Modelling and Forecasting the Electromobility Uptake in Greece by 2030: A Regional Perspective for Strategic Policy Assessment

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Acronyms

EV Electric Vehicle

ICE Internal Combustion Engine Vehicle

BEV Battery Electric Vehicle

PHEV Plug-in Hybrid Electric Vehicle

NUTS-2 Nomenclature of Territorial Units for Statistics

BEV Battery Electric Vehicle

NECP National Energy and Climate Plan

MMI Market Maturity Index

Abstract

Electromobility represents a strong option to reduce carbon emissions in the road transport sector. This study presents a model that forecasts the evolution of the market share of Battery Electric Vehicles (BEVs) in the new car market across three vehicle type segments, i.e., small, medium, and large-SUV. The model adopts a regional resolution that accounts for regional characteristics on the NUTS-2 level, such as population density, GDP/capita, education levels, current EV charger distribution, and a Technology Acceptance Model (TAM) based EV readiness index, to simulate the uptake of BEVs in different regions. The model applies a discrete choice model considering tangible and intangible elements. It calculates the cost index of vehicles, including the initial and operating costs of the different vehicle options, taxes, subsidies, and an estimated cost for range anxiety and public charging. The analysis is based on four different scenarios referring to the Greek National Energy Climate Plan. The results reveal that regions with higher average income, GDP/capita, and population density show a higher uptake of BEVs. However, the cost index parity is reached much sooner than the point where BEV market share overtakes that of Internal Combustion Engine (ICE) vehicles. This implies that the cost index is not the barrier to BEV uptake, but it is rather market maturity and consumer awareness and acceptance limiting the uptake of electromobility. Overall, the model provides a method to calculate the market share and cost index of BEVs in reference to regional parameters, highlighting the regions requiring the most attention to achieve national targets. The results can inform policymakers in developing strategies and growing infrastructure to accelerate the adoption of BEVs, particularly in regions where their uptake is currently lower.

Keywords: E-Mobility Adoption, Consumer Preferences, Sustainable Transportation, Regional Analysis, Discrete Choice Model, Transport Mode Forecasting Model

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1 Introduction

This chapter introduces the background and motivations of this project.

1.1 Motivation

The electrification of the transport sector is a key strategy for reducing carbon emissions and reducing the impacts of climate change. In the European Union (EU), transportation accounts for approximately 22.5% of all greenhouse gas emissions, making it a critical sector in which to achieve progress [1]. As a result, electric vehicles (EVs) have gained traction as a cleaner and more sustainable alternative to traditional combustion engines. The EU's Fit For 55 legislation aims to reduce carbon emissions by 55% or more by 2030 in order to be on track to achieving carbon neutrality by 2050, and hence the electrification of transport is an essential step at achieving this goal [2].

According to the European Environment Agency, electric car registrations for 2022 were close to 2 million units, up from 1.7 million units in 2021 and 1.1 million units in 2020 [3]. However, EVs still represent a relatively small share of the total vehicle market in the EU. To accelerate the growth of EVs and achieve carbon neutrality by 2050, policymakers and industry leaders must understand the complex factors that influence the adoption of EVs.

This thesis develops a forecasting model that estimates the regional market share of electromobility in the passenger transport sector and the necessary charging infrastructure to support it until 2035. The model incorporates key variables, such as demographic features of vehicle users, vehicle technology and prices, energy prices, market maturity and charging infrastructure, and government schemes and incentives. The outputs of the model include a forecast of the expected stock of EVs, the market share of electromobility, the required infrastructure to support this growth, and varying results based on different scenarios for the relevant stakeholders. The regional variation between the results is then analyzed in order to further identify the most impactful regional characteristics causing some regions to lead the e-mobility uptake and others to be more lagging.

This project contributes to the ongoing discussion of sustainable transportation by providing a detailed analysis of the factors that drive the growth of electromobility from a user choice perspective. It provides a method to test the market impact of policymaker actions on the electromobility market. The results of this model will be valuable to policymakers, industry leaders, and other stakeholders seeking to promote the adoption of EVs and reduce carbon emissions in the transportation sector, as well as maintain market competitiveness in the transport sector. By using a data-driven approach to understand the future of EVs in the EU, this thesis aims to inform policy decisions and guide industry strategies in the transition to sustainable transportation.

1.2 Scope and Granularity

The scope of the model and the study are defined below.

- Market Scope: This model only takes into account new registrations of passenger cars. It does not account for the second-hand vehicles market or other types of transportation alternatives, such as ride-sharing or public transport. Additionally, it does not account for the granularity of types of passenger cars such as private cars, taxis, rental cars, etc. and only analyses a generalized passenger car category. The model is based on the assumption of a single-vehicle purchase and does not account for consumer choice of a second or third vehicle.
- Time Scope: The time scope of the model extends from the present day to 2030. Projections for years beyond this scope would require a re-evaluation of the model parameters. The model operates on a yearly time frequency using aggregated yearly inputs.
- Regional Scope: The model operates on a regional granularity of the European Union Nomenclature of Territorial Units for Statistics (NUTS 2) regions specifically in Greece [4].

1.3 Objectives

The following section discusses the objectives of this project.

- To develop a forecasting model that accurately estimates the market share of electromobility in the NUTS-2 regions of Greece until 2030.
- To identify the key factors that influence the adoption of battery electric vehicles (BEVs) in the EU, including demographic features of vehicle users, vehicle

technology and prices, energy prices, market maturity and charging infrastructure, and government schemes and incentives.

- To test the market impact of different government support scenarios on the growth of EVs in the EU.
- To provide valuable insights and recommendations to policymakers, industry leaders, and other stakeholders seeking to promote the adoption of EVs and reduce carbon emissions in the transportation sector.

2 Background

This section evaluates the existing literature. It is divided into sections based on the various relevant aspects of the model.

2.1 Global Outlook on the Electric Vehicle Market Growth

The market for electric vehicles is currently experiencing very strong growth. According to the International Energy Agency (IEA), the EV Market Share from total new vehicle registration, including both BEVs and PHEVs, has doubled from 2.3% in 2018 to 4.2% in 2020 [5]. In the past 2 years, however, the market share has more than tripled to 14% in 2022 and is expected to grow to almost 40% by 2030. This growth however is highly geographically unbalanced, where some regions are leading the transition, such as China, where the market share in 2022 was at 29%, and other regions, such as Greece are lagging at 7.9%. This growth is defined by two factors: the growth of supply of EVs, and the growth in demand. EVs are becoming more competitive every year due to both the improvements in EV technology making them more desirable than ICE and the policy and legislation promoting EVs and setting transport decarbonization targets.

The growth in supply is driven by the development of EV technology, which is not only bringing EV costs closer to traditional internal combustion (ICE) engine vehicles but also showing continuous growth in fuel efficiency and further bringing operation costs down.

The uptake of electric vehicles globally can be defined within the technology adoption lifecycle parameters which define the market uptake of new technologies introduced as a replacement of current technologies in developed markets [6]. This lifecycle is defined by very slow initial growth, due to the immaturity of the market, high costs, and lack of consumer awareness and supporting infrastructure. This is then followed by an exponential growth period where the market is growing rapidly, and costs are falling. Finally, the new technology reaches a period of complete maturity where there are virtually no limitations for market uptake. The technology adoption lifecycle can also be defined by the consumers of the new technology, which can be classified into the following basic classifications: innovators, early adopters, early majority, late majority, and laggards, as can be seen in **Error! Reference source not found.**.

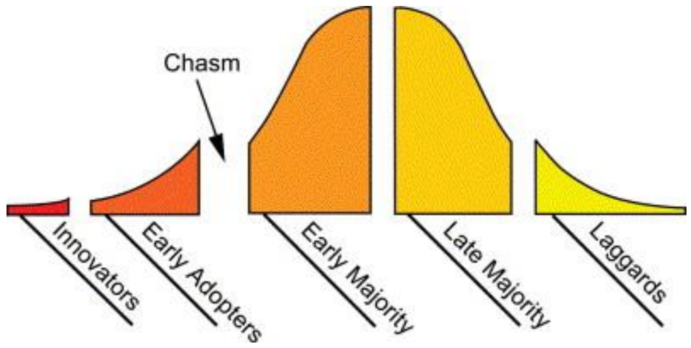

Figure 1: Technology Adoption Lifecycle Consumer Classification [6]

The consumers of Electric vehicles can be defined according to the classifications based on the likeliness of them to be part of the innovators and early adopters and majority group or the late majority and laggards' group.

A successful forecasting model takes into account consumer classification when considering market uptake. We currently see this classification globally with the variation between regions, but it can also be seen at a regional level. The future of electric vehicles lies in transitioning in the lifecycle to reach the late majority and the laggards.

2.2 Electric Vehicle Adopters

A comprehensive literature review has been conducted to collect and analyze the various factors influencing the adoption of Electric Vehicles [7]. The study categorizes the influencing factors into 4 main classes, based on the studied literature: demographic, situational, contextual, and psychological factors. The review summarized the results of several studies to show demographic features of EV adopters as middle-aged, highly educated, high-occupation individuals are most likely to adopt EVs. On the other hand, the review interestingly also points out other studies that have shown that education levels have little impact on EV adoption. This demonstrates the variations that might be brought by different samples.

Situational factors include environmental, technological, financial, and market factors. The review demonstrates the variations between different studies in showing user priorities when it comes to relevant situational factors. For some studies, the financial factors, such as purchasing cost and operation costs were the most significant concern of users, while other studies showed the environmental factors or market factors were the most impactful. As for the contextual factors, the review shows how government incentives and a reliable and established charging infrastructure go hand in hand. Finally, the psychological factors are relatively more difficult to quantify from a modelling perspective, since they include consumer attitudes toward new technologies, environmental responsibility, and social trends. However, several studies demonstrate the importance of accounting for psychological factors when studying EV adoption [7].

Most studies conducted that had the goal of characterizing the typical electric vehicle user were based on stated preference in survey form rather than EV ownership patterns. One study tested both methods and analyzed whether individual stated preference is consistent with real-world patterns. Interestingly, the study showed inconsistency when it comes to household income and age. While the stated preference survey demonstrated higher rates of EV adoption for individuals, the observable pattern showed that older populations show higher EV adoption. This result shows how it is important to have an analytical approach when considering the results of stated-preference survey-based studies [8].

Additionally, it is also important to acknowledge the variation in the results due to the variations in the sample participants taken in each study. For example, a study based in Germany has concluded that likely EV adopters are middle-aged men in technical occupations and with relatively higher education levels living in rural or suburban households [9]. Another study completed in Germany which mainly surveyed current users of EVs reaches similar conclusions, particularly regarding age, gender, and education. On the other hand, a study completed in the Nordic region concluded that the likely EV adopters are below middle-aged men in civil society or academia [10].

2.3 Regional Characteristics

It is important to account for the relation between initial costs and running costs regarding the transition between one vehicle type and another. The opportunity cost of a higher initial investment must be warranted through the reduced running cost in order to result in a lower total cost. Several studies have been conducted to demonstrate the role of this opportunity cost in the area of electromobility. rates

One such study utilizes a series of studies to test several user decision-making hypotheses based on demographic attributes and individual preferences. It is important to note that this study was based on a questionnaire response from the study participants and not their observed behavior. According to those responses, the results show that the economic factors involved with purchasing an electric vehicle correlate with user vehicle choice. More specifically, the economic tradeoff between the Capital Expenditure (CapEx), such as purchasing price, and the Operating Expenditure (OpEx), such as fuel and maintenance. This demonstrates the importance of accounting for discount rates when calculating the total cost of ownership of vehicles between different user groups [11].

Another study attempts to quantify the individual discount rate for energy-efficient vehicles and transport, only to observe large variability of 19 ± 17% and hence concluding that the purchasing decision is dependent on a combination of factors that are based on time and context and is user-specific. This shows how the use of a generalized discount rate for a large group of users can prove to be inaccurate. However, the use of varying discount rates based on individual characteristics can prove valuable in modelling market penetration of different technologies. Additionally, the users' lack of ability to visualize the return of investment in energy-efficient transport in operational cost savings further impacts user choices [12].

The regional variations are discussed in more detail in each input methodology section.

3 Model Significance

This chapter discusses the business need and use of this model to relevant stakeholders.

3.1 Model Outputs

The outputs of the model are based on aggregated results. The discrete choice model runs on vehicles per segment per region. Those results are aggregated to a per region level using historical trends on how new registrations are distributed among segments. The regional results can then be further aggregated to national results based on the historical trends on how new registrations are distributed between regions and the aggregation can be further visualized in **Error! Reference source not found.**. The direct consumer choice model result is the market share breakdown per segment per region. The results can be used to determine several derived results based on the aforementioned aggregations and several key assumptions regarding the breakdown of new vehicle registrations per segment and per region as can be seen in Figure 3.

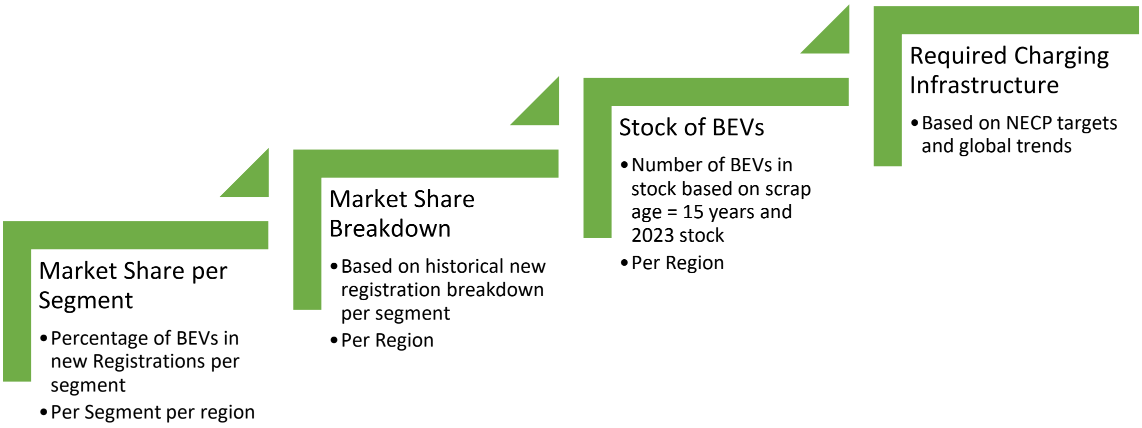

Figure 2: Visual Representation of Model Results Flow

3.2 Stakeholders and Model Utility

The relevant stakeholders who would benefit from the results of this model can be summarized below.

