



About SHURA Energy Transition Center

SHURA Energy Transition Center, founded by the European Climate Foundation (ECF), Agora Energiewende and Istanbul Policy Center (IPC) at Sabancı University, contributes to decarbonisation of the energy sector via an innovative energy transition platform. It caters to the need for a sustainable and broadly recognized platform for discussions on technological, economic, and policy aspects of Turkey's energy sector. SHURA supports the debate on the transition to a low-carbon energy system through energy efficiency and renewable energy by using fact-based analysis and the best available data. Taking into account all relevant perspectives by a multitude of stakeholders, it contributes to an enhanced understanding of the economic potential, technical feasibility, and the relevant policy tools for this transition.

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Acknowledgements

We would like to thank the Ministry of Energy and Natural Resources, especially the Department of Energy Efficiency and Environment for their valuable guidance and contributions to the report and appreciate valuable suggestions and comments during the preparation process of the report. Enerjisa Enerji A.Ş., E-Şarj EA Şarj Sistemleri A.Ş. and Başkent Elektrik Dağıtım A.Ş. supported the development of methodology and determination of assumptions. An earlier draft of this report was reviewed by the Department of Energy Efficiency and Environment in two stakeholder consultation meetings that took place in December 2018 and May 2019. We would also like to thank the valuable stakeholder groups of the energy and transport sectors for evaluating the results of the study at a public stakeholder consultation meeting organized on 8 August 2019 in partnership with the SHURA Energy Transition Center and Department of Energy Efficiency and Environment. Furthermore, the report has benefited from the valuable input from the national and international stakeholders: Arkin Akbay (Turcas), Cem Bahar and Ceren Sümer (E-Şarj EA Şarj Sistemleri A.Ş.), Francisco Boshell (International Renewable Energy Agency), Oytun Babacan (Imperial College London), Özlem Gemici (Enerjisa Enerji A.Ş.), Murat Şenzeybek and Peter Mock (The International Council On Clean Transportation) and Tuğçe Yüksel (Sabancı University). Selahattin Hakman and Philipp Godron (Agora Energiewende) of the SHURA Energy Transition Center also provided their valuable review and feedback to the report. This report was finalised with the support of Hasan Aksoy and Tuğçe Eruydaş from the SHURA team.

SHURA Energy Transition Center is grateful to the generous funding provided by the ECF.

This report is available for download from www.shura.org.tr.

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Design

Tasarımhane Tanıtım Ltd. Şti.

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Fabrika Basım ve Tic. Ltd. Şti.

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Transport sector transformation:
Integrating electric vehicles into Turkey's
distribution grids





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LIST OF ABBREVIATIONS

AC	alternating current
cm ³	cubic centimetre
CO ₂	carbon dioxide
ÇŞB	Çevre ve Şehircilik Bakanlığı (Ministry of Environment and Urbanisation)
DC	direct current
DSOs	distributions system operators
EPDK	Enerji Piyasası Düzenleme Kurulu (Energy Market Regulatory Authority)
EPIAŞ	Enerji Piyasaları İşletme Anonim Şirketi (Energy Markets Operator Company)
EU	European Union
EVs	electric vehicles
EVSE	electric vehicle supply equipment

g	gram
CO ₂ /km	carbon dioxide/kilometre
G20	Group of Twenty
GDP	gross domestic product
GIS	geographical information system
GS	gas station
GWh	gigawatt-hour
HCS	home charging station
HV	high voltage
IEA	International Energy Agency
INDC	Intended Nationally Determined Contribution
IRENA	International Renewable Energy Agency
kg	kilogram
kW	kilowatt
kWh	kilowatt-hour
LPG	liquefied petroleum gas
LV	low voltage
Mtoe	millions of tonnes of oil equivalent
MTV	Motorlu Taşıtlar Vergisi (Tax for Engine Vehicles)
MV	medium voltage
MVA	mega volt ampere
MW	megawatt
MWh	megawatt-hour
OECD	Organisation for Economic Co-operation and Development
PDF	probability distribution functions
PV	photovoltaic
R&D	research and development
RDC	relative development coefficient
SMEs	small and medium-sized enterprises
SoC	state-of-charge
TEHAD	Türkiye Elektrikli ve Hibrid Araçlar Derneği (Turkey Electric and Hybrid Vehicles Association)
TEİAŞ	Türkiye Elektrik İletim Anonim Şirketi (Turkey Electricity Transmission Company)
TL	Turkish Lira
TM	substation
ToUT	time-of-use tariff
UEVEP	Ulusal Enerji Verimliliği Eylem Planı (National Energy Efficiency Action Plan)
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
US\$	United States dollar
UYEEP	Ulusal Yenilenebilir Enerji Eylem Planı (National Renewable Energy Action Pan)
V2G	vehicle-to-grid
VW Group	Volkswagen Group
ÖTV	Özel Tüketim Vergisi (Special Consumption Tax)



Global electric vehicle (EV) sales are on the rise thanks to policies that address the development of different types of EVs and the rollout of charging infrastructure. By the end of 2018, the total number of EVs in the global vehicle stock exceeded 5 million with a similar number of charging stations in place. Projections show that the total number of EVs worldwide could increase to between 120 and 250 million by 2030. Compared to these developments, Turkey is only starting now with the development of its EV sector with around 1,000 EVs being driven. However, with the increasing ownership of cars and growing population, there is a significant potential to increase EV use in the country. This will help reduce urban air pollution, and provided that electricity is supplied from renewables, it will also reduce emissions of carbon dioxide in both transport and power sectors.

Integration of EVs into the power system is a major concern since their charging, when uncontrolled, can create negative impacts on the operation of distribution grids. To limit these impacts and manage the additional electricity load of EVs, smart charging concepts and business models are emerging to help cost-effective charging for EV users and encourage more efficient grid use. To date, no such assessment has been carried out for Turkey to understand how a high share of EVs can be integrated into distribution grids and how different charging optimisation strategies can help reduce impacts related to their integration.

In this study, carried out by SHURA Enerji Dönüşümü Merkezi the “High Growth” market scenario takes the total number of passenger vehicle EVs in Turkey’s total stock to more than 2.5 million by 2030, which represents 10% of the total vehicle stock in the same year, while the sales of battery and plug-in hybrid EVs reach 55% of all vehicle sales in the same year.¹ To charge these vehicles, five types of charging options that differentiate between home, workplace and public charging have been considered at alternate (AC) and direct current (DC) levels. A total of 1 million charging points have been assumed, up to 25,000 points of which are DC level fast chargers. To estimate the distribution grid impact (measured by the additional capacity and investments in distribution grid lines and transformers, voltage violations and overloading) between 2018 and 2030, an hourly resolution distribution grid model has been developed based on real grid data that represent Aegean, Central Anatolia, Marmara and Mediterranean regions of Turkey. These regions are the places where the first market development of EVs is expected since they are the most populated areas with the highest economic activity. Different charging behaviour and patterns, as well as charging point locations and technologies, have been assessed.

In the case where the total electricity demand excluding EVs grows by 5% per year between 2018 and 2030² (80% increase in total) and grid investments needed to manage this load are undertaken³, analysis shows that EVs can be integrated with limited impact on grid operation and nearly no additional capacity expansion in the

¹ In this context the term “growth” has been used to refer to the adoption rate of EVs in Turkey’s passenger vehicle market. Battery and plug-in hybrid EVs are defined together as EV in this study, hence any other type of hybrid vehicle which does not need to be plugged for charging is excluded from this study’s scope.

² This growth rate excludes any additional load from EVs, and has been set as an assumption after discussion with the distribution companies that shared their grid data for the purpose of this study. It is also in line with the growth rate assumption in SHURA’s earlier renewable energy grid integration study (SHURA, 2018).

³ Medium- and low-voltage distribution transformer capacity and medium voltage line length are estimated to increase by 48% and 43% by 2030 respectively, compared to the level in 2018. This requires an average total investment of 3.8 million Turkish Liras (TL) in the same period.

distribution grid. Hence, there is sufficient capacity in the four selected distribution grids to integrate 10% EV in the vehicle stock by 2030. To achieve this, grid investments need to continue in line with demand growth; charging optimisation mechanisms need to be in place so as to incentivise EV owners to charge their cars during off-peak hours, like after midnight; and charging points need to be placed in the most optimum locations. Such consumer behaviour can be encouraged, for example, with a regulatory framework to be put in place to set time-varying electricity tariffs, and encourage intelligent charging technology take up and integrated grid- and mobility-based infrastructure planning. In addition, results highlight the crucial benefits offered by distributed renewable energy and storage systems, particularly during summer. While the analysis shows favourable results for grid integration of EVs, which would represent 10% of the total vehicle stock by 2030, a higher EV take up would require further investments, and consequently a broader implementation of smart charging tools to reduce cost. It would also require a transition to a more efficient, electrified transport system with a reduced share of private passenger car-based mobility overall. This would require expanding this analysis to the wider electrification of transport, excluded from the present analysis, such as electrification of taxis and other light duty vehicle fleets, delivery vans and logistics, trucks and buses, where electrification is taking up rapidly. In addition, the battery size of some of these vehicle types is significantly larger than that of passenger vehicles and could have much larger impact on the grids despite fewer vehicle numbers. These should be taken into account in the next stages of grid modelling, along with other electric mobility trends that can potentially create impacts on the distribution grids, such as much faster uptake of EVs in the vehicle fleet, growing size of batteries in passenger vehicles, and the potential customer choices towards fast charging equipment. As the results indicate, there could be grid integration challenges if strategies fail to realise additional grid capacity and smart charging approaches, thus significantly increasing investment needs. Major drivers are time of charging, location of charging and size of charging station capacity. In dealing with these challenges, electricity tariff design, smart technology roll-out and optimised planning for the location of charging points will play a key role to minimize stress on the grid and encourage efficient utilisation, without negatively affecting the comfort of using and charging EVs.

Based on the results of this study, seven priority areas have been outlined for energy policy makers, the market regulator, distribution grid companies, the automotive industry, charging technology developers and investors, urban planners and the academia:

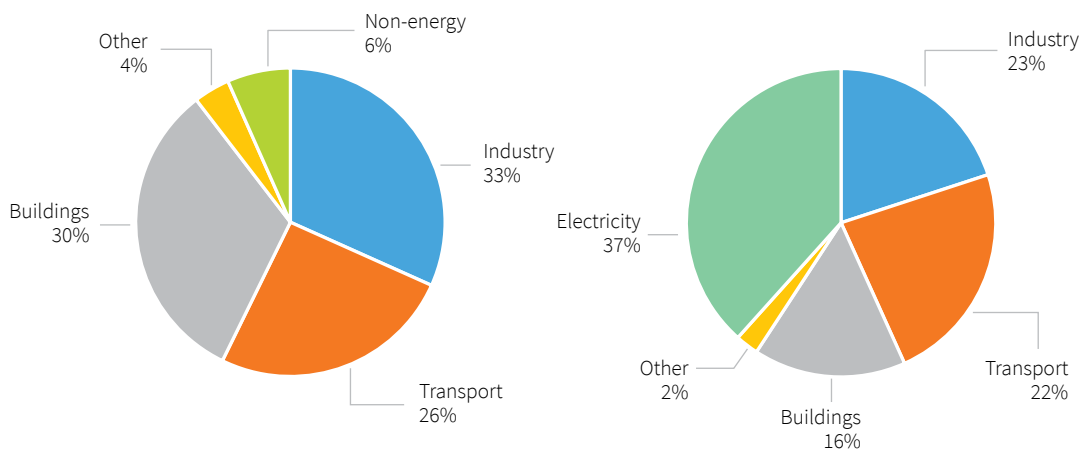
- 1) Accelerate the market for EVs and charging services in parallel,
- 2) Develop and implement smart charging mechanisms for load management,
- 3) Develop region-specific measures to avoid overloading and voltage violations,
- 4) Assess, develop and implement new business models for EV charging,
- 5) Continue the planned investments in distribution grids in line with the growth in electricity demand,
- 6) Utilise synergies between EV charging and renewable energy integration and energy storage,
- 7) Assess and plan for utilising the benefits of EV development jointly with other sectors.

1. Introduction

Electricity's share is 0.4% and renewables represent 0.5% of the total energy mix.

Transport represents 26% of Turkey's total final energy demand. It is the sector with the second least share in total demand ahead of agriculture and behind the manufacturing industry and buildings. In terms of carbon dioxide (CO₂) emissions, however, it ranks as the second largest contributor following the power sector, accounting for more than one fifth of CO₂ emissions. of Turkey's all emissions. The underlying reason is that the transport sector's energy mix is predominantly based on oil products (>99%). Electricity's share is 0.4% and renewables represent 0.5% of the total energy mix (see Figure 1).

Figure 1: Breakdown of total final energy consumption and energy-related CO₂ emissions in Turkey, 2017/18



Sources: Enerji İşleri Genel Müdürlüğü (2019); IEA (2019a)

There were around 1,000 electric vehicles in Turkey out of a total number of around 12.5 million passenger vehicles. Total demand for electricity from these vehicles is estimated to be around 1.5 gigawatt-hour (GWh) per year. A single small-scale solar photovoltaic (PV) plant with a total capacity of 1 megawatt (MW) could provide their electricity needs.

Several options exist to decarbonise the transport sector: energy and material efficiency (more efficient motor designs, lightweight materials), electrification, low-carbon alternatives to petroleum-based products and modal shift. Electric vehicles (EVs) are being increasingly used across many countries because of their various benefits, including contribution to cleaner urban landscape, electricity load management and better efficiency. Their total number worldwide exceeded 5 million by the end of 2018, a development driven by declining cost trends and policy efforts to create a vehicle market and establish infrastructure. By the same year, there were 657 fully battery EVs (BEVs) and around 250 plug-in hybrid electric vehicles (PHEVs) in Turkey out of a total number of around 12.5 million passenger vehicles in Turkey (Otomotiv Sanayii Derneği, 2019). Total demand for electricity from these vehicles is estimated to be around 1.5 gigawatt-hour (GWh) per year. A single small-scale solar photovoltaic (PV) plant with a total capacity of 1 megawatt (MW) could provide their electricity needs. Transport is not only limited to passenger cars. Buses, mini-buses and other types of road public transport represent a notable share of passenger transport in Turkey with a total number of 7 million of such vehicles on the road (Otomotiv Sanayii Derneği, 2019). Two/three wheelers are also common for passenger transport. These vehicles can also be electrified. The potential for electrification exists also for road freight and city logistics. In order to ensure low-carbon transition and improve the quality of the environment (i.e. reduced local air pollution and mitigation of greenhouse gas emissions), electric mobility requires that the power sector is decarbonised. Today, around one-third of Turkey's total electricity supply is sourced from renewables, with hydropower representing a large share of the total. According to Turkey's 11th Development Plan, which was submitted to the Grand National Assembly of Turkey in July 2019, the renewable energy target for 2023 is set at 38.8% (Presidency

of The Republic of Turkey Strategy and Budgeting Office, 2019). SHURA's recent analysis has shown that Turkey can achieve at least 50% renewable energy by 2026, a considerable share of this being sourced from wind and solar energy (SHURA, 2018).

An EV and a conventional vehicle with an internal combustion engine have the same objective of use: moving passengers and freight from one location to the other. From an energy perspective, however, there are fundamental differences. The energy storage system of a conventional vehicle is petrol tank and the 12-volt battery that is used to fuel an engine with an exhaust system controlled by an alternator and a fuel injector. Oil products made from non-renewable crude oil are typically used to run these engines. The operating principle of a conventional vehicle is one way; fuel purchased from a gas station is stored in the tank, and is combusted and subsequently, motor drive is generated. The EV has an electric motor and a battery pack with a charger and an AC-DC inverter that is used to control the motor. The battery pack of the EV can be charged wherever electricity is available, such as in houses or workplaces. In principle, the stored electricity is used for transport, but it can also be sold back to the grid for purposes like grid flexibility and ancillary services when needed, basically fulfilling the services provided by a distributed energy source.

Filling the tank of a conventional car takes few minutes, whereas charging an electric car can take from few minutes to hours depending on the charging technology and the battery size.

The key enabler of EVs is the availability of charging infrastructure. Filling the tank of a conventional car takes few minutes, whereas charging an electric car can take from few minutes to hours depending on the charging technology and the battery size. Depending on the available charging business models, electricity price signals and driving choices, the time of the day when the car would be charged will vary. On average, day trip of a passenger vehicle in an urban area could be about 50 kilometres (kms) (there is a wide range depending on the city size, type, infrastructure availability, and other factors). An owner who charges the EV upon returning from work in the evening hours would have enough electricity to drive 100-150 kms overnight, which means that cars do not need to be plugged in for 8-10 hours overnight. Within 2-3 hours they would be charged to cover the average day trip distances. While this gives room for optimising charging hours to limit any potential impacts on the electricity load profile during evening hours, if all owners follow the same charging patterns during similar hours, unmanageable loads can occur. By comparison, if more EVs are charged in workplaces or public locations like parking lots, this would increase the day load (whilst this does not necessarily mean that this will coincide with the day peak). This is also where it could become challenging for the grid; if charging is not planned and managed, it can exacerbate the existing load profiles. Understanding and planning for these impacts will be crucial to manage the load on distribution grids.

Grid charging of an EV means the amount of energy sources consumed to generate a unit of electricity at any given moment in time. For instance, during a windy summer day, low cost sources of energy, like wind and sun, can be used. EVs can also be charged at nights with the electricity generated and stored during the day with rooftop solar PV panels. Various charging optimisation strategies could offer system flexibility for grid integration of variable renewable energy sources, if managed properly. Hence, EVs are not only means of transport, but also energy devices that can be used to couple the transport sector with the power sector. These synergies should also be better understood.

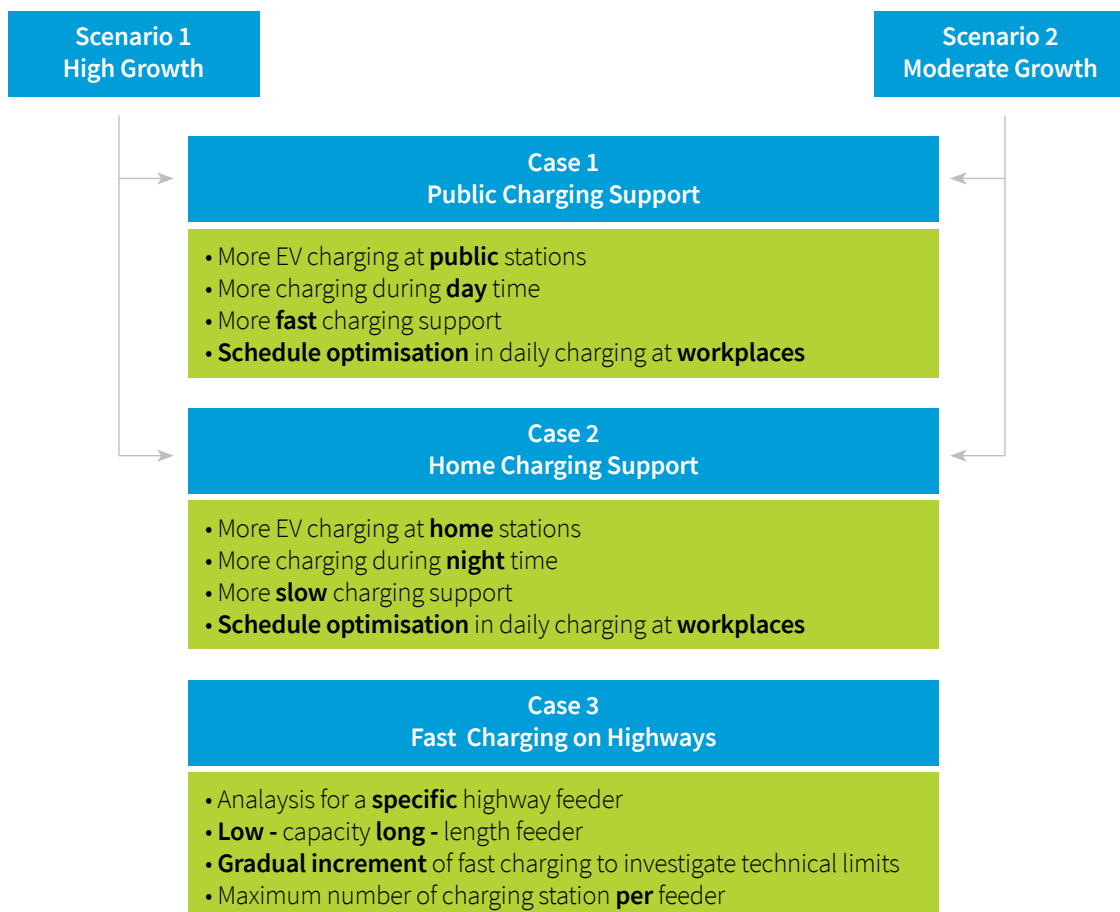
Distribution grids are planned based on the time when the demand is the highest, also by taking into account factors such as the location, number and type of buildings, and the

demand for heating and cooling. So far, no criteria exist in Turkey that concern EV charging. As the total number of EVs is expected to increase with the potential introduction of the locally produced EV in Turkey by 2022/23, it is necessary to understand the potential impacts of EVs on the distribution grid, given the concerns about the additional costs of expanding the distribution grid and how these costs can be reduced.

The purpose of this analysis is to analyse the impacts of transport sector electrification on the four largest electricity distribution grids (out of the 21 grids in total) in Turkey by 2030 that currently serve around one-third of the total population (and a similar share of the total electricity demand).

The purpose of this analysis is to analyse the impacts of transport sector electrification on the four largest electricity distribution grids (out of the 21 grids in total) in Turkey by 2030 that currently serve around one-third of the total population (and a similar share of the total electricity demand). For this purpose, two distinct EV market scenarios have been investigated. The “High-Growth” scenario projects more than 2.5 million EVs in the total vehicle stock by 2030 (reaching 55% penetration in the total passenger vehicle sales by 2030 and around 10% of the total passenger vehicle stock by the same year). The “Moderate-Growth” scenario projects just above 1 million in the same time frame. The market outlook is used as a testbed for assessing the impacts of EVs on the distribution grids through the investigation of three cases for each scenario: mainly public charging (case 1), mainly home charging (case 2), and a separate case for fast charging on highways (case 3) are explored. These cases differ in terms of charging patterns, as indicated in Figure 2. In both cases 1 and 2, charging pattern at workplaces is assumed to be uniform after optimisation, given the fact that not all of the EVs at workplaces will be charged at the same time and companies will likely apply a mechanism which optimises EV charging by schedule (i.e., charging in turn, which is a sort of a smart mechanism). However, for the home charging support case, midnight shifting at homes is investigated separately as a smart mechanism, as illustrated in Figure 2.

Figure 2: Scenarios and cases investigated in the study



This report is organised as follows: the next section takes a snapshot of Turkey's transport sector. Section 3 provides international examples from EV markets, focusing on the developments in charging and policies. The section defines the concept of smart charging. Section 4 provides further details on the methodology and the background data used for this analysis. An Annex to this report provides additional details. Section 5 presents and discusses the results of the analysis. The report ends with Section 6, which provides 7 priority areas for distribution system operators (DSOs), power system planners, EV manufacturers, and charging infrastructure planners and licensors about how Turkey's transport sector transformation can be accelerated through electric mobility.

2. Current situation of Turkey's transport sector

2.1 Passenger vehicle market

By the end of 2014, the share of road vehicles in total passenger transport reached 90%.

By the end of 2014, the share of road vehicles in total passenger transport reached 90%. The majority of the remaining 10% was in aviation, the fastest growing transport mode in Turkey in recent years. Similarly, around 90% of all freight transport was carried out by road vehicles. The remaining 10% was shared equally by railways and marine transport (Ministry of Transport, Maritime Affairs and Communications, 2015).

Road transport represents more than 90% of all energy demand in Turkey. This includes passenger transport by cars, two-wheelers (like motorcycles, scooters, etc), minibuses, and buses; and freight transport by trucks, light commercial vehicles, etc. Another 8% of the total energy demand is split between aviation, navigation, railways, and pipeline transport. The demand for energy in the transport sector is growing rapidly with the increasing per capita income levels, growing population and Turkey's continued status as a large automotive producer (ranking 14th worldwide and 5th in Europe after Germany, Spain, France, and the United Kingdom) (Invest in Turkey and EY, 2019). In 2017, approximately 1.7 million cars were produced in Turkey (Invest in Turkey, 2018). At the hub of Turkey's automotive sector in Bursa, on average 2,000 vehicles are being produced per day, 80% of which is being exported (Daily Sabah, 2018).

The passenger vehicle ownership rate has reached 154 out of 1,000 people.

The rapid growth in Turkey's passenger vehicle segment is striking. At the end of 2018, there were about 12.5 million passenger vehicles on the road. This compares to the 22.7 million road vehicles in total that were on the road, including 3.7 million small trucks, 3.2 million motorcycles, and 1.9 million tractors following the total number of passenger vehicles (OSD, 2018a).⁴ The passenger vehicle ownership rate has reached 154 out of 1,000 people. This is a low level when compared with other countries of the Organisation for Economic Co-operation and Development (OECD), such as Germany and the United States. However, ownership rates are rapidly increasing with passenger cars representing 6 out of the total of 10 vehicles sold in Turkey (Mock, 2016). Each year, around 750,000 vehicles are being registered. 2018 was an exceptionally low year, with registered cars staying below 500,000 due to the economic uncertainty the country has experienced (HaberTürk, 2019). Against these additions, annually 15,000 vehicles on average are being taken out of the stock as scrap. The year 2018 saw a significant increase in the number of scrapped vehicles, as the government introduced a tax reduction of up to 10,000 Turkish Liras for purchasing a new car and scrapping the old car (Hürriyet, 2018a). The tax reduction has been increased to 15,000 TL in 2019 (HaberTürk, 2019).⁵

In the past years, Turkey's car market was characterised by a large share of vehicles that used gasoline. The share of gasoline vehicles, which was at 75% in 2004, has been declining ever since (OSD, 2018b). At the end of the first quarter of 2018, the share of gasoline vehicles was just above 25%, with vehicles using liquefied petroleum gas (LPG) and diesel accounting for the majority of the vehicle stock as these constituted 38.1% and 36% of the latter, respectively. This shift in fuel types has been driven by the price advantages offered by LPG and diesel, compared to gasoline-fuelled cars. In addition, diesel cars could, on average, drive longer distances per litre of fuel depending on car size. However, the price gap is being closed as diesel price is now on par with gasoline (less than 4% difference in prices per litre). Hence, the prospects

⁴ This excludes vehicles imported from other countries by individuals.

