future prices of electricity and gasoline are uncertain. Because resources used in electrical energy generation and their usage rates differ among countries. Electricity price is highly related to the shares of different resources in the generation mix, taxes, or economical or political development. Future prices of gasoline is also an uncertain factor for vehicle diffusion because gasoline prices may be dramatically affected by global fuel prices, exchange rates, and political and economical developments (World Energy Council Turkish National Committe, 2011). These reasons make it hard to predict future trends of electricity and gasoline prices. In this scenario, it is assumed that gasoline prices may rapidly rise due to the reasons such as political or economical issues, relationship of countries, supply problem, or new tax regulations. It is assumed that gasoline cost increases normally (7.5% in every year) until 2020. After 2020, it shows exponential increase.

However, electricity cost increases like base run (9% per year) throughout simulation. Patterns of market share of vehicles under Scenario 1 are respectively given in Figure 12 and 13. It should be noted that the term of cost does not exactly represent power prices. Cost refers to operating cost of a vehicle for a km drive. However, cost directly reflects increase or decrease of the gasoline and electricity prices.

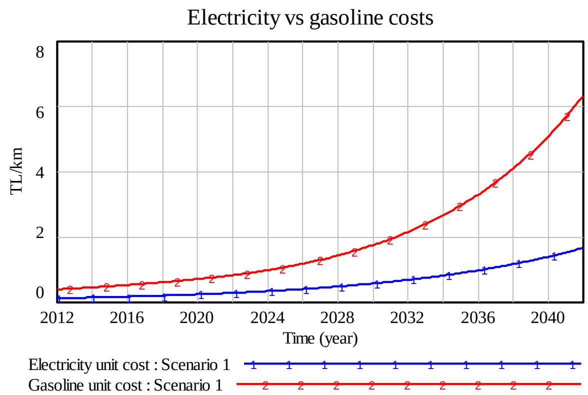

Figure 12. Fueling costs under Scenario 1

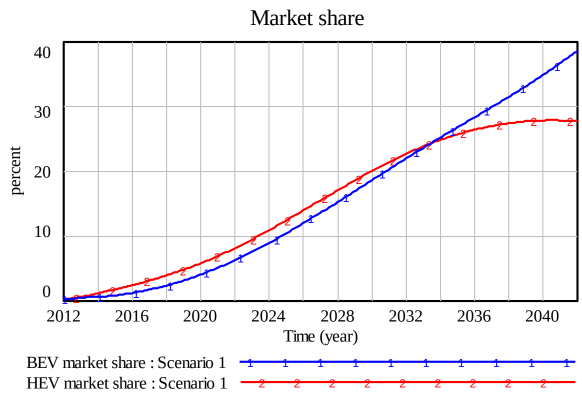

Figure 13. Market shares under Scenario 1

Results show that the gap between electricity and gasoline costs widens gradually until around 2030. However, the gap begins to increase rapidly after this year. Thus, after around 2030, BEV sales exceed HEV sales and BEV sales continue to show its existing trend. However, HEV sales firstly begin to increase decreasingly and then begin to decrease. This shows that if gasoline cost increases substantially while electricity cost keeps rising gradually, after a while market share of HEV begins to decline. The results imply that both gasoline costs and electricity costs pose an influence on vehicle sales, and thus EV diffusion. However, it must be noted that these influences are mainly related to the driving cost gap between the use of gasoline and electricity. In other words, the rapid increase in gasoline cost would not heavily influence BEV and HEV sales unless the gap between electricity and gasoline costs becomes notably large.

4.2.2. Technological Development Related Scenario (Scenario 2)

Vehicle attributes are influential factors on customer preferences about vehicle types. Although BEVs have competitive properties such as lower operating cost or lower emission rate compared to CV and HEV; BEVs may fall behind them due to the insufficient infrastructure and the limited battery properties such as lower driving range, longer refueling hour, or higher maintenance cost. Although research and developments have been continuing all over the world and it is believed that technological improvements about battery are going to occur, possible improvement level and time are highly uncertain. In this scenario, it is assumed that there would be no improvement about technology, or reduction of the purchase price of BEVs. In addition, it is assumed that construction of recharging points to be continued. However, they remain insufficient to meet the recharging demand throughout the simulation.