- **Policy Makers:**
    - Evaluate the effectiveness of existing and proposed policies in achieving national and regional e-mobility targets.
    - Test policies and incentives effect on the e-mobility market
    - Identify leading and lagging EV uptake regions and tailor targeted strategies for lagging regions.
- **Utility Companies and Distribution Network Operators**
    - Awareness and preparation for increased energy demand from electromobility per region and energy availability.
    - Involvement in preparing the grid and infrastructure for the increased demand at each geographical location.
- **Independent Charging Infrastructure Operators**
    - Market opportunity to account for regional electromobility expansion in strategy development.
    - A chance to identify suitable regions and markets for investment in infrastructure development.

3.3 The Significance of Regional Analysis

The model is based on a nested formulation of the discrete choice model as developed and used in the TRIMODE (TRansport Integrated MODel for Europe) [13]. The model developed in this study utilizes several socio-technical assumptions based on the current literature to expand on the model through the application of the model on a regional scale with a more refined yearly resolution. This regional perspective on the market share analysis allows for the possibility of addressing regional progress in regard to meeting e-mobility targets and the sufficiency of the current charging infrastructure.

A regional analysis of EV market shares in different US states was analyzed in other studies in order to identify the relationship between fiscal incentives and market share, which was found to be weaker than the authors anticipated, and demonstrates the presence of additional factors for consideration [14]. This model accounts for the direct costs and additionally considers hidden costs and market maturity in the calculation of the utility function of different vehicle options to different consumer groups.

A review completed in 2013 evaluates the different models and techniques used to forecast the market penetration of e-mobility and analyses the main parameters and challenges with different model types [15]. One of the conclusions drawn by the review is that consumer choice models are generally limited by the lack of historical data on relatively new technologies in the market such as BEVs and PHEVs. The current market for EVs is drastically more developed in 2023 than it was 10 years ago, and consumer behavior globally has provided guidance and indication on future behavior. Additionally, the current legislations in place, such as the high incentives and strict regulation on vehicle carbon emission provide further evidence on the potential growth of market maturity of EVs. Finally, the advancing technologies of EVs are removing many of the technical limitations of EVs, such as range anxiety due to the development in battery capacities and fast charging technology and hence the forecasting of the consumer behavior towards EVs is becoming clearer and more direct.

In summary, this model methodology applies a regional approach to the consumer discrete choice model with additional consideration of hidden costs and EV acceptance across different regions.

4 Methodology

This chapter explains the process of model development and the relevant inputs and key assumptions.

4.1 Discrete Choice Model

The statistical base of this model is a novel form discrete choice model as formulated and used in the TRIMODE fleet model used by the European Commission [13]. A discrete choice model is a statistical model that can be used to estimate the probability of a consumer making a specific choice when presented with other alternative options that can be discretely and independently defined[16]. The decision-making process of the consumer is based on a utility function, which allows for a uniform comparison between the available options [17]. A decision maker's behavior is based on maximizing the utility of their choice. In other words, the consumer chooses the alternative that provides the highest utility to them, based on the utility function. The utility function would ideally capture the consumer-specific attributes of the user in addition to the attributes of the alternatives and is hence a function of both consumer and alternative choices. This is due to how the same alternatives can have different utilities for different consumers.

The main components of a discrete choice model are the following:

Alternatives:
The set of discrete and independent options that the user can choose from. In this model, the alternatives are the fuel type of chosen vehicles.

Decision-makers:
The decision-makers are the individuals making the choice between the different alternatives based on their individual preferences. For this model, the decision-maker attributes are defined by average representative values from each region as a measure of the typical average decision-maker in each region.

Utility Function Attributes:
The attributes of the utility function are the relevant factors and inputs that affect the utility of each alternative to each user and affect their decision-making. In this model, the utility function is defined based on two factors: the cost index and the market maturity index (MMI). The cost index captures direct and indirect monetary costs associated with

each alternative to each user. The MMI captures the non-monetary attributes that affect the decision-making process of each user for each alternative. Both factors are discussed in more detail in their respective sections below.

Discrete choice models estimate the likelihood or probability of a consumer choosing a particular option within a given choice set. These estimated probabilities can then be used to estimate the market share of certain products or alternatives when considered in a setting of a larger market.

Discrete choice models are particularly suitable for alternatives that serve as substitutes for each other rather than being complementary. This is because the model focuses on capturing the trade-offs and preferences individuals have when selecting one option over another. For example, this model uses the discrete choice between vehicle fuel types which are alternatives, but it does not measure the choice between public transportation and a specific vehicle type, since public transport is an alternative to private vehicles as a whole and not a specific vehicle type.

The form of the discrete choice model can be seen in equation) and it is based on a Weibull functional form. It is important to note that the results are a function of both the user and the vehicle.

$$MS_{u,v} = \frac{w_{u,v} \cdot {C_{u,v}}^{y_u}}{\sum_{u,v} w_{u,v} \cdot {C_{u,v}}^{y_u}} \quad (1)$$

u: user

v: vehicle

MS: Market Share

C: Cost Index(€/year)

w: Market Maturity Index

y: degree of substitution

This functional form encompasses both the cost index and the MMI into the utility function and hence accounts for hidden costs that cannot be expressed in monetary terms. It is a novel approach to consumer discrete choice modelling, due to its independence from stated-preference survey data. The parameters are tuned and forecasted using historical data and trends. The model inputs are set according to the most up-to-date studies and research to provide an accurate forecast of future parameters. This enables the model to be used and applied to populations with no available survey capability or data. The inputs of the model are summarized in

Figure 3: Parameter Breakdown of Model and further discussed below.

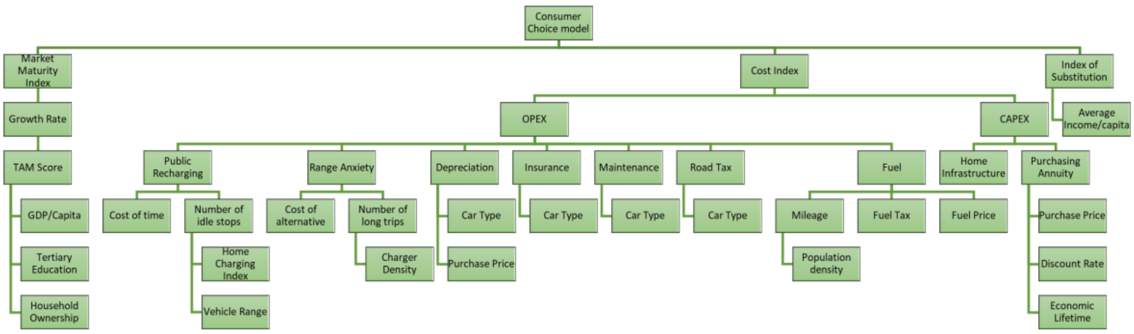

Figure 3: Parameter Breakdown of Model

Cost Index

The cost index is a unified and consistent measure of cost between different vehicle options for different users. In this model, it is measured on a per-kilometer basis. This cost index does not only include the running costs for each vehicle choice, but also the initial costs using an annuity rate, based on individual discount rates and economic lifetime. The components included in the cost index are the primary measurable inputs to the model and are discussed in more detail in the inputs section. The equation used for the cost index can be seen in equation (2) where it is represented in €/km terms.

$$C_{u,v} = \frac{IC_{u,v} + OC_{u,v}}{M_u} \qquad (2)$$

IC: Initial Cost(€/year)

OC: Operation Cost(€/year/km)

M: Yearly Mileage

The Initial costs are included in the calculation using an annuity rate as can be seen in equation (3).

$$IC_{u,v} = PC_v \,.\, \partial_u \,.\, \frac{(1+\partial_u)^{n_u}}{(1+\partial_u)^{n_u}-1} \tag{3}$$

PC: Purchasing Cost (€)

∂: Discount Rate

n: economic Lifetime

Market Maturity Index

The MMI, as discussed earlier, is a component of the utility function that captures the non-monetary influencing factors on the consumer's decision-making process. In the application of this model, it represents two kinds of factors: factors specific to the vehicle alternatives, and factors specific to the consumer. Vehicle factors include the availability of a convenient charging infrastructure, range anxiety, reliability of the vehicle [18]. Consumer-specific factors are a representation of the likeliness of an individual to become an early adopter of EVs and this is based on several factors including knowledge of alternative vehicle options, consumer environmental responsibility, consumer knowledge of maintenance and technology, attitude and willingness to take a risk [19].

The MMI is relevant in all emerging technology markets and has been demonstrated in more mature BEV markets and other industries. A study analyzing the market maturity of EVs in Norway which can provide an outlook on the future of E-Mobility in other lagging markets [20]. The study refers to market maturity in terms of critical mass constraints based on indirect network effects. The indirect network effect can be defined as the effect of the availability of complementary goods on the adoption of new technologies. In the E-Mobility industry, complementary goods can be defined as charging infrastructure, reliable maintenance, and reliable support services. The study demonstrates how all regions in Norway have overcome critical mass constraints since 2019.

Two main attributes have been chosen to control the MMI of different vehicles: range anxiety/available infrastructure and consumer attitude independently from costs. Petrol vehicles are assumed to have full maturity since they have no range or infrastructure constraints and are fully accepted by consumers. This signifies that the utility function of petrol vehicles is solely dependent on costs, and market maturity does not provide additional barriers. Diesel vehicles on the other hand have no range or infrastructure concerns either, however, it has been observed from historical data that the market maturity of Diesel is still not 1 which signifies incomplete acceptance by the consumers. Diesel maturity is expected to remain constant over the coming years, as there is no expected attitude change. While Diesel was speculated to grow in maturity to match that of petrol, the market has been disrupted by EVs and hence the Diesel market will not reach full maturity.

EVs including both BEVs and PHEVs on the other hand exhibit very low market maturity as of 2022 and based on available historical data since the infancy of the EV market in Greece in 2019. It is expected for the EV market maturity to grow very rapidly over the coming years, as exhibited in other leading markets. Regarding PHEVs, due to their hybrid nature, their maturity constraints are brought forward by the electric capability of the vehicle. This validates the assumption that BEV and PHEV market maturity will grow at the same rate. It is important to note, however, that given the reduced support for PHEVs and non-reducing costs, the growing market maturity will not directly translate to a large PHEV market share.

The estimation of the future market maturity indices of BEVs and PHEVs can be done based on a logistic growth model which starts from current market maturity values from available data [21]. The formulation and parameters of a logistic growth function can be seen in equation (4).

$$\omega_t = \frac{1}{1 + \frac{\omega_t - \omega_0}{\omega_0} . e^{-g \, . \, (t - t_0)}} \qquad (4)$$

t: year

ω_t: market maturity index at year t

g: growth rate

The most important parameter of this logistic growth model is the growth rate g. As discussed, the market maturity is based on two main attributes: range anxiety/available infrastructure and consumer attitude independently from costs. Both those factors vary between different consumers and hence this variation must be accounted for.

A technology acceptance model (TAM) based scoring methodology was used to scale the growth rate of the EV MMI. The score is normalized between the compared regions between 0 and 1, where the region with the highest technology acceptance and hence highest growth rate is the region with the highest score. TAM is based on highlighting how perceived usefulness (PU) and perceived ease of use (PEU) are the core of technology acceptance by an individual [22]. PEU is used as a parallel to available infrastructure and PU is used as a parallel to consumer attitude.

Regarding the PEU, the charging infrastructure availability and ease of use of EVs vary depending on the region. We use charger area density in charger/km as a measure of PEU. On the other hand, it is more difficult to quantify and score the PU and consumer attitudes. Attributes of early adopters of EVs have been analyzed in several studies that have shown that regions with higher GDP/capita and higher education levels have a more positive attitude towards EVs due to their knowledge of technology and environmental awareness and responsibility. We use the ratio of adults with a tertiary education and GDP/capita as a measure of PU. In summary, the TAM score is dependent on three factors: charger density, education levels, and GDP/capita.

It is also necessary to accurately approximate the base growth rate of the logistic growth model. Linear forecasting can be used to estimate the trend of the MMI. While logistic growth better accounts for the slow early growth and rapid later growth, estimating the growth rate may prove challenging. We use linear forecasting to tune the growth parameter of the logistic growth model. To account for the different maturity rates between different regions, complete data on the market share of both BEVs and PHEVs per region is necessary. This data breakdown is not available in Greece, but a range on the regional variation of EV market share in 2022 was approximated using data from the Hellenic Association of Motor Vehicle Importers [23]. The TAM score was then normalized against the range and 2022 market share values for each region were available for use for a linear forecasting of market maturity for each region. Finally, the growth rate of the logistic growth model was tuned against the linear forecasting results and the logistic growth parameter was identified. This scoring methodology has been observed to show consistent results with available data.

Degree of substitution

The degree of substitution is a quantitative measure of how the choices of the discrete choice model are alternatives to each other. It signifies the ease of switching from one choice to another in response to a change in the cost. A recent study analyzing consumer behavior in choosing between vehicles demonstrated the relation between the degree of substitution and income where higher-income consumers are observed to have a higher degree of substitution [24], [25]. This effect can be attributed to several factors. Firstly, higher-income consumers have a lower risk in the substitution between vehicle types. Higher-income consumers also can afford more vehicle options to choose from and hence it is easier for them to switch to an alternative due to their higher purchasing power. Finally, higher income generally correlates with a higher awareness of up-to-date technology, which makes them more knowledgeable about substitutions and alternatives.

In this model, a range for the degree of substitution is taken between -7 and -4 where the regions with the highest average income/capita takes a value of -7 and the region with the lowest average income per capita takes a value of -4. This range is found to be consistent with the other model parameters.

4.2 Model Parameters

Consumers

As mentioned in the model scope section, the consumers in the model are based on the 13 NUTS-2 regions of Greece. A regional average approach is taken for each region, due to the limited data availability regarding the complete breakdown of the population within each region. The regions as well as their main used demographic attributes are collected from EUROSTAT and ELSTAT and can be seen in Table 1 [26], [27].