⁵ The average currency exchange rate in 2018 was 4.849 TL/USD. In August 2019, the average currency exchange rate was 5.64 TL/USD.

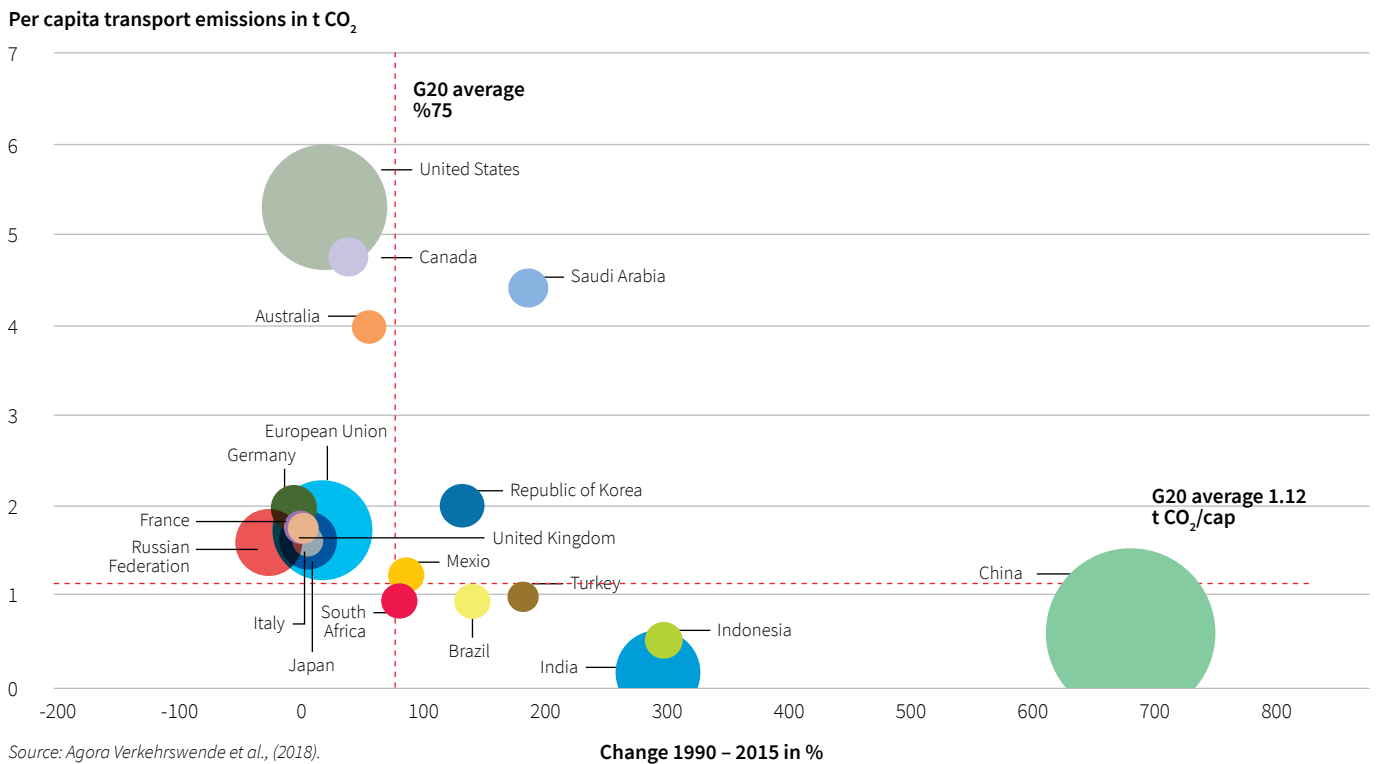
for diesel in Turkey are becoming uncertain. The share of EV and hybrid vehicles in the stock is small at less than 0.1%. The share of gas is negligible, representing less than 0.1% of the road transport sector's total energy demand in Turkey.

2.2 Low-carbon transition policy framework

In Turkey, around 45% of all passenger vehicles are still above 10 years old. These vehicles are inefficient and consume more energy.

In Turkey, around 45% of all passenger vehicles are still above 10 years old. These vehicles are inefficient and consume more energy (Ministry of Environment and Urbanisation, 2018). They also result in more emissions of particulate matter, carbon monoxide, nitrogen oxides, and volatile organic carbon to drive the same km. Notably, much of these emissions occur in urban areas with high traffic congestion, resulting in adverse impacts on human health. Today, transport sector is the major source of air pollution in urban areas, with 8 cities of Turkey being in the league of top-10 particulate matter emitters in Europe (Bernard et al., 2018; Istanbul Policy Center, 2017). There are growing concerns related to the environmental impacts of the booming vehicle use in Turkey. Within the Group of Twenty (G20), Turkey stands out as one of the countries which have experienced a rapid growth in its per capita transport CO₂ emissions with a change of nearly 200% in the period between 1990 and 2015 (see Figure 3) (Agora Verkehrswende et al., 2018).

Figure 3: Change in transport sector related CO₂ emissions in the G20 countries between 1990 and 2015



Within the Group of Twenty (G20), Turkey stands out as one of the countries which have experienced a rapid growth in its per capita transport CO₂ emissions with a change of nearly 200% in the period between 1990 and 2015.

There are several policy and strategy documents that support the transport sector transformation in Turkey.

In 2008, a “Communique on Measures for Increasing the Energy Efficiency in Transportation” was released (Resmi Gazete, 2008). The National Smart Transportation Systems Strategy Document (2014-2023) and its Action Plan (2014-2016), released in 2014, are the backbone of Turkey’s transport sector related energy and technology strategy (Ministry of Transport, Maritime Affairs and Communications, 2014). The

Intended Nationally Determined Contribution (INDC) that was released in 2015 has a list of actions for realising Turkey's greenhouse gas emission reduction goals by 2030 (UNFCCC, 2015):

- Ensuring balanced utilisation of transport modes in freight and passenger transport by reducing the share of road transport and increasing the share of maritime and rail transport
- Enhancing combined transport
- Implementing sustainable transport approaches in urban areas
- Promoting alternative fuels and clean vehicles
- Reducing fuel consumption and emissions of road transport with National Intelligent Transport Systems Strategy Document (2014-2023) and its Action Plan (2014-2016)
- Realising high speed railway projects
- Increasing urban railway systems
- Achieving fuel savings by tunnel projects
- Scrapping of old vehicles from traffic
- Implementing green port and green airport projects to ensure energy efficiency
- Implementing special consumption tax exemptions for maritime transport

To put this average in perspective, the EU has set a target of 95 g CO₂/km to be met by 2021. The target for the US is slightly above that at 97 g CO₂/km for 2025.

Regarding CO₂ emissions, many countries worldwide have introduced mandatory standards for passenger and light commercial vehicles. Turkey is one of the few countries with a large automotive sector that still do not implement such standards despite the fact that an emissions standard is in place for light passenger and commercial duty vehicles since the end of August 2019 (Resmi Gazete, 2019a). The average CO₂ emissions of new passenger vehicles in Turkey were at a level of around 120 g CO₂/km (Mock, 2016), but cars in Turkey are generally lighter and have smaller engine power than their counterparts in the European Union (EU). To put this average in perspective, the EU has set a target of 95 g CO₂/km to be met by 2021. The target for the US is slightly above that at 97 g CO₂/km for 2025 (ICCT, 2019a).

Starting with 2003, biodiesel blend has been included as one of the commodities under the Law of Petroleum Market (Çelebi and Uğur, 2015). In 2005, Biodiesel Standards that comply with the equivalent standards of the EU have been published. These standards allow for up to 5% blending with biodiesel and ethanol. On 16 June 2017, the regulation on blending with biodiesel came into force setting a minimum blending limit of diesel at 0.5% (on a volume basis) (Resmi Gazete, 2017a). Diesel consumption in Turkey is around 25 million tonnes, which means that at least 125 thousand tonnes of biodiesel is either produced or imported (YEGM, 2017). Currently, there is sufficient capacity in Turkey obtained from four plants that are in operation to supply this volume. The regulation on ethanol blending came into force on 7 July 2012, setting a minimum blending standard of 2% (on a volume basis) starting on 1 January 2013 and 3% starting on 1 January 2014 (Resmi Gazete, 2012). Turkey's total ethanol production is around 150 million litres, which is sufficient to meet a blending rate equivalent to 3% (Biyoenjerji Derneği, 2017). Biodiesel and ethanol production is sufficient to meet the standards set by regulations, but the current levels fall short of the blending targets. The current level of liquid biofuel share is especially worrying in view of the 10% target set in Turkey's National Renewable Energy Action Plan (Ulusal Yenilenebilir Enerji Eylem Planı, UYEEP) to be reached by 2023 (MENR, 2014). Especially when transport fuel demand is rising rapidly, it can be questioned to which extent liquid biofuels can provide a local resource alternative to petroleum products.

There are several reasons why biofuels had achieved limited success in the past. One reason was the limited ambitions in percentage-based targets and there were no production and consumption targets, goals and planning. Another reason was that with the exception of excise tax exemption, there was no other incentive available such as area specific incentives (Euro/ha) for producers, agriculture sector actors and/or small and medium enterprises (SMEs) that are active in the field and for research and development (R&D) to expand the use of biofuels. In addition, there were limited awareness campaigns. In addition, Turkey's biomass resources for the production of sustainable and advanced biofuels are limited. For instance, the biomass waste potential is equivalent to 8.6 million tonnes of oil equivalent (Mtoe), which represents 6% of the current total primary energy supply. Assuming that this potential would also be utilised for the generation of heating and electricity, little opportunity remains for the transport sector.

The National Energy Efficiency Action Plan (Ulusal Enerji Verimliliği Eylem Planı, UEVEP) of Turkey, which was officially launched by the former Minister of Energy and Natural Resources Mr. Berat Albayrak in March 2018, puts forward 9 actions specific to the transport sector (Resmi Gazete, 2017b). These are:

- Promotion of energy-efficient vehicles
- Development of a comparative study about alternative fuels and new technologies
- Development and improvement of cycling and pedestrian transport modes
- Reducing the traffic load in cities: reducing vehicle use
- Expanding the use of public transport
- Improvement of the institutional restructuring and its implementation for urban transport
- Strengthening marine transport
- Strengthening railway transport
- Collection of transport related data

In addition, in May 2019, a legislation was put in place by the Ministry of Transport and Infrastructure on improving energy efficiency in the transport sector (Resmi Gazete, 2019b).

These are important steps towards a low-carbon transition in Turkey's transport sector. The first action is particularly important, as it highlights several activities to be undertaken for the uptake of EVs.

- The Special Excise Law includes tax discrimination for electric and hybrid vehicles; analyses will be conducted for additional tax discrimination, and according to results, a new legislative framework will be considered.
- The infrastructure will be developed in order to introduce differentiated taxation according to the fuel consumption and emission values (CO₂/km). Tax advantage will be provided to low emission vehicles by improving the current motor vehicle tax system. The imposition of higher taxes for older vehicles will be included in this system considering the balance of environmental impact and purchasing power.
- A database where the CO₂ emission figures of all vehicles on the market will be recorded will be created. The tax system will be supported by this database.
- Standards and infrastructure will be established for the installation of charging stations for electric and hybrid vehicles.
- Awareness on electric and hybrid vehicles will be raised, and low emission vehicle culture will be established. Vehicle manufacturers will play an active role in the introduction and promotion of electric and hybrid vehicles to the public.

2.3 Electric vehicles in Turkey: Markets and policies

Provided that the electricity demand of an EV is supplied with renewable energy sources, it can also help increase the share of renewable energy in the transport system, and thus lead to lower emissions and contribute to a clean urban environment.

EVs offer various benefits to the energy system. Compared to a conventional vehicle with an internal combustion engine, an EV could be up to three times more energy efficient for driving the same passenger distance. Provided that the electricity demand of an EV is supplied with renewable energy sources, it can also help increase the share of renewable energy in the transport system,⁶ and thus lead to lower emissions and contribute to a clean urban environment. An EV is also like a mobile battery storage system. It can provide grid services like flexibility, for instance, by selling demand response to the grid in integrating variable renewable energy sources like wind and solar power.

There are also challenges to the deployment of EVs. Their costs, mainly driven by battery systems, must fall, and their market growth needs to go hand in hand with the deployment of charging infrastructure. As the number of EVs grow, they can create impacts, depending on their charging time and mode, on the distribution grids, which will require the deployment and planning of strategies for load management. Another challenge is the security of material supply for batteries, but this will depend on the developments in battery technologies.

In recent years, a series of incentives were introduced related to EVs.

In recent years, a series of incentives were introduced related to EVs (ICCT, 2019b). These are summarised below:

- The first incentive to EV sales was introduced in 2011 through a reduction in the so-called Special Consumption Tax (Özel Tüketim Vergisi, ÖTV). Depending on the power capacity of the battery EV, the ÖTV was set between 3% and 15% (Resmi Gazete, 2011, p. 1). To give an example, a battery EV that has a power capacity equivalent to a conventional car with a 1,600 cubic meter (cm³) engine would only receive 3% ÖTV, instead of 45%. However, hybrid cars were left out of this scheme at the time.
- Another round of reductions in ÖTV rates were introduced in 2016 for EVs with electric engine power of >50 kW (and cylinder volume <1,800 cm³) and >100 kW (and cylinder volume <2,500 cm³) from 90% to 45%, and from 145% to 90%, respectively (Resmi Gazete, 2016). This regulation change was received with concerns since the defined vehicle categories did not really cover a wide spectrum of EVs that were being sold in Turkey at the time. The regulation's scope was rather limited to plug-in hybrid vehicles with internal combustion engine size more than 1.6 liter (TeslaTürk, 2016). Battery EVs are exempt from the Tax for Engine Vehicles (Motorlu Taşıtlar Vergisi, MTV).
- At the beginning of 2018, as part of a broader set of tax regulations, it was proposed to introduce a 25% MTV rate for EVs as well and this regulation is in place since 27 March 2018 (Resmi Gazete, 2018a).
- A new tax scheme for batteries was under discussion at the end of November 2018. The idea was to introduce a tax of 15 TL per kg of batteries used in vehicles, which would put an additional economic burden on EVs ranging between 6,000 and 20,000 TL. This scheme was somewhat misinterpreted by the sector, which led to clarifications by the government at a later stage. The Ministry of Environment and Urbanisation (Çevre ve Şehircilik Bakanlığı, ÇŞB) clarified that this scheme, which was still under discussion, aimed to charge 15 TL per kg as a deposit for those batteries that had reached the end of their life when the batteries were renewed for recycling.

⁶ In order to account for such an increase, the share of electricity sourced from renewable energy carriers needs to be accounted for under the total final energy consumption of the transport sector.

There are several regulations that address the charging infrastructure. The regulation published by the Energy Regulatory Market Authority (Enerji Piyasası Düzenleme Kurulu, EPDK) on 2 January 2014 stipulates that consumers who apply for connections access should provide a detailed electricity project to the distribution company that includes the technical specifications and other details of the charging infrastructure (Resmi Gazete, 2014). The regulation published by the ÇŞB on 8 September 2013 provides that it is possible to install charging infrastructure in parking lots, petrol stations, and other areas that are found suitable and are approved by the responsible electricity distribution company (Resmi Gazete, 2013). The reason why charging infrastructure is rather vaguely addressed in the existing regulations is that their number has so far been limited. A regulation issued by the ÇŞB in February 2018 requires the installation of at least one charger per 50 car parking space in parking lots in public areas and in shopping malls. Currently, charging infrastructure is covered under the mandate of the Ministry of Science, Industry and Technology of Turkey (Resmi Gazete, 2018b).

Financing investments is crucial for accelerating the deployment of EVs. İş Portföy Yönetim A.Ş. provides funds to companies that develop and manufacture EVs, smart meter technologies and battery storage, as well as to those that process the materials that are used in the manufacture of batteries. At least 80% of company portfolios must include any of these activities (KAP, 2018).

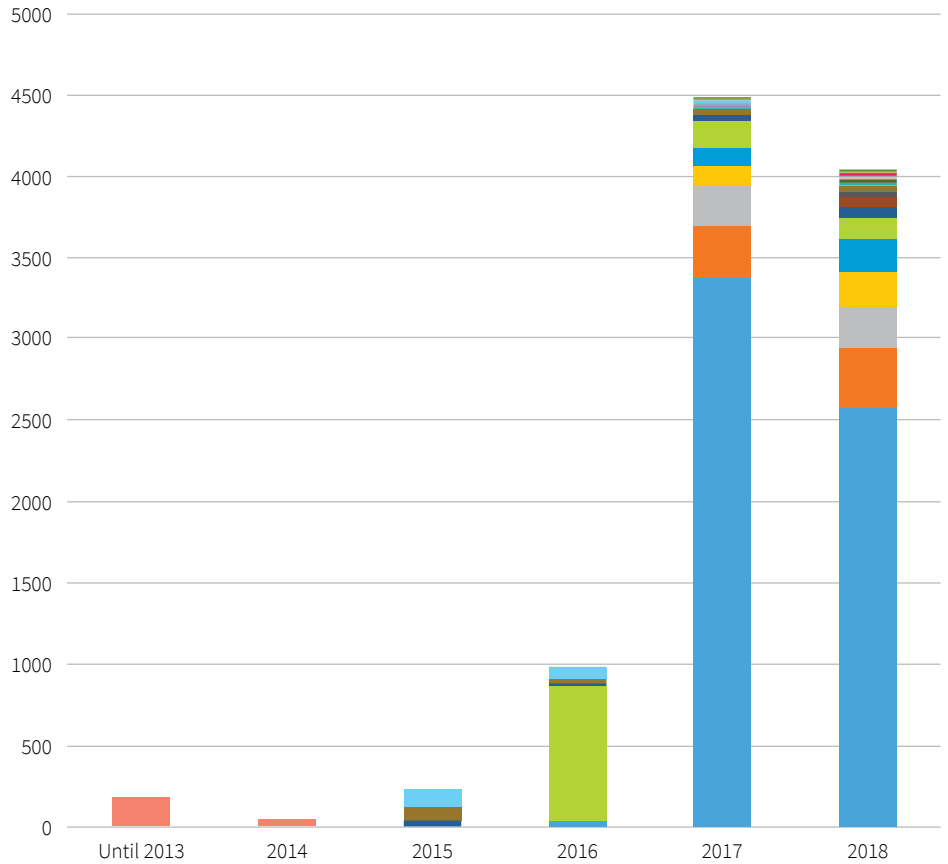
This puts the total number of hybrids and EVs in Turkey at more than 10,000, which constitutes around 0.08% of the total stock.

Turkey's EV market is currently starting from a very low base (see Figure 4). Until the end of 2013, a total of 215 EVs were sold (ODD, 2014). 47 new EVs were sold in 2014, a number that subsequently increased to 119 in the following year (ODD, 2016). A total of 44 battery EV were sold in 2016, compared to 950 hybrids (TEHAD, 2019). In 2017, hybrid sales saw a new record at 4,451 were sold (ODD, 2019). An additional 33 battery EV and 11 plug-in hybrid vehicles were sold. By the end of 2018, EV and hybrid car sales exceeded 4,000. In total, 155 battery EV and 39 plug-in hybrid vehicles were sold. Hybrid sales were more than 3,800. This puts the total number of hybrids and EVs in Turkey at 10,000, which constitutes around 0.08% of the total stock. Hybrid and EV sales in 2018 represent a share of 2% in total passenger vehicle sales in Turkey (ODD, 2019). While this is remarkable, 2018 is an exception because of the overall decline in total car sales by around 35% compared to the year before. In previous years, EV share in total sales did not exceed 0.2%.

Three of the most sold hybrid models are Toyota C-HR (currently more than 2,700 in the stock), Toyota YARIS (>400) and Toyota RAV4 (>200). Toyota Auris (>160), Hyundai IONIQ (>150) and Kia NIRO (>130) are also gaining a share in the EV market. Renault Zoe (~100 cars) and BMW i3 (~70) constitute the battery EV market. Since there is no distribution channel for Tesla, actual numbers are not available, but it is estimated that around 150 Tesla cars are in the stock (TEHAD, 2018).

Figure 4: Breakdown of electric vehicle and hybrid vehicle sales in Turkey, 2013-2018

Vehicle sales per year



- Toyota C-HR (Hybrid)
- Toyota Auris (Hybrid)
- Toyota RAV4 (Hybrid)
- Hyundai IONIQ (Hybrid)
- Kia NIRO (Hybrid)
- Toyota YARIS (Hybrid)
- Renault ZOE (battery EVs)
- Toyota PRIUS (plug-in hybrid vehicles)
- Toyota Auris Touring (Hybrid)
- Jaguar I-Pace (battery EVs)
- BMW i3 (i3s dahil) (battery EVs)
- Lexus CT200 (Hybrid)
- MercedesBenz GLC350e (plug-in hybrid vehicles)
- Volvo XC90 T8 Plug-in (Hybrid)
- BMW 740Le xDrive (plug-in hybrid vehicles)
- Lexus IS300 (Hybrid)
- Lexus NX300 (Hybrid)
- Lexus LS500 (Hybrid)
- BMW i8 (incl. Roadster) (plug-in hybrid vehicles)
- Lexus RX450 (Hybrid)
- Honda NSX (Hybrid)
- BMW 330e Sedan (plug-in hybrid vehicles)
- Lexus GS300 (Hybrid)

Source: TEHAD (2019)
Note: Data excludes Tesla cars and commercial vehicles

With fast charging, providing charging power of 50 kW or more (also known as direct-current fast charging), it would take less than half an hour. Car makers and energy providers are developing high-power or ultra-fast charging options of 150 kW.

One crucial factor that impedes the wider deployment of EVs is the time needed to charge them. This factor depends on the car type, its charge power and allowable charging speed, as well as on the connection type on the charging infrastructure. Driving patterns and charging locations determine the extent to which consumers are willing to accept minimum charging hours. For instance, most consumers would park their EVs for between 8 and 12 hours at night, and home charging can be the easiest and the most cost-effective way. A wall box, which would be the home-charging option, would require 50 hours. By comparison, 3-phase connection with 22 kW power capacity in operation can reduce the charging time bandwidth to between 2 and 7 hours. With fast charging, providing charging power of 50 kW or more (also known as direct-current fast charging), it would take less than half an hour. Car makers and energy providers are developing high-power or ultra-fast charging options of 150 kW.

Available statistics point to a range for the number of charging stations in Turkey. According to Turkey Electric & Hybrid Vehicles Association (Türkiye Elektrikli ve Hibrid Araçlar Platformu, TEHAD), there were about 1,000 stations in total by the end of 2016. Only 400 of these were accessible and providing service, which is also in line with the statistics provided by the EPDK (TEHAD, 2019). By the end of 2017, the total number of stations increased to 1,500 (TEHAD, 2017). Other estimates provide a range between 500 and 800 charging stations (Hürriyet, 2018b; Polat et al., 2018; YeniŞafak, 2018). The most recent data for public charging stations shows that there were 582 charging points (excluding home chargers) in Turkey by end of March 2019 (TEHAD, 2019). The total number of battery EVs and plug-in hybrid vehicles in Turkey reached 650 by the end of 2018, and 1,310 by September, 2019. This means that there are 2 public chargers per vehicle in Turkey. It can be assumed that each EV owner also has access to 1 home charging station on average, which would add around another 1,000 charging points.

There are 2 public chargers per vehicle in Turkey.

There are several companies that develop and provide charging infrastructure in Turkey. Eşarj, G-Charge (Gersan), Voltrun, Yeşil Güç (Greenway), Zorlu Energy Solutions (ZES) and ABB have each implemented one or more of their station models across the country. Several station models are available. All companies offer options for home charging that would provide the possibility to charge EVs within a duration of maximum 8 hours. Some companies have models that charge in less than half an hour through DC connection with a 50-kW charging capacity. This is the lower end of the range offered by fast charging stations available worldwide, a range that goes up to 120 kW (Dünya Enerji Konseyi Türk Milli Komitesi, 2018). There are plans from other companies to expand the charging infrastructure in Turkey. ZES has installed a total of 10 fast charging stations throughout the Istanbul-Izmir-Ankara highway network. The company's plan was to increase this to 25 by the end of 2018, with an additional plan to install another 200 stations across the entire country. An estimated total of US\$10 million in investments would be needed for this, averaging US\$50,000 per fast charging infrastructure (Hürriyet, 2018c).

There is limited information available about the business models offered by different companies in Turkey. Eşarj company webpage provides some interesting insights, however (Eşarj, 2019). The pricing for EV charging is based on a time-basis. This has two practical reasons: selling electricity on a kWh-basis requires receiving a license, and there is a need to avoid waiting time for the next customer once the EV is 100% full. For different charging powers, Eşarj applies the following prices per minute: 3.7 kW (MCN37M): 0.06 TL, 7.4 kW (MCN74M): 0.12 TL, 11 kW (MCN11M): 0.21 TL, 22 kW (MCN22M): 0.33 TL, and 45 kW (MCQ45M): 0.86 TL. For all EV types, an additional 50 TL is charged to the customer per charging. To give an example, a Renault Zoe with a battery capacity of 22 kWh requires 45 minutes to charge 75% of its battery at a charging capacity of 22 kW (max) at AC 1-phase charging station. So, charging 17 kWh would cost 14.85 TL (priced with the MCN22M electricity tariff). If a Tesla Model S with a 60-kWh battery capacity would be charged with the same amount of electricity of 17 kWh at a DC station, it would take 21 minutes to fill 30% of its battery capacity. This would cost 18.06 TL (priced with the MCQ45M electricity tariff). To avoid waiting times at charging stations and unnecessary costs to consumers, it is crucial to address what happens if a consumer keeps the car plugged in even after the battery is fully charged. This is an important question because, in the future, waiting times at charging points can become an issue. It would be important to prevent EV drivers from using charging points for long-time parking (without actually charging). Pricing is the key driver here. In many countries, charging becomes more expensive as the time an EV spends at

the charging point increases, which gives the consumer an incentive to move away after the minimum charge limit. For a Renault Zoe that arrives at the station with half-full battery capacity, it would take 30 minutes to charge the remainder of its battery capacity (22 kWh at 22 kW). This would cost 9.90 TL. To charge the consumer who would keep the car for another 90 minutes at the station, the total amount of electricity that is used for charging (11 kWh) is divided by the total duration when the car was connected (2 hours) in order to estimate the charging power (5.5 kW) and the corresponding electricity tariff (MCN74M). This would cost the driver an additional 14.40 TL.