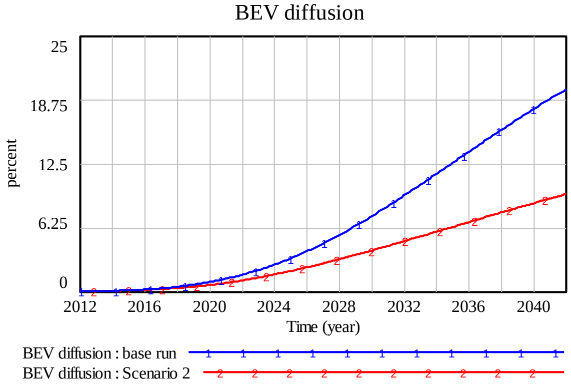

Figure 14. BEV diffusion under Scenario 2

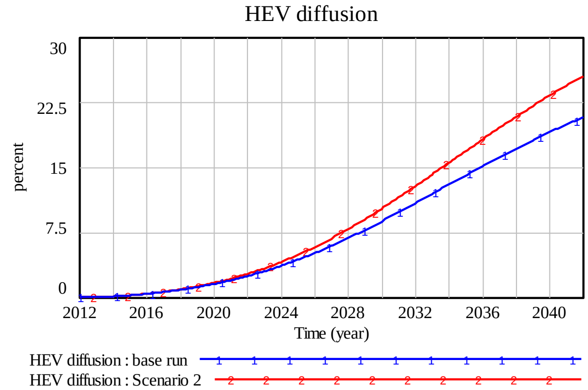

Figure 15. HEV diffusion under Scenario 2

The results of the scenario indicate that even if there were no improvements about technology, purchase price, and infrastructure, BEV may succeed to penetrate around 10% of the market. This means that BEVs may survive with their current technology. Furthermore, Figure 15 shows that if BEV technology remains at its current level, more customers will choose HEVs and CVs compared to the base run. This situation causes HEVs and CVs to capture higher market share. We can deduce from these consequences that although both BEVs and HEVs are categorized as electric vehicles and CVs is supposed to be their competitor, these two distinct electrical vehicles also compete with each other.

4.2.3. Introducing only BEV to the Market (Scenario 3)

As stated earlier, the model includes three types of vehicles; CV, HEV, and BEV. However, there has been a debate about the possibility of HEV inhibiting BEV diffusion. In addition to this debate, people also argue that how much CO_2 reduction would be if only BEVs were introduced to the market. Therefore, in this scenario, the model is reconstructed considering imaginary world that only CVs and BEVs are available in the market. Results are given in Figure 16 and Figure 17.