Table 1: Regional Demographic Data [26], [27]

	Average income/capita (€)	Population Density (resident/km2)	Area (km)	GDP/Capita (€)	Household Ownership (%)	Tertiary Education 25-64 (%)
Attica	11645.64	987.5	3808	23,000	79%	45%
North Aegean	8703.491	59.3	3836	11,100	90%	27.9%
South Aegean	10028.43	66.1	5286	17,200	81%	24.1%
Crete	9175.058	76.5	8336	14,000	87%	27.6%
Eastern Macedonia and Thrace	8775.399	42.8	14157	12,000	87%	24.9%
Central Macedonia	9681.141	101.2	18811	13,400	85%	33.3%
Western Macedonia	10447.52	28.8	9451	14,100	90%	27.7%
Epirus	9639.114	36.8	9203	12,200	84%	30%
Thessaly	9216.956	51.4	14037	13,200	85%	32.8%
Ionian Islands	11246.04	89.4	2307	15,100	91%	18.8%
Western Greece	8851.252	59.2	11350	12,700	83%	26%
Central Greece	8861.872	36.1	15549	17,400	88%	24.7%
Peloponnese	9375.247	37.1	15490	14,800	87%	24.7%

Vehicle Options

The choice for the user is set between 4 fuel types. It is important to note that the discrete choice model is run separately for each vehicle segment under the assumption that the market for each vehicle segment is separate. Generally, an individual chooses their vehicle segment based on their needs and preferences. The discrete choice model results are compiled afterward using the market distribution average observed historically between vehicle segments. For each segment, the vehicle choices are petrol, diesel, BEV, and PHEV.

Vehicle Segments

The segmentation by vehicle size was guided by data availability and breakdown. The segmentation follows the methodology used in the Study on new mobility patterns in European cities: Task C, Development of a consistent dataset for quantitative analysis (NMP)[28]. The equivalent European Commission segmentation can be seen in Table 2 [29]. The inputs to the model vary per segment and hence it is important not to combine all the segments in the discrete choice model due to the varying utility.

Table 2: Vehicle Segments [28], [29]

Model Segment	**European Commission Segment**
Small	A+B
Medium	C+D
Large-SUV	E+F+MPV+SUV

4.3 Model Inputs

The inputs to the model are spanned over its scope. The model input variations are defined by two parameters: regional variations and time variations. Regional variations are how some of the model inputs vary between regions, based on the demographics of the region and characteristics of the typical user in said region. The time variations are variations in model inputs over time based on assumptions or an anticipated final value. Through the considerations of both the regional and the time variations, yearly values per year and per regions are devised for each model input. The cost index inputs are summarized in Table 3 before being discussed in detail below.

Table 3: Cost Index Inputs Summary

Input	**Variation / Time**	**Variation / Region**
Purchase Costs	Price parity with ICE ahieved by 2030	Purchase Annuity varies based on discount rate (average income/capita)
Fuel Costs	Fuel price: 20% increase for ICEs, 8% increase for EVs, 30% Fuel economy: 30% improvements for ICEs, 10% improvement for EVs	Vary based on mileage (population density)
Depreciation	Constant	Constant
Insurance	Constant	Constant
Maintenance	Constant	Constant
Public Charging Waiting Costs	Calculated based on number of emergency public charging stops. Reduced by 30% from 2023-2030	Vary based on homeownership rate
Range Anxiety Costs	Calculated based on number of long trips requiring an alternative vehicle. Reduced by 30% from 2023-2030.	Vary based on existing charger density

4.3.1 Initial Costs

The initial purchasing cost of a vehicle is often the first thing to consider when deciding to acquire a vehicle. The choice between different vehicle options is often limited to this initial bulk cost and the total cost of ownership is often disregarded. This often translates into a lack of knowledge of the consumer of whether the higher purchasing cost option is the option that will incur more costs overall or not. Potential buyers of EVs often state the higher initial cost of EVs as the limitation to their choice of Evs [11].

Additionally, several studies explore the shift in consumer opinion and willingness to purchase an EV based on information on the total cost of ownership rather than the initialized purchasing costs. The total cost of ownership approach is the one taken in this model and it accounts for both the initial costs (CAPex) and the running costs (OPex) to provide a complete measurements of all incurred costs over a unit of measurement, such as time or mileage. In other words, total cost of ownership can be calculated in terms of monetary units per distance or monetary units per time.

Two relevant studies use stated preference and ranked-order logit regression to analyse the change in consumer stated ranking between different vehicle types. One of those studies conducts the survey in US metropolitan areas in 2015, a period of time with little consumer awareness and market maturity of Evs or EV-supporting infrastructure [30]. The study shows an insignificant effect of the additional knowledge to user preference. On the other hand, another study completed in China at the same time concluded remarkable significance in the effect on consumers following the total cost of ownership knowledge [31]. China is a leading EV market and the difference in results between both studies can be attributed to the levels of market maturity of EVs in China compared to the US.

The EV market now is more mature and hence the results from China show more relevance when considering the current factors affecting EV uptake in most countries, including Greece, where the total cost of ownership carries greater significance to the consumer. For this reason, the total cost of ownership approach is the one taken for this analysis.

Discount Rate

To translate CAPex into the total cost of ownership, the discount rate associated with the initial investment must be taken into account. The term "discount rate" is used in individual investment to describe the rate at which a person values future cash flows in relation to their current value. Essentially, it is the rate of return required by the individual to account for factors, such as the time value of money and investment risk. In the context of vehicle investment, an individual may use a discount rate to assess the potential returns from buying a vehicle versus investing that money in an alternative. It is a measure of the cost of risk involved with the initial investment and is hence essential when calculating the cost inform to different consumer groups.

A review of the different total cost of ownership of vehicles calculation methodologies highlights the importance of incorporating the discount rate into the analysis to ensure uniformity with similar investments and to more accurately refelect the variation in total cost of ownership driven by this cost of risk quantified by the discount ratecorrelationation between household income and discount rate is taken as demonstrated by various studies showing the lower-income households usually have a higher individual investment discount rate specifically for vehicle choice investments with a mean value of 8% [33].

Another study calculates the discount for energy-efficient vehicles and transport only to observe large variability of 19 ± 17%[12]. We take a discount rate range between 8%-12% correlated with average income per capita per region as an estimate of the expected discount rate for the typical consumer of each region. In addition to discount rate, an economic lifetime value is additionally necessary to calculate the annuity rate to be used for the calculation and is taken at an average of 10 years.

Government Incentives and taxes

The purchase of a new vehicle involves several government costs separate from the purchasing from the vehicle provider. The Value Added Tax (VAT) is an applicable tax to all purchases however, a registration tax specific to vehicles also incurs an additional cost at initial purchase. Finally, subsidies can also be included to alleviate part of the purchasing cost. In 2023 in Greece, the VAT for an ICE is 24% of purchasing price however it is reduced to 13% for Evs. Additionally, EVs are exempt from registration tax completely whereas it is at an average of 16% for ICEs and reduced to 8% for PHEVs considering how it varies according to the fuel efficiency and emission ratings of each vehicle. Finally, the purchasing of BEVs is currently subsidized at 30% up to 8,000 €. The following can be summarized below in Table 4. The significance of those taxes and subsidies on the actual incurred purchasing cost is very clear and hence those rates must be carefully accounted for especially when analyzing the prospectives of various policies and incentives.

Table 4: Taxes and Subsidies per Vehicle Type in Greece in 2023

Vehicle Type	VAT	Registration Tax	Subsidies
ICE	+26%	+16%	0%
PHEV	+13%	+8%	0%
BEV	+13%	+0%	-30% up to 8,000 €

For this model, the user has the ability to control the different government fiscal tools independently including VAT, registration Tax, subsidies, and excise duties. The data until 2023 is automatically included in the model but the user can visualize future measures. The subsidy and excise duty control additionally allows the user to specify an end date for the measure.

Home Infrastructure Cost

In addition to vehicle purchasing, for this model it is assumed that EV users will additionally purchase a level 2 home electric vehicle charger since this is an expected additional cost only incurred on the EV consumer and not applicable for ICEs and currently have achieved a stable price which can be approximated at 1,000 €. We add this cost as an annuity payment similar to vehicle purchasing price for the purpose of this analysis. It is however important to note that the charging habits of individuals are likely to shift to more public charging as the market and the infrastructure mature.

Current subsidies on home chargers were not taken into account in this model and they were added to the purchasing cost directly.

Vehicle Price Change

There is no doubt that EVs have been becoming closer in price to ICE and will continue to do so over the coming years until it reaches complete price parity. This price progression is due to two main factors: the increase in BEV supply from manufacturers and the progression in VEV technology and production capabilities, and improvements in BEV technology.

Many manufacturers have set and announced plans on accelerating BEV production and bringing ICE production to a halt in certain markets [35]. This response in the European market is an expected result of the total ban of sale of ICE vehicles including PHEVs by 2035 by the European Parliament and European Council. Additionally, many of the countries within the European Union including Greece aim to place this ban sooner than the

2035 target year [36]. This aggressive shift in vehicle supply will lead to further accelerated efficiency improvements in BEV production and the increased supply will also increase competition between manufacturers and continue to drive vehicle prices down.

Regarding the technological changes affecting BEV prices, the current most expensive element of a BEV is the battery and hence the changes in battery prices will directly transfer to BEV prices. Additionally, more efficient batteries will be more lightweight and hence further increase the fuel efficiency [37]. A review done by the International Council on Clean Transport (ICCT) identifies the battery pack as the most expensive component of a BEV and as per the analysis completed in the study based on several technical reviews, it approximates that battery prices will reduce by 7% every year. On the other hand, it does not anticipate any component price changes for ICEs. The ICCT concludes that EVs of all segments and ranges should achieve price parity with ICEs between 2024-2030 [38].

In order to more accurately reflect for the importance of the price difference between ICEs and BEVs and to account for the currently still limited choices for BEVs at all price levels, we keep the price of ICEs constant and change the price of BEVs from a current markup to a reduced mark-up from current values by 20%. The used price changes can be seen in Table 5. In other words, if a large-SUV segment vehicle was 40% more expensive than its ICE counterpart in 2023, it is assumed it will only be 20% more expensive by 2030. It is important to note that the price difference varies per size segment whereas larger vehicles exhibit a smaller price premium for EVs.

This methodology follows the approach taken by the New Mobility Patterns Project which approximate purchasing cost as a relative difference with petrol equivalents per segment [28]. The expert opinion coming from most studies and analyses speculate price parity in Europe between 2028-2030 for all vehicle segments where smaller segments achieve price parity sooner [39]–[43]. We hence assume price parity of BEVs with petrol vehicles is reached for all segments by 2030 starting from current values based on a compilation of price boards as can be seen in Table 5.

On the other hand, PHEVs are assumed to remain stable in price at current market value. This is due to several factors. Firstly, the battery only contributes a small portion of a PHEV's cost since it still includes an ICE system in addition to the battery system. We have already seen from historical trends how BEVs have fallen in price at a faster rate than PHEVs and often PHEVs are the same price or sometimes more expensive than their

BEV counterparts. Additionally, Greece is an example where subsidies on PHEVs were removed in 2023 which is an expected step due to how PHEV are part of the ban that is planned to be imposed. In summary, there is little motivation to reduce PHEV prices in a regulated e-mobility market such as the European market and hence for this analysis we assume no reduction in PHEV prices [38].

Table 5: Relative price difference of BEVs relative to Petrol Vehicles

Segment	**2023**	**2030**
Small	+50%	0%
Medium	+45%	0%
Large-SUV	+35%	0%

4.3.2 Fuel Cost

Fuel costs are the most direct cost of operation of vehicles and is often the source of the largest variation between EVs and ICE. Fuel costs are calculated based on 3 main components: fuel economy which is the efficiency of the use of fuel in the vehicle, fuel price which is a set based on market values, and fuel taxes and excise duties which are imposed by the government. Each component is discussed independently below.

Fuel Economy

In addition to the fuel costs, fuel efficiency is another important factor to consider when analysing the cost incurred from fuel on the user. For the starting values, we take the fuel efficiency values from the NMP database. Given the current strict emission and fuel efficiency regulation and based on expert opinion from various sources regarding ICEs, we aassumea fuel usage efficiency improvement in ICE vehicles of 30% by 2030 [44]. As for BEVs, as previously discussed and based on technological advances we assume a fuel efficiency improvement of 10% [45].

Fuel Price

Fuel price is set based on the market forces. For the purpose of this model, household electricity pricing is used for BEVs despite the varying costs incurred depending on where the user chooses to charge their vehicle. Further granularity can be added in future progress of this work. As for fuel price of PHEV, an assumption that 75% of the time

PHEVs are fuelled with petrol and 25% with electricity is used. The previous years have shown extremely strong variations and instability in fuel pricing due to political and economic factors and hence averages of 2021-2023 prices are taken for the starting values at 2023 and a steady increase in petrol and diesel prices of 20% by 2030 and an increase in electricity by 8% for electricity prices is assumed to follow observed trends and based on an ICCT study based on US fuel prices [38].

Fuel Tax

Fuel taxes in greece have remained stable and are assumed to remain stable for the time scope of the model however, the model allows the user to alter the fuel tax if needed. It is however observed that this fuel tax incurs a very small cost on the user which has a very insignificant effect. Additionally, varying VAT costs in electricity sales are not considered in this model and it is assumed all electricity incurs the same rate of taxation.

Mileage

The cost index in a per km basis. To ensure that all the inputs are measured against the same base, average yearly mileage is considered in the calculation. It is used specifically when calculating the fuel cost for a single year whereas a higher mileage would equate to higher fuel operating costs. A study completed in Japan by analyzing passenger vehicle certifications across different regions has found a strong inverse corellation between average annual mileage and population density varying around 10,000 km/year [46]. Several other studies have demonstrated the same relationship between vehicle miles traveled and population density in other global regions [47]–[49]. A range of 9,000 km-12,000 km is taken for the mileage across different population densitites in the regions analysed in the model as per the base case [50].

4.3.3 Depreciation

Depreciation is a necessary incurred cost to consider when analyzing the cost index of alternative vehicle options. Most notably, this is due to how the depreciation rate of BEVs is generally higher than that of its more mature ICE counterparts. This is due to how the EV technology is currently rapidly developing and vehicles are becoming outdated at a relatively higher rate than ICE vehicles. Not all similar models include depreciation as an incurred cost however, several studies demonstrate the variation in depreciation rates between vehicle types and hence it is a necessary inclusion for consideration [51]. The approximated yearly rate of depreciation are assumed over a 10 year economic lifetime of a vehicle and approximated at 63% of purchasing price for ICEs and 74% of BEVs according to a study specifically comparing the relative depreciation rates between ICEs and BEVs [52].

4.3.4 Insurance

Insurance costs are assumed to remain constant and based on historical NMP data. The data is consistent with the market cost of insurance which is approximately 35% higher for BEVs than ICE vehicles [53], [54]. Varying insurance costs between users are not taken into account under the assumption that the variation in insurance cost will apply to all vehicle types. For example, an individual might have higher insurance costs for either a choice of a BEV or a petrol vehicle.