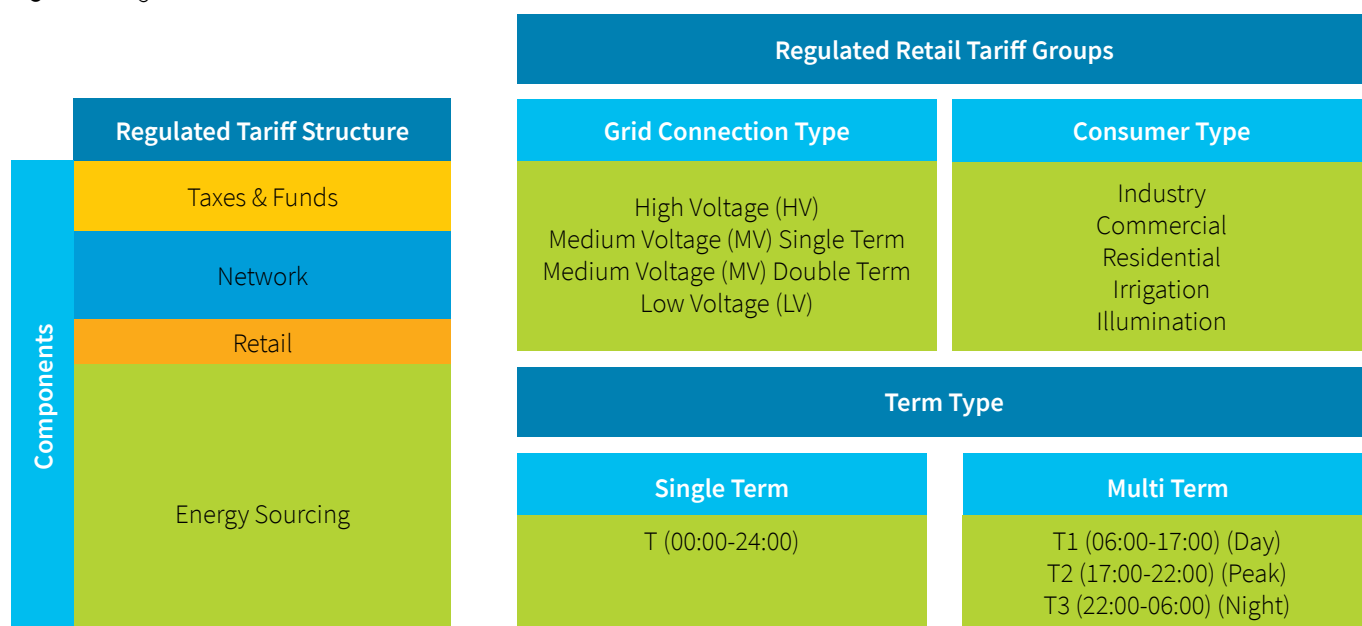
2.4 Electricity pricing strategies in Turkey

The liberalisation process in the Turkish electricity market started with the “Electricity Market Law” in 2001 (EPDK, 2018a). The structural change that affected all aspects of the value chain has been implemented to create a more competitive, environmentally sensitive and consumer-focused market. The Day Ahead Market, the Balancing Power Market and the collateral mechanism are in place since December 2011. In addition, the privatisation process of distribution companies were successfully completed and the distribution and retail activities were unbundled in 2013. This was a major step towards a fully liberal market. The market operations were moved from under the Turkish Electricity Transmission Corporation (Türkiye Elektrik İletim A.Ş., TEİAŞ) to an independent energy exchange company (Enerji Piyasaları İşletme A.Ş., EPIAŞ), which was established in 2015. At the same date, the intraday market was opened in order to provide an additional platform for balancing activities especially for renewables. BORSA İstanbul started operating the derivatives power market as well. The process of liberalisation is still ongoing.

Customers that are industrial zones, and commercial facilities, as well as household consumers with consumption of more than 1.6 megawatt-hour (MWh) per year (as of July 2019) as directly connected to the system, have the right to choose their own suppliers (the so-called eligible customers). The Energy Market Regulatory Authority (Energy Piyasası Düzenleme Kurulu, EPDK) reduces the eligibility limits each year - aiming to reach zero, with a view to increasing the competitive market structure in the electricity sector. The amount of eligible electricity consumption (kWh), a theoretical market opening ratio, reached almost 95% by the end of 2018.

Incumbent regional suppliers provide electricity to non-eligible consumers in their assigned region, where they are also the supplier of last resort, as well as to eligible consumers countrywide. The unit cost for eligible consumers who exercise their right to choose their suppliers is the price offered by the contracted supplier company, while for non-eligible consumers, the price is determined by the EPDK. In other words, there is a nationally regulated retail electricity tariff for non-eligible consumers. Regulated tariffs (for captive consumers) are assessed and approved by the EPDK through a cost based automatic pricing mechanism on a quarterly basis. The nationally regulated tariff is relevant not only for the majority of consumers who use it, but also as a reference point for pricing in the eligible consumer market where prices are generally negotiated as a discount on the national tariff rate.

Figure 5: Regulated Retail Tariff Structure



Source: SHURA (2019b)

The end-user retail price in electricity consists of four main components: energy sourcing cost, retail fees, network fees, and taxes and funds, as indicated in Figure 5. The regulated tariff is categorised according to the type of the grid connection and the consumer group. Moreover, the tariff is proposed to the consumer as two different products: single term (uniform pricing across the day) or multi-term tariff (a three-period Time-of-Use Tariff, ToUT). The price is the same throughout the day in the single term tariff. On the other hand, the price is segmented in three time zones in the multi-term tariff, as indicated in Table 1. The current retail tariff prices are indicated in the following figure:

Table 1: Regulated retail tariff prices (as of October 2019)

1/10/2019	Regulated retail tariffs (in Turkish Lira per MWh)				
Distribution Company users	Retail single term energy sourcing fee	Retail multi term (Day) energy sourcing fee	Retail multi term (Peak) energy sourcing fee	Retail multi term (Night) energy sourcing fee	Distribution company fee
Low voltage					
Industry	499.5830	506.3080	827.8390	246.8020	157.3550
Commercial	543.6730	549.7810	899.6850	271.3760	213.2490
Residential	364.1890	371.4550	636.0530	159.8570	208.5650

Source: TEDAŞ (2019)

One of the aims of the liberalisation and reform process of the electricity sector in Turkey was to gradually phase out the national tariff in favour of market-based tariffs between eligible consumers and independent suppliers. The intended system is 100% market opening where cost-based regulated tariffs remain only in distribution and transmission, and power is sold as a market-based commodity. Large regional disparities in loss and theft and in bill collection rates have so far impeded the realisation of the intended system. In 2018, the Last Resort Tariff was introduced as an intermediate step in the transition to a fully liberalised market.

The Last Resort Tariff was devised to eliminate very low tariffs applied by incumbents to large industrial consumers, and to replace them with a tariff that reflects the full cost recovery plus profit. The last resort tariff will apply to consumers procuring from incumbent companies whose annual consumption exceeds 50 GWh for 2018, and 10 GWh for 2019. The Last Resort Tariff structure is simpler than the regulated retail tariff. There is no product differentiation according to grid connection type, consumer group, term usage, or any other criteria. The tariff has a customised pricing formula where the actual energy sourcing cost is calculated on the basis of actual hourly consumption and market clearing price by adding a gross profit margin. The margin covers the cost of customer acquisition, retention and operation, other cost elements in sourcing, such as profiling and balancing, and net profit margin of the supplier (Table 2).

The main logic in the Last Resort Tariff is to force eligible consumers to switch to the free market in order to select a more attractive tariff and sign a new bilateral contract offered by any retailer, including the regional incumbent supplier. The Last Resort Tariff can be considered a price cap in electric energy costing for eligible large-scale consumers. Its level depends on gross profit margin, which is 12.8% currently, and may change depending on the regulator's decision. The current gross margin seems to be enough to encourage almost all eligible large consumers to enter into free bilateral contracts according to current market conditions. The tariff will also facilitate transition to a system based more on demand response and efficiency. As stated above, the regulated retail tariff is applicable for non-eligible consumers and eligible small-scale consumers who do not prefer a free tariff from a supplier. For this reason, the regulated retail tariff, like the Last Resort Tariff, can be considered a price cap, or a reference point in the competitive market for eligible small-scale consumers.

Table 2: The Last Resort Tariff Structure

The Last Resort Tariff: Specific Price to Each Consumer
Taxes & Funds
Network
The same with regulated retail tariff fees
Energy Sourcing + Retail
(Actual Energy Cost @ Actual Weighted Average Market Clearing Price and Renewable Support Mechanism Cost) x (1+ Gross Profit Margin)

Source: SHURA (2019b)

In the current system, all 21 regional retail sale incumbent companies are required to use a single national tariff which applies to all consumers who do not choose to purchase electricity in the national market. Each company has different energy sourcing costs, technical & non-technical losses and collection rates, as well as different operating costs and investment requirements, all of which are averaged out in the national tariff. After each company invoices the amount to be paid for the electricity it sells to end-users utilising the national tariff, any amount above the regulated regional income cap is transferred to the equalisation mechanism to be redistributed to regions whose regulated income cap is above the national average.



3. Recent developments in the global electric vehicle market

3.1 Market developments

By the end of 2018, the total number of EVs on the road reached 5.1 million. The time needed to add the next 1 million EVs to the stock is now less than 6 months.

As an outcome of policies to support EVs and accelerate the deployment of charging infrastructure, the global EV market is seeing a rapid growth. By the end of 2018, the total number of EVs on the road reached 5.1 million. The time needed to add the next 1 million EVs to the stock is now less than 6 months (BloombergNEF, 2018; IEA, 2019b). China accounts for the largest share of the global stock, representing nearly half of all EVs. Only in 2018, around 1 million EVs were sold in China. Europe and the United States follow China, each with more than 1 million EVs driven.

Around half of all EVs in use are in 25 cities, with China leading in the number of cities. Shanghai led the global EV sales with more than 162,000 cars being sold between 2011 and 2017. This is equivalent to more than 5% of the global EV stock. Beijing and Los Angeles follow Shanghai with a share just below 5% (ICCT, 2018).

How often EVs need to be charged depends not only on the distance driven, but also on the capacity of the battery. Average distance of a passenger EV is now approximately 200 km and is expected to increase with the improvements in battery technology (U.S. Department of Energy's Office, 2019). This will impact the need for charging occurrences, as well as for the density of charging infrastructure outside homes, including at workplaces, shopping places, and other public areas. A perceived market uptake barrier for EVs has been the long duration needed for charging – typically up to 8 hours for a full charge when using Level 1 or 2 “normal” chargers (with max. 22 kW charging capacity) (EAFO, 2019).⁷ 7, 11 or 22 kW charging is desirable, though not essential, for private passenger car charging in most situations (such as at home, or at work, where most charging occurs), and a balance must be observed/struck between shortening charging time in line with consumer needs and exploiting longer charging times, for example, an office day, to provide grid flexibility. The need for public fast charging for passenger EVs in cities may in fact be modest, given that daily driving needs for private cars are in most cases within the range of most EV models, and the new battery electric vehicles' range has been increasing quickly with battery development.⁸ However, this can change, if more EVs are integrated in fleets (taxi/service fleets), as well as for electrified ridesharing services – in all these use cases, profitability depends on mileage, and using EVs with comparatively low running cost presents a cost advantage, making future uptake more likely (see more in section 3.5). In addition, fast charging is likely to increase battery stress and degradation at the current level of technology development; therefore, battery technology licensors are developing measures to mitigate battery ageing from such affects as battery ageing is also impacted from distribution of charging over the timer period.

The need for public fast charging for passenger EVs in cities may in fact be modest, given that daily driving needs for private cars are in most cases within the range of most EV models, and the new battery electric vehicles' range has been increasing quickly with battery development. A similar number of chargers serve the EV stock with around 5.1 million in use worldwide.

A similar number of chargers serve the EV stock with around 5.1 million in use worldwide (IEA, 2019b). 2018 saw an increase of 44% in charging infrastructure compared to the year before. Most of the increase was for private charging infrastructure. The majority of the total chargers in use worldwide are private and slow charging infrastructure in residences and workplaces (levels 1 and 2). More than 10%

⁷ Here, we use the EU definition of a “normal” charger with capacities up to 22 kW. This capacity range would be defined as “slow” charger in the US. In the rest of this study, chargers with a capacity above 22 kW is referred to as “fast” chargers.

⁸ Range anxiety does not apply to plug-in hybrid vehicles since these can run on combustion engines, too. However, user experience from the Netherlands suggests that in the absence of convenient charging infrastructure, plug-in hybrid vehicles tend to only be driven in electric mode 40% of the time, thus contributing less to pollution and energy consumption reduction.

of these chargers, which amounts to 632,000, are accessible in public places (half of them in China) (BloombergNEF, 2019). The number of fast chargers available for use is 150,000, nearly 80% of which is located in China (IEA, 2019b). The United States has the most private chargers. So, today's ratio is, on average, 1 charger per 1 EV and 1 public charger for 10 EVs. Charging habits differ by region and by city within the regions. In northern European countries, the majority of the EV owners prefer to charge at home either for the entire week at once or on a daily basis. In the United States, the number of charging stations per EV in houses and in public areas is on average 0.9 and 0.33, respectively. This is more typical for early market deployment, and over time, one could expect that this ratio will most likely shift towards more public infrastructure as consumer confidence and availability grow. In addition, in emerging countries not all cars have access to a private parking place at home or at work. Therefore, public charging will also be more relevant in these countries. China's target is 0.93 private EV supply equipment (EVSE) by 2020, up from 0.8 in 2017 (IEA, 2018). While these current country statistics provide a good basis to reveal the total number of charging stations per EVs at different locations, each country has its unique circumstances. Therefore, when planning for Turkey, in addition to EV charging stations at home and at work, the total number of the charging points and their optimal locations for public charging need to be calculated by taking into consideration the impacts on the distribution grids. In Turkey, the urbanisation characteristics are somewhat different than in most cities in Europe and in the United States where the urban landscape is more vertically constructed. Out of around 8 million residential buildings there are only a limited number of single-family houses (Saygin et al., 2019).

3.2 Projections

For the year 2030, the global EV stock is projected to reach 120-250 million.

There are various global EV outlook scenarios. For the year 2030, the global EV stock is projected to reach 120-250 million according to scenarios by the BloombergNEF, International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) (IRENA, 2018). Reaching the high end of this range would require nearly 40% share in total passenger vehicle sales, which are estimated to be around 90 million by 2030. In 2018, the sales of 2 million EVs represented 2% of all car sales.

The sales of an additional 13 million battery and plug-in hybrid vehicles worldwide will result in sufficient cost decline due to technological learning that will ensure cost-competitiveness.

In order to achieve significant market shares, EVs will need to be competitive on the total cost of ownership vis-à-vis conventional internal combustion engine vehicles in multiple markets. This will be realised by technology development and policies, including purchase incentives (tax subsidies, purchase bonus, scrapping schemes, etc.), that reduce high upfront cost, but eventually need to be replaced by economies of scale. The sales of an additional 13 million battery and plug-in hybrid vehicles worldwide will result in sufficient cost decline due to technological learning that will ensure cost-competitiveness (Weiss et al., 2019). This means around 20 million EVs in the total stock to be achieved by 2021/22. In order to achieve such cost declines and realise the EV market projections, the decline in the costs of battery storage technologies will also need to continue.

Several countries, including the EU countries, China, India, Indonesia, Japan, South Africa and South Korea, have clearly highlighted targets regarding the increased uptake of EVs.

3.3 Policies accelerating the electric vehicle rollout

In the Nationally Determined Contribution (NDC) submitted by countries to the United Nations Framework Convention on Climate Change (UNFCCC), several countries, including the EU countries, China, India, Indonesia, Japan, South Africa and South Korea, have clearly highlighted targets regarding the increased uptake of EVs.

China, as part of its industrial and clean air policies, promotes the use of EVs. A production quota system, complemented with credit-based market mechanism, spurs production in the country, as well as the local value chain, including electronics and battery production (IEA, 2018). There are minimum levels set for distance and efficiency of EVs that are manufactured in the country. Sales incentives in China are tailored to the maximum distance, efficiency and the energy density of the storage systems. As discussed in many other countries, a potential ban on the sales of internal combustion engines is on the table (SLoCaT, 2019). In the EU, a benchmark for sales of low or zero emission vehicles has been set at 15% in 2025 and at 35% in 2030, as part of CO₂ emission standards for car makers. India is working on an ambitious plan to transform its transport sector into a fully electrified one with electric two- and three-wheelers (Times of India, 2019). In the country, the public sector has launched leading initiatives through procurement tenders, and has undertaken infrastructure planning to meet a certain level of the total electricity demand generated by EVs. In the United States, ambitious state-level initiatives, such as California's zero emission vehicle programme, exist in 9 other states (IEA, 2018). In many other countries, volumetric (% of sales or stock) and targets in absolute figures exist to accelerate the EV uptake.

3.4 Charging infrastructure

The market is segmented into AC charging station, DC charging station, and inductive charging station. The AC and DC charging station segments are sub-segmented into residential and commercial. DC charging stations are expected to be the fastest growing segment of the market.

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The European Commission has two main criteria guiding the member states' public EV charging infrastructure. There is a recommended density ratio of 1 charging point per 10 EVs by 2020 (European Union, 2014). This corresponds to today's global average value, but in Europe the ratio is 1 to 5 currently. At the current rate of EV growth, by 2020 there should be around 220,000 public charging points (Transport & Environment, 2018a). In addition, there is a recommendation of placing a charging point at every 60 kms on the main highways (Transport & Environment, 2018b). These guidelines, issued as part of the implementation of the EU's legal framework defining the public charging infrastructure, are based on the modelling carried out at urban and regional levels (European Commission, 2016). With these developments, a strong layout of fast (5,000 50 kW) and ultra-fast (1,000 150-350 kW) charging points is expected to be achieved by the end of 2020. This would actually mean, on average, one charging point at every 34 km along the TEN-T Core Network (Transport & Environment, 2018a). So, the current progress shows that there will be sufficient charging points available for EU's EV stock if the countries follow their national plans. However, with the exponential growth expected in the EV sales in the coming years, there will be significant levels of investment and planning needed for infrastructure (Transport & Environment, 2018b). In some countries, as in the United Kingdom, however, the charging infrastructure is considered rather "poor" and "lacking in size and geographical scope", which presents a major obstacle to the adoption of EVs in the country (Campbell and Thomas, 2019).

A recent study focuses on the lessons learned from fast charging deployments in many markets around the world through mid-2018 and on the usage by battery EVs, thereby highlighting the crucial role of planning for determining how much fast charging will be needed (Nicholas and Hall, 2018). Key determinants are the expected sales of EVs that can technically be connected to fast-chargers, ranges of those EVs, and

the availability and location of other types of charging equipment. As the EV market grows, the number of fast chargers may have to rapidly increase. Trends are mixed in terms of charging choices. Some EV owners tend to use fast chargers that are closer to their homes, others find fast charging convenient if fast chargers are placed in front of restaurants, supermarkets, etc, and if the prices are reasonable as charging at home is cheaper and could be more convenient. The growth of fast charging will also depend on how stations are utilised, on the charging speed, and on the business cases that emerge. On the other hand, if other types of chargers are fewer in number, then more fast chargers may be needed. However, it is important to note that charging types are not mutually exclusive, but use cases will rather complement each other as the market evolves. With increasing numbers, use cases are likely to differentiate. For private EV owners, fast chargers will be convenient mostly when they are in front of commercial sites with short average visit time (restaurants, supermarkets, etc.), and if prices are competitive.

From an electricity cost point of view, fast charging has a business case at electricity prices below the equivalent price of diesel/gasoline. In addition, a certain level of the installed charging capacity must be utilised to cover for the costs.

From an electricity cost point of view, fast charging has a business case at electricity prices below the equivalent price of diesel/gasoline. In addition, a certain level of the installed charging capacity must be utilised to cover for the costs, which would otherwise require policy intervention.

Private and workplace charging infrastructure deployment requires updating building codes, and governments in many EV markets are in the process of setting minimum equipment criteria for shared parkings. In Norway, there is a minimum requirement to reserve 6% of parking places for electric vehicles in new buildings.

Who is responsible for building EV charging infrastructure and how costs should be shared are key regulatory questions in the context of EV integration, particularly for energy market actors. Currently, roles and responsibilities are distributed differently in each case. In China, the government owns and operates the electricity system, and issues licences to businesses in urban areas to deliver charging services. The EU's recently reviewed electricity market design rules stipulate that DSOs cannot own or operate EV recharging points, as long as the market can deliver charging services (Council of the European Union, 2017), except in cases where there is no third-party interested.⁹ In India, small-scale companies were not able to gain a market share because of the challenges in acquiring licenses, so there is the right to unlicensed operation (IEA, 2018). Similarly, in the US, retail companies do not have the right to operation, but the states are changing this rule to accelerate market development (IEA, 2018). For example, in California, after having achieved a sufficient level of private market investments, the regulator (California Public Service Utility Commission) allowed energy suppliers to build and operate charging infrastructure on a case-by-case basis, a step to accelerate the development of charging infrastructure overall and make a business case for third parties.¹⁰

As EV penetration increases, the way EVs are charged (i.e., when, where and how much) can have significantly different implications for the costs of integrating them.

3.5 Smart charging

As EV penetration increases, the way EVs are charged (i.e., when, where and how much) can have significantly different implications for the costs of integrating them.

⁹ In Spain, DSO Iberdrola argued that third-party interest was missing and that, in order to offer EV charging, DSO involvement was needed. A royal decree was passed in October 2018 to allow for this as a last-resort option under certain conditions, such as the lack of private interest after a competitive tender, and to require review once there is private interest (Boletín Oficial del Estado [Official State Gazette, Spain], 2018). Similar rules are in place in Germany and the United Kingdom.

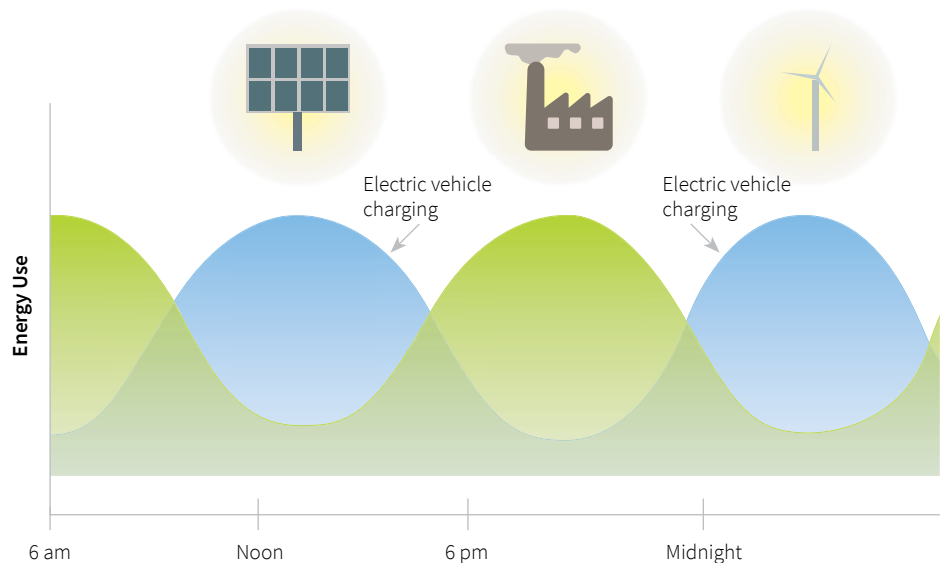
¹⁰ Since 2016, the CPUC even requires energy suppliers to plan for charging infrastructure roll-out (CPUC, 2016).

Uncontrolled charging of electric vehicles would lead to substantial cost increases for meeting their power and delivery needs, as EVs would likely be charged during existing peak periods, thus exacerbating peak demands. This would inevitably result in significant investment in new generation and network capacity that would operate at very low load factors simply to serve this exacerbated peak. Research from Norway, a more mature EV market, suggests that without any incentives or price signals from, for example, time-varying tariffs, EV owners tend to charge during existing peaks. For instance, most EV drivers plug in when coming home from work at around 18:00. For Turkey, a similar peak exacerbation is likely to be expected as both public and home charging rise at around 19:00.

We define smart charging as EV charging (from grid to vehicle) that can be shifted to times when the costs for producing and delivering electricity are lower, without compromising the vehicle owner's needs.

We define smart charging as EV charging (from grid to vehicle) that can be shifted to times when the costs for producing and delivering electricity are lower, without compromising the vehicle owner's needs (Hildermeier and Kolokathis, 2019). The concept of smart charging seeks to make EV charging (and possibly other flexible consumption) beneficial to consumers, the electricity grid and the environment, by lowering costs and shifting consumption away from peak hours to times of demand and, subsequently, grid use, as explained schematically in Figure 6 below.

Figure 6: Smart charging impacts on the load curve



Source: Hildermeier and Kolokathis (2019)

Smart EV charging helps accelerate the use of low-carbon resources. For example, when there is a significant amount of renewable energy on the grid relative to “business as usual” demand, wholesale market prices may be quite low. Shifting EV charging to such periods can mitigate uneconomic curtailment, or output reduction, of renewable energy. For instance, in California, the traditional midday peak has, on many days, become a valley, creating the opportunity to charge EVs at low cost and improving the utilisation of increasing solar production in the middle of the day. Similarly, charging could occur when ample grid capacity is available to deliver the required electricity, usually during night time hours.

In Turkey, electricity demand is at its lowest levels during night time hours and starts increasing in the early morning. It peaks in the evening before dropping toward midnight (Hildermeier and Kolokathis, 2019). This pattern is typical also in European

countries and beyond, although variations have started to appear in recent years due to increases in the use of distributed energy resources. The significant valley that occurs during night time hours could be used to take up new electricity loads depending on the availability of renewable energy supply.