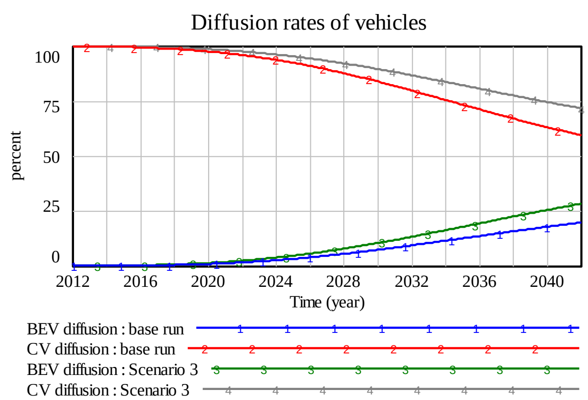

Figure 16. Diffusion rates under Scenario 3

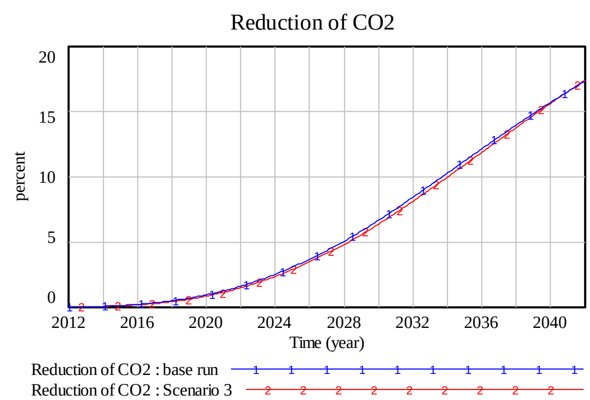

Figure 17. CO_2 reduction under Scenario 3

As is seen from the graphs, if there were only CVs and BEVs in the market, diffusion rate of BEV would become higher than its diffusion in the base run. However, Figure 17 shows that if there were only CVs and BEVs in the market, reduction of CO_2 level would be almost same compared to the base run. This is because of the fact that even diffusion rate of BEV increases; most of potential HEV customers prefer CVs over BEVs and the more CV causes the more gas emissions. In addition, the amount of CO_2 released from CVs is greater than the gas stemming from BEVs or HEVs. In this regard, it can be deduced that not introducing HEVs to the market does not cause significant change to the climate, in terms of CO_2 reduction.

4.2.4. Word of Mouth Related Scenarios (WoM) (Scenario 4)

A customer intending to buy a vehicle needs to be aware of vehicle types to take them into her/his choice set. The awareness about new type of vehicles is provided via marketing and word of mouth. There are two WoM related scenarios. In the first scenario (Scenario 4_a), influence of WoM of non-EV drivers, and in the second one influence of non-EV drivers are intensified (Scenario 4_b). Intensified means exposure level coming from drivers is doubled. In other words, it is assumed that they are twice as effective as in the base run in terms of creating awareness about EVs. Results are given in Figure 18 and Figure 19.

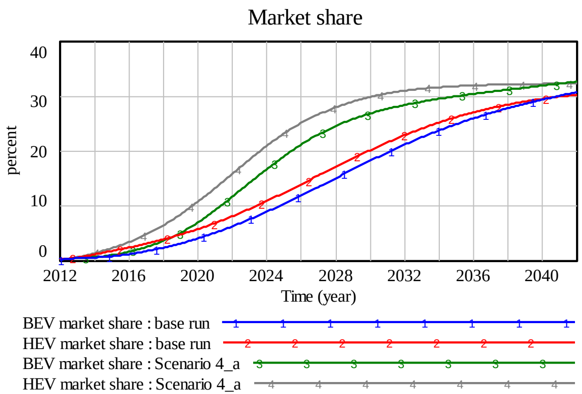

Figure 18. Market shares under Scenario 4_a

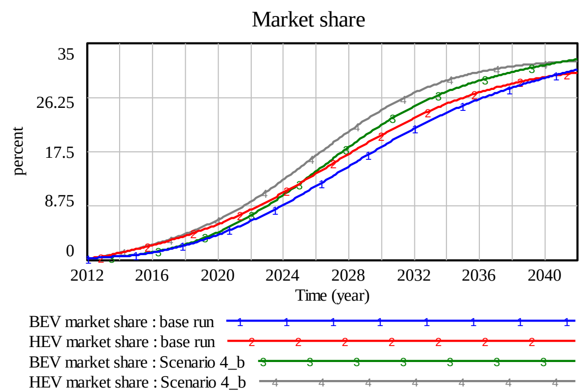

Figure 19. Market shares under Scenario 4_b

According to the simulation results, word of mouth (WoMs) of both EV drivers and non-EV drivers has a remarkable impact on EV penetration. WoM influence strengthens particularly between 2016 and 2038 because the number of EV users and aware non-EV drivers are very low in the first years of diffusion. Thus, even if all of them talk about EVs, drive them on the road, or mention them in the social media, their total impact still remains quite small in the opening years. However, when the number of aware people increases, the amount of exposure also increases. Hence, more people recognize EVs between 2016 and 2038. However, after 2038, the influence of WoM on EV market share begins to decline because the number of people who are not familiar with EV becomes considerably lower. As unaware people diminish, WoM does not then cause a huge number of people to gain awareness about EVs. Moreover, exposure coming from non-adopters may be more influential compared to adopters of the technology due to a greater number of non-EV drivers. Besides, in the first scenario, cumulative CO_2 reduction would be around 25 x 10^6 tons by 2042 and in the second scenario, it would be around 19.7 x 10^6 tons by 2042 while it is around 17.07x10^6 tons in the base run.