4.3.5 Maintenance

Maintenance costs, similarly to insurance costs, are assumed to remain stable based on NMP data which shows consistent trends with market analysis showing how maintenance of EVs is approximately 40% lower for BEVs than ICE due to a lower number of components requiring maintenance and replacement [55]. The most significant cost of maintenance in a BEV is the replacement of a battery out of warranty which is often assumed to have the same lifetime as the vehicle and hence requires no replacement [56]. Knowledge of maintenance technique and its impact on consumer choice independently from maintenance cost is not considered of this analysis however, it is important to note that with the maturity of the BEV market, this will not be a relevant factor despite it currently being an indirect barrier to EV adoption [57].

4.3.6 Public Charging Waiting Cost

BEVs and PHEVs are typically charged privately overnight. PHEVs are assumed to not be charged publicly and exclusively refueled. This section is specific to BEVs that may require public charging.

Utility factor is the percentage of the user mileage that can be completed with home charging only. The National Argonne Laboratory developed a methodology to calculate the utility factor and the percentage of home charging as a function of EV range [58]. Another study uses the utility factor to calculate the percentage of home charging and through this percentage, the number of public charging sessions are calculated according to equationError! Reference source not found. and for the baseline, the term public charging refers to DC fast chargers which is assumed to require the user to passively wait for the charging.

$$Number\ of\ Public\ Charging\ Sessions = \frac{Mileage\ of\ Public\ Charging}{EV\ range} \quad (5)$$

For the baseline scenario, the average BEV range is taken as 400 km and the average of 10,000 km/year is taken for the yearly mileage and a utility factor of 88% which would equate to 84% home charging and 16% public charging or an average of 7 public charging stops [59]. Taking the average DC fast-charging duration to be 45 minutes and 15 minutes to redirect the route to find a charger for a total of 1 hour and the average hourly wage in Greece to be 18 € which would put the average recharging time cost/year at approximately 126 € [27]. On the other hand, Level 2 public chargers such as those in residential areas and places of work are assumed not to require any additional time spent since the car is parked and hence only DC fast charging time is considered.

Over the years, the range of BEV is assumed to rise from 300 km to double and match the average of ICE vehicles at 600 km by 2030 [60]. As the range gradually changes over time, the anticipated need for DC fast charging will fall from 16% to 6% and from 7 stops to 3 stops. To account for the current stage of the curbside charging where it is still in a developing stage, we assume that by 2030 the number of stops will only reduce to 5 stops for the base scenario. This would lead to a cost reduction from 126€ to 90€. The feasibility and ease of home charging which would alleviate the need for public charging can be attributed to several features of the consumer and their household and trip patterns. Home ownership, in contrast with home rental, has been shown to be a feature affecting EV adoption due to the convenience of installing a home charger on an owned property rather than in a rented property [61]. Another study analyzing the demographic features of the BEV adopters at a regional level in the US identifies the percentage of owner-occupied units with the regional uptake [62]. The average rate of home ownership was used to scale the number of public charging stops whereas the regions with the lowest ownership rate were assumed to have to make 12 stops and the region with the highest ownership rate was assumed to have to make 7 stops.

The time cost associated with public charging of EVs is usually overestimated by potential buyers due to misinformation regarding vehicle ranges and an overestimation of their own driving habits and daily range needs. As seen above, the cost incurred from public charging with the assumption of completely lost time is very low compared to the barrier this factor places on BEV adoption. While this cost is hidden and not explicit in nature, this model accounts for it to provide a more quantifiable and complete cost comparison.

With infrastructure development and advancing battery and charging technology, the time required for public charging is expected to significantly drop to reach an equivalent of the re-fueling time of a traditional ICE vehicle.

4.3.7 Range Anxiety Cost

Range anxiety cost is another hidden cost of BEVs. This cost can be calculated using an range-limitation cost approach that approximates the range-limitation costs as the number of days requiring an alternative vehicle due to out of range trips multiplied by the cost of the alternative vehicle [63]. The out-of-range trips are affected by two factors: vehicle ranges and infrastructure availability. For the purpose of this calculation, a conservative alternative rental vehicle costing 50 € a day is used. As ranges and infrastructure develops, the number of out of range trips is reduced from 12 trips a year (one trip/month) by 25% to 8 trips per year [64].

As discussed, the charging infrastructure availability and reliability plays a big role on the user perspective on range anxiety. To account for the variations between regions on the charger infrastructure, the number of chargers/areas was calculated for each region and the number of steps was scaled from 12 trips at regions with high charging density to 20 trips for the regions with the lowest charger density. The number of chargers in each region as extracted using an API from Open Charge Maps [65]. The total number of chargers available was unfortunately only 10% of the total number of chargers reported in other sources, however no other source provided a distribution of the chargers over the regions. Hence, the data from Open Charge Maps was reasonable to use since the range anxiety scaling index is based on relative charger density from other regions rather than the absolute charger density. The Greek government is currently working on a uniform database of all publicly available EV chargers on a map [66]. Once this database is complete, the information used in the model can be updated accordingly.

A more detailed analysis of trip habits as well as alternatives including a second vehicle or public transportation are not considered but would provide a more personalized and complete estimation of the range-anxiety costs.

4.4 Derivative Results

The discrete choice model results are the market share of each vehicle option. Those results can be processed to estimate EV unit sales, EV fleet size, and required charging infrastructure to support EV fleet.

4.4.1 BEV Share of total Stock

The market share of BEVs in new vehicles is not sufficient on its own to show the spread of BEVs. This is especially important to note in Greece since the average age of a vehicle before it is scrapped is one of the highest in Europe standing at 33.9 years [67]. BEVs are currently only replacing new vehicles since there is a very small market and stock of BEVs is available in the resale market. Each region has a different rate of buying new vehicles. In order to account for the variation between regions in regards to buying additional new vehicles into the stock, we use the 2022 data of vehicle registrations in Greece and calibrate the new vehicle registration and BEV market share accordingly to produce the absolute number of BEVs registered each year as can be seen in Table 6 [68].

We also use the Greece NECP values for forecasted new vehicle registrations until 2030 and keep it constant until 2035 for the purpose of this analysis as can be seen in Table 7 [69]. The values used can be observed below. Furthermore, we also account for how the stock of vehicles is distributed across regions and we keep this as a constant for the model assuming the stock distribution will remain the same. Those assumptions and values allow us to calculate the percentage of BEVs out of the stock of vehicles in the region. Finally, the model also assumes that while new vehicle registrations might increase, the vehicle stock will remain constant. This is a valid assumption especially considering the current efforts and policies regarding the scrappage of older vehicles due to their strong fuel inefficiency and effect on the environment.

Table 6: Yearly New Registrations Forecast bases on NECP [69]

Year	**New Registrations(units)**
2017	103,000
2018	103,000
2019	114330

2020	126906.3
2021	137058.8
2022	148023.5
2023	159865.4
2024	172654.6
2025	186467
2026	201384.3
2027	217495.1
2028	234894.7
2029	253686.3
2030	273981.2
2031	273981.2
2032	273981.2
2033	273981.2
2034	273981.2
2035	273981.2

Table 7: New Registration and Stock Regional Distribution [68]

	Stock Ratio	**New Vehicle Ratio**
Attica	55%	73%
North Aegean	1%	1%
South Aegean	2%	1%
Crete	5%	5%
Eastern Macedonia and Thrace	4%	2%
Central Macedonia	14%	7%
Western Macedonia	2%	2%
Epirus	2%	2%

Thessaly	5%	2%
Ionian Islands	2%	1%
Western Greece	3%	2%
Central Greece	2%	1%
Peloponnese	2%	1%

4.4.2 Charging Infrastructure

The NECP update completed in 2022 additionally sets a goal of a charging infrastructure/EV ratio of 10 EVs per charger and this target was used to calculate the necessary number of chargers per region.

5 Scenarios

Various scenarios can be analyzed to assess the success or failure of EV policies. Additionally, the scenarios can provide guidelines on future steps that can be taken to further increase the EV uptake in relevant regions. A summary of the 4 scenarios can be seen in

Scenario	**Baseline**	**Extended Incentives**	**ICE Excise**	**Accelerated Market Maturity**
Subsidies	- 2022 subsidies valid until 2024 - VAT reduction and Road Tax Exemption kept until 2030	- 2022 subsidies kept until 2030 - VAT reduction and Road Tax Exemption kept until 2030	- 2022 subsidies valid until 2024 - VAT reduction and Road Tax Exemption kept until 2030	- 2022 subsidies valid until 2024 - VAT reduction and Road Tax Exemption kept until 2030
Excise Duties	No additional Excise Duties	No additional Excise Duties	Additional 10% excise duty on ICE vehicles	No additional Excise Duties
Market Maturity	Baseline	Baseline	Baseline	Market Maturity Accelerated

5.1 Baseline Scenario

The baseline scenario is based on current regulations and incentives announced and in place. It assumes no renewal of the current subsidy incentive in place under the assumption that the measure budget will deplete.

This is the most important scenario since it measures the success of the current National Energy and Climate Plan goals in place, and it is the one expanded on in further analysis.

The VAT reduction and Registration tax exemptions are assumed to remain in place until full maturity of EVs.

5.2 Extended EV Incentives Scenario

This scenario explores the effect of keeping the current subsidy incentives in place for an extended period until 2030.

This scenario demonstrates the result of an extension of the current subsidies in place. The MMI is preserved at the baseline rate.

5.3 ICE Excise Duties Scenario

This scenario analyses the effect of additional excises duties on the purchasing of ICE vehicles. It demonstrates the effect of ICE disincentives on EV demand.

5.4 Accelerated Market Maturity Scenario

This scenario analyses the effect of accelerating the growth factor of the MMI. The MMI parameter is defined theoretically, and no quantitative tool or fiscal measure can be used to alter this parameter. The main factors affecting it based on the TAM including charging infrastructure and consumer attitude are relevant to government policy design and action. The purpose of this scenario is to demonstrate the impact of non-fiscal measures on the EV market share.

6 Results and Key Observations

The following section discusses some key observations made while building and testing the model using the chosen scenarios. It additionally includes results from the chosen scenarios discussed in the relevant section and analysis of how the results relate to the current targets in place. The results are expressed in terms of BEVs and places a smaller focus on PHEVs. This is due to how PHEVs are planned for phase-out as per the European Commission ICE ban and hence is less relevant to government effort. Subsidies on PHEVs have been removed in Greece in July 2022 and the updated NECP places the focus on a BEV goal rather than a general EV goal where the BEV market share of new vehicles target is 20% by 2030 and 7% by 2025.

It is important to note that the model allows for control over all the relevant parameters and the following results are a demonstration of the model capabilities and results in the Greek market context.

6.1 National Results

This section explores the results on a national level which aggregates the regional results based on new vehicle registration and fleet distribution across all regions.

6.1.1 National Market Share of BEVs in new vehicles

Table 8 shows the National BEV Market Share Results obtained from each analyzed scenario. Table 9 additionally shows the share of BEVs from the total fleet of vehicles in circulation. The results are compared against the current NECP e-mobility targets to show that the base scenario successfully reaches the 2030 target. The 2025 target is however not met due to a dip in market share in 2025 due to the anticipated removal of current subsidies in place as can be seen in Figure 4. On the other hand, the 2025 target is met and exceeded in the extended incentive scenario. This demonstrates the impact of the purchase subsidies. While maintaining current subsidies would prove extremely costly, it provides a base to how subsidies should be revised to continuously close the price gap between EVs and ICE vehicles. As discussed in the purchasing price section, EVs are anticipated to achieve purchase price parity by 2030 and subsidies should be continuously revised to remove the purchasing barrier. On the other hand, the impact of additional excise duties and taxation on ICE vehicles could continue to make BEVs more favorable. Excise duties are a common tool used to discourage good consumption, but it is a difficult measure to enforce due to the anticipated disagreement of the consumers. Finally, the accelerated market maturity.

The accelerated market maturity scenario is an optimistic extension of the base scenario under two assumptions: an improved consumer acceptance of BEVs and an accelerated development of charging infrastructure. It does not numerically corollate with specific government action or policy, but it signifies the power of the hidden limitations of market maturity on the E-mobility market. Fiscal tools are powerful in growing the market of EVs, however, additional tools addressing the market maturity and hidden limitations of EVs must be equally addressed.

Table 8: BEV Market Share of New Registrations for Each Scenario

Scenario	**2022**	**2023**	**2024**	***2025***	**2026**	**2027**	**2028**	**2029**	***2030***
Base	2.87 %	4.82 %	6.53 %	4.38 %	6.01%	8.23%	11.25 %	15.29 %	20.57 %
Extended Incentives	2.87 %	4.82 %	6.53 %	8.82 %	11.88 %	15.90 %	21.06 %	27.38 %	*34.80 %*
ICE Excise	2.87 %	4.89 %	8.62 %	5.84 %	7.97%	10.84 %	14.67 %	19.68 %	*26.03 %*
Accelerated Market Maturity	2.87 %	5.12 %	7.31 %	5.20 %	7.46%	10.62 %	14.91 %	20.57 %	*27.71 %*