3.5.1 Time varying electricity pricing

To enable smart charging, electricity pricing signals that reflect the cost of generating electricity (the energy part of the bill) and delivering this electricity to the final consumer (the network part of the bill) can steer consumption optimally to hours of lower demand.

To enable smart charging, electricity pricing signals that reflect the cost of generating electricity (the energy part of the bill) and delivering this electricity to the final consumer (the network part of the bill) can steer consumption optimally to hours of lower demand. Dynamic pricing differentiates retail electricity prices (ideally both for energy and the network) across the day to provide an economic incentive for consumers to adapt their charging behaviour. If applied well, electricity prices align the choices that consumers make to minimise their own bills with the choices that also minimise overall system costs.

Dynamic electricity tariff designs exist across most EU countries, but their adoption is limited overall. Examples of such pricing range from ToUT — where the consumer pays a variable, predetermined fee for specific blocks of time based on historical usage patterns (such as a day and night, or a weekday and weekend tariff) — to the most granular real-time pricing, where the price is determined by actual conditions on the system from one interval to the next.¹¹ ToUTs are the most common form of time-varying pricing and generally apply to the energy component of the bill, although there are examples of time varying tariffs for the network component of the bill, too. Real-time pricing is also becoming more common across the world.¹²

3.5.2 Technology

In general, experience from dynamic pricing pilots shows that dynamic pricing schemes are more effective in reducing peak demand when coupled with intelligent technology (Faruqui et al., 2012). Technology required to support dynamic tariffs can range from simple smart meters that monitor a customer's real-time (or close to real-time) consumption and communicate this information to customers actively adjusting their consumption, to more advanced forms in which tariffs can be managed with smart devices that can automatically control consumption by responding to a certain type of signal, such as pricing or carbon emissions, and adjust consumption – for example, determine when the EV is charged – without the need for consumer intervention.

An optimal charging point location should not only meet mobility demand but also use, as much as possible, the existing grid or street infrastructure to reduce costs.

3.5.3 Siting of infrastructure

Siting of infrastructure can also be optimised by location. An optimal charging point location should not only meet mobility demand but also use, as much as possible, the existing grid or street infrastructure to reduce costs. Furthermore, planners have options to evaluate what kind of charging infrastructure is needed to allow for

¹¹ Among the two, critical peak pricing sets significantly higher prices for a limited number of pre-notified “critical peak” periods. Another emerging tariff form is the peak-time rebate. Consumers on such a tariff receive a partial refund if they avoid using electricity during peak hours, but face the same charge if they consume electricity during these hours, as with any other time of the day.

¹² In Europe, the members states that have liberalised their retail markets for a longer time, such as the Scandinavian countries, the UK, and the Netherlands, provide an increasing number of real-time pricing offers, while there is no real-time pricing in countries where the majority of households are under regulated prices. For more information, see: European Commission, Directorate-General for Energy (2019). Most recently, New Zealand has decided to go ahead with plans to introduce Real Time Pricing by 2022. See, for example: Lord (2019).

optimised charging (fast / normal charging, battery-assisted, or grid-based) depending on the anticipated use cases (private charging / fleet charging of passenger, or utility vehicles).¹³

In addition to the unidirectional optimised charging modelled in this report, bi-directional discharging of EVs to the grid (vehicle-to-grid, V2G) offers a substantial peak reduction potential. V2G can be defined as all services that a vehicle can deliver to the grid as a “battery on wheels” by participating in the energy market, for example, providing renewable energy storage, or improving grid stability and reliability by providing grid balancing services, and generating revenues with these services. Though the potential is large, most of the current V2Gs in Europe and in other world regions are small-scale, and promising practices of larger-scale projects are mainly found in the United States. Due to scalability and regulatory barriers to grid integration, this market potential cannot be exploited in the short term, and is therefore not covered by this study. It, nevertheless, constitutes an important mid-term resource for EV grid integration, especially at scale (HEV TCP, 2018; IRENA, 2019a; Transport & Environment, 2019).

¹³ For a discussion of examples, see Hildermeier et al.(2019).

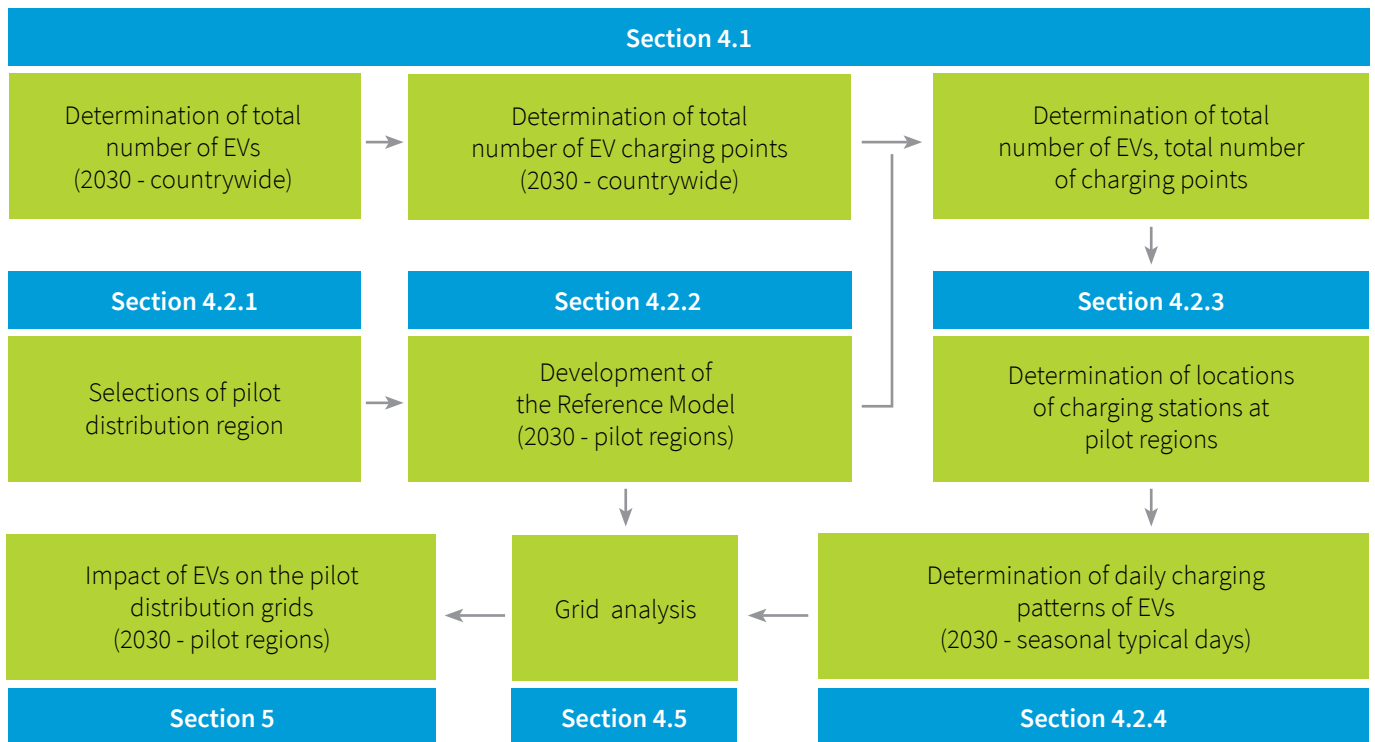


4. Methodology

The first step is to estimate the market outlook for electric vehicles and charging infrastructure for the entire country between 2017/18 and 2030.

This section explains the methodology and background data used to estimate the total number of EVs and charging points in Turkey, as well as the key steps of the methodology developed to model the grid integration of EVs in selected distribution areas in Turkey. According to Figure 7, the first step is to estimate the market outlook for electric vehicles and charging infrastructure for the entire country between 2017/18 and 2030. As the next step, an impact analysis is carried out for selected pilot distribution grids in Turkey. This step includes several sub-steps, including: i) selection of pilot distribution regions for the EV impact analysis, ii) allocation of the number of EVs and charging points in pilot distribution regions for the target year 2030, and iii) development of two distinct distribution grid models for each pilot region, one for a case with no-EV uptake (referred to as the “Reference Model” throughout the study), and one for a case with EV uptake.

Figure 7: Key steps of the methodology



The rest of this section is split into two parts. The first part presents the background data and assumptions for the EV and charging infrastructure market outlook (section 4.1). The second part discusses the details of the distribution grid modelling approach, including the locational distribution of charging points and the daily charging patterns of the EVs (section 4.2).

4.1 Market outlook

The following steps are followed in estimating the total number of EVs in the stock:

- Total vehicle ownership in Turkey was assumed to be 300 vehicles per 1000 people by 2030, which is almost twice as many as the 154 vehicles in 2018. This growth rate is higher than the 60% growth rate that was experienced in the past decade. A higher growth rate between 2018-2030 was assumed reasonable as ownership will increase with growing prosperity. The estimate of 300 vehicles per 1,000

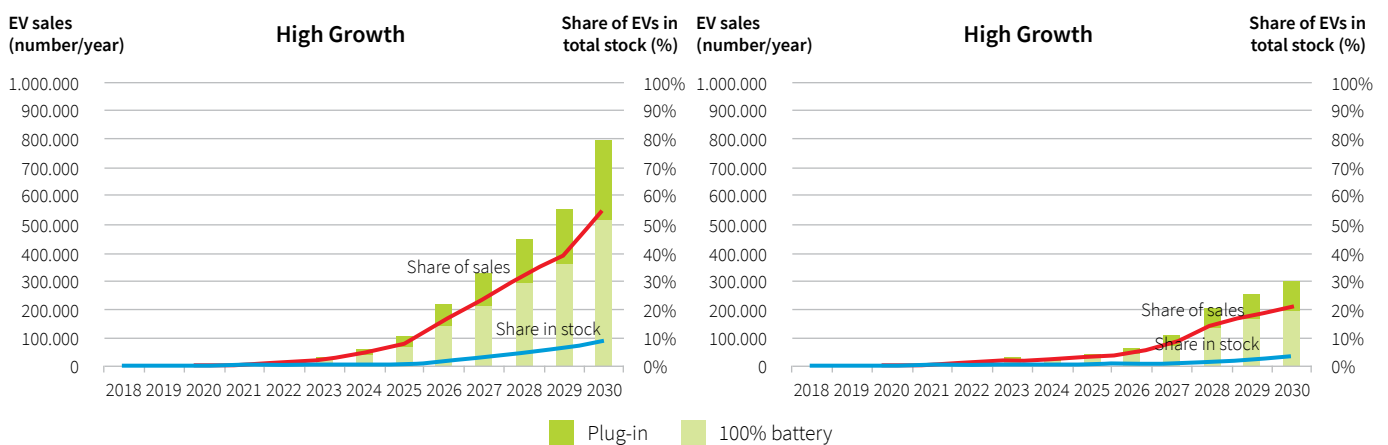
people remains lower than the OECD average, which stood at 460 vehicles in 2017. According to recent projections, Turkey’s population reaches 93 million by 2030, up from 81 million in 2018. By 2030, the total number of passenger vehicles reaches 27.9 million. This is by a factor 2.5 higher than the 2018 level of 12.5 million.

- Annually, between 600,000 and 750,000 vehicles have been sold in Turkey on average between 2013 and 2017. Each year around 15,000 vehicles are being scrapped. It is assumed that, on average, 25,000 vehicles will be scrapped annually until 2030. In order to reach the estimated 27.9 million vehicle stock by 2030, a net increase in the number of new vehicles that enter the stock, starting from 1.15 million in 2019 and reaching up to 1.4 million by 2030, should be achieved annually.
- It is assumed that the sales of EVs (battery and plug-in hybrid) and hybrids (i.e. vehicles that are not plugged for charging) reach 65% of all vehicle sales by 2030 in the “High-Growth”, and 30% in the “Medium-Growth” scenario. In Turkey, the share was 2.5% in the first half of 2019 (Yeşil Ekonomi, 2019a). The increase in sales follows a somewhat slow trend till 2022/23, the year when Turkey plans to introduce its locally manufactured EV. From 2023 onwards, sales grow exponentially until 2030.
- While hybrid sales constitute 95% of all EV and hybrid sales today, this share decreases to 15% by 2030 according to the High-Growth scenario, and to 30% according to the Moderate-Growth scenario. The share of battery electric vehicles increases to 55% and to 45% in the High-Growth and Moderate-Growth scenarios, respectively. The remaining 30% and 25% are represented by plug-in hybrid vehicles.¹⁴ With these sales figures, the total number of battery and plug-in hybrid vehicles increases to 2.5 million and to 1 million in the High-Growth and Moderate-Growth scenarios, respectively. So, the High-Growth scenario’s estimate is 2.000 times higher than the current level. Transport sector in Turkey is equal to 1% of the total final energy demand in the global transport sector. When this ratio is taken into consideration, 1-2.5 million EVs estimated for 2030 represent 1% of the total 120-250 million vehicles expected to be in the global vehicle market in the same year.

The total number of battery and plug-in hybrid vehicles increases to 2.5 million and to 1 million in the High-Growth and Moderate-Growth scenarios.

A summary of the total number of EV estimations in 2030 is presented in Figure 8. These projections exclude non-passenger electric mobility options, such as light duty vehicles used for commercial purposes, e-buses, e-trucks, two- and three-wheelers, and e-tractors. Foreign-plate vehicles that enter Turkey through borders are also excluded.

Figure 8: Estimations of the total number of electric vehicles in the country in 2030



¹⁴ Breakdown of EV and hybrid car sales according to the High Growth and Moderate Growth scenarios represents a range that corresponds to the 2030 estimates, according to a recent study carried out by the Cambridge Econometrics for Europe covering the period till 2050 (2018).

The analysis distinguishes between “home charging support case”, where home charging has a higher share, and “public charging support case”, where more cars are being charged in public places.

Estimations of the total number of EV charging points in the country in 2030 under the Moderate- and High-Growth scenarios are presented in Table 3. Turkey is a country that has a high urbanisation rate, with much of its population living in multi-family houses today. The share of these buildings is much less than in several of the European countries and the United States. It is assumed that by 2030, only a quarter of all EV owners will have a home charging station in both cases. It is assumed that in workplaces there will be a charger per 2 EVs by 2025 and per 10 EVs by 2030, in both home and public charging support cases (assuming that these will be located in shopping centres and there are suitable infrastructures that allow for charging EVs during work times). For public chargers, it is assumed that by 2030 there will be 10 EVs per charger in the home charging support case and 5 EVs per charger in the public charging support case. Of all public charging stations, 10% is DC (100 kW), and 90% is level 2 AC (22 kW). At homes, 70% of charging stations are level 2 AC (3.7 kW), and 30% level 1 AC (2.3 kW). 2 charging points are located in each station at workplaces and public places.

Table 3: Estimations of the total number of electric vehicle charging points in the country in 2030

Scenario	Rating (kW)	Moderate-growth		High-growth	
Charging case		Home charging	Public charging	Home charging	Public charging
AC1 – home (AC1 H)	2.3	78,160	78,160	193,953	193,953
AC2 – home (AC2 H)	3.7	182,372	182,372	452,557	452,557
AC2 – work (AC2 W)	22	52,106	52,106	129,302	129,302
AC2 – public (AC2 P)	22	46,896	93,791	116,372	232,744
DC3 – public (DC3 P)	100	5,211	10,421	12,930	25,860
Total		364,745	416,580	905,114	1,034,416

2.5 million EV fleet by 2030 would result in an additional 4.1 TWh electricity demand in Turkey. Currently, Turkey's electricity demand is just above 300 TWh, and is projected to reach between 453 TWh and 515 TWh per year by 2030.

Currently, two-thirds of all electricity demand for EVs is used at homes, a situation resulting from an early adopter phenomenon (ICCT, 2017). The remaining 35% is split between workplaces (20%) and public areas (15%). By 2030, it is assumed that this ratio will shift towards more public charging at the expense of home charging, resulting in a 25:25:50 ratio for “home”：“workplace”：“public” in the home charging support case and a ratio of 10:20:70 in the public charging support case.

The average EV modelled in this analysis has electricity consumption of 17 kWh per 100 km¹⁵, and on average, it is driven for 10,000 km per year in the year 2030. Plug-in hybrid vehicles drive half of their mileage on electricity.¹⁶ The maximum distance an EV can drive increases from 200 km in 2018 to 500 km by 2030. 2.5 million EV fleet by 2030 would result in an additional 4.1 TWh electricity demand in Turkey. Currently, Turkey's

¹⁵ This is the average of the following models: BMWi3s (16.8), Renault Zoe (15.8), Jaguar I-Pace (22.4), Nissan Leaf (16.3), Hyundai Kona (17.4), Tesla Model X 75D (21.4), and VW E-Golf (12.4).

¹⁶ Today, most of the current plug-in hybrid vehicle models drive electrically at around 40 km. Evidence shows that as the range of plug-in hybrid vehicle increases, they are driven electrically over longer distances (Transport & Environment, 2018c).

electricity demand is just above 300 TWh, and is projected to reach between 453 TWh and 515 TWh per year by 2030 (MENR, 2019).

4.2 Modelling the distribution grids

4.2.1 Selected pilot distribution regions

Selected regions include 33% of Turkey's total population, and the share of these regions in Turkey's energy consumption is around 35%.

Impacts of EVs on distribution grids are investigated through four selected distribution regions in Turkey. Distribution grids are selected from four DSOs which provide distribution service in different areas in Turkey that are characterised by large population and high consumption of electricity, represented by a mix of residential, commercial, industrial, and irrigation customers. High voltage (HV) substations are picked from each DSO on the following basis: two substations in each DSO - one supplying an urban region and one supplying a rural region - as presented in Table 4. A breakdown of consumers in the selected regions is illustrated in Figure 9. Consumer ratios in Figure 9 represent the ratio of different types of consumers in the selected regions. In addition, the population and the electrical energy consumption amount in the selected regions are depicted in Figure 10. As can be seen, the selected regions include 33% of Turkey's total population, and the share of these regions in Turkey's energy consumption is around 35%. Given the diversity of the loads available in the selected regions (i.e., residential, commercial, etc.), and these regions' considerable share in population and electrical energy consumption, it can be stated that the distribution grid regions in question can represent a good level of EVs impact diversity throughout Turkey.

Table 4: Distribution companies and corresponding pilot high voltage substations

Distribution company	Pilot HV Substations	
	Urban Region	Rural Region
AYEDAŞ	Kartal	Şile
BAŞKENT	Akköprü	Beypazarı
TOROSLAR	Karahan	Kadirli
GDZ	Bornova	Bergama

Figure 9: Breakdown of consumers in pilot regions, 2017

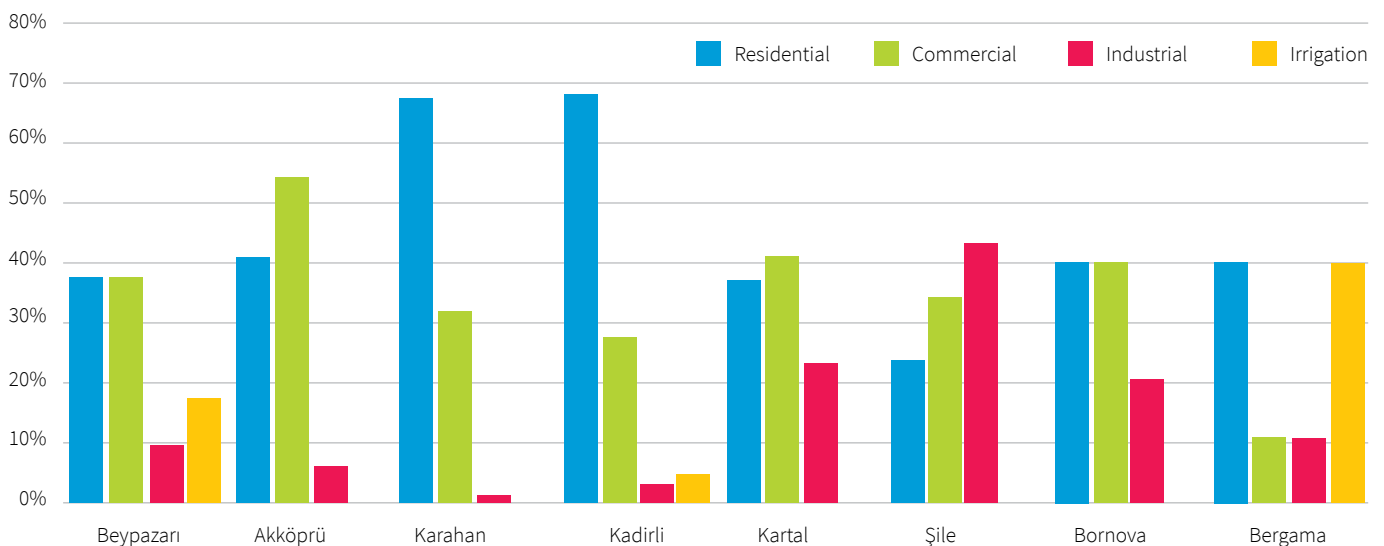
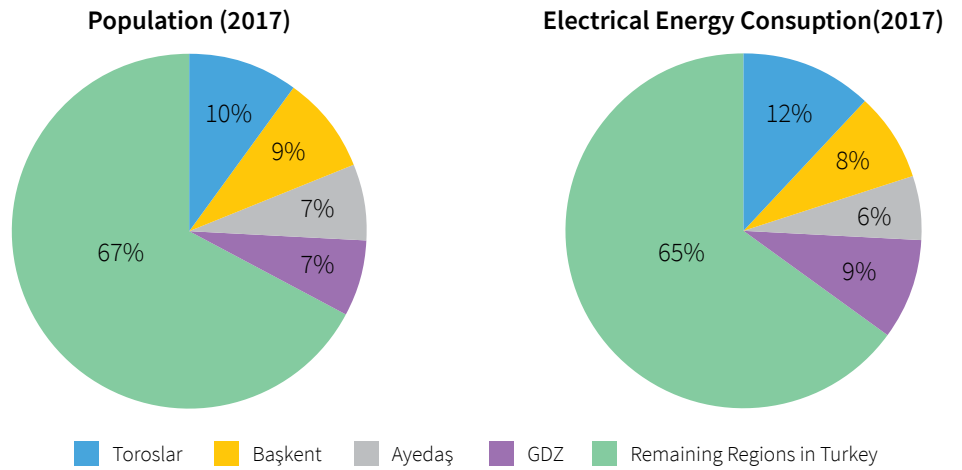


Figure 10: Population and electrical energy consumption share of the pilot regions in Turkey



A key step is to estimate the total number of EVs and charging points in each pilot distribution region. The following approach is employed:

- Each pilot distribution region is supplied by specific HV substations. It is assumed that the ratios of the total capacity in mega volt ampere (MVA) of those HV substations to the country-wide total capacity of HV substations (i.e., 92433 MVA in 2030) give an indication about the ratio of EVs in the pilot regions (1). Since the pilot areas are determined on the basis of TEİAŞ substation supply zones, these regions comprise only a part of the city. There is no indicator for population, education, etc. for only a certain part of the city. On the other hand, since the total electricity consumption of the pilot zones is proportional to the capacity of the substation power transformer feeding the zone and this ratio is similar in all centers, the substation capacity ratios can be used as an indicator of the electricity consumption of the pilot zones. Since total electricity consumption would give an idea for population, development, and education etc. parameters, substation capacity ratios were used as a multiplier. In the literature, there are studies utilizing electricity consumption as an indicator of development (İsmiç, 2015). The development indicator was also considered as a determining factor in the number of EVs.

$$SS_i = \frac{\sum_j^{N_i} S_j^i \text{ (MVA)}}{\sum_j^{N_T} S_j \text{ (MVA)}} \quad (1)$$

where;

- SS_i HV substation capacity ratio index of the pilot region i
- i Pilot region index
- j HV substation index
- S_j Capacity of the HV substation that supply the pilot region i
- N_i Total number of HV substations in the pilot region i (2030)
- N_T Total number of HV substations in Turkey (2030)

- Gross Domestic Product (GDP) per capita of the cities- in which the pilot regions are located is considered as one of the multiplication factors in estimating the total number of EVs and charging points in the pilot regions. GDP per capita figures for 2014 are utilised in the calculations (TÜİK, 2019).
- Development coefficient (RDC) of the cities is considered another multiplication factor (Dinçer and Özaslan, 2004).
- Other socio-economic factor (OF) of the cities, which include the relative education level, is considered the final multiplication factor.

Total number of EVs in each pilot region (EV_i) is calculated by (2) and (3);

$$EV_i = F_i^{EV} + EV_i \quad (2)$$

$$F_i^{EV} = SS_i + GDP_i \times RDC_t + OF_t \quad (3)$$

where;

- EV_c Total number of EVs in the country in 2030
 F_i^{EV} Breakdown factor for the region i
 GDP_i Relative GDP per capita index of the pilot region i
 RDC_t Relative development coefficient of the pilot region i
 OF_t Relative other socio-economic factor index of the pilot region i

The EV factors of the pilot regions and the total number of EVs, which are calculated by using the approach described above, are presented in Table 5 and Table 6, respectively. It is assumed that all of these relative multiplication factors will somehow affect the total number of EV usage. This is because the relatively higher GDP and development level is expected for the population using EVs. Total numbers of charging points in the pilot regions are presented in Table 7.

Table 5: EV factors of the pilot regions

Pilot Region	DSO	Total SS capacity (MVA)	SS_i	GDP_i	RDC_t	OF_t	F_i^{EV}
Akköprü	BAŞKENT	200	0.0022	1.38	1	1.18	0.0035
Beypazarı		50	0.00054	1.38	0.35	1.18	0.0003
Kartal	AYEDAŞ	200	0.0022	1.64	1	1.05	0.0037
Şile		94	0.0010	1.64	0.4	1.05	0.0007
Karahan	TOROSLAR	200	0.0022	0.73	1.00	1	0.0016
Kadirli		100	0.0011	0.6	0.29	0.98	0.0002
Bornova	GDZ	225	0.00243	1.17	1	1.09	0.003104
Bergama		162.5	0.00176	1.17	0.33	1.09	0.00074

Note: Unless otherwise stated, all parameters are relative and are unitless.