4.3. Policy Analysis

4.3.1. Subsidy Based Policies (Policy 1)

Most automobile manufacturers and researchers claim that financial incentive is necessary for successful EV adoption. Subsidy for a purchase price is considered as one of the financial incentive options (Kwon, 2012; Shepherd, Bonsall, & Harrison, 2012; Struben & Sterman, 2008). Impacts of subsidy strategies are assessed with the help two basic different strategies; 5000 TL subsidy throughout the simulation and 10000 TL subsidy for the First 10 Years of diffusion. Firstly, each one is applied to only BEVs, and then for only HEVs. Afterwards, they are applied to both BEVs and HEVs.

Results show that subsidies have a relatively small impact on the sales of both BEVs and HEVs in Turkey. Because even with 5000 TL or 10000 TL subsidy, EV prices become higher compared to the CVs throughout the majority of the simulation. In addition, there is low number of potential EV customers in the beginning of the simulation. However, influence of 5000 TL subsidy regime on EV sales begins to increase gradually but slightly after 2035. Because potential EV customers increase and EV prices come close to CV prices due to both subsidies and decrease in EV price coming from learning by doing. Even so, implementation of subsidy strategies may not be adequate alone to provide for a rise of the market share of EVs. For this reason, subsidies do not show a considerable change in CO_2 reduction. In addition to its small impact, it is important to point out that subsidy regimes result in a huge total cost. For example '5000 TL for all EV subsidy-regime' may cause more than 10000 million TL.

4.3.3. Marketing Based Policies (Policy 2)

As mentioned before, people need social exposure to take EVs into their consideration set. Two distinct social exposures are defined in the study. First one is word of mouth of people and second one is marketing. Impacts of marketing strategies on EV penetration are analyzed via two policies. First policy helps to observe behavior if there were no marketing activities about EVs. In the second policy, it is assumed that marketing activities would continue for limited duration and it would be stopped. In addition, it is important to say that marketing activities are also included in the base run throughout simulation.

<u>No Marketing Activities (Policy 2_a):</u> In the Policy 3_a, it is assumed that there would be no marketing activities about EVs. The effects of this case can be seen in Figure 20.

As is seen from the graphs, if there would be no marketing activity for EV, adoption process is heavily affected from this situation since people do not recognize EVs or they do not know any information about them. Hence, they do not naturally take EVs into their choice set, which results in low sales. The results also show that if marketing activities are not implemented, the penetration of EVs to will be delayed more than one decade. Therefore, sufficient marketing activities are necessary to provide successful and rapid EV penetration

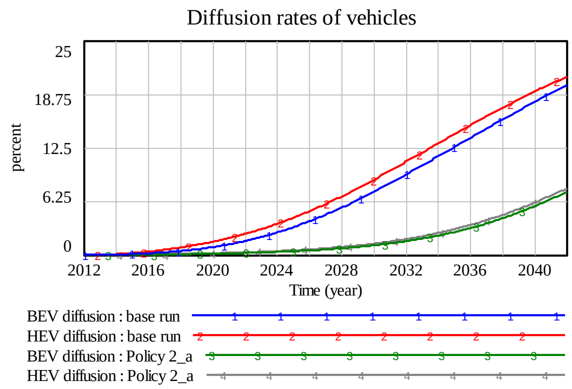

Figure 20. Diffusion rates under Policy 2_a

<u>Marketing Activities for Limited Duration (Policy 2_b)</u>: In this scenario, it is assumed that marketing activities continue for a while and then they are stopped. In this context, influence of different marketing durations on the market shares is analyzed to assess roughly optimum marketing duration. Hence, four different marketing periods are determined that are 15, 10, 5, and 3 years. To illustrate, if the first period is regarded, marketing activities will continue through 15 years from the beginning and then all activities would be stopped at the end of 15th the year. The results of the limited marketing duration are given in Figure 7.21.