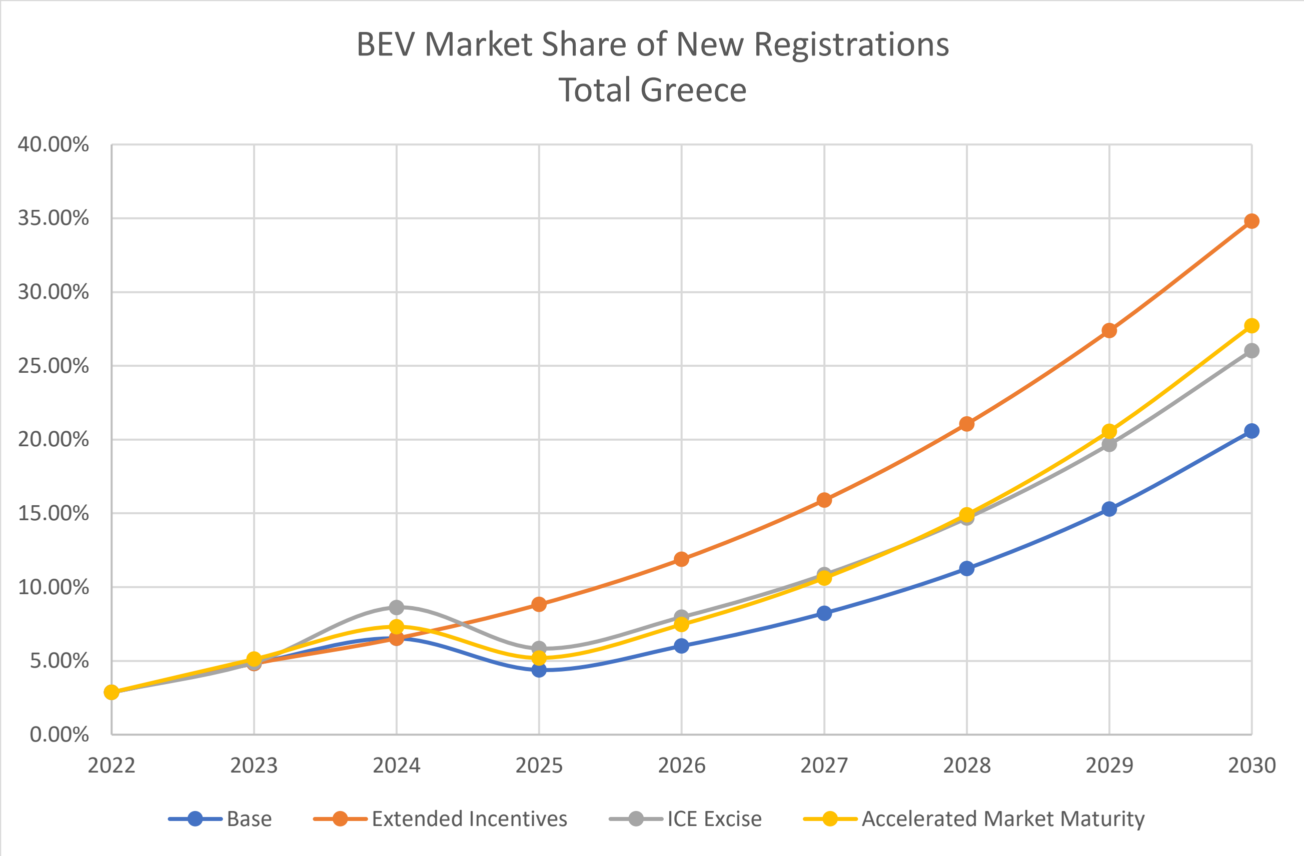

Figure 4: BEV Market Share Results for Each Scenario

Table 9 shows the percentage of BEVs from the total fleet at each scenario. This information can be used to analyze the necessary measures necessary to meet vehicles in circulation targets. It also allows for the calculation of the number of BEVs in circulation in order to plan infrastructure accordingly to meet charging targets.

Table 9: BEV Share of Total Fleet for Each Scenario

Scenario	**2022**	**2023**	**2024**	***2025***	**2026**	**2027**	**2028**	**2029**	***2030***
Base	0.12 %	0.21 %	0.36 %	0.46 %	0.61 %	0.84 %	1.18 %	1.67 %	*2.39 %*
Extended Incentives	0.12 %	0.21 %	0.36 %	0.57 %	0.87 %	1.31 %	1.94 %	2.82 %	*4.03 %*
ICE Excise	0.12 %	0.21 %	0.40 %	0.54 %	0.75 %	1.05 %	1.48 %	2.12 %	*3.02 %*

Accelerated Market Maturity	0.12 %	0.22 %	0.38 %	0.50 %	0.69 %	0.99 %	1.43 %	2.10 %	*3.06 %*

6.1.2 Cost Index

The cost index of BEVs is presented here for the base scenario and the extended incentive scenario since ICE excise duties only impact ICE cost index and the market maturity scenario has no change from the baseline scenario. The cost index is shown separately for each segment due to the large variation in costs for small BEVs in Table 10, medium BEVs in Table 11, and large-SUV BEVs in Table 12. The relative cost difference between BEVs and petrol vehicles additionally provides valuable insight. Table 13 shows the €/km Cost Index of each vehicle segment for each scenario as a percentage difference from petrol vehicles of same segment – as a weighted average across all regions based on population size. The superior cost competitiveness of EVs for larger vehicle segments is also demonstrated, which follows the current market trends in the global EV market. Additionally, we can see the 2025 brief increase in the cost index of BEVs which can is a direct result of the subsidy removal. Policy makers can draw guidelines on the necessary subsidies and timelines needed to ensure the cost index of EVs remains competitive. The model allows for control over such parameters.

Table 10: Cost Index of small BEVs for the base scenario and the extended incentive scenario [€/km]

Scenario	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	***2030***
Bases	0.86	0.78	0.75	0.69	0.66	0.74	0.71	0.68	0.65	0.61	*0.58*
Extended Incentives	0.86	0.78	0.75	0.69	0.66	0.64	0.61	0.58	0.56	0.53	*0.51*

Table 11: Cost Index of medium BEVs for the base scenario and the extended incentive scenario [€/km]

Scenario	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	***2030***
Bases	1.34	1.22	1.18	1.09	1.05	1.15	1.10	1.05	1.00	0.96	*0.91*
Extended Incentives	1.34	1.22	1.18	1.09	1.05	1.00	0.95	0.91	0.86	0.82	*0.78*

Table 12: Cost Index of large-SUV BEVs for the base scenario and the extended incentive scenario [€/km]

Scenario	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	***2030***
Bases	2.11	1.98	1.91	1.81	1.75	1.83	1.77	1.70	1.64	1.57	*1.51*
Extended Incentives	2.11	1.98	1.91	1.81	1.75	1.69	1.62	1.56	1.49	1.43	*1.36*

Table 13: Cost index average difference of BEVs relative to Petrol Vehicles for Base Scenario

Segment	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	***2030***
Small	38%	14%	11%	2%	-1%	11%	6%	2%	-2%	-7%	-11%
Medium	31%	12%	9%	1%	-3%	7%	3%	-1%	-6%	-10%	-14%
Large – SUV	21%	8%	5%	0%	-3%	1%	-2%	-5%	-9%	-12%	-15%

6.2 Regional Results for Base Scenario

The base scenario is used the results on a regional level. The trends observed for the base scenario are consistent across the studied analysis because the current scenarios analyzed here are applied on a national level. The results may vary if analyzing scenarios with an effect on a regional level such as additional subsidies on specific regions only.

6.2.1 Market Share Results

The market share of BEVs amongst new vehicle registrations is one of the most essential outputs of the model. Different regional characteristics were incorporated in building a region-specific utility function and MMI for each of the regions. The model results allow for an analysis of the impact of the used region characteristics in impacting the cost index and the overall market share of BEVs.

Regional Market Share of BEVs in New Vehicles

Table 14 shows the market share of BEVs out of all the new vehicle market alternatives. It is calculated across all segments using the historical data on segment distribution in the new vehicle market which is broken down into 79% small vehicles, 18% medium vehicle, and 3% large-SUV vehicles. This distribution is applied to all regions due to the in-availability of a regional data breakdown, however it has an impact on the results since larger vehicles have a smaller cost-index gap between EVs and ICEs.

Additionally, the starting market share in 2022 is not directly available. The only available data is a distribution by manufacturer for specific regions only. To overcome this limitation, the market shares of EVs for the available regions was approximated using the national data of registrations by EV make. This resulted in a range of market shares which was then correlated with the full national data based on the TAM score and checked for validity with major markets such as Attica and Central Macedonia which confirmed the validity of this approximation.

Table 14: Market Share of BEVs in the New Vehicle Market Across all Segments

	2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Attica	3.09 %	5.18 %	7.04 %	4.81 %	6.61 %	9.07 %	12.40 %	16.82 %	22.56 %
North Aegean	1.31 %	2.24 %	2.96 %	1.70 %	2.29 %	3.11 %	4.26 %	5.87 %	8.14 %
South Aegean	2.39 %	4.01 %	5.38 %	3.46 %	4.71 %	6.44 %	8.81 %	12.04 %	16.40 %
Crete	2.48 %	4.27 %	5.76 %	3.51 %	4.80 %	6.59 %	9.07 %	12.45 %	17.03 %
Eastern Macedonia and Thrace	1.14 %	1.92 %	2.52 %	1.44 %	1.92 %	2.59 %	3.51 %	4.81 %	6.64 %
Central Macedonia	2.73 %	4.68 %	6.31 %	4.01 %	5.49 %	7.54 %	10.34 %	14.13 %	19.18 %
Western Macedonia	2.41 %	3.84 %	5.08 %	3.46 %	4.64 %	6.24 %	8.41 %	11.33 %	15.22 %
Epirus	2.07 %	3.38 %	4.47 %	2.87 %	3.85 %	5.19 %	7.03 %	9.53 %	12.93 %
Thessaly	2.43 %	4.15 %	5.58 %	3.46 %	4.73 %	6.49 %	8.91 %	12.22 %	16.70 %

Ionian Islands	2.57 %	4.26 %	5.69 %	3.77 %	5.11 %	6.94 %	9.43 %	12.80 %	17.28 %
Western Greece	1.70 %	2.91 %	3.86 %	2.23 %	3.01 %	4.10 %	5.61 %	7.72 %	10.65 %
Central Greece	1.71 %	2.82 %	3.74 %	2.28 %	3.07 %	4.14 %	5.63 %	7.69 %	10.53 %
Peloponnese	2.18 %	3.70 %	4.91 %	2.93 %	3.97 %	5.38 %	7.33 %	10.01 %	13.67 %
total	2.87 %	4.82 %	6.53 %	4.38 %	6.01 %	8.23 %	11.25 %	15.29 %	20.57 %

Figure 6 shows the market share of BEVs in new vehicles across all segments for each region. It can be observed that the market share in 2030 largely varies between 7% and 22%. This is due to the variation in the growth rate of the market maturity for each region and is further explored in the discussion section. Additionally, Figure 6 also shows how only a single region, Attica, has an individual market share above the national total. This is attributed to how new registrations of vehicles is highly concentrated in Attica where almost 77% of new registrations are done as shown in Table 7 and hence while on the National level, the NECP targets are met, the results on a regional level mostly do not meet the targets. For this reason, it is necessary for regions to municipally enforce e-mobility targets. The variation and distribution of BEV market share is shown on the map in Figure 5 as per the Bing Geonames Microsoft Excel Mapping Functionality.