Table 6: Total number of electric vehicles in the pilot regions in 2030

Pilot Region	High-Growth Scenario	Moderate-Growth Scenario
Akköprü	9,112	3,672
Beypazarı	798	322
Kartal	9,636	3,883
Şile	1,812	730
Karahan	4,074	1,642
Kadirli	478	193
Bornova	8,028	3,236
Bergama	1,914	772

Table 7: Total number of charging points in the pilot regions in 2030

Pilot Region	High-Growth Scenario		Moderate-Growth Scenario	
	Home charging	Public charging	Home charging	Public charging
Akköprü	3,190	3,645	1,286	1,469
Beypazarı	280	319	113	129
Kartal	3,373	3,855	1,360	1,554
Şile	635	725	256	292
Karahan	1,426	1,630	575	657
Kadirli	167	191	68	77
Bornova	2,810	3,212	1,133	1,295
Bergama	670	766	270	309

4.2.2 Reference Models

In order to assess the impacts of EVs on the pilot distribution regions, medium voltage (MV) Reference Models are developed till 2030.

In order to assess the impacts of EVs on the pilot distribution regions, medium voltage (MV) Reference Models are developed till 2030. It is assumed that there is no EV charging load in the Reference Model (i.e., no-EV uptake), which is therefore defined as the non-EV reference grid model. The following steps are performed to develop the Reference Model for each pilot region:

- **Load forecast:** The annual demand increase is assumed to be $\approx 5\%$ (SHURA, 2018). This excludes any additional demand from EV charging. The annual load curves of the HV substations that supply the pilot regions are determined by scaling their current (2017) load curve to the target year 2030 with the annual demand increase ratio. A sensitivity analysis is also performed for 3% growth rate as well to consider a low-growth scenario (TEİAŞ, 2017).
- **Load profiles of different type of consumers:** Daily load characteristics, which are identified by the EPDK for each distribution company separately for residential, commercial, industrial, irrigation, and lighting loads for typical seasonal weekdays, are taken into account in the model.¹⁷ These reference load profiles are utilised in the study.

¹⁷ EPDK, Load profiles of consumer groups

- **Distribution grid topology:** Current (2018) MV grid model of each pilot region is created based on the geographical information system (GIS) database of each pilot region.
- **Reinforcement requirements:** Grid investment requirements, which are driven by the load growth, are determined by taking into account the following technical constraints: i) overloadings on the existing branches; ii) voltage drop at the consumer points; and iii) N-1 contingency at the primary distribution network (generally regarded as the backbone of the MV grid - Figure 11) in the pilot regions. New branch investments to satisfy these criteria are assumed to be in parallel with the available routes to simplify the planning process.

In the 5% annual electricity demand increase from 2018 to 2030 (i.e., 80% demand increase in total), the total increases in the MV/LV distribution transformer capacity (kVA) and in the MV line length (km) are estimated as 48% and 43%, respectively. This corresponds to 3.8 million TL investment cost per year for distribution transformers and MV lines.

Such a process would essentially provide the necessary branch investments in the primary distribution network. The current ratio between the primary and the secondary (MV branches that supply distribution transformers) networks in the pilot regions are taken as a reference point in estimating the total amount of investments in terms of both primary and secondary grids. The details of the approach is presented in Annex A.

The primary and secondary networks in the pilot region of Akköprü, Ankara, in 2018 are illustrated in Figure 11. As can be seen from the figure, primary network refers to branches between main substations and laterals. However, secondary network includes only the laterals feeding the distribution transformers. The ratio of the total length of the secondary MV branches to the primary branches is 3.25 in 2018, as presented in Table 8. For example, the total amount of investment requirements for the target year 2030 is calculated as 20 km at the primary network of the Akköprü pilot distribution region. This corresponds to 65 km secondary network branch investment under the current secondary/primary ratio, as presented in Table 8.

Figure 11: Primary and secondary networks in the pilot region of Akköprü, 2018

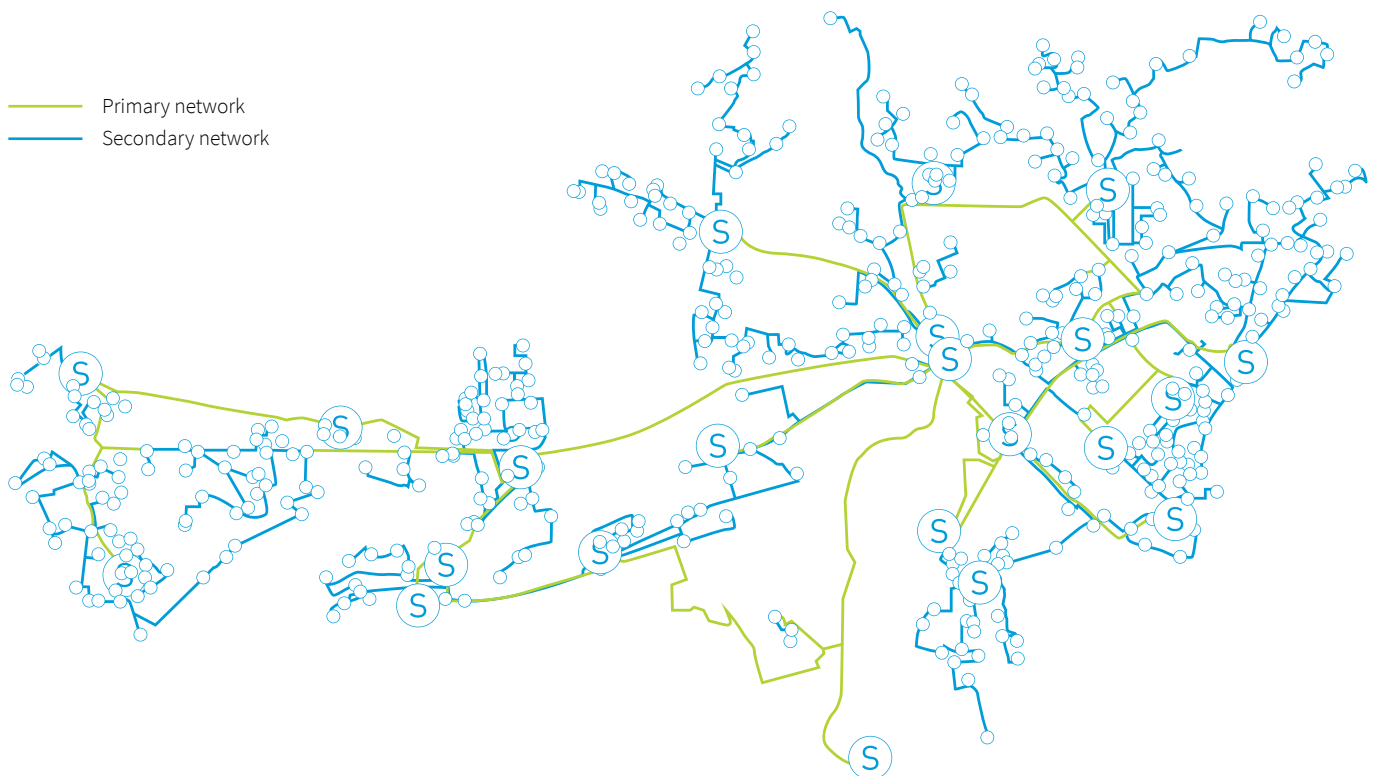


Table 8: Medium voltage line investment requirements in the Reference Model (Akköprü)

Akköprü TM	Current MV line (2018, km)	MV line investment requirements (2030, km)	Total MV line (2030, km)
Primary	80	20 Reference Model	100
Secondary	260	65 estimation	325
Secondary / Primary ratio	3.25	3.25 assumption	3.25
Total	340	85	425

The results of the Reference Model for the Kartal region for 2030 are provided in the following tables along with the figures for 2018. In the 5% annual electricity demand increase from 2018 to 2030 (i.e., 80% demand increase in total), the total increases in the MV/LV distribution transformer capacity (kVA) and in the MV line length (km) are estimated as 48% and 43%, respectively. This corresponds to 3.8 million TL investment cost per year for distribution transformers and MV lines (in real 2018 prices).

Table 9: Installed transformer capacity technical figures (Kartal)

Pilot Region	Installed Transformer Capacity						
	HV/MV				MV/LV		
	2018		2030		2018	2030	
	MVA	#	MVA	#	kVA	Current (#) Additions for Non-EV Reference Model (#)	
Kartal	100	2	-	-	100	2	-
					160	1	-
					250	34	14
					400	15	10
					630	110	75
					800	8	5
					1000	96	47
					1250	15	7
					1600	61	22
					2000	4	-
Total (MVA)	200	-	-	-	311	150	
Increase in the Installed Capacity of MV/LV Transformers (%)						48%	
Annual Increase in the Installed Capacity of MV/LV Transformers (MVA/year)						12.48	

Table 10: Installed transformer capacity financial figures (Kartal)

Kartal Pilot Region	2018	2030
	Current	Additions in the Reference Model
Cost of Installed MV/LV Transformers (million TL, 2018)	29.38	14.84
Annual Increase in the Cost of MV/LV Transformers (million TL/year)		1.24
Increase in Installed Cost of MV/LV Transformers (%)		51%

Table 11: Installed medium voltage line technical figures (Kartal)

Pilot Region	Installed MV Line		
	Type	2018	2030
		Current	Additions in the Reference Model
Kartal	Al_150_34.5kV (km)	1.81	-
	Al_95_34.5kV (km)	0.15	-
	Cu_120_10.5kV (km)	38.97	15.57
	Cu_120_34.5kV (km)	3.61	-
	Cu_150_10.5kV (km)	4.64	-
	Cu_150_34.5kV (km)	33.73	4.96
	Cu_240_34.5kV (km)	61.18	27.48
	Cu_25_10.5kV (km)	0.33	-
	Cu_25_34.5kV (km)	0.01	-
	Cu_50_34.5kV (km)	5.35	8.17
	Cu_70_10.5kV (km)	9.22	-
	Cu_95_10.5kV (km)	4.6	-
	Cu_95_34.5kV (km)	91.5	55.77
	Other (km)	4.6	-
Total (km)	260	112	
Annual Increase in Installed MV Line (km/year)		9.33	
Increase in Installed MV Line (%)		43%	

Table 12: Installed medium voltage line financial figures (Kartal)

Cost of Installed MV Lines (million TL)	75.04	31.00
Annual Increase in Cost (million TL)		2.58
Increase in Installed Cost (%)		41%

Table 13: Total financial figures (Kartal) (2018 prices)

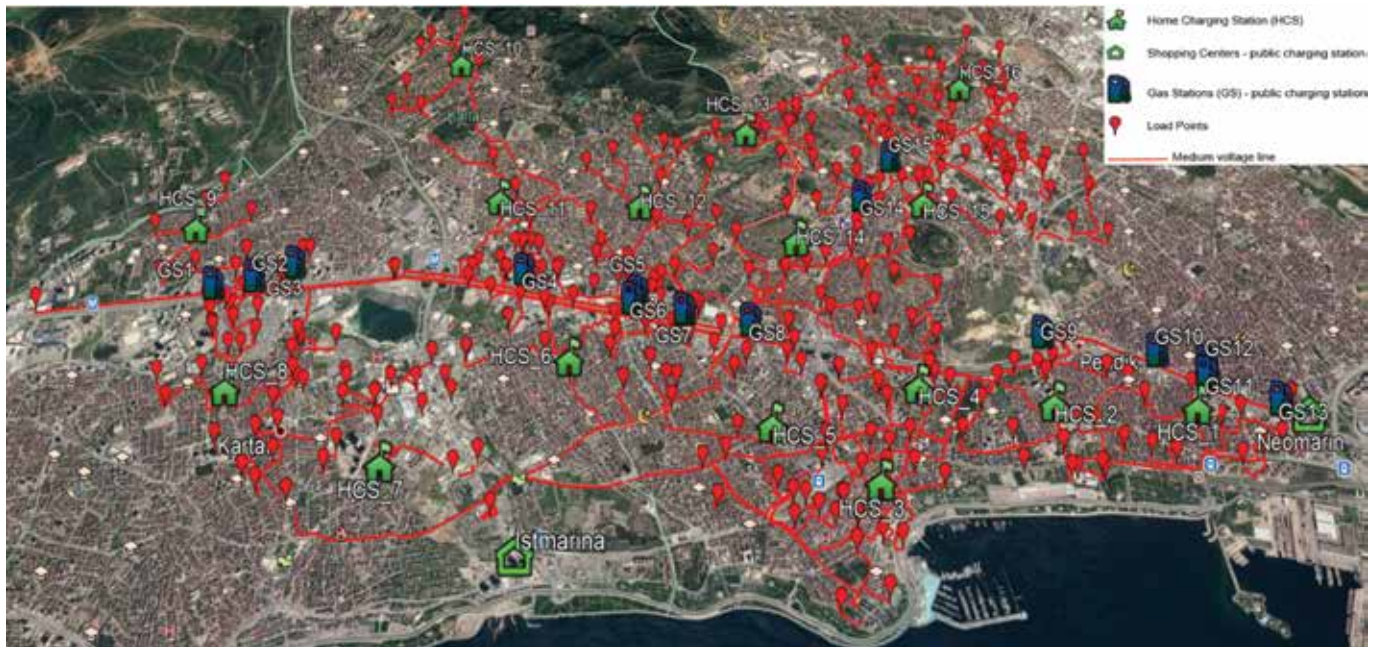
Kartal Pilot Region	2018	2030
	Current	Additions in the Reference Model
Cost of Installed Transformer & Lines (million TL)	104.42	45.84
Increase in Installed Cost of Transformer & Lines (%)		44%
Annual Increase in Installed Cost of Transformer & Lines (million TL)		3.82
Increase in Demand (%)		80%

4.2.3 Locational distribution of the EV charging points in the pilot distribution regions

Public charging is mainly for commercial and public applications, and is intended to perform in a similar way to commercial gasoline service stations (Borges et al., 2010). At present, many charging points are built either alongside motorways or at points-of-interest (such as shopping centres, etc.), offering drivers the convenience of charging their vehicles while working, eating, or shopping (Interreg, 2017). Therefore, public charging points are assumed to be located at the current gas stations on the main boulevards and at the shopping centres located in the pilot regions. Home charging points are assumed to be distributed uniformly to transformers which mainly supply residential consumers. For the workplaces, it is assumed that there is a suitable infrastructure so that all the EVs can be charged within the work times. In other words, not all of the EVs at workplaces will be charged at the same time, and there exists a sort of a smart mechanism which optimises EV charging by schedule, that is charging EVs in turn. This assumption is made based on the discussions with E-Şarj. For that matter, shopping centres are assumed to be equipped with such a mechanism, and hence, charging at workplaces are assumed to take place at shopping centres. It is worth emphasising that charging in turn mechanisms at workplaces are embedded in all scenarios (i.e., not an alternative scenario).

Figure 12 illustrates the location of the EV charging stations assumed in the Kartal pilot region. The current gas stations, which are mainly located on the Istanbul – Ankara highway, are assumed to be equipped with public charging points. In addition, two big shopping centres are also assumed to provide public charging service.

Figure 12: Locational distribution of the electric vehicle charging points in the pilot distribution region of Kartal, Istanbul



4.2.4 Daily charging patterns of the EVs

A stochastic or random process can be defined as a collection of random variables that is indexed by some mathematical set, meaning that each random variable of the stochastic process is uniquely associated with an element in the set (Wikipedia, 2019). It is common to use probability distribution functions (PDF) to identify a list of all the possible outcomes of a random variable along with their corresponding probability values. Since arrival time of EVs to the charging stations and associated state of charge of EVs at arrival time are random variables, we modelled daily charging patterns of the EVs with a stochastic approach.

Time resolution is selected as 30 minutes to take into account fast charging at public DC points. Probability distribution functions (PDF) of the following random variables are modelled to represent the stochasticity:

- Arrival time of the EVs to the charging stations (Figure 13); and State-of-charge (SOC) of the EVs at arrival time (Figure 16)

As illustrated in Figure 13:

- Mean of arrival time to home is assumed to be 19:00 hours with standard deviation of two hours represented by normal distribution for the AC1 and AC2 home charging stations.
- Mean of charging time is assumed to be 11:00 hours for the AC2 workplace stations with three hours standard deviation.

For the public charging stations (i.e., AC 2 and DC), uniform distribution is considered with a range of 07:00 – 22:00 hours. The reason for this assumption is that, in Turkey, rush hours typically start at 07:00 in the morning and continue till 22:00 in the evening – which is also valid within the analysed pilot regions. For the workplaces, the arrival times of EVs are considered normal distribution; however, it is assumed that not all of the EVs at workplaces will be charged at the same time, and there exists a sort of a smart mechanism which optimises EV charging by schedule (i.e., charging in turn). PDFs for arrival times and SOC assumed in the study are presented in Figure 13 and Figure 14, respectively for all type of charging technologies.

Figure 13: Probability distribution functions at the charging points

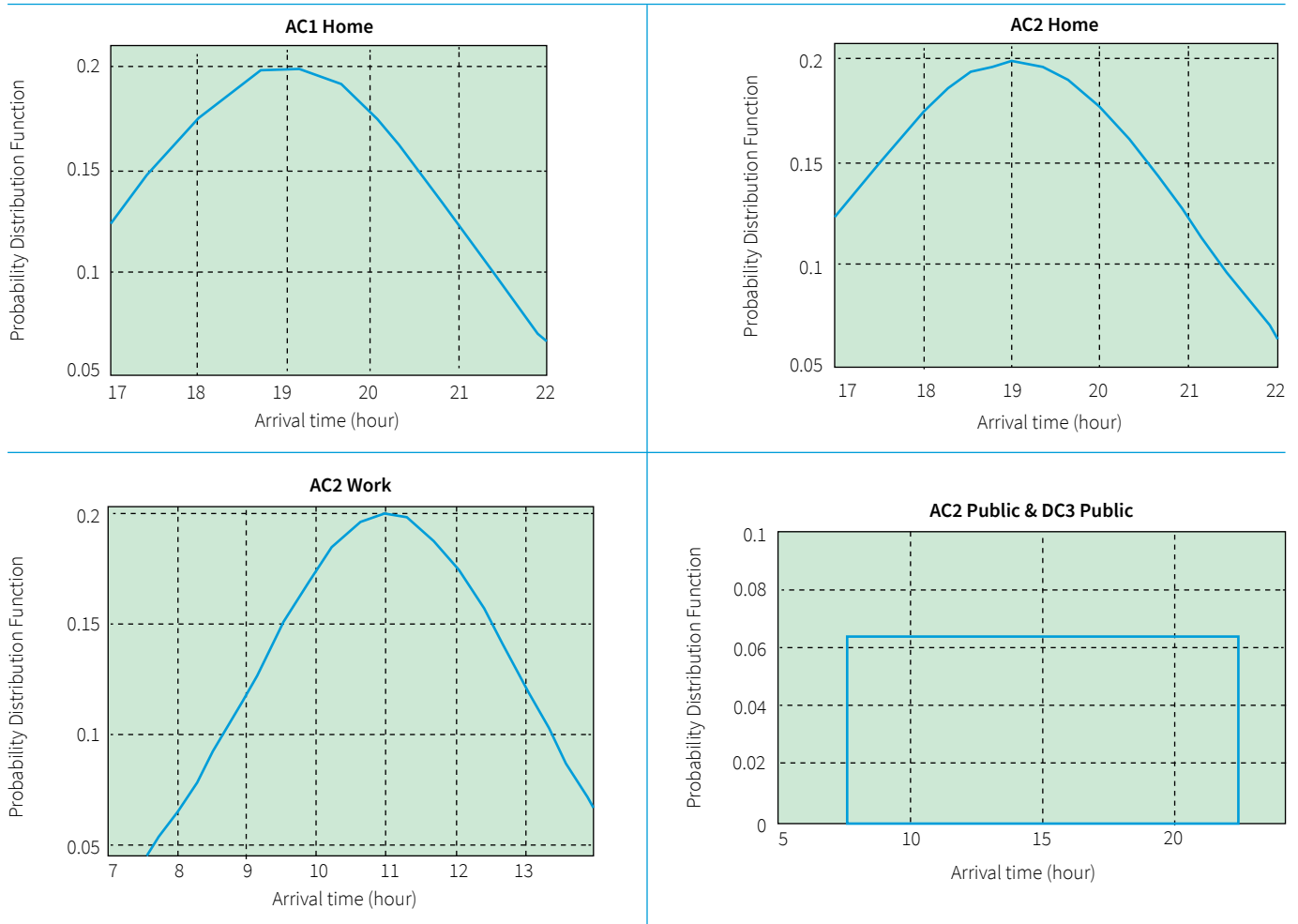
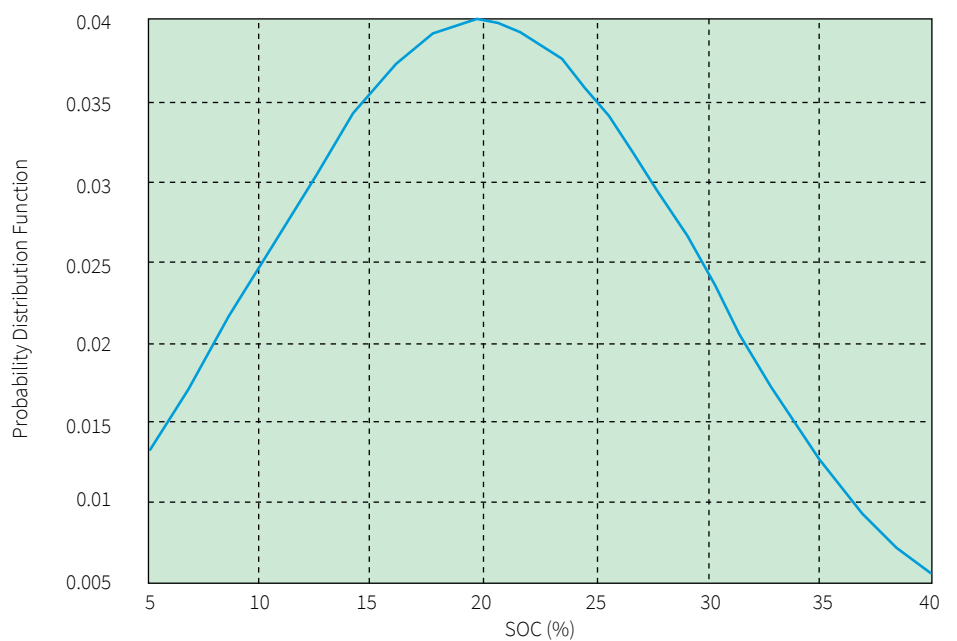
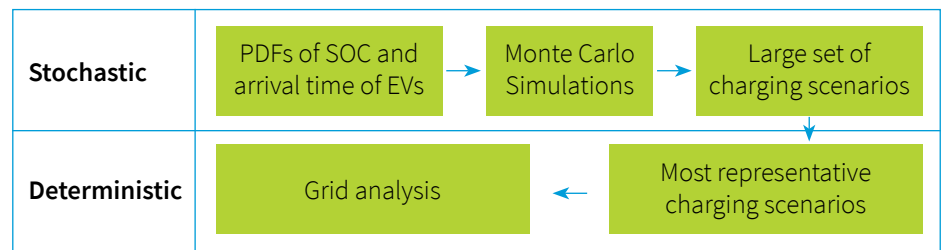


Figure 14: State-of-charge of electric vehicles when connected to a charging point



In principle, Monte Carlo methods can be used to solve any problem having a probabilistic interpretation which can be modelled by a PDF (Hastings, 1970). Therefore, Monte Carlo simulations are performed with these PDFs to generate a set of daily charging patterns. In total, one million different charging scenarios are created by the Monte Carlo simulations. The generated scenarios are reduced to five most representative charging scenarios. For scenario reduction, probability distance scenario reduction approach is utilised (Conejo et al., 2010). In this approach, one million scenarios are clustered into five categories with respect to their probability value. Subsequently, a demonstrative member out of each cluster is calculated and nominated as the representative scenario of the associated category. Afterwards, these scenarios are considered as deterministic inputs for grid analysis for high-growth and moderate-growth scenarios, separately. The flowchart of the methodology is presented in Figure 15.

Figure 15: Flowchart of the methodology to generate the most representative charging scenarios



For example, the most expected daily charging pattern, which is determined by the scenario reduction approach indicated above, for the Kartal region (Public Charging Support - High Growth Scenario) is illustrated in Figure 16. In this case, there is no midnight shifting at homes as a smart charging mechanism (only uniform daily charging at workplaces). Some critical results of this example are summarised in Table 14 and Table 15. The results of the other scenarios are provided in Section 5 along with the results of the other pilot regions.