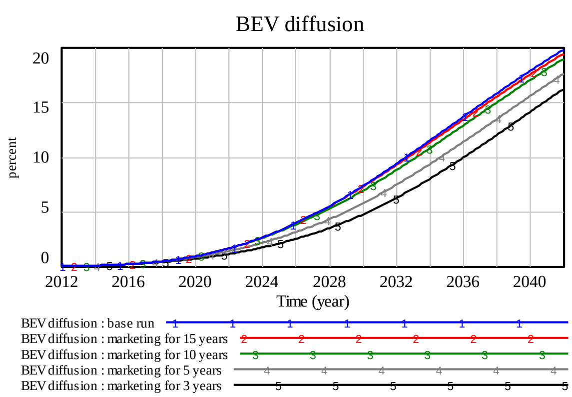

Figure 21. BEV diffusion rate under Policy 2_b

According to the simulation results, marketing is particularly important in the first years of the diffusion process. If marketing activities are stopped before the 5th year of the penetration process, certain amount of people would less likely recognize EVs or learn information about them. As a matter of course, this situation causes low level of EV sales. However, after 5 years, the number of people who are familiar with EVs sufficiently increases to sustain adequate social exposure. Thus, marketing duration needs to exceed minimum 5 years for EVs to be adequate for self-sustaining.

Additionally, after 10 years, marketing activities begin to lose its effect on the EVs sales since most people are already aware of EVs. Thus, after 10 years, marketing activities can be stopped or their level can be reduced to cut cost. In this regard, manufacturers should give importance to their marketing activities and these activities should not be removed before the market share is high enough to sustain a steady social exposure rate. Besides, according to the results, marketing for 3 years may result in around 12x10^6 tons cumulative CO_2 reduction, while marketing for 15 years may result in around 17x10^6 tons cumulative CO_2 reduction. If WoM and marketing scenarios are considered together, it can be deduced that marketing is particularly important in the first 5 years of penetration. In the same years, WoM has a weak influence due to the small number of aware people. However, after 5 years, WoM get strong enough to sustain awareness without marketing.

5. Conclusion

In the study, a simulation model is constructed by employing system dynamics methodology to analyze diffusion dynamics of EVs in Istanbul. It is observed that the sales volumes for EVs are always lower than the CV sales throughout the simulation period, which is from 2012 to 2042, within the base case. After three decades, diffusions of BEVs and HEVs reach respectively 19.76% and 20.77% in Istanbul by 2042. Moreover, according to the results, CO_2 reduction in the transportation sector would still only reach around 17% in 2042 and cumulative CO_2 reduction in Istanbul will be around 17.10^6 tons by 2042.

Gasoline costs and electricity costs have influence on EV diffusion. However, it is important to point out that their impact on diffusion is mainly associated with a mobility cost discrepancy between gasoline and electricity. Furthermore, contrary to expectations, even if no technological improvements were realized, BEVs would still succeed to penetrate around 10% of the market based solely on its current technology within the 30-year span of the model.

Both marketing activities and word of mouth have a remarkable impact on rapid EV diffusion. Marketing activities should continue to spread information about EVs in order to guarantee consumer recognition, particularly in the first years of the diffusion process. However, after the first 5 years, WoM becomes strong enough to sustain an adequate social exposure without marketing. Moreover, after the 10th year of the penetration process, the effectiveness of marketing activities on EV sales begins to decline since most of people are already aware of EVs. So, after the 10th year, stopping marketing activities or reducing its level would be profitable in terms of cutting the costs for the government and automobile companies.