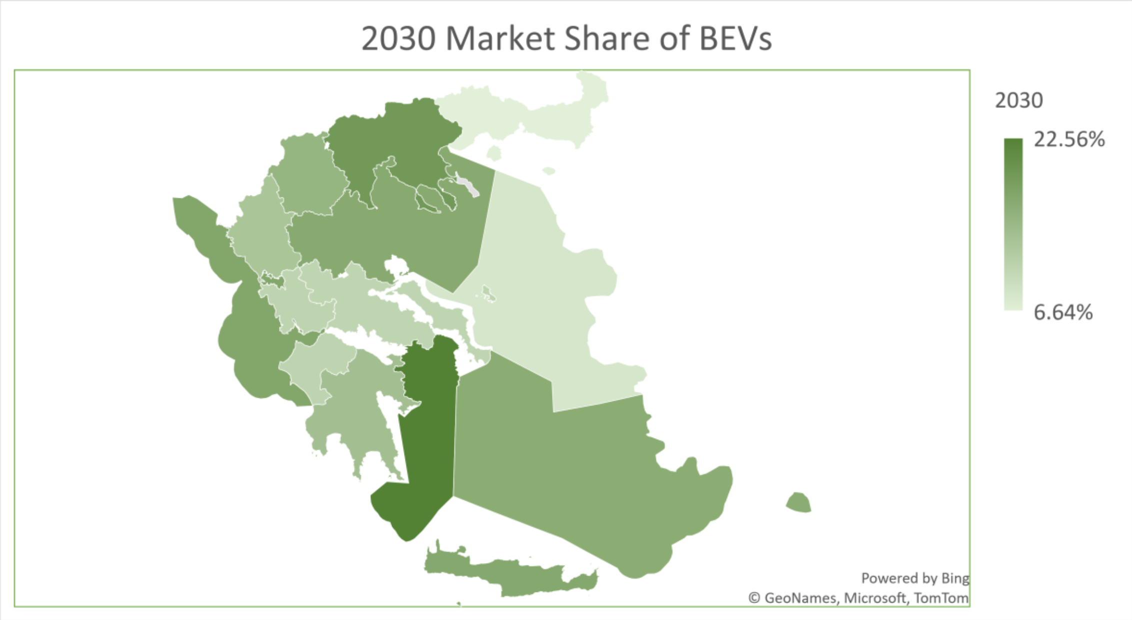

Figure 5: Map Distribution of BEV Market Share in 2030

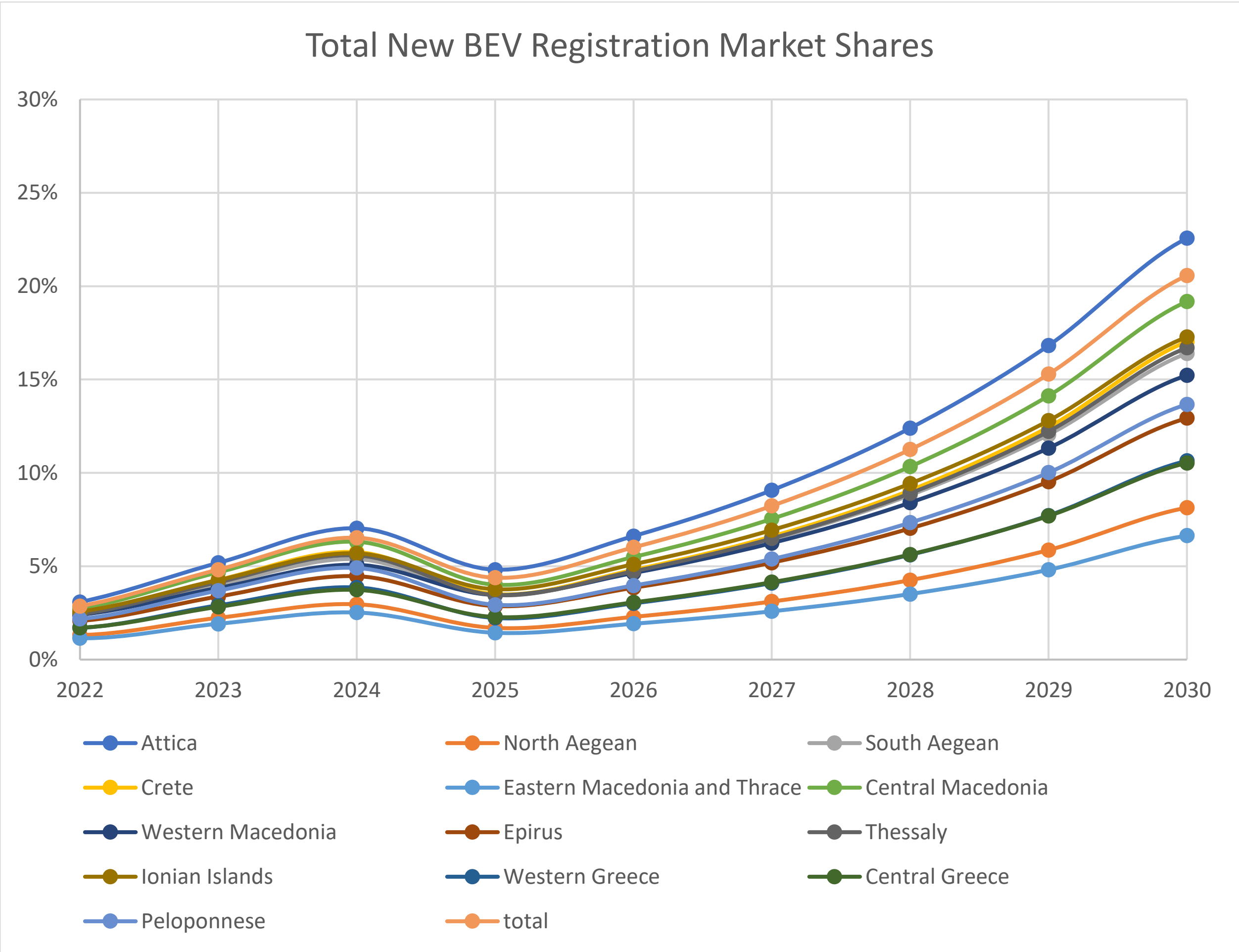

Figure 6: Market Share of BEVs for Each Region

6.2.2 Regional share of BEVs in Total Fleet

As discussed earlier, there is a large mismatch between the new registration distribution and the fleet distribution. The current rate of fleet turnover is currently very low, falling below 2% per year. This means that if 100% of new vehicle registrations are EVs, it will still take Greece approximately 50 years to completely replace the current fleet. The e-mobility transition requires a fleet turnover and re-shaping, and this process will take much longer in regions with relatively low new registrations compared to their fleet size. To resolve this matter, accelerated effort is required to promote old vehicle scrappage at a higher rate. Currently, there are some incentives in place which provide additional subsidies for the scrappage of old vehicles. While this model does not account for an accelerated fleet turnover rate, it is undoubtful that it is necessary for the success of the e-mobility transition. Additional efforts must be made to ensure that all regions are replacing old vehicles with new EVs. This issue is further demonstrated in Figure 7 which shows the growth of EVs share of the total fleet in circulation and this demonstrates the large variation in how EVs are replacing the current fleet depending on the rate of new vehicle registration.

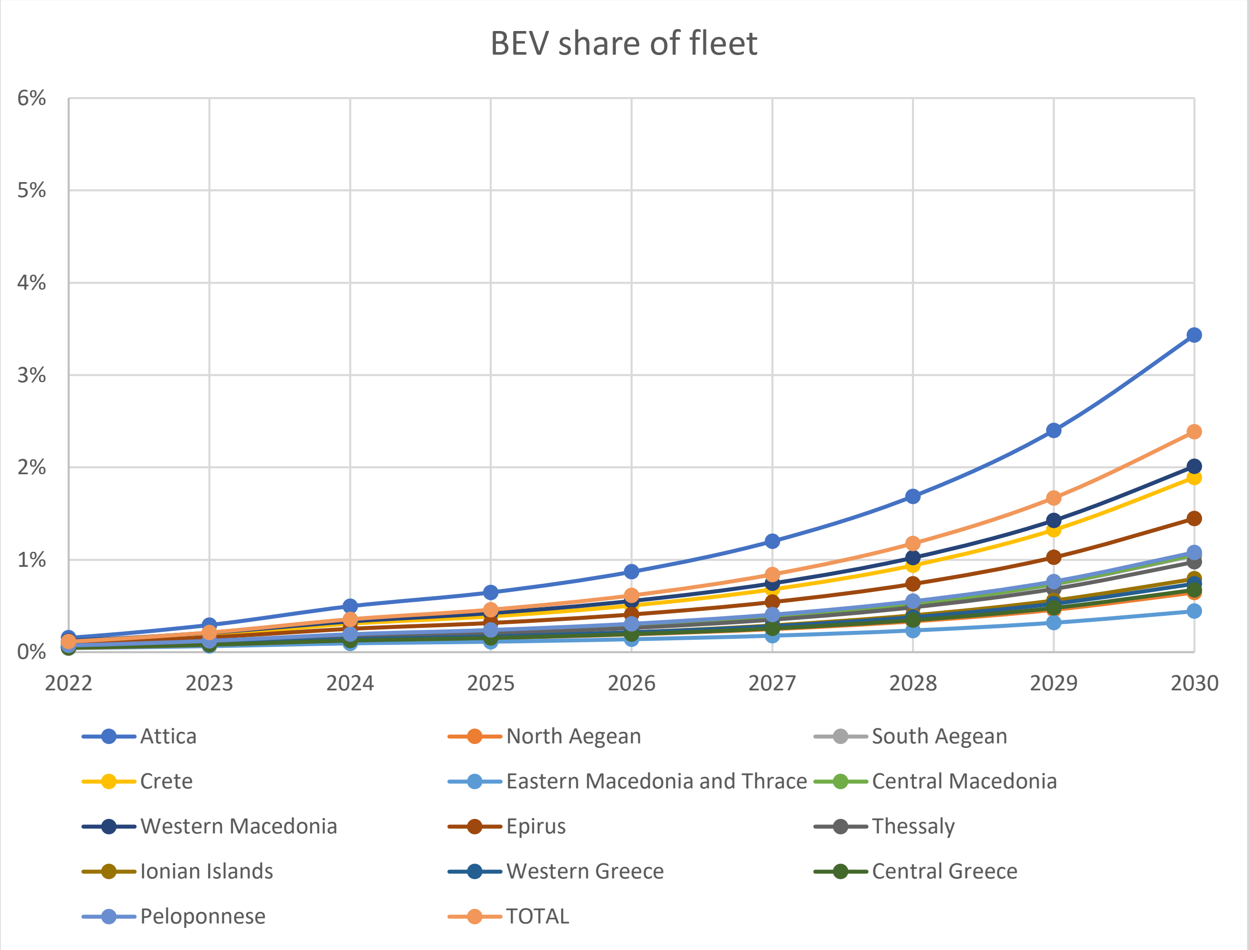

Figure 7: BEV Share of Total Fleet

The reverse ranking of cost index was compared with the resultant market share in 2030 and can be seen in Table 15. This demonstrates how the regions with the lowest cost index did not necessarily correlate to the highest market share due to the difference in the index of substitution and the MMI.

Table 15: Market Share Rank and BEV Reverse Cost Index Rank

Region	**Market Share Rank**	**Cost Index Rank**
Attica	1	5
North Aegean	12	13
South Aegean	6	7
Crete	4	10

Eastern Macedonia and Thrace	13	12
Central Macedonia	2	9
Western Macedonia	7	1
Epirus	9	2
Thessaly	5	8
Ionian Islands	3	4
Western Greece	10	11
Central Greece	11	3
Peloponnese	8	6

6.2.3 BEV Fleet Stock and Infrastructure Requirement

The infrastructure calculation is based on the simple target of the NECP of 10 BEVs/charger. The results of the fleet growth can be seen in Figure 8. The number of chargers in 2030 in the base scenario can be seen in Table 16.

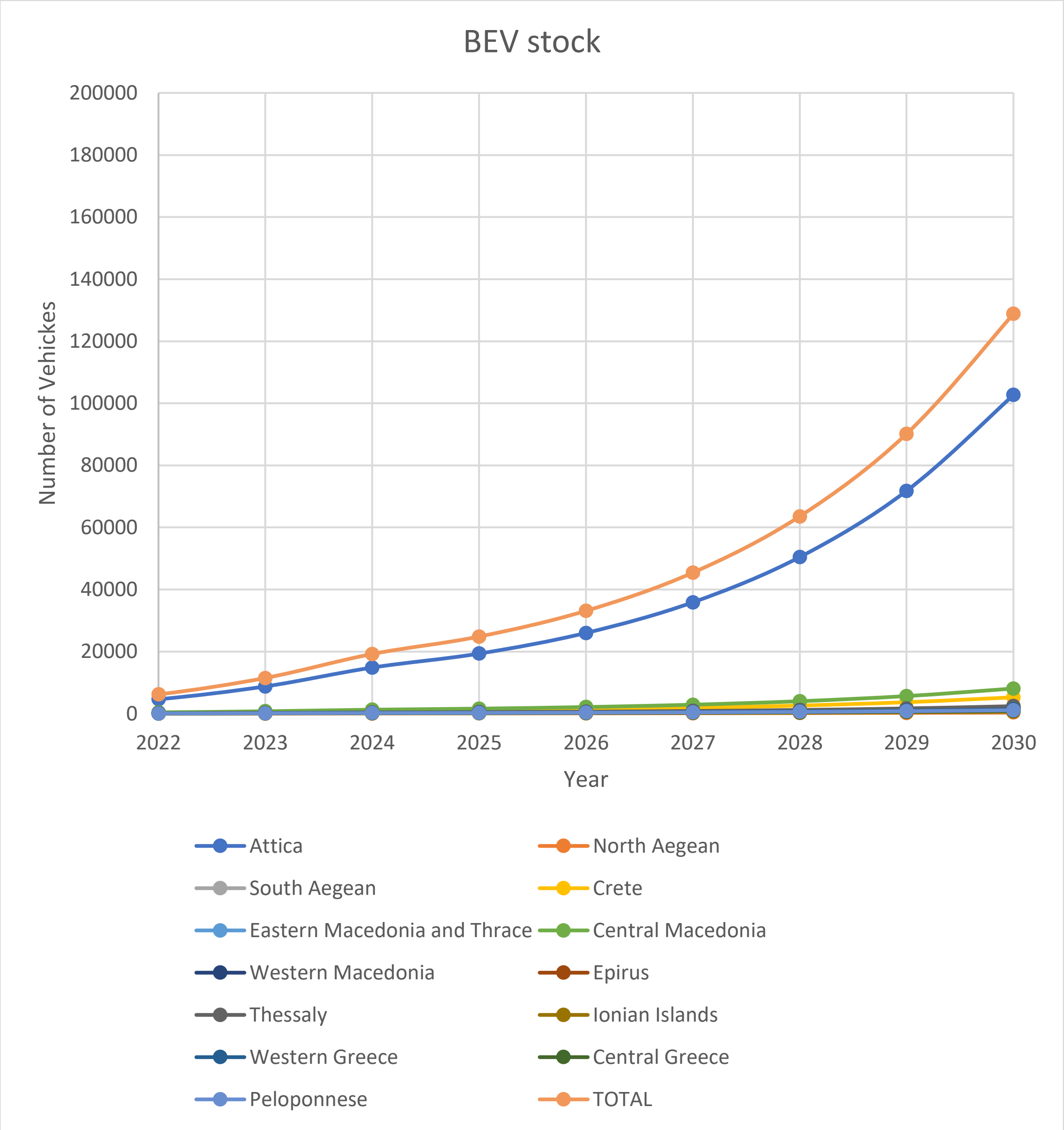

Figure 8 : Regional Fleet of BEVs

Table 16: Number of Chargers per Region based on NECP target 10 BEVs/Charger

Region	**Chargers in 2030**
Attica	10272
North Aegean	38
South Aegean	124
Crete	528

Eastern Macedonia and Thrace	95
Central Macedonia	810
Western Macedonia	198
Epirus	174
Thessaly	242
Ionian Islands	68
Western Greece	137
Central Greece	87
Peloponnese	113
TOTAL	12886

7 Analysis and Discussion

7.1 Regional Analysis

One of the most notable and important observations from the results of the simulation is the variation in the market share of BEVs across the different regions. This variation is a result of the different parameters chosen for the model analysis. The result additionally demonstrates the interrelation of all the different parameters at play. A correlation analysis is completed on the 2030 market share results and the demographic data used in the parametrization of the model.

The coefficient results can be seen in Table 17. It can be observed from the results that the parameters with the strongest correlation are firstly average income per capita, charger Density, and GDP/capita. On the other hand, household ownership holds the lowest correlation coefficient. This weak correlation can be attributed to how urban centers or cities usually have a lower household ownership rate, but a higher technology acceptance. The details of those results are further explored using an additional correlation analysis that directly compares the first-level inputs of the discrete choice model and the main parameters of the utility function which are the cost index, the MMI, and the index of substitution as demonstrated in Figure 3 and the results can be seen in Table 18.

Table 17: Correlation Coefficients with BEV Market Share in 2030

Independent Variable	Correlation Coefficient
Tertiary Education 25-64	0.54
GDP/Capita	0.62
Population Density	0.58
Charger Density	0.67
Household Ownership	-0.41
Average income/capita (€)	0.76

Table 18: Correlation Coefficients of Main Utility Function Parameters with BEV Market Share in 2030

Market Maturity Index	Cost Index BEV	Index of Substitution
0.99	-0.27	0.32

To further investigate the impact of the different demographic characteristics on the resulting market share, a correlation analysis was applied using normalized data between 0 and 1 for the dependent variable (market share) and the independent variables (demographic data) for the model results between 2022 - 2030. The normalization was completed in order to more clearly compare the strength of the different variables in the regression through their regression coefficients. Additionally, the market share results were also normalized since the focus of this analysis was on the variables causing variations between the regions rather than the resulting market share. The results are presented in Table 19. The results show that all independent variables exhibit a low to moderate positive correlation with the exception of household ownership which exhibits a weak negative correlation. The negative correlation can be explained by how urban centers and cities usually have a lower ownership rate but a higher technology acceptance. Average income exhibits the highest. This is an expected result due to the impact of a higher income on technology acceptance and purchasing power. The correlation coefficient of average income is higher than GDP/capita which is a result of the consumer choice modelling approach taken. Charger density additionally exhibits a moderate correlation. This is a direct reflection of the importance of the development of the charging infrastructure to the development of the EV market. While the positive correlation with tertiary education, income, and charger density can be directly attributed to the TAM scoring methodology used, the results of population density are of great interest. The positive correlation coefficient of population density indicates that regions with more dense regions exhibit relatively higher BEV market share. This result can be attributed to how regions with high population densities are usually cities and urban centers with higher awareness regarding new technologies, environmental awareness, and developed infrastructure, and are usually a more welcoming environment for early adopters of technologies.