Figure 16: The most expected daily charging patterns (Kartal, Public Charging Support - High Growth Scenario)

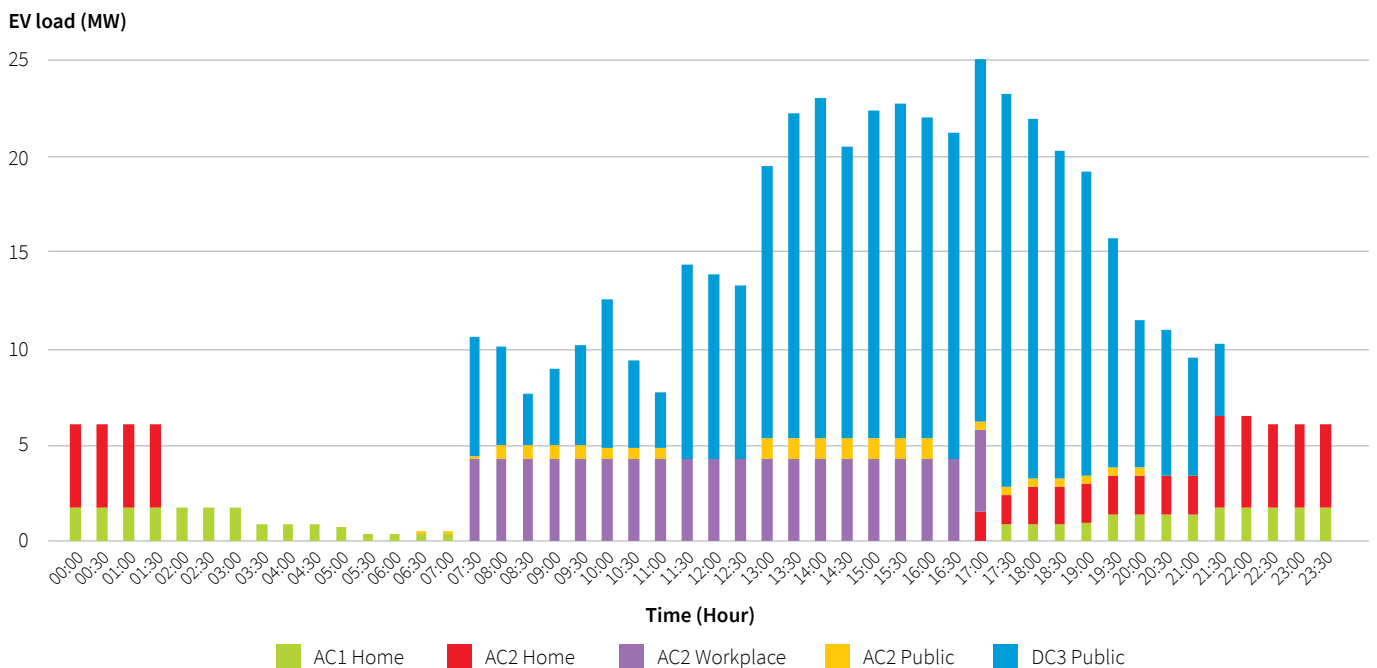


Table 14: Summary table for the most expected daily charging patterns (Kartal, Public Charging Support - High Growth)

Peak EV demand	Peak EV demand hour	Minimum EV demand	Minimum EV demand hour
25 MW	17:00	0.37 MW	05:30

Table 15: Daily capacity factors (charging utilisation) of different electric vehicle charging technologies (Kartal, Public Charging Support - High Growth Scenario)

Charging Technology	Capacity Factor (Charging Utilisation)	
	Public Charging Support	Home Charging Support
AC1H	41.7%	41.7%
AC2H	18.8%	20.4%
AC2W	22.4%	16.5%
AC2P	19.8%	9.7%
DC3P	10.7%	4.2%

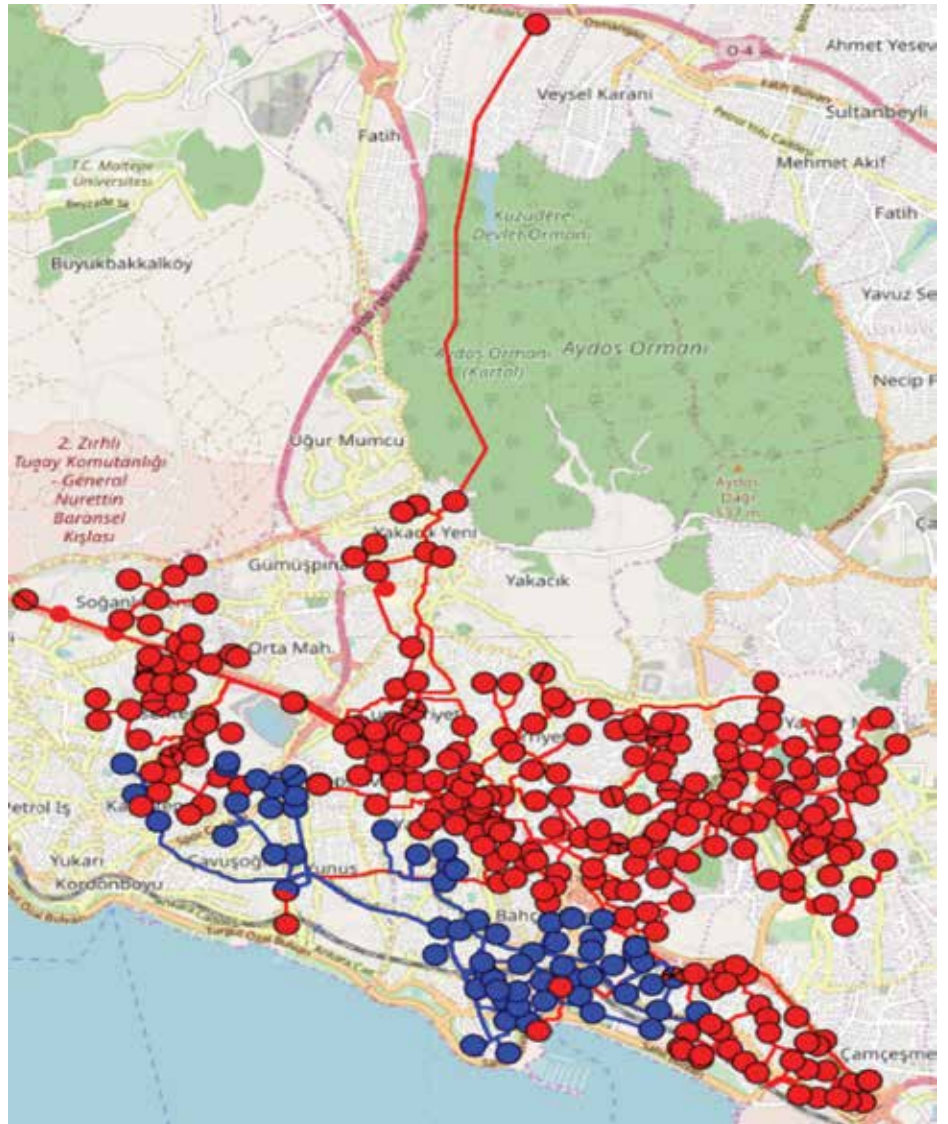
4.2.5 Fast charging stations at highways

The feeders supplying charging stations at highways are normally designed to feed mainly the charging station and no significant local loads are connected. Therefore, low capacity factors are expected in such feeders. To investigate the effects of EV charging at highways, it is assumed that a low capacity - long length feeder is connected to a weak point in the distribution grid. It should be noted that connecting a fast charging station to the end of a low capacity - long length feeder represents the worst possible condition in terms of the voltage drop concern. Afterwards, fast charging EV load at the charging station is increased gradually, and associated effects from feeder loading and voltage drop are investigated.

To model the impact, a weak point on a feeder (in terms of SCMVA¹⁸) in the Kartal pilot region that supply gas stations located on the Ankara – Istanbul highway is selected. (see Figure 17). Note that Kartal is the most suitable region among all the regions selected for this study to investigate the effect of fast EV charging at highways. As can be seen from Figure 17, a 5.6 km Swallow type conductor, which has the lowest loading capacity among the commercially available MV conductors, is selected to have a conservative assumption. Then, the EV load at the charging station is gradually increased in one MW step, and feeder loading and voltage magnitude indices are monitored.

¹⁸ Short circuit Mega Volt Ampere (SCMVA) is a method to determine the fault currents for points within a power system.

Figure 17: Charging station located on Ankara – Istanbul highway



4.5 Grid analysis and key performance indices

Grid analyses include load flow simulations for typical seasonal weekdays (i.e., four typical days over the target year 2030). That is, each season is represented by a typical weekday.

Grid analyses are performed for each pilot distribution region separately to simulate electrical indices of the pilot grids under study. The first step is modelling the pilot grids. For instance, the Kartal pilot region grid model is depicted in Figure 18 where the main feeders are illustrated with different colours. Grid analyses include load flow simulations for typical seasonal weekdays (i.e., four typical days over the target year 2030). That is, each season is represented by a typical weekday. As an example, daily load profiles of residential, commercial, and industrial consumers in summer, which are taken from the EPDK, are provided in Figure 19 for Kartal. In addition, Figure 20 shows the active load seen from HV substation in Kartal on typical days. Computer simulations are performed with DigSilent PowerFactory software.

Figure 18: Grid model of the Kartal pilot region

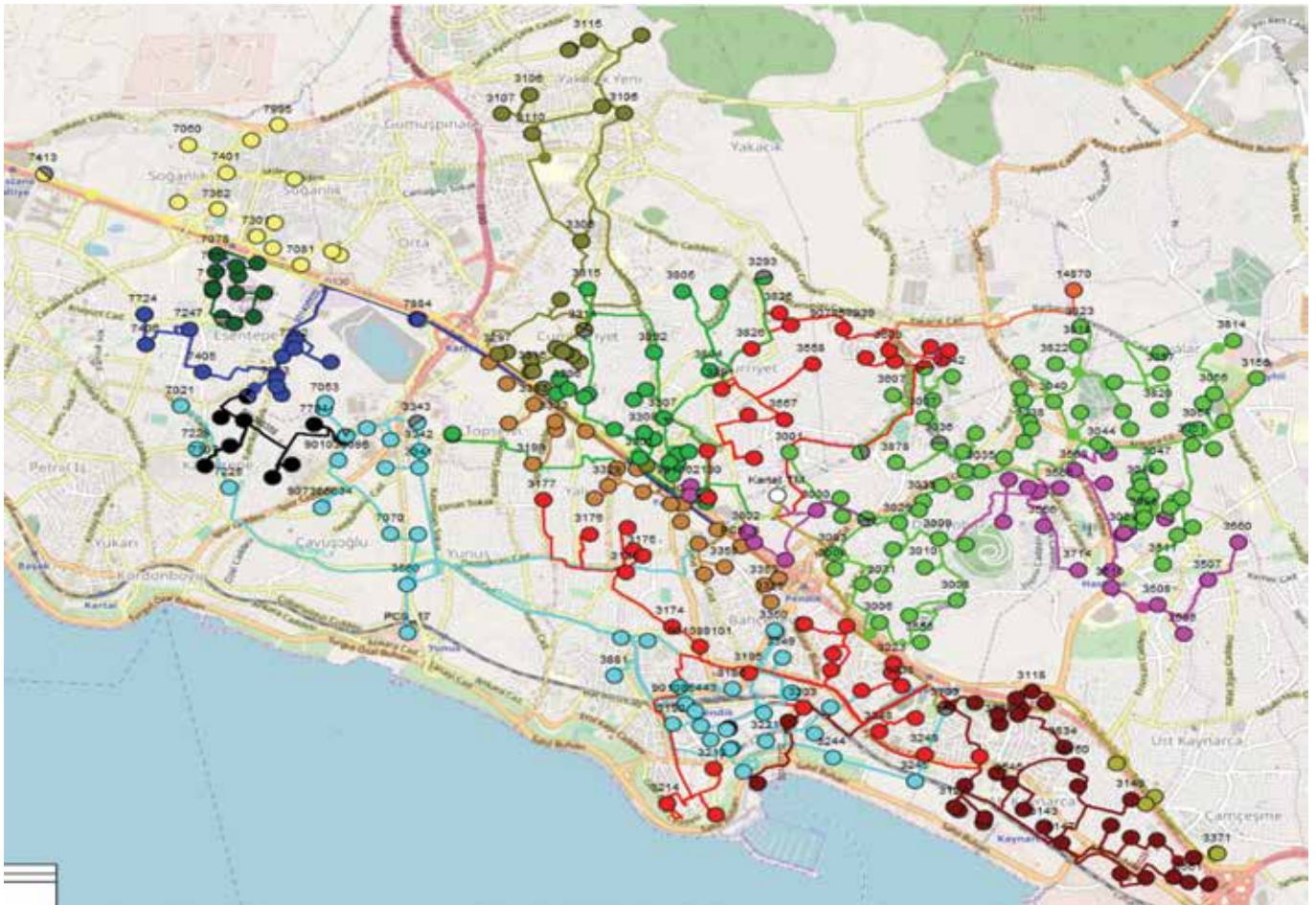


Figure 19: Daily load profiles of residential, commercial, and industrial consumers - Kartal pilot region, summer

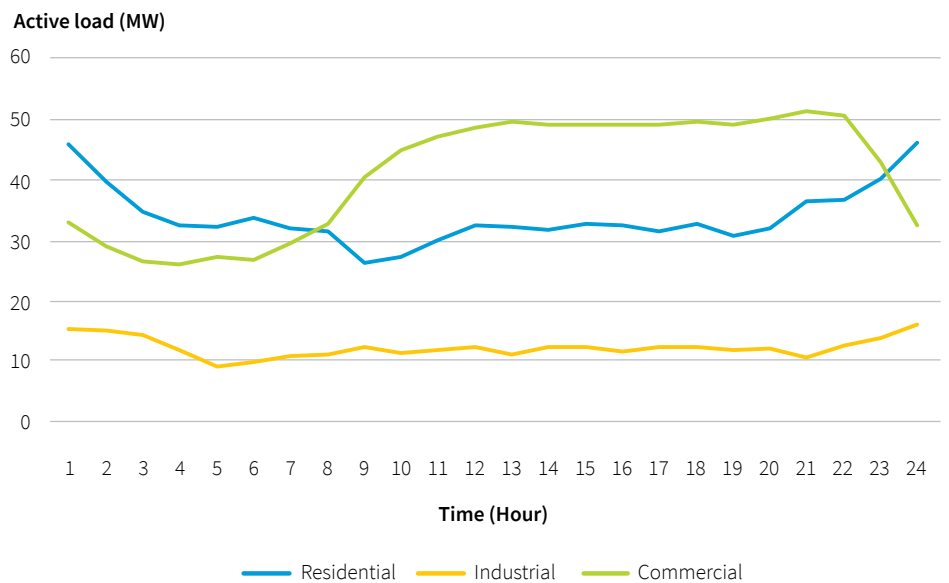
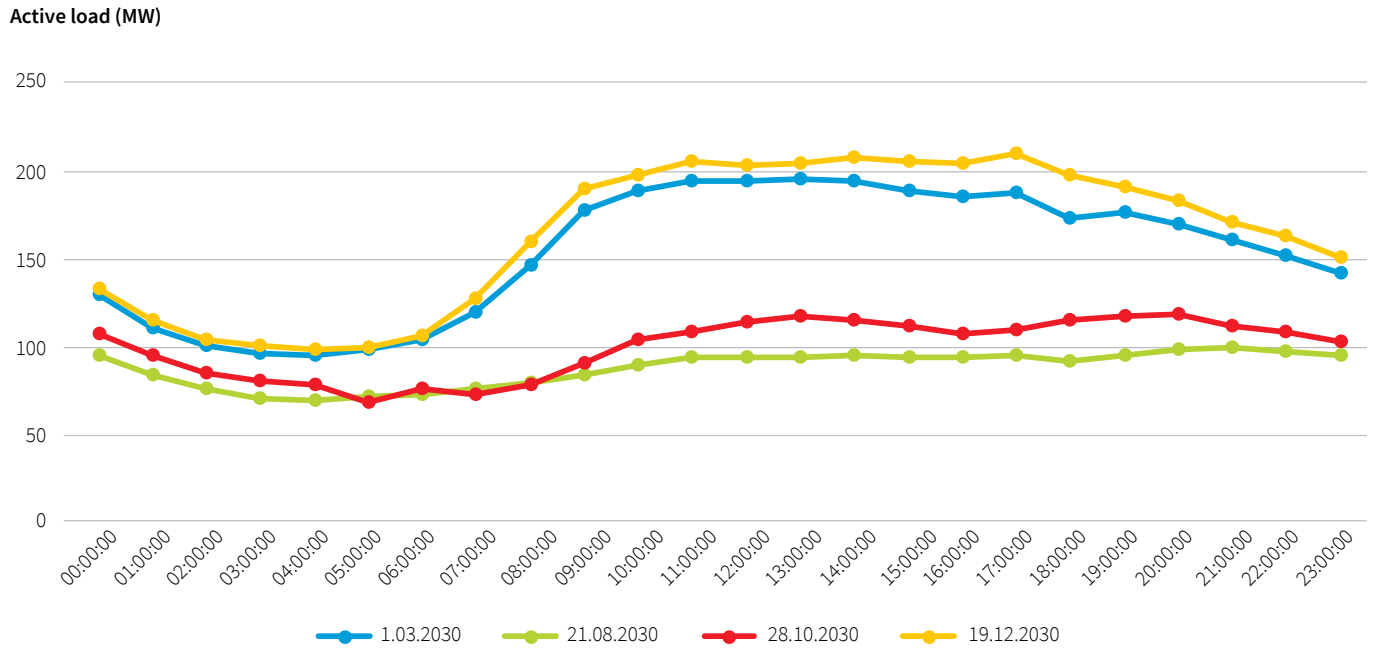


Figure 20: Active load seen from high voltage substation in the Kartal region on typical days



The following key performance indices are determined through computer simulations:

- Overloadings (congestions) on the MV and LV branches (%)
- Voltage drops on the MV and LV busbars (%)
- Capacity factors of MV feeders and MV/LV transformers (%)
- Investment requirements (MV lines, LV lines, and MV/LV transformers)

A branch is assumed to be overloaded if loading on the branch at a given hour is more than its thermal loading capacity (i.e., 100%). A voltage drop by more than 10% of nominal voltage at a given hour is assumed to result in under-voltage problem. These problems are referred to as operational violations in the study. The total number of operational violations are recorded for the Reference Model and the scenario where EV uptake is considered to assess effects of EVs on the grid. Capacity factors of MV feeders and MV/LV transformers are calculated for all typical seasonal days. To do so, the ratio of equipment usage is calculated and divided by the equipment capacity.

It is worth mentioning that for each pilot region, the available distribution equipment in 2018, the amount of investments for meeting the Reference Model by 2030, and the amount of additional investments for eliminating the operational violations after the EV introduction are determined.

4.6 Sensitivity analysis

Sensitivity analyses are performed to address the effects of key assumptions on the results. The cases investigated in the sensitivity analyses are summarised in Table 16 along with key parameter assumptions.

Table 16: Key parameters, assumptions, and sensitivity analysis

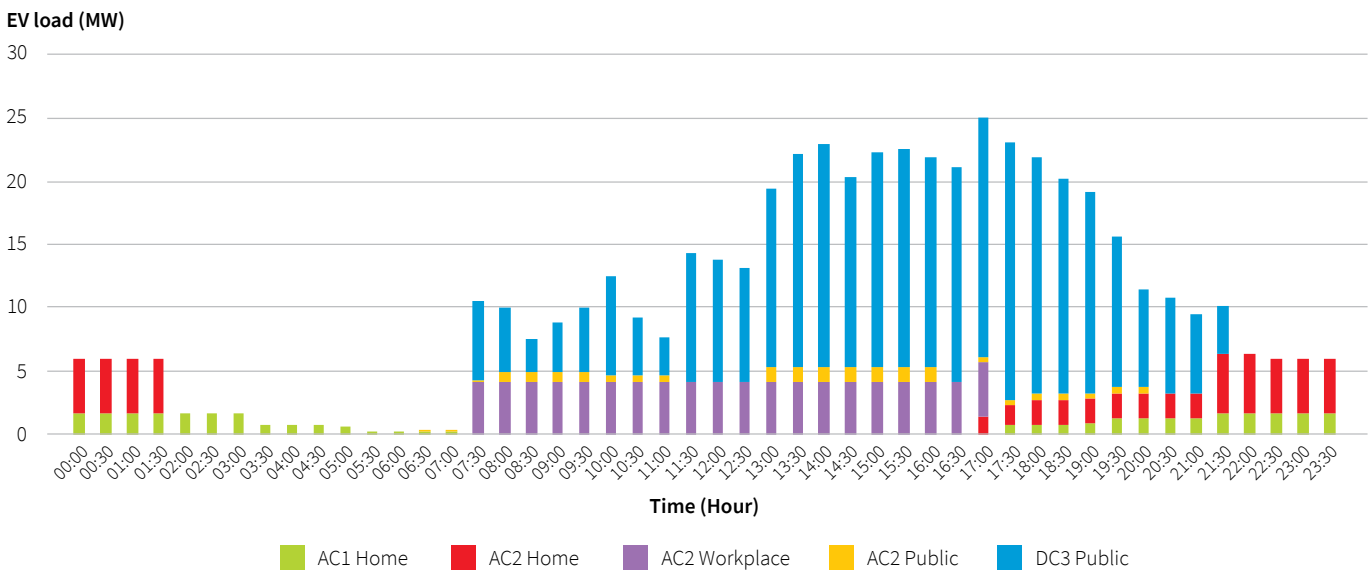
No	Key parameter	Default Assumption	Sensitivity	Explanation
Case I	Load increase	5% per year	3% per year	Reference Model is reconstructed with 3% load increment
Case II	Public charging behavior	Normal behaviour	Extreme behavior	More public fast charging during peak time
Case III	Distribution of charging points on MV feeders	Distributed uniformly	Concentrated (More chargers on few feeders)	Public charging points are reduced considering fixed amount of total EV load
Case IV	Renewables integration	Capacity of renewables in 2030 is equal to that of 2018	Additional renewables in 2030 (wind and solar)	10 MW renewable-based generation capacity (50% solar, 50% wind)
Case V	Storage integration	No storage in 2030	Storage in 2030	Storage with 5 MWh energy capacity

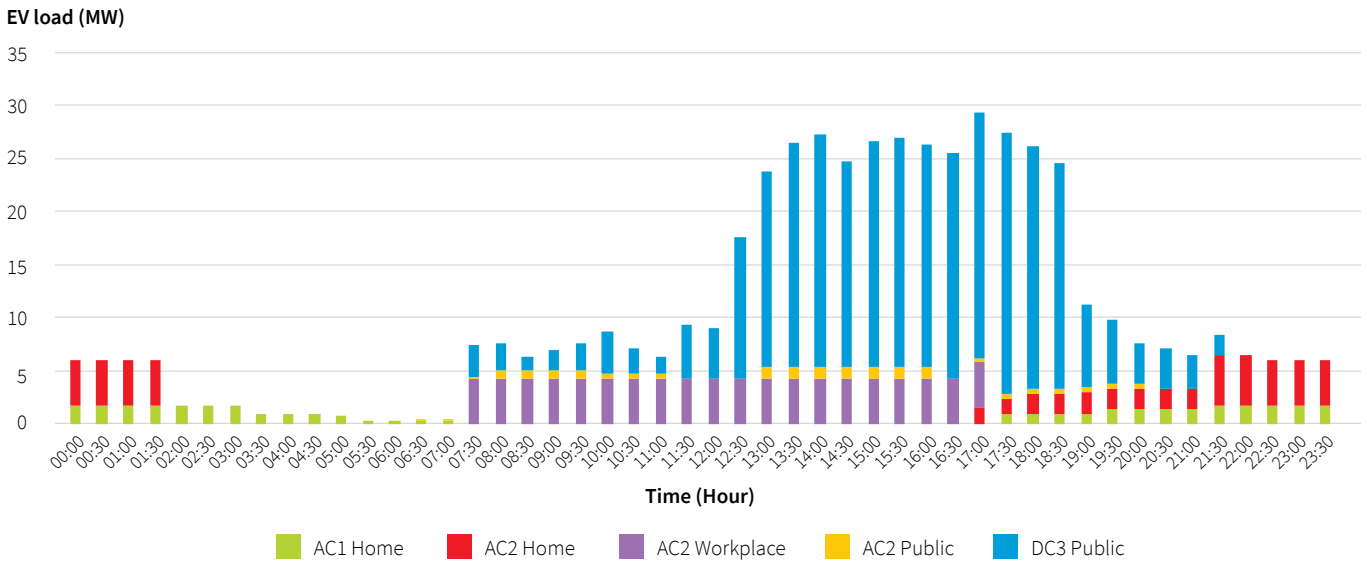
Note: The electricity mix of the grid does not have any impact on the results. As additional information, by 2030 more than half of all electricity demand in Turkey can be sourced from renewable energy sources, with 30% from wind and solar energy, and 20% from other renewables (including large hydropower) (SHURA, 2018).

In Case I, the impact of decreasing the growth in annual demand from 5% to 3% is investigated, and the Reference Model is reconstructed using the same approach described above. The total amount of investments in the distribution grids significantly declines in comparison to the case where demand grows by 5% per year (without the penetration of EVs).

Expected behaviour versus extreme behaviour of public charging in Table 16 are depicted in Figure 21 (Case II). As can be seen, the amount of public charging at the extreme behaviour is increased during the peak time, compared to normal behaviour. Here, extreme pattern refers to a pattern with a sharper summit. That is, in extreme charging pattern, the difference between EV charging at 12:00 and at 13:00 hours is increased considerably, compared to the normal charging pattern.

Figure 21: Expected behaviour (top) versus extreme behaviour (bottom) of public charging





In Case III, more chargers are located in fewer number of feeders to increase the effect of EVs on the distribution system. For example, in the Kartal pilot region, 17 public charging points are reduced to 9 considering fixed amount of total EV load, as illustrated in Figure 22 and Figure 23. As can be seen from the figure, charging points 10 to 17 are removed and their EV load are connected to the stations no.1 to 9.

Figure 22: Example from the Kartal pilot region (17 public charging points)



Figure 23: Example from the Kartal pilot region (9 public charging points)



In Case IV, in addition to the already available (2018) renewable energy sources, 10 MW of renewable-based generation installed capacity (50% solar and 50% wind) are added to the pilot regions. The generation patterns of renewables are acquired from publicly available resources.¹⁹ They are modelled as negative load and are distributed uniformly in 10 different locations at the pilot grids. These locations are assumed to be equipped uniformly with storage devices in Case V. The total installed capacity of storage devices is 5 MWh. The charging and discharging pattern of storage devices follows a price-based scheme where storage charging is realised during midnight (when the prices are lowest) and discharging is realised during peak hours (daytime). The results of the sensitivity analysis and a discussion of these results will be provided in the following section.

¹⁹ Renewable-Ninja platform. Jan. 2017. [Online]. Available at: <https://www.renewables.ninja/>



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5. Results and discussion

In section 5.1, the results of the analysis will be presented. Section 5.2 shows the results of the impact of rapid charging on highways, and section 5.3 shows the capacity utilisation factors of the charging points. Section 5.4 will show the results of the sensitivity analysis. In section 5.5, these results will be discussed. We will present the results for the “High Growth” scenario where the total number of EVs in Turkey’s vehicle stock reaches 2.5 million by 2030. This choice was made on the basis of the fact that almost no distribution grid impacts have been identified for the “Medium Growth” scenario with 1 million EVs by 2030.