Subsidies will have a small impact on the sales of both BEVs and HEVs in Turkey. Because of this, subsidies would less likely create considerable change on CO_2 reduction. Apart from its low impact on sales, subsidy regimes also are likely to bring about a huge overall cost.

Finally, both BEVs and HEVs are categorized as electric vehicles; while CVs are considered as their basic competitor within the transportation sector. It is believed that HEVs are crucial to attract CV customers in EV diffusion process. However, if HEVs are supported too much by the government or manufacturers, this situation may inhibit BEV penetration in Istanbul because BEVs and HEVs also compete with each other. Therefore, after HEVs succeed to attract attention of CV customers, the government and automobile firms may reduce or stop incentives for HEVs to provide broader BEV penetration.

As future research, different type of alternative fuel vehicles such as plug in hybrid vehicles, and fuel cell vehicles, may be included in the model. Moreover, adding new vehicle attributes may enrich the model. In the study, it is assumed that CVs do not have technological progress throughout 3 decades. Improvement in CV technology can be regarded in future researches. Finally, marketing is an exogenous variable in the study. It may be turn into an endogenous variable with a good extension of the model.

REFERENCES

Aftabuzzaman, M., & Mazloumi, E. (2011). Achieving Sustainable Urban Transport Mobility in Post Peak Oil Era. *Transport Policy*, *18*(5), 695–702. doi:10.1016/j.tranpol.2011.01.004

Andersson, S.-L., Elofsson, A. K., Galus, M. D., Göransson, L., Karlsson, S., Johnsson, F., & Andersson, G. (2010). Plug-in Hybrid Electric Vehicles as Regulating Power Providers: Case Studies of Sweden and Germany. *Energy Policy*, *38*(6), 2751–2762. doi:10.1016/j.enpol.2010.01.006

Barlas, Y. (1996). Formal Aspects of Model Validity and Validation in System Dynamics. *System Dynamics Review*, *12*(3), 183–210. doi:10.1002/(SICI)1099-1727(199623)12:3<183::AID-SDR103>3.0.CO;2-4

Barlas, Y. (2002). *System Dynamics: Systemic Feedback Modeling for Policy Analysis*. *Knowledge for Sustainable Development - An Insight into the Encyclopedia of Life Support Systems* (pp. 1131–1175). Paris: UNESCO-EOLSS Publishers.

Barut, A. (2013). Eşarj-Şarj İstasyonları. Retrieved from http://esarj.com/elektrikli-arac-sarj-istasyonlari/

Brownstone, D., Bunch, D. S., & Train, K. (2000). Joint Mixed Logit Models of Stated and Revealed Preferences for Alternative Fuel Vehicles. *Transportation Research Part B*, *34*, 315–338.

Christidis, P., Hernandez, H., & Georgakaki, A. (2005). *Hybrids for Road Transport*. Spain.

Eaves, S., & Eaves, J. (2004). A Cost Comparison of Fuel-Cell and Battery Electric Vehicles. *Journal of Power Sources*, *130*(1-2), 208–212. doi:10.1016/j.jpowsour.2003.12.016

Egbue, O., & Long, S. (2012). Barriers to Widespread Adoption of Electric Vehicles: An Analysis of Consumer Attitudes and Perceptions. *Energy Policy*, *48*, 717–729. doi:10.1016/j.enpol.2012.06.009

EPA. (2011). Overview of Greenhouse Gases. Retrieved from http://www.epa.gov/climatechange/ghgemissions/gases.html

Fuglestvedt, J., Berntsen, T., Myhre, G., Rypdal, K., & Skeie, R. B. (2008). Climate Forcing From the Transport Sectors. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(2), 454–8. doi:10.1073/pnas.0702958104

Geyer, R., Koehn, J., & Olsen, T. (2005). *Reducing Greenhouse Gas Emissions with Hybrid-Electric Vehicles : An Environmental and Economic Analysis*. Donald Bren School of Environmental Science and Management.