Table 19: Correlation Coefficient Results for Normalized Market Share Variation

Independent Variable	Correlation Coefficient
Tertiary Education 25-64	0.518232
GDP/Capita	0.615455
Population Density	0.564318
Charger Density	0.658538
Household ownership	-0.38495
Average income/capita (€)	0.771128

To further investigate the most impactful factors affecting the variation in the cost index of BEVs across different regions, an additional correlation analysis is run the for the cost index and the different demographic factors. The normalized cost index is used in order to highlight the variation in cost index between regions. The results can be seen in Table 20. The results show a weak negative correlation relation between average income and GDP/capita and no correlation between the remaining independent variables.

Table 20 : Correlation Analysis for the Normalized Cost Index Between Regions

Independent Variable	Correlation Coefficient
Tertiary Education 25-64	-0.01733451
GDP/Capita	-0.275068137

Population Density	-0.012418358
Charger Density	-0.031305636
Household ownership	-0.047521339
Average income/capita (€)	-0.461582134

7.2 Policy Implications

7.2.1 Implications based on the Model Results

The results of this model allow policymakers to forecast the regional uptake and market share in each region and hence identify leading and lagging regions. Additionally, the forecasts enable the relevant stakeholders to assess the success of their policies on a regional scale and allocate resources across regions accordingly. The results ensure that sufficient infrastructure is developed to accommodate for the changing market.

7.2.2 Implications based on the Analysis of the Model Results

An extremely interesting observation is the weakness in the correlation of the resulting market share with the Cost Index compared to the strength of the Correlation with the MMI. This observation further supports the importance of increasing the MMI in addition to fiscal measures reducing the cost index. Policy efforts are usually focused on fiscal tools, however, with the current technological and market progress trends, EVs will exhibit lower cost indices between 2026 and 2030. The impact of fiscal tools is clear and demonstrated in the comparison between the base scenario and the extended incentive scenario where the extended incentive scenario did not experience a dip in market share compared to the base scenario. Additionally, fiscal incentives are often interrelated with the MMI through their role in altering consumer attitude and market acceptance. Another important implication of the results is how for the success of the financial incentives currently in place, MMI improvements are needed in parallel to such measures for the success of such incentives.

Many stated preference surveys have been conducted globally regarding the factors impacting the market maturity of EVs. The results shown in this study further demonstrate the importance of a more region-focused survey to identify the best strategy for increasing market maturity and consumer attitude. This study follows a literature-guided regional approximation of the development of the market maturity. However, this index requires further investigation.

The analysis of normalized market shares and cost indices provides insight into the variation between regions and can guide policymakers in identifying lagging regions in their adoption rates. The results further highlight the large gap in the adoption rates of e-mobility between regions and the necessity of tailored e-mobility development programs for lagging regions.

The results

In summary, the results of this mod

8 Model Replicability and Future Work

8.1.1 Factors to Consider in Future Work

Several factors can be additionally considered for more robust results. Those factors include regional aspects and vehicle aspects. Firstly, an extended analysis of the MMI development and variations across regions would provide significant value. This can be done through stated-preference studies aimed at identifying the factors affecting the growth of this index for different regions specifically in the target market.

Representative averages are currently being used to represent the different consumers across regions. A segmented market approach per region can provide more accurate results, since it removes the effect of outliers. Such an approach would allow us to create different consumer profiles within each region.

Additional data regarding driving habits across regions can also help more accurately predict the hidden costs of EVs, such as range anxiety and public charging. This information could be extracted through surveys of existing and potential users of EVs within different regions and environmental limitations. For example, more information regarding the availability of a second car in a household can alter some of the hidden costs associated with public recharging and range anxiety. Additionally, more details regarding potential charging habits including the feasibility of home charging and charging at work can allow for a more a more accurate calculation of charging costs and the ease of ownership of EVs.

The model currently operates under a general passenger car umbrella which, in addition to private cars, includes taxis, rental cars, business cars, car-sharing cars, and more. Different utility functions can be further defined for each type of car and different data inputs must also be considered. Current legislation in Greece, as of 2023, sets fourth separate targets and guidelines for taxis and business cars. For example, there are additional subsidies and incentives specific to electric taxis and business cars that would require separate consideration and analysis [70].

Additionally, as future work on this project and as more data becomes available, the validity of the TAM scoring methodology can be tested further and tuned more accurately to region-specific data. The methodology can also be further tested on other more mature markets than Greece such as Norway or China.

The model can be even further enhanced to operate on a more granular level with more data available on consumers in smaller regions. Such increased detail can prove extremely helpful for infrastructure planning, since it would provide a breakdown of the EVs in circulation on a smaller geographical scope.

Further consideration of rising technologies, such as vehicle-to-grid (V2G) technology, and their impact on the utility and market share of EVs to different users can provide great insight into the impact of such technologies on the vehicle market and the energy market as a whole.

8.1.2 Model Replicability and Threats to Validity

As previously stated, the model can be easily replicated and reused for other markets. This would depend on the availability of two different types of data. Firstly, vehicle-specific model inputs in reference to the model market. The input data must be available for the different vehicle options considered in the discrete choice model to accurately output the relative utility of each choice to the decision maker. This includes policies, and financial incentives historically and currently enforced. Secondly, the consumer data must also be available for the target market.

For a regional approach similar to the one taken in this project, ranges for the relevant parameters must be adapted for the market. For example, the range used for average yearly mileage in this model has been taken to range from 9,000km – 12,000 km based on the available data specific to the Greek Market. This range could widely vary for other markets with different driving habits. Additionally, the MMI must be tuned and parametrized based on historical trends observed in the market.

On the other hand, a similar model can be adapted for other vehicle markets such as the compressed Natural Gas (CNG) vehicle market or the Fuel Cell Electric Vehicle (FCEV) market powered by hydrogen. This would require a thorough analysis of the utility function for such vehicle alternatives, but the model can still be used for such examples.

Despite the rigorous methodology employed in this study, it is essential to acknowledge and address potential threats to validity. Those threats are mainly brought forward from data sources whereas the results of the model are highly dependent on the quality and accuracy of the data incorporated into the model. Furthermore, the discrete choice model assumes rational decision-making and may not fully capture all the complexities and nuances of consumer behavior, especially for such a young market. The MMI is utilized to overcome this challenge. However, exceptional circumstances play a huge role in consumer behavior as has been demonstrated following the Covid-19 pandemic and the current global political instabilities. Regular re-evaluation of all input parameters when employing this model could help ensure the continued validity of the results given the changing circumstances.

9 Concluding Remarks

This study presented a comprehensive model for forecasting the market share of Battery Electric Vehicles (BEVs) in the new car market, across different vehicle segments. By considering regional characteristics, such as population density, GDP per capita, education levels, EV charger distribution, and an EV readiness index, the model captures the regional variations in BEV uptake. The model incorporates a discrete choice framework that accounts for both tangible and intangible factors affecting consumer preferences.

In addition to evaluating the cost index of vehicles, which encompasses various cost components and factors like taxes, subsidies, range anxiety, and public charging, the analysis has explored different scenarios aligned with the Greek National Energy Climate Plan. The findings indicate that regions with higher average income, GDP per capita, and population density exhibit a higher adoption of BEVs. However, it is noteworthy that the cost index parity between BEVs and Internal Combustion Engine (ICE) vehicles is achieved before BEV market share surpasses that of ICE vehicles. This suggests that factors such as market maturity, consumer awareness, and acceptance play a pivotal role in limiting the uptake of electromobility, rather than the cost index alone.

Overall, this model serves as a valuable tool for calculating the market share and cost index of BEVs based on regional parameters. By identifying regions that require particular attention to achieve national targets, the results can inform policymakers in formulating effective strategies and infrastructure development plans to accelerate the adoption of BEVs. Specifically, policymakers can focus their efforts on regions with lower BEV uptake, thereby promoting the transition towards a more sustainable road transport sector.

This study contributes to the understanding of the dynamics of electromobility and provides insights that can drive policy decisions and facilitate the growth of BEV adoption. By recognizing the interplay between regional characteristics, market maturity, and consumer acceptance, policymakers can devise targeted interventions and create an enabling environment for the successful integration of BEVs into the transportation system.

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Appendix

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Model Manual

This document will include a description of the different parts of the model, the formulas, the methodology, and Excel file contents.

Model base

The model is applied for each vehicle segment, based on Table 2,within each region. For example, the calculation is applied independently for small, medium, and large-SUV vehicles in Attica. The results from each segment are then aggregated into total vehicle results using the historical ratio distribution between vehicle segments in new registrations as can be seen in Table 2.

Those results can then be further aggregated to national results based on the historical new vehicle registration distribution between regions in Table 2.

The results can be transformed from market share percentages to an absolute number of units using the NECP yearly new registration values as can be seen in Table 21. Finally, those results can be used to calculate the total vehicle stock under the assumption that vehicles in Greece have a 20-year average lifetime and hence no scrappage and the stock is a compilation of previous year registrations. This is summarized in Figure 9.

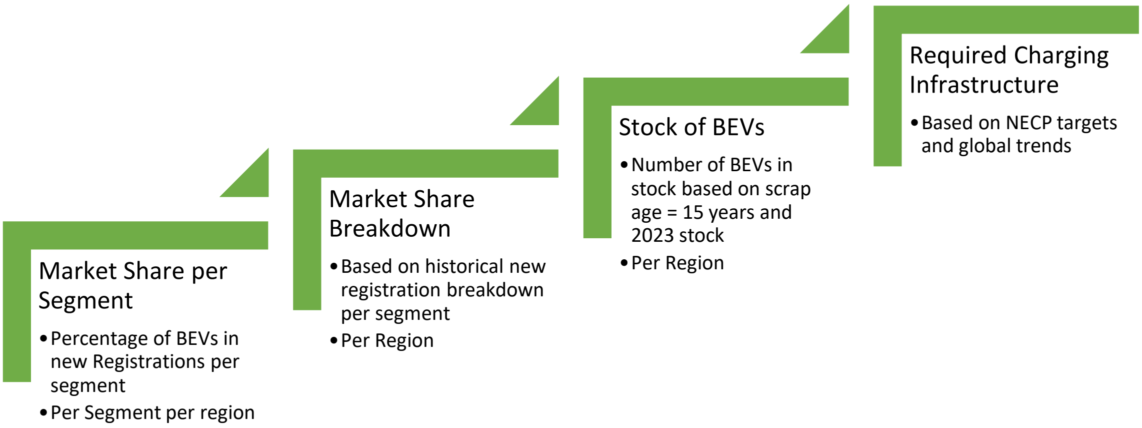

Figure 9: Model Process

Table 21: Yearly New Registrations Forecast based on NECP [69]

Year	**New Registrations(units)**
2017	103,000
2018	103,000
2019	114330
2020	126906.3
2021	137058.8
2022	148023.5
2023	159865.4
2024	172654.6
2025	186467
2026	201384.3
2027	217495.1
2028	234894.7
2029	253686.3
2030	273981.2
2031	273981.2
2032	273981.2
2033	273981.2

2034	273981.2
2035	273981.2

Table 22: New Registration and Stock Regional Distribution [68]

	Stock Ratio	**New Vehicle Ratio**
Attica	55%	73%
North Aegean	1%	1%
South Aegean	2%	1%
Crete	5%	5%
Eastern Macedonia and Thrace	4%	2%
Central Macedonia	14%	7%
Western Macedonia	2%	2%
Epirus	2%	2%
Thessaly	5%	2%
Ionian Islands	2%	1%
Western Greece	3%	2%
Central Greece	2%	1%
Peloponnese	2%	1%

Table 23: Vehicle Segments [28], [29]

Model Segment	**European Commission Segment**	**The ratio of Total New Registrations**
Small	A+B	79%
Medium	C+D	18%
Large-SUV	E+F+MPV+SUV	3%

Model Formulation

The market share calculation is based on the following formulas summarized below in Table 24: Formulas of Model where regionally varying parameters are in bold. The calculation for the regional parameters follows.

Formulas of Model

Table 24: Formulas of Model

$$MS_{u,v} = \frac{w_{u,v} \,.\, {C_{u,v}}^{y_u}}{\sum_{u,v} w_{u,v} .\; {C_{u,v}}^{y_u}}$$	(6)
u: user v: vehicle MS: Market Share C: Cost Index(€/year) w: Market Maturity Index y: degree of substitution	
$$C_{u,v} = \frac{IC_{u,v} + OC_{u,v}}{M_u}$$	(7)
IC: Initial Cost(€/year) OC: Operation Cost(€/year/km) M: Yearly Mileage	
$$IC_{u,v} = (PC_v + HC_v).\ \partial_u \,.\ \frac{(1+\partial_u)^{n_u}}{(1+\partial_u)^{n_u} - 1}$$	(8)
PC: Purchasing Cost including tax (€) HC: Home Infrastructure Cost (€) ∂: Discount Rate n: economic Lifetime	
$$OC_{u,v} = FE_v \,.\, \boldsymbol{M_u} . FP_v + (PC_v + HC_v).dp_v + ins_v + maint_v + \boldsymbol{PBI_u} \,.\, Pb_v + \boldsymbol{RAI_u} \,.\, RA_v$$	(9)
FE: Fuel Efficiency	

M: Yearly Mileage FP: Fuel Price PC: Purchasing Cost including tax HC: Home Infrastructure cost Ins: Insurance costs Maint: maintenance costs PBI: Public Charging Index **Pb: Public Charging Cost** RA: Range anxiety cost **RAI: Range Anxiety Index**	
$Pb_v = stops\ .hw$	(10)
Stops: number of emergency stops for charging not at destination/year hw: hourly wage average	
$RA_v = OT\ .Av$	(11)
OT: number of out of range trips/year Av: cost of alternative vehicle	
$\omega_t = \frac{1}{1 + \frac{\omega_t - \omega_0}{\omega_0} . e^{-\boldsymbol{g}_u \cdot\ (t-t_0)}}$	(12)
t: year ω_0: market maturity index at the year 2022 ω_t: market maturity index at year t g: growth rate	
$g_u = g_b.(1 + \boldsymbol{TAM_u})$	(13)
Gb: growth rate base TAM: Technology Acceptance Model Score	

Regional Parameters

Regional Parameters are calculated based on a variation within a specified range defined in the literature. The regions are split into 4 quartiles based on the relevant demographic statistics and then assigned values based on the chosen range. For example, the Average income per capita is split into 4 quartiles for a range of 8%-20%. The highest quartile regions are assigned a value of 8% and the lowest quartile regions are assigned a value of 20%.