5.1. Impact on the distribution grids

The Reference Model represents the status of the pilot distribution grids in the target year 2030 until when the electricity demand is assumed to grow by 5% per year and grid capacity expands to meet this growth. As a result of the growing demand, overloading and voltage drop problems could occur in the distribution grids. To eliminate these issues, three options have been considered:

1. Investment at high voltage level (transmission substation level)
 - Increasing capacity of HV/MV transformers
 - Constructing new high voltage substations
2. Investment at medium voltage level (distribution level)
 - Increasing capacity of MV/LV transformers
 - Constructing new MV lines
3. Investment at low voltage level (distribution level)
 - Constructing new LV lines

The impact of EVs is assessed for each one of the 8 pilot regions. As a first step, the daily charging pattern is constructed for all regions. For instance, the EV charging pattern in Kartal for public charging support and home charging support cases are shown in Figure 24 and Figure 25, respectively. While the same charging characteristics apply to all regions, new electricity load created by EVs differs among the pilot regions since the vehicle stock varies by region based on income, population, and other factors (see section 2).

Figure 24: Estimated daily charging pattern in the Kartal region according to the High Growth Scenario and the Public Charging Support case

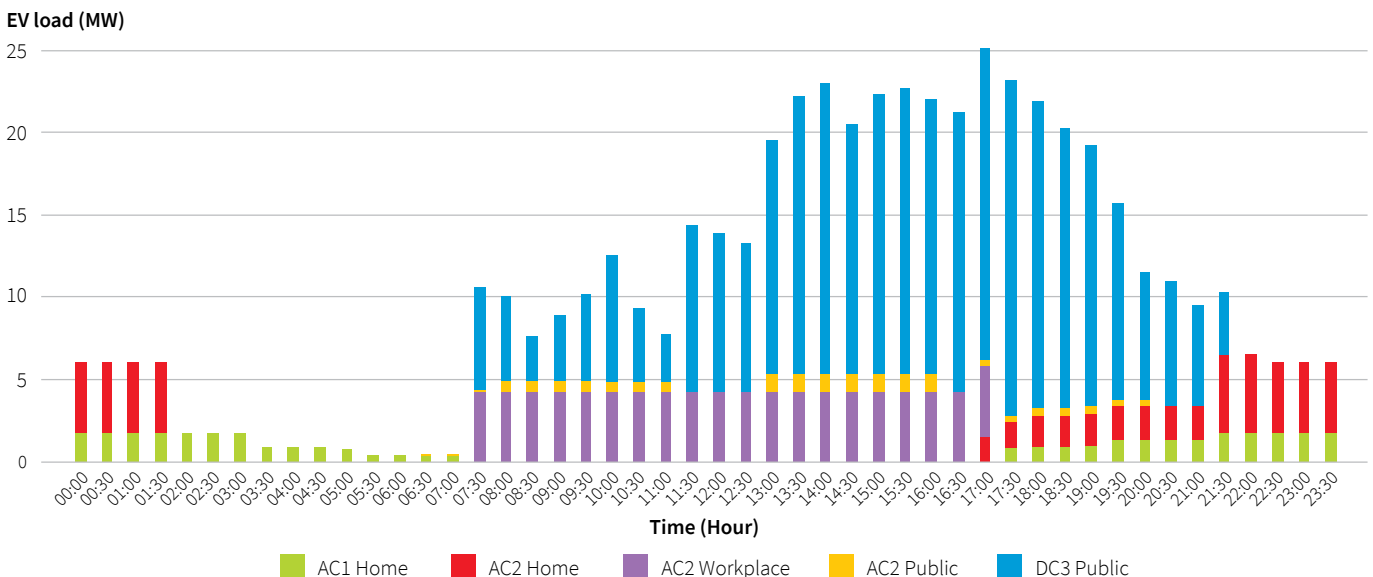
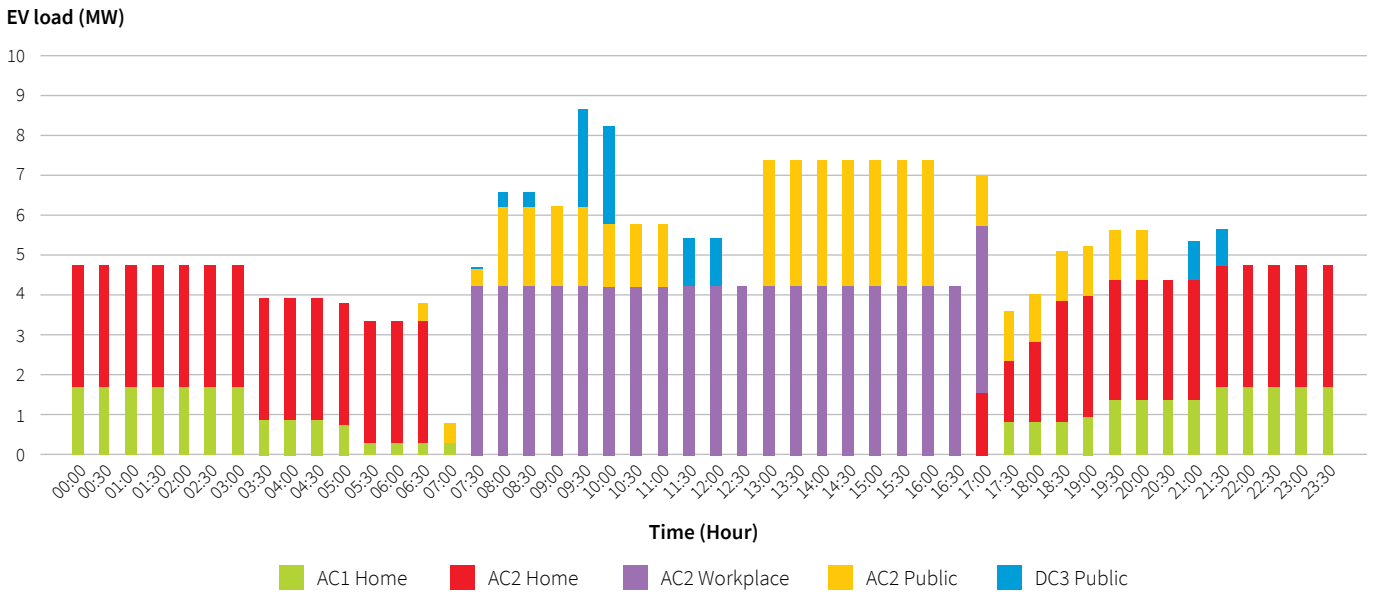


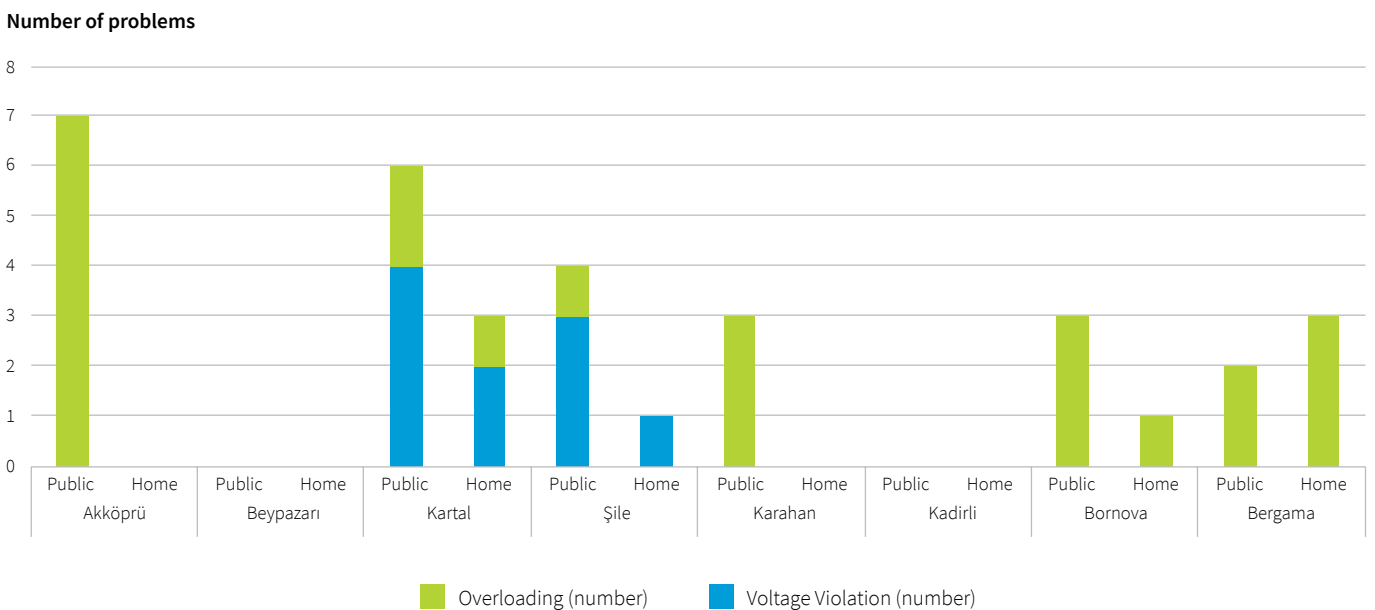
Figure 25: Estimated daily charging pattern in the Kartal region according to the High Growth Scenario and the Home Charging Support



The number of violations is small, since the capacity factors of branches and transformers in the pilot regions are small, providing a significant room for EV charging.

The key performance indices to estimate the impact of EVs on the distribution grid are overloadings on the MV and LV branches, voltage drops on the MV and LV busbars, capacity factors of MV feeders and MV/LV transformers, and additional capacity needs for MV and LV lines, as well as for MV/LV transformers. Figure 26 summarises the number of overloading and voltage violations that occur following the penetration of EVs in all pilot regions. Loadings of branches and transformer, and voltage magnitude at some buses are subject to violation. However, the number of violations is small (e.g., maximum 7 violations in the Akköprü region) since the capacity factors of branches and transformers in the pilot regions are small, providing a significant room for EV charging (see Figure 27).

Figure 26: Number of voltage violations and branch overloadings in pilot regions after electric vehicle introduction (Public Charging Support vs Home Charging Support)

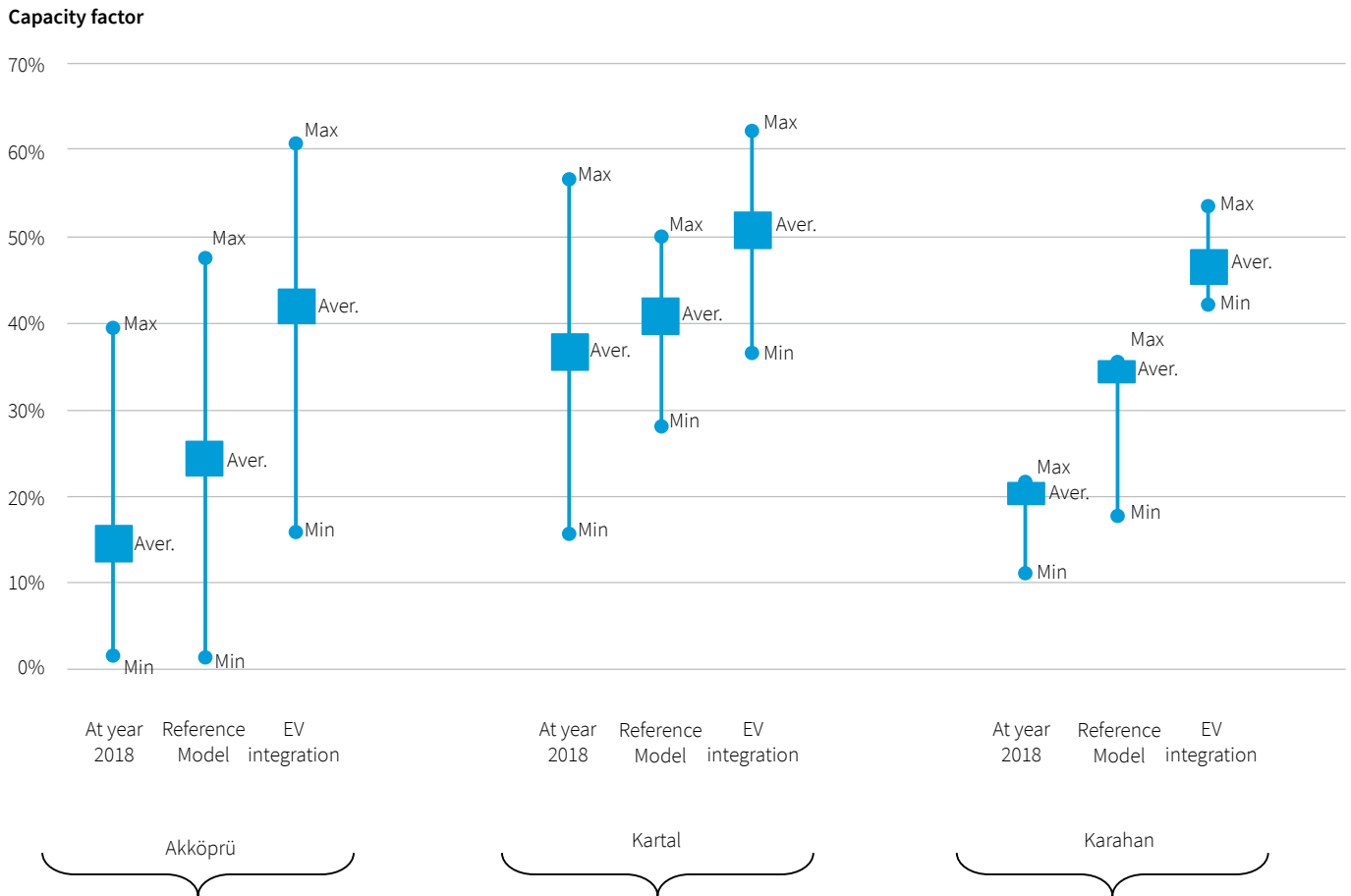


The average capacity factor of MV/LV transformers in 2018 was 14%, 36%, and 20% for Akköprü, Kartal, and Karahan regions, respectively.

Although the introduction of EVs increases capacity factors by between 10 and 20 percentage points, maximum capacity factors are still below 100% and the total number of violations are tolerable. EV grid integration is not an issue with 2.5 million EVs in Turkey by 2030 as even more EVs can be integrated and charged.

As can be seen from Figure 27, the capacity factors of transformers in metropolitan regions are quite low in 2018. This, indeed, indicates that there is enough idle capacity to accommodate higher shares of EV in the vehicle stock. According to Figure 28, the average capacity factor of MV/LV transformers in 2018 was 14%, 36%, and 20% for Akköprü, Kartal, and Karahan regions, respectively. These values are estimated to respectively increase to 24%, 40%, and 33% by 2030 following the growth in total electricity demand in the Reference Model (non-EV). Although the introduction of EVs increases capacity factors by between 10 and 20 percentage points, maximum capacity factors are still below 100% and the total number of violations are tolerable. The key finding from the pilot regions is that EV grid integration is not an issue with 2.5 million EVs in Turkey by 2030 as even more EVs can be integrated and charged, under the assumption that grid capacity investments continue with the historical investment trend of the distribution companies (under 5% annual non-EV demand growth). From the perspective of utilising the grid infrastructure, the EV demand actually provides benefits as it increases the current low-level capacity factors. This can help reduce the distribution grid tariffs. (The more utilisation of the assets, the less tariffs to cover revenue requirement of the utility.)

Figure 27: Medium voltage/Low voltage transformer capacity factor statistics for year 2018, Reference Model and electric vehicle Integrated Model (Metropolitan regions²⁰)



²⁰ 200 MVA of additional HV/MV transformer capacity is added in the Bornova and Bergama pilot regions according to the results of a master plan study. Since no master plan studies were available for the other pilot regions, new capacity additions in these regions were considered only at medium and low voltage levels. In other words, it is assumed that the current HV/MV substations in the other pilot regions will not be upgraded.

In order to have a better insight, the loading statistics of the MV/LV transformers in 2018 and in 2030 are shown in Figure 28. Although with the introduction of EVs some overloadings (e.g. 120% in Akköprü) are observable, the number of MV/LV transformers with overloading is less (see Figure 26) and the loading for most of the MV/LV transformers, on average, is less than 100%. Moreover, increment in MV/LV transformers and MV feeders capacity factor after EV introduction for public charging support and home charging support cases are depicted in Figure 29, and Figure 30. In addition, the increase in the average capacity factor of MV/LV transformer and MV feeder capacity after introduction of EVs for public charging support and home charging support cases are compared in Figure 31, and Figure 32. As can be seen from the figures, both public and home charging support cases can be accommodated by the distribution grid and might not result in severe problems for the operation of the distribution system.

Figure 28: Medium voltage/Low voltage transformer loading statistics for year 2018, Reference Model and electric vehicle integrated model (Metropolitan regions)

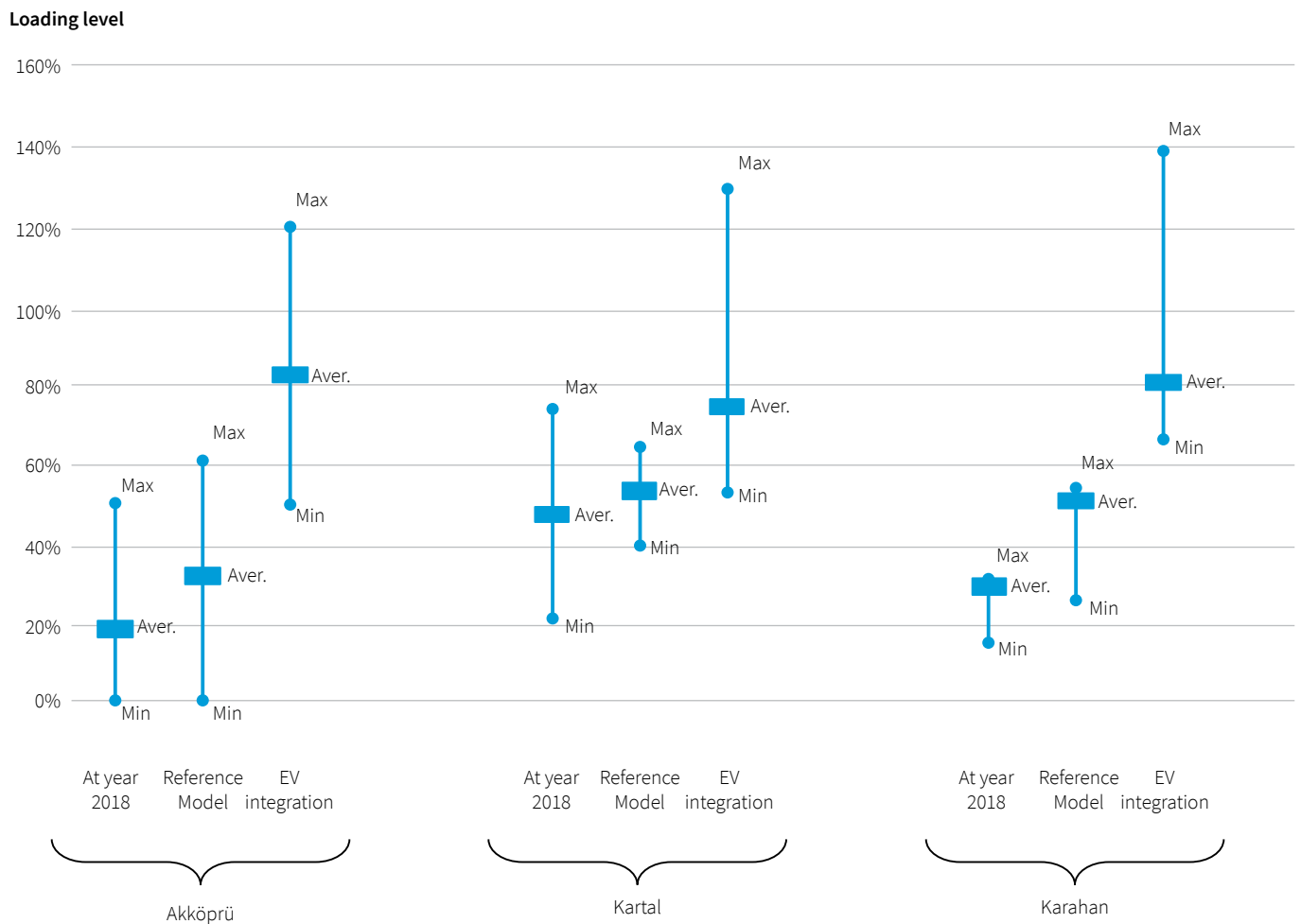


Figure 29: Medium voltage/Low voltage transformer capacity factor increment after electric vehicle introduction in pilot regions

Capacity factor increment

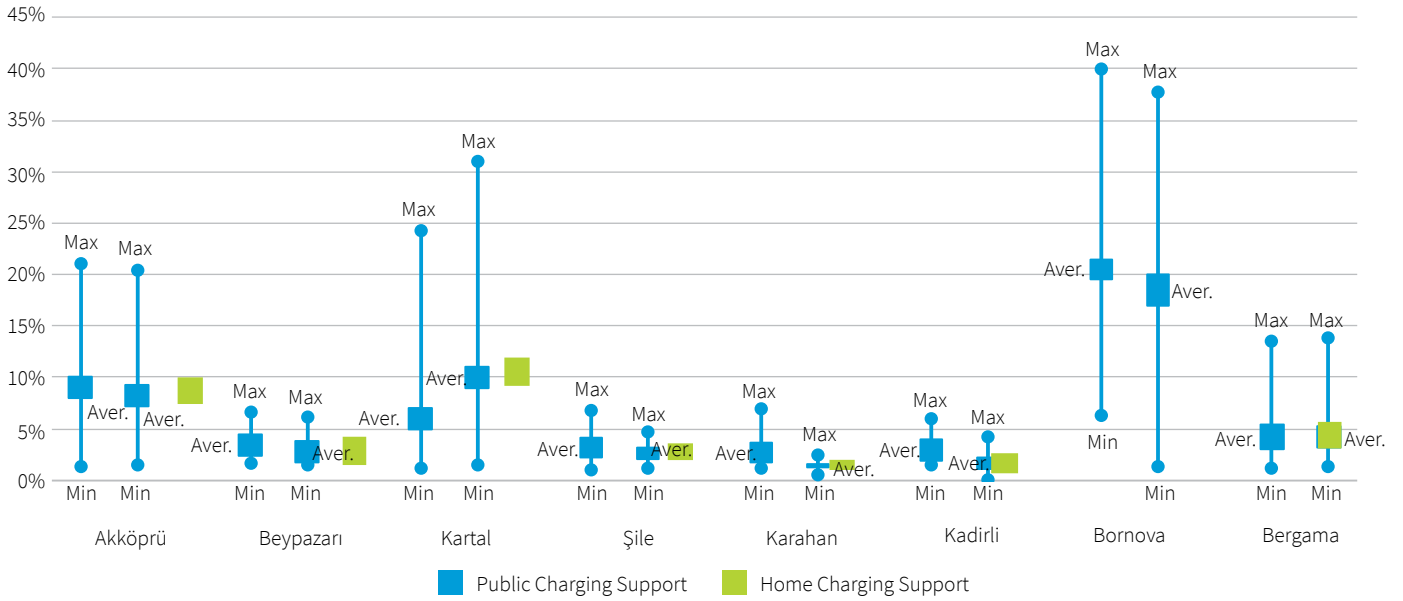


Figure 30: Medium voltage line capacity factor increment after electric vehicle introduction in pilot regions

Capacity factor increment

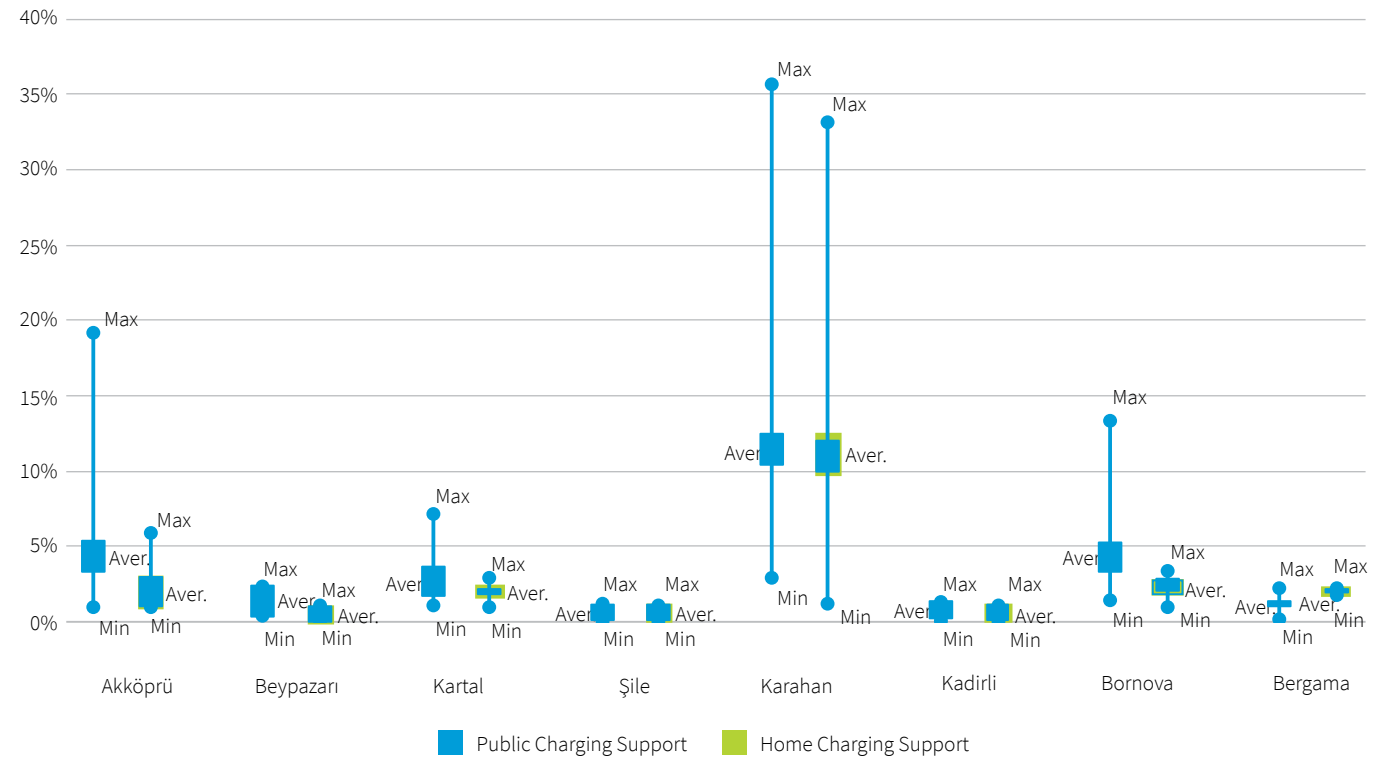


Figure 31: Average of Medium voltage/Low voltage transformer capacity factor increment after electric vehicle introduction – Public Charging Support versus Home Charging Support