Granovskii, M., Dincer, I., & Rosen, M. a. (2006). Economic and Environmental Comparison of Conventional, Hybrid, Electric and Hydrogen Fuel Cell Vehicles. *Journal of Power Sources*, *159*(2), 1186–1193. doi:10.1016/j.jpowsour.2005.11.086

Greene, D. L., Hopson, J. L., & Li, J. (2006). Have We Run Out of Oil Yet? Oil Peaking Analysis From an Optimist's Perspective. *Energy Policy*, *34*(5), 515–531. doi:10.1016/j.enpol.2005.11.025

Gupta, H. (2006). *Fundamentals of Internal Combustion Engines*. New Delhi: Prentice Hall of India. Retrieved from http://books.google.com/books?hl=en&lr=&id=MFx4VRErHNoC&oi=fnd&pg=PR17&dq=Fundamentals+Of+Internal+Combustion+Engines+-+H&ots=fkf8Q43Hqh&sig=Js08bE45z0tdreHRPicrSF3hk2A

Hackbarth, A., & Madlener, R. (2013). Consumer Preferences for Alternative Fuel Vehicles: A Discrete Choice Analysis. *Transportation Research Part D: Transport and Environment*, *25*, 5–17. doi:10.1016/j.trd.2013.07.002

Helms, H., Pehnt, M., Lambrecht, U., & Liebich, A. (2010). Electric Vehicle and Plug-in Hybrid Energy Efficiency and Life Cycle Emissions. *18th International Symposium Transport and Air Pollution Session 3: Electro and Hybrid Vehicles* (pp. 113–124).

Kwon, T. (2012). Strategic Niche Management of Alternative Fuel Vehicles: A System Dynamics Model of the Policy Effect. *Technological Forecasting and Social Change*, *79*(9), 1672–1680. doi:10.1016/j.techfore.2012.05.015

Lemoine, D. M., & Kammen, D. M. (2009). Addendum to "An Innovation and Policy Agenda for Commercially Competitive Plug-in Hybrid Electric Vehicles". *Environmental Research Letters*, *4*(3), 039701. doi:10.1088/1748-9326/4/3/039701

Lopes, J. A. P., Soares, F. J., Almeida, P. M. R., Baptista, P. C., Silva, C. M., Farias, T. L., & Architecture, A. G. (2009). Quantification of Technical Impacts and Environmental Benefits of Electric Vehicles Integration on Electricity Grids. *Advanced Electromechanical Motion Systems & Electric Drives Joint Symposium* (pp. 1–3).

Manzie, C., Watson, H., & Halgamuge, S. (2007). Fuel Economy Improvements for Urban Driving: Hybrid vs. Intelligent Vehicles. *Transportation Research Part C: Emerging Technologies*, *15*(1), 1–16. doi:10.1016/j.trc.2006.11.003

Markel, T., & Simpson, A. (2006). Cost-Benefit Analysis of Plug-In Hybrid Electric Vehicle Technology. *22nd International Electric Vehicle Symposium* (Vol. 1).

McFadden, D. (1980). Econometric Models for Probabilistic Choice Among Products. *The Journal of the Business*, *53*(3), 13–29.

Samaras, C., & Meisterling, K. (2008). Life Cycle Assessment of Greenhouse Gas Emissions From Plug-in Hybrid Vehicles: Implications for Policy. *Environmental science & technology*, *42*(9), 3170–76. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18522090

Scott, M., Kintner-Meyer, M., Elliott, D., & Warwick, W. (2007). Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional US Power Grids. *Online Journal of EUEC*. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Impacts+Assessment+of+Plug-in+Hybrid+Vehicles+on+electric+utilities+and+regional+U.S.+Power+Grids#9

Shafiei, E., Thorkelsson, H., Ásgeirsson, E. I., Davidsdottir, B., Raberto, M., & Stefansson, H. (2012). An Agent-Based Modeling Approach to Predict the Evolution of Market Share of Electric Vehicles: A Case Study From Iceland. *Technological Forecasting and Social Change*, *79*(9), 1638–1653. doi:10.1016/j.techfore.2012.05.011