Table 25: Regional Parameters

Region Number	Region	Average income/capita (€)	**DISCOUNT RATE**	Population Density (resident/km2)	**Mileage (km)**
1	**Attica**	11645.63686	**8%**	987.5	**9,000.0**
2	**North Aegean**	8703.490839	**20%**	59.3	**10,000.0**
3	**South Aegean**	10028.42668	**12%**	66.1	**10,000.0**
4	**Crete**	9175.058086	**16%**	76.5	**10,000.0**
5	**Eastern Macedonia and Thrace**	8775.398995	**20%**	42.8	**11,000.0**
6	**Central Macedonia**	9681.140783	**12%**	101.2	**9,000.0**
7	**Western Macedonia**	10447.51776	**8%**	28.8	**12,000.0**
8	**Epirus**	9639.114223	**12%**	36.8	**12,000.0**
9	**Thessaly**	9216.955937	**16%**	51.4	**11,000.0**
10	**Ionian Islands**	11246.03827	**8%**	89.4	**9,000.0**
11	**Western Greece**	8851.25222	**20%**	59.2	**11,000.0**
12	**Central Greece**	8861.871999	**16%**	36.1	**12,000.0**
13	**Peloponnese**	9375.247448	**16%**	37.1	**11,000.0**
Range					

Region Number	Region	Chargers (units)	Area (km)	chargers/km	**Range Anxiety Index**	GDP/Capita (€)	**Index of Substitution (y)**	Household Ownership (%)	**Public Charging Index**
1	**Attica**	57	3808	0.01497	**1.0**	23,000	**-7.00**	79%	**1.75**
2	**North Aegean**	1	3836	0.00026	**1.8**	11,100	**-4.00**	90%	**1.00**

3	**South Aegean**	12	5286	0.00227	**1.3**	17,200	**-7.00**	81%	**1.75**
4	**Crete**	16	8336	0.00192	**1.3**	14,000	**-5.00**	87%	**1.50**
5	**Eastern Macedonia and Thrace**	3	14157	0.00021	**1.8**	12,000	**-4.00**	87%	**1.25**
6	**Central Macedonia**	43	18811	0.00229	**1.0**	13,400	**-5.00**	85%	**1.50**
7	**Western Macedonia**	4	9451	0.00042	**1.5**	14,100	**-6.00**	90%	**1.00**
8	**Epirus**	7	9203	0.00076	**1.5**	12,200	**-4.00**	84%	**1.50**
9	**Thessaly**	18	14037	0.00128	**1.5**	13,200	**-5.00**	85%	**1.50**
10	**Ionian Islands**	6	2307	0.00260	**1.0**	15,100	**-6.00**	91%	**1.00**
11	**Western Greece**	14	11350	0.00123	**1.5**	12,700	**-5.00**	83%	**1.75**
12	**Central Greece**	6	15549	0.00039	**1.8**	17,400	**-7.00**	88%	**1.25**
13	**Peloponnese**	21	15490	0.00136	**1.3**	14,800	**-6.00**	87%	**1.25**
Range							**-4 - -7**		

Region Number	Region	Tertiary Education 25-64	score	Chargers (units)	Area (km)	Chargers/area	score	GDP/Capita (€)	score	Total Score	**TAM Score**
1	**Attica**	45	4	57.0	3,808.0	0.014968	4	23,000	4	12.0	**1.0**
2	**North Aegean**	27.9	3	1.0	3,836.0	0.000261	1	11,100	1	5.0	**0.1**
3	**South Aegean**	24.1	1	12.0	5,286.0	0.00227	4	17,200	4	9.0	**0.6**
4	**Crete**	27.6	3	16.0	8,336.0	0.001919	3	14,000	3	9.0	**0.6**
5	**Eastern Macedonia and Thrace**	24.9	2	3.0	14,157.0	0.000212	1	12,000	1	4.0	**0.0**
6	**Central Macedonia**	33.3	4	43.0	18,811.0	0.002286	4	13,400	2	10.0	**0.8**
7	**Western Macedonia**	27.7	3	4.0	9,451.0	0.000423	2	14,100	3	8.0	**0.5**
8	**Epirus**	30	4	7.0	9,203.0	0.000761	2	12,200	1	7.0	**0.4**

9	**Thessaly**	32.8	4	18.0	14,037.0	0.001282	3	13,200	2	9.0	**0.6**
10	**Ionian Islands**	18.8	1	6.0	2,307.0	0.002601	4	15,100	4	9.0	**0.6**
11	**Western Greece**	26	2	14.0	11,350.0	0.001233	2	12,700	2	6.0	**0.3**
12	**Central Greece**	24.7	1	6.0	15,549.0	0.000386	1	17,400	4	6.0	**0.3**
13	**Peloponnese**	24.7	1	21.0	15,490.0	0.001356	3	14,800	3	7.0	**0.4**
Range											

Model Outline

The spreadsheet model is designed to run on excel. It consists of the following worksheets as can be seen in Table 26.

Table 26: Model Breakdown

Workbook Name	**Description**
0.Conrol_Panel	Control Panel for model parameters
1.Costs_RegionalParameters	Inputs for cost index calculation
2.CostIndex_perRegion	Cost Index results per region
3.MarketMaturity_perRegion	Market Maturity Index per region
4.MarketShare_perRegion	Market Share Results per Region + Results Dashboard
5.ChargingDemand	Energy Demand (MWh) and charger requirements

Control Panel

This workbook allows the user to alter any of the model parameters. Each sheet in this workbook is connected to the other workbooks and automatically updates the relevant parameters. The control options are summarized in the table of contents in Table 27.

Table 27: Control Panel Details

Sheet	Description/Control
PurchasePrice_relativeChange	BEV/PHEV vs Petrol Price Growth
Purchase_tax	VAT/Registration Tax/Subsidies/Excise Duties
FuelPrice_Tax	Fuel Price Growth and Fuel Tax
Road_Tax	Road Tax
PublicChargingWaitingCost	Number of Public Charging Stops per year growth
Range Anxiety Cost	Number of out of range trips requiring alternative vehicle per year growth
Fuel_Efficiency	Fuel Efficiency Growth
Depreciation	Depreciation Rate
Market Maturity	Market Maturity Growth Rate

Costs and Regional Parameters

This workbook includes the different costs per vehicle as per the control panel parameters as well as the regional statistics used for the regional index variations. Users can observe how different costs are calculated per vehicle type per year. The table of contents can be seen in Table 28.

Table 28: Table of Contents of Costs and Regional Parameters Sheet

Sheet	Description
PurchasingPrice_excl_tax	Purchasing Price Excluding Taxes
Purchasing_tax	Tax and subsidy value
Purchasing_incl_tax	Purchasing Price Including Taxes and subsidies
FuelPrice_incl_taxes	Fuel Price Including Taxes
RoadTax	Yearly Road Tax
FuelEconomy	Fuel Efficiency of each vehicle
FuelOperationCost	Fuel Costs per vehicle based on fuel price and fuel economy

HomeInfrastructureCost	Purchasing Price of additional Home Infrastructure
MaintenanceCost	Maintenance Cost
InsuranceCost	Insurance Cost
PublicRechargingCost	Cost of Public Recharing
RangeAnxietyCost	Cost of Range Anxiety
Depreciation	Depreciation Costs
UnknownCost	Additional Unknown Costs
regional_model_inputs	Model Inputs per region
Input_Regional_Data	Regional Data
regional_index_creation	Regional Model Input Calculation per region
Stock_Registration_Distribution	Stock and registration distribution between regions

Cost Index

This workbook is linked to the Control Panel and the Cost_RegionalParameters Sheet to calculate the cost index for each region. There is a base sheet, 1 sheet for each region, a BEV cost index summary sheet for all regions, and a percentage difference between BEV and Petrol Cost index summary sheet for all regions.

Changes in the control panel or the Cost_RegionalParameters will reflect in this workbook. The table of contents can be seen in Table 29.

Table 29: Cost Index Table of Contents

Sheet Name	**Description**
costIndexPercentageOfPetrol	Percentage Difference in BEV and Petrol Cost Index for all Regions
costIndex_summary	Cost Index of BEVs for all Regions
costIndex_base	Cost Index Base Sheet
costIndex_1	Cost Index of Region 1
costIndex_2	Cost Index of Region 2
costIndex_3	Cost Index of Region 3

costIndex_4	Cost Index of Region 4
costIndex_5	Cost Index of Region 5
costIndex_6	Cost Index of Region 6
costIndex_7	Cost Index of Region 7
costIndex_8	Cost Index of Region 8
costIndex_9	Cost Index of Region 9
costIndex_10	Cost Index of Region 10
costIndex_11	Cost Index of Region 11
costIndex_12	Cost Index of Region 12
costIndex_13	Cost Index of Region 13

Market Maturity Index

This workbook is linked to the control panel and the Cost_RegionalParameters Sheet to calculate the market maturity index growth for each region. There is a base sheet, 1 sheet for each region, and a BEV index summary for all regions. Additionally, there are two sheets titled "logistic_growth" and "linear_growth" that can be copied into the "w_base". The user can use the buttons in the table of contents to automatically apply the preferred growth function.

Please note that there are 3 VBA Macros in this workbook: the "logistic_copy" and "lin-ear_copy" are used to update the growth function. "copy_w" applies any update made in w_base to all regional sheets. Please make sure to check references if using this macro. The table of contents is in Table 30.

Table 30: Table of Contents of Market Maturity Index Sheet

Sheet	Description
w_base	Base Market Maturity Index
w_1	Market Maturity Index for Region 1
w_2	Market Maturity Index for Region 2
w_3	Market Maturity Index for Region 3

w_4	Market Maturity Index for Region 4
w_5	Market Maturity Index for Region 5
w_6	Market Maturity Index for Region 6
w_7	Market Maturity Index for Region 7
w_8	Market Maturity Index for Region 8
w_9	Market Maturity Index for Region 9
w_10	Market Maturity Index for Region 10
w_11	Market Maturity Index for Region 11
w_12	Market Maturity Index for Region 12
w_13	Market Maturity Index for Region 13
SummarySheet	Summary of BEV Market Maturity Index all regions
logistic_growth	Logistic Growth Function Base Sheet
linear_growth	Linear Growth Function Base Sheet

Market Share

This workbook has the market share results and derived results. It includes three main parts:

1. Aggregated National Results based on new vehicle distribution by region
2. Market Share by Vehicle Type
3. Market Share Per Region

The user can use the table of contents as can be seen in Table 31 to navigate to the relevant results they would like to view.

Table 31: Market Share Sheet Table of Contents

Sheet	**Description**
Results_total_Greece	Aggregated National Results Summary
BEV_Statistics_stock_ratio	BEV Stock Ratio Results
Stock_total_all	Total Vehicle Stock Per Year
BEV_stock_all	Total BEV stock per Year

Market Share by vehicle type Results	
PHEV_MS_unit_all	PHEV Market Share in Percentage
PHEV_MS_ratio_all	PHEV units new registrations per year
Diesel_MS_unit_all	Diesel Market Share in Percentage
Diesel_MS_ratio_all	Diesel units new registrations per year
Petrol_MS_unit_all	Petrol Market Share in Percentage
Petrol_MS_ratio_all	Petrol units new registrations per year
BEV_MS_unit_all	BEV Market Share in Percentage
BEV_MS_ratio_all	BEV units new registrations per year
Market Share by region Results	
MarketShare_base	Market Share per Vehicle base Sheet
MarketShare_1	Market Share per Vehicle for Region 1
MarketShare_2	Market Share per Vehicle for Region 2
MarketShare_3	Market Share per Vehicle for Region 3
MarketShare_4	Market Share per Vehicle for Region 4
MarketShare_5	Market Share per Vehicle for Region 5
MarketShare_6	Market Share per Vehicle for Region 6
MarketShare_7	Market Share per Vehicle for Region 7
MarketShare_8	Market Share per Vehicle for Region 8
MarketShare_9	Market Share per Vehicle for Region 9
MarketShare_10	Market Share per Vehicle for Region 10
MarketShare_11	Market Share per Vehicle for Region 11
MarketShare_12	Market Share per Vehicle for Region 12
MarketShare_13	Market Share per Vehicle for Region 13
Intermediate Calculation	
wc^y_base	Intermediate Market Share Calculation
wc^y_1	Intermediate Market Share Calculation
wc^y_2	Intermediate Market Share Calculation

wc^y_3	Intermediate Market Share Calculation
wc^y_4	Intermediate Market Share Calculation
wc^y_5	Intermediate Market Share Calculation
wc^y_6	Intermediate Market Share Calculation
wc^y_7	Intermediate Market Share Calculation
wc^y_8	Intermediate Market Share Calculation
wc^y_9	Intermediate Market Share Calculation
wc^y_10	Intermediate Market Share Calculation
wc^y_11	Intermediate Market Share Calculation
wc^y_12	Intermediate Market Share Calculation
wc^y_13	Intermediate Market Share Calculation
Stock_Registration_distribution	Stock and new Registration distribution between regions

Charging Demand

This workbook includes the calculation of the energy demand in (MWh) based on the stock of BEVs and fuel efficiency of each vehicle segment in each region as can be seen in equation (14). Additionally, it includes a sheet to calculate the number of chargers in each region based on the stock and several specifications and the ratio of BEVs in stock to chargers. The table of contents can be seen in Table 32.

$$EnergyDemand_{region} = \sum_{segment} FE_{segment} \,.\, M \,.\, BEV_{segment} \qquad (14)$$

Segment: size segment

BEV: BEV stock per segment (units)

FE: Fuel Efficiency (kWh/km)

M: (km)

Table 32: Charging Demand Table of Contents

Sheet	Description
Fuel Usage	BEV Fuel Usage Rate
EnergyDemand_Year_Region	Yearly Energy Demand from BEVs per region in MWh
Regional_SlowFast_yearly	Number of slow and fast chargers per region based on user parameters (controls in sheet)
Regional_VehiclePerCharger	Vehicle per Charger Ratio
Regional_PowerPerVehicle	Power per BEV in kW/vehicle

The calculation of the number of chargers per region is based on the following specifications:

1. Average ratio of public charging to private charging. Example: 20% of all BEV charging is done using public chargers including slow and fast chargers.
2. Average ratio of slow to fast chargers: Example: 20% of all public chargers are fast and the remainder is slow.
3. Power of slow chargers and fast chargers: Example: slow chargers at 22 kWh and fast chargers are 100 kWh
4. Number of hours chargers are actively charging vehicles: Example: slow chargers are continuously in operation or available for operation for 8 hours every day.
5. Scaler. This can be used to adjust the number of chargers based on the target Vehicle to Charger ratio. Example: to achieve a 10 BEV to Charger ratio the scaler must be set to 8 or to set the power to vehicle ratio to 2.1kW/vehicle.