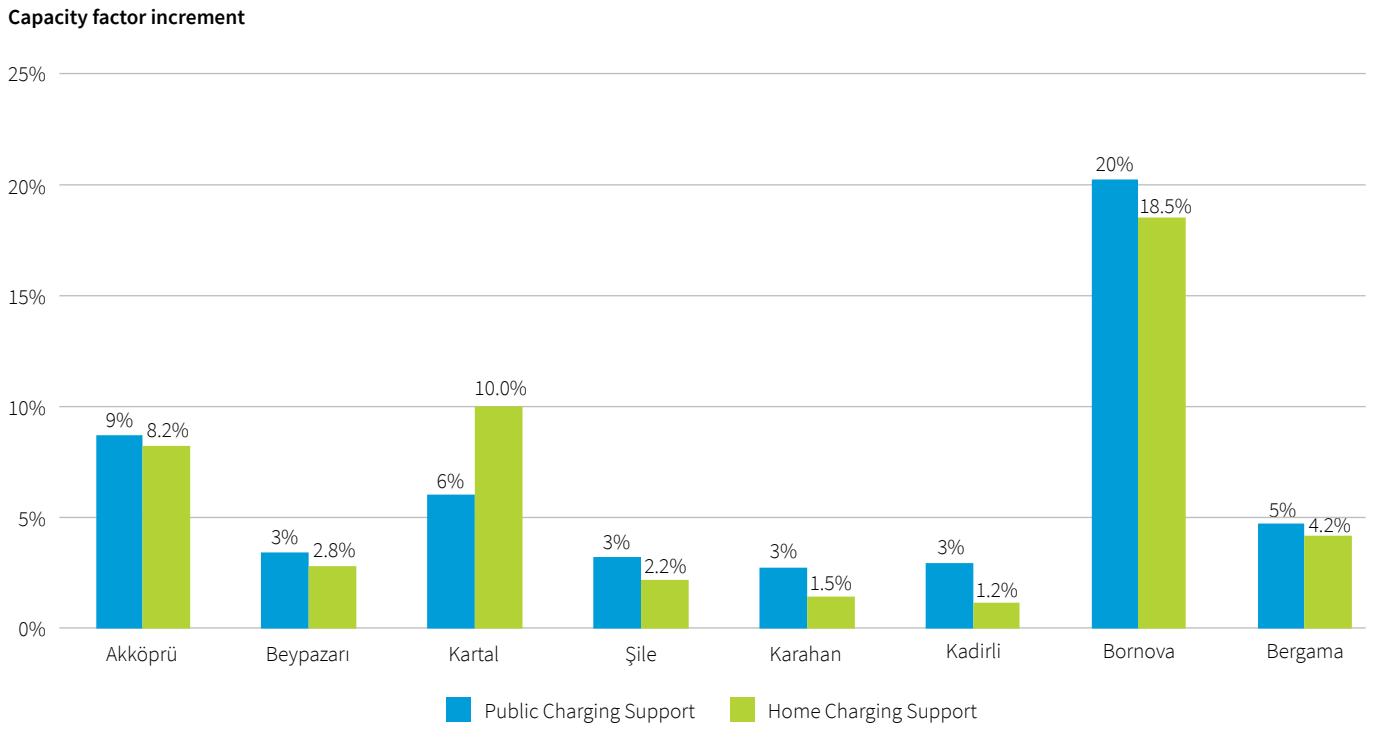
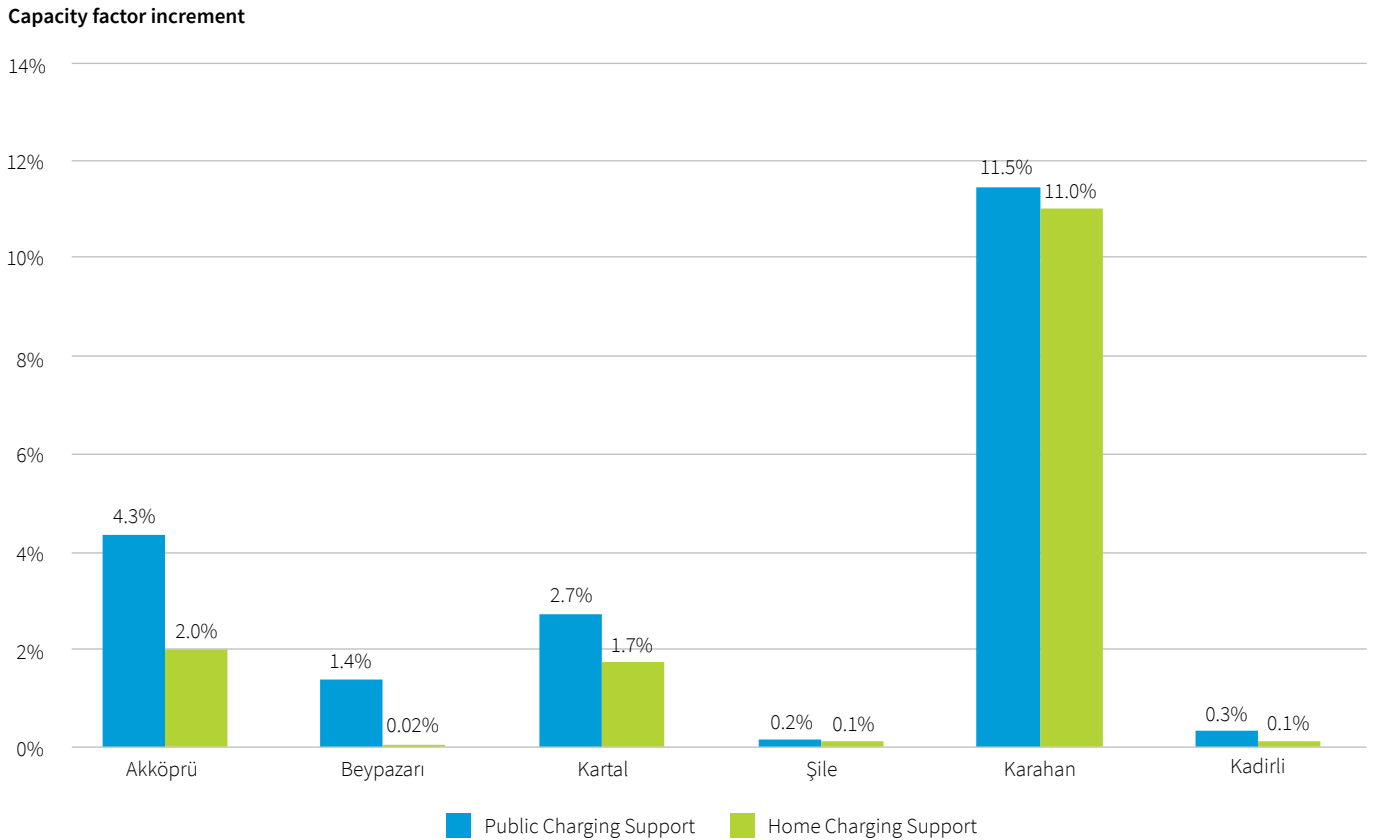


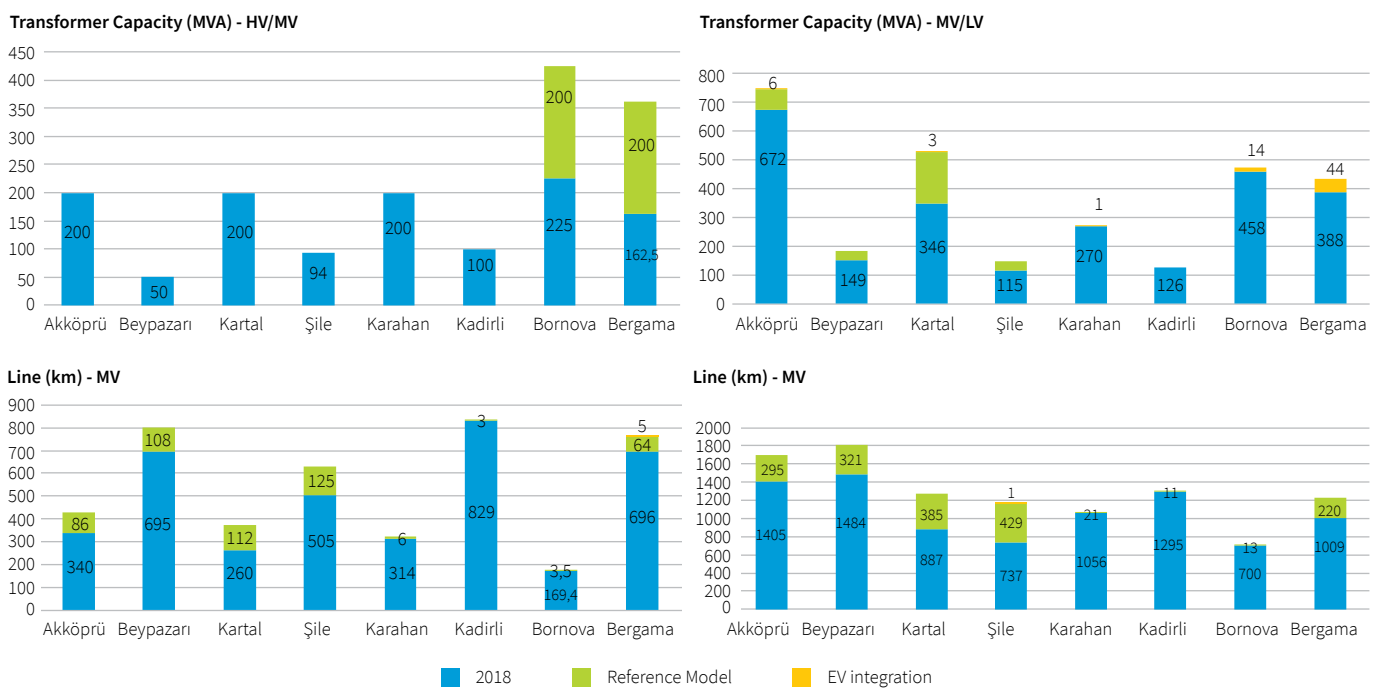
Figure 32: Average of medium voltage feeder capacity factor increment after electric vehicle introduction - Public Charging Support versus Home Charging Support



With the exception of the Bornova and Bergama regions, considerable additional capacity at MV and LV levels is needed according to the Reference Model where no EV uptake was foreseen.

Figure 33 shows the required expansion in the transformer capacity and distribution grid lines to integrate EVs, compared to the modelled capacity in 2030 (Reference Model) and in 2018 for each distribution grid selected in this analysis. 200 MVA of additional HV/MV transformer capacity is added in the Bornova and Bergama regions according to the results of a master plan study carried out for the GDZ.²¹ Since no master plan studies were available for the other regions, new capacity additions were considered only at MV/LV levels. It is assumed that the current HV/MV substations in the other pilot regions will not be upgraded (although could actually be upgraded). Indeed, this is specifically preferred for obtaining results from a conservative standpoint. As can be seen, with the exception of the Bornova and Bergama regions, considerable additional capacity at MV and LV levels is needed according to the Reference Model where no EV uptake was foreseen. This is explained by the new capacity added at HV level in the Bornova and Bergama regions, which relieves MV and LV grids, thereby diminishing the need for new capacity additions. In order to limit the violations that result from charging of EVs, additional grid capacity is needed. The violations can be resolved with marginal additions of new capacity.

Figure 33: Medium voltage/Low voltage transformer capacity available in year 2018, additional capacity added for making Reference Model (2030), and additional investment to limit the violations after EV introduction in year 2030



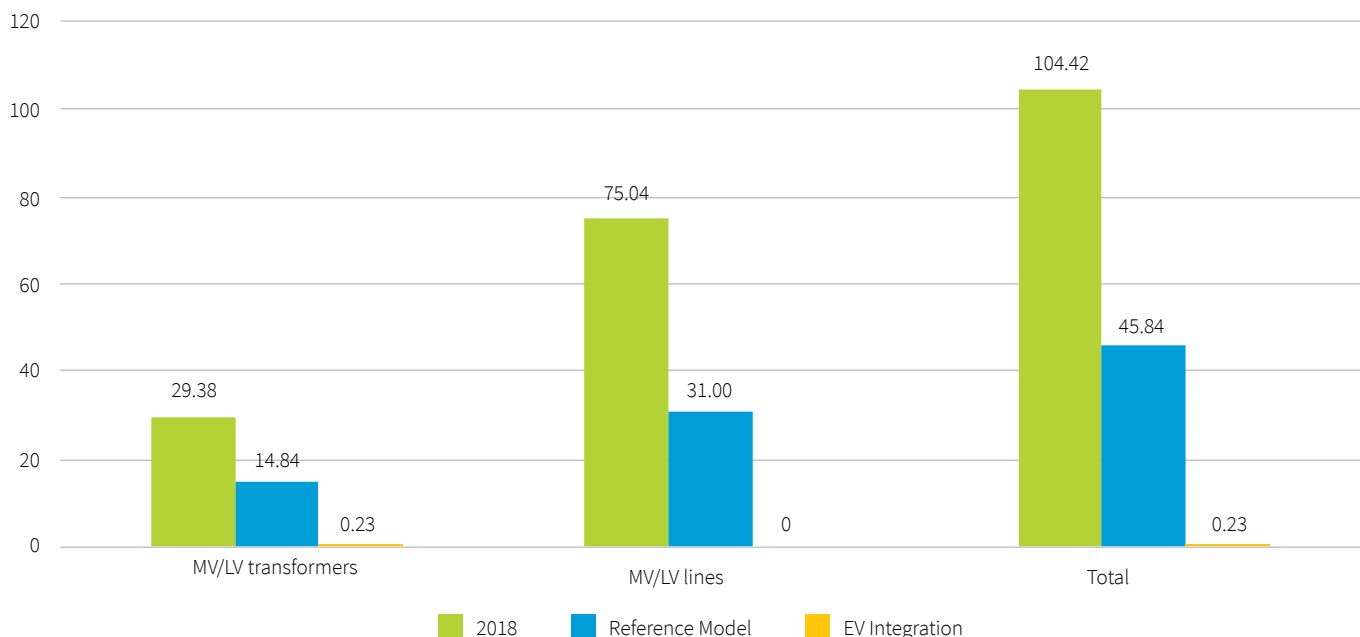
The cost of limiting violations in Kartal region after EV integration is only 0.23 million TL.

Estimated grid investments in the Kartal region are provided in Figure 34. Under 5% annual demand increase from 2018 to 2030, the total cost of MV distribution transformers and of MV lines are 14.84 million TL and 31 million TL (in 2018 prices), respectively. The cost of limiting violations after EV integration is only 0.23 Million TL, which is owing to the installation of 3 transformers indicated in Figure 33 above. These figures show that, if the electricity demand excluding EVs grows by 5% per year between 2018 and 2030, and the grid investments needed to manage this load are undertaken properly, 9,636 EVs (see Table 6) can be integrated to the Kartal region without any technical violation in the grid operation and with negligible additional investment cost. According to the results shown in Figure 33, this conclusion is valid for the other pilot regions as well.

²¹ Master plan study results for the Bornova and Bergama pilot regions were made available by the GDZ.

Figure 34: Cost of investments (Kartal – 5% annual demand forecast, public charging support)

Million TL (2018 prices)



5.2. Impact of fast charging at highways

In this section, the results of EV charging at a highway feeder are presented for the Kartal pilot region. As mentioned in Section 4.2.5, it is assumed that a low capacity - long length feeder is connected to a weak point in the distribution grid. Fast charging EV load at the charging station is increased gradually and associated effects from feeder loading and voltage drop are investigated.

Figure 35 depicts the trend of voltage drop as EV load charging is increased on a highway feeder. As can be seen from the figure, in the case of/with regard to voltage drop, up to 7 MW EV load can be hosted on a feeder with negligible load (such as highway feeders). In case of local load, the amount of EV integration is 7 MW minus the amount of local load on the feeder. Figure 36 illustrates the amount of feeder loading on a highway feeder as a function of the increase in the EV charging load. In this figure, the blue line represents the loading of the feeder which supplies the fast charging station. On the other hand, the green line is the loading of the main feeder supplying the Kartal pilot region. Here, the boundary constraint reaches 100% loading level by either green line or blue line. Figure 36 shows that the highway feeder can supply up to 8.5 MW EV load in terms of/in case of overloading. Considering both voltage drop and overloading constraints, 7 MW is the permissible amount of EV fast charging load on the highway feeder. It is obvious that the amount of local load on the feeder can reduce the amount of permissible fast charging of the EV load.

Figure 35: Voltage drop versus electric vehicle charging load on highway feeder

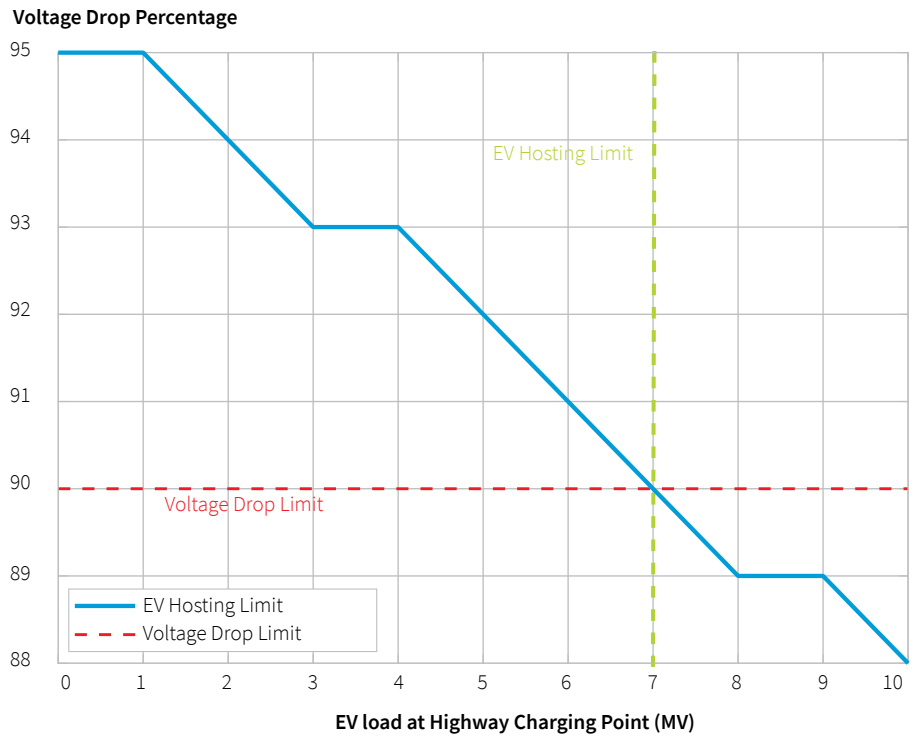
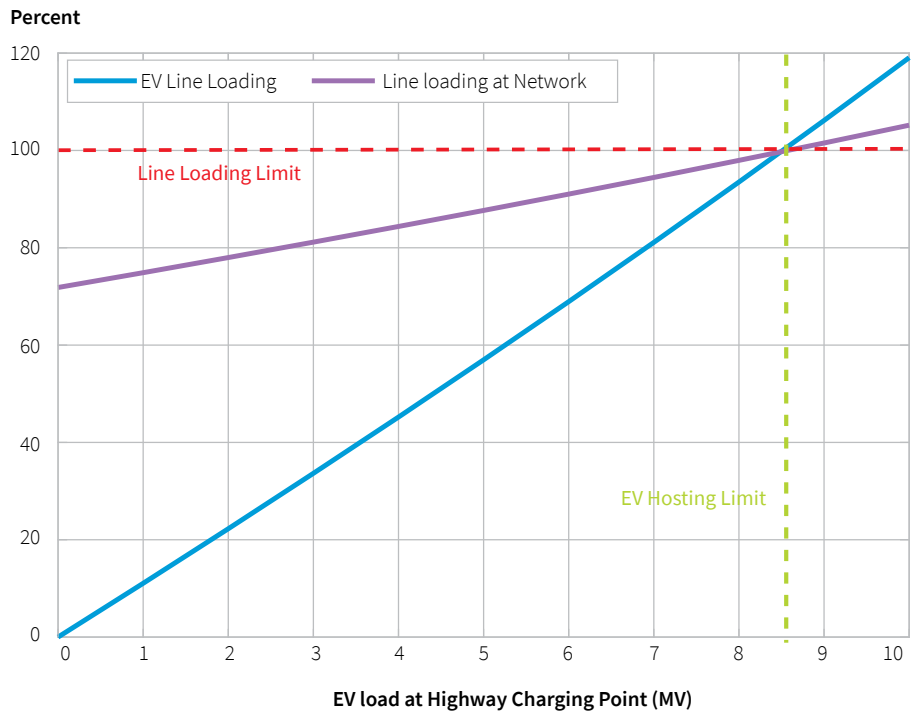


Figure 36: Highway feeder loading versus electric vehicle charging load



According to the simulation results, a highway feeder with negligible local load can supply up to 4 fast charging stations, each hosting 16 simultaneous 100kW DC type charging.

According to the simulation results, a highway feeder with negligible local load can supply up to 4 fast charging stations, each hosting 16 simultaneous 100kW DC type charging (i.e., $4 \times 16 \times 100\text{kW} = 6.4\text{MW}$). Note that a new charging station (other than these four) is expected to be established at a significant distance from these four stations. Essentially, such a new charging station is supposed to be supplied through another feeder, given the long distance involved.

5.3. Capacity factors of EV charging points

The majority of the data points in the literature show that the public utilisation range is between 5% and 15%.

Capacity factor (charging utilisation) of an EV charging infrastructure is a key indicator. Charging station utilisation is a function of both the number of charging stations and the number of EVs in a market. If the number of EVs in a geographic area grows faster than the number of charging stations in that area, utilisation can be expected to increase. If the number of charging stations in an area grows faster than the number of EVs, utilisation can be expected to decrease in the short term. (An increase in EVSE may encourage more people to drive EVs to longer distances and join EVSE networks. So, in the long term it could increase usage rates at all (or most) stations.) (NYSERDA, 2015). One would expect that a higher capacity factor at charging stations makes investments more feasible. There is little public data available on charging utilisation, but the majority of the data points in the literature show that the public utilisation range is between 5% and 15% (NYSERDA, 2019). The New York State published a report back in 2015 that found its fast charging stations to have an average utilisation of 3%–4%. In contrast, gas stations have been found to have a utilisation of 34% (Grabner and Sussman, 2019).

According to Figure 37 and Figure 38, the annual average capacity factors of home charging stations are higher than those of other charging stations (i.e., public and work) in all pilot regions. The reason is that home charging stations follow a normal PDF for charging while the others follow a uniform PDF. Furthermore, the total charging duration of home charging stations (i.e., AC1 and AC2-home) is longer than that of public charging stations (i.e., AC2-public and DC).

Figure 37: Average annual capacity factor of charging infrastructures - Public Charging Support in 2030

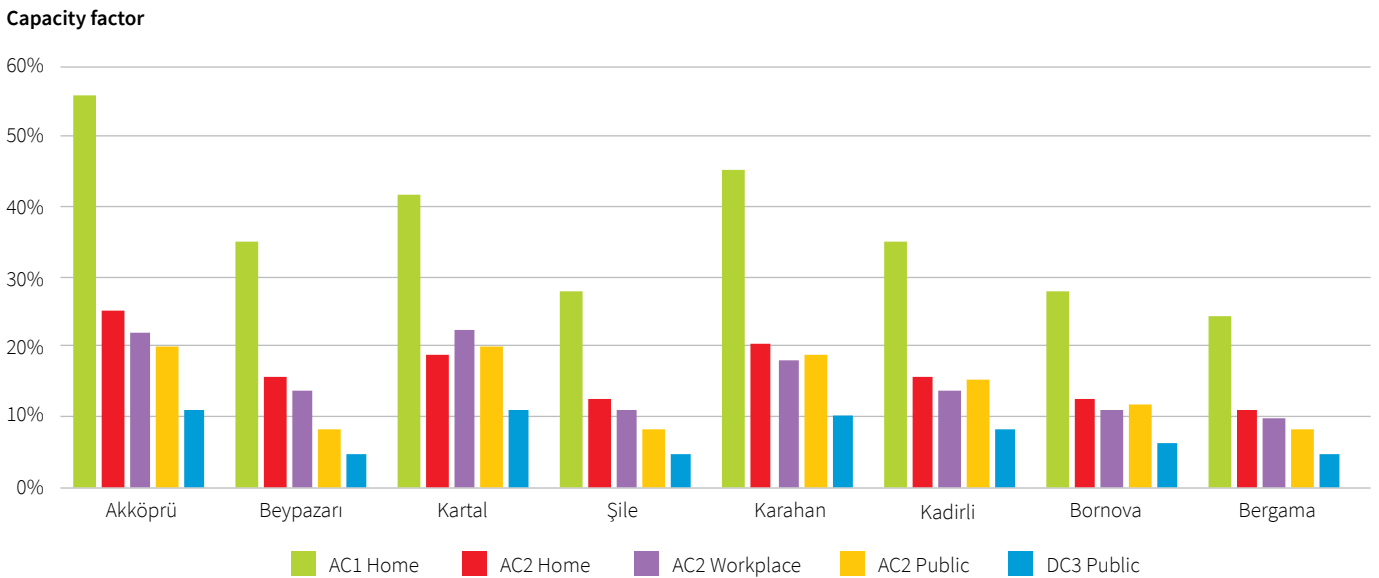