Shepherd, S., Bonsall, P., & Harrison, G. (2012). Factors Affecting Future Demand for Electric Vehicles: A Model Based Study. *Transport Policy*, *20*, 62–74. doi:10.1016/j.tranpol.2011.12.006

Sioshansi, R., & Denholm, P. (2009). Emissions Impacts and Benefits of Plug-in Hybrid Electric Vehicles and Vehicle-to-Grid Services. *Environmental Science & Technology*, *43*(4), 1199–204. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/19320180

Sterman, J. D. (2000). *Business Dynamics: System Thinking and Modeling for a Complex World*. Boston, MA: Irwin/McGraw-Hill.

Struben, J., & Sterman, J. D. (2008). Transition Challenges for Alternative Fuel Vehicle and Transportation Systems. *Environment and Planning B: Planning and Design*, *35*(6), 1070–1097. doi:10.1068/b33022t

TEB ARVAL, & Corporate Vehicle Observatory. (2012). Şirket Filolarındaki Araç Sayısı 1.8 Milyona Ulaştı.

TEİAŞ. (2004). *Türkiye Elektrik Enerjisi Üretim Planlama Çalışması*. Retrieved from http://www.teias.gov.tr/ElektrikUretimPlani.aspx

Tran, M., Banister, D., Bishop, J. D. K., & McCulloch, M. D. (2012). Simulating Early Adoption of Alternative Fuel Vehicles for Sustainability. *Technological Forecasting and Social Change*. doi:10.1016/j.techfore.2012.09.009

Turkish Statistical Institute. (2012). *İllere Göre Motorlu Kara Taşıtları Sayısı*.

Turkish Statistical Institute. (2013). *Nüfus Projeksiyonları, 2013-2075*. Retrieved from http://www.tuik.gov.tr/PreHaberBultenleri.do?id=15844

United States Enviormental Protection Agency. (2011). *Greenhouse Gas Emissions From a Typical Passenger Vehicle*. Retrieved from http://www.epa.gov/otaq/climate/documents/420f11041.pdf

Van Rijnsoever, F. J., Hagen, P., & Willems, M. (2013). Preferences for Alternative Fuel Vehicles by Dutch Local Governments. *Transportation Research Part D: Transport and Environment*, *20*(June 2012), 15–20. doi:10.1016/j.trd.2013.01.005

Von Albrichsfeld, C., & Karner, J. (2011). Brake System for Hybrid and Electric Vehicles. In R. K. Jurgen (Ed.), *Electric and Hybrid-Electric Braking Systems and NVH Considerations* (pp. 11–17). Pennsylvania.

Wansart, J., & Schnieder, E. (2010). Modeling Market Development of Electric Vehicles. *Systems Conference, 2010 4th Annual IEEE*, 371–376. doi:10.1109/SYSTEMS.2010.5482453

Wiedmann, K.-P., Hennigs, N., Pankalla, L., Kassubek, M., & Seegebarth, B. (2011). Adoption Barriers and Resistance to Sustainable Solutions in the Automotive Sector. *Journal of Business Research*, *64*(11), 1201–1206. doi:10.1016/j.jbusres.2011.06.023

World Energy Council Turkish National Committe. (2011). *Enerji Raporu*. Ankara: Poyraz Ofset.

Yücel, G. (2013). Facilitating Diffusion of Innovations Through Niche Management Strategies. *System Dynamics Conference* (p. 116).

Zhang, L., Brown, T., & Samuelsen, G. S. (2011). Fuel Reduction and Electricity Consumption Impact of Different Charging Scenarios for Plug-in Hybrid Electric Vehicles. *Journal of Power Sources*, *196*(15), 6559–6566. doi:10.1016/j.jpowsour.2011.03.003

Zhang, T., Gensler, S., & Garcia, R. (2011). A Study of the Diffusion of Alternative Fuel Vehicles: An Agent-Based Modeling Approach. *Journal of Product Innovation Management*, *28*(2), 152–168. doi:10.1111/j.1540-5885.2011.00789.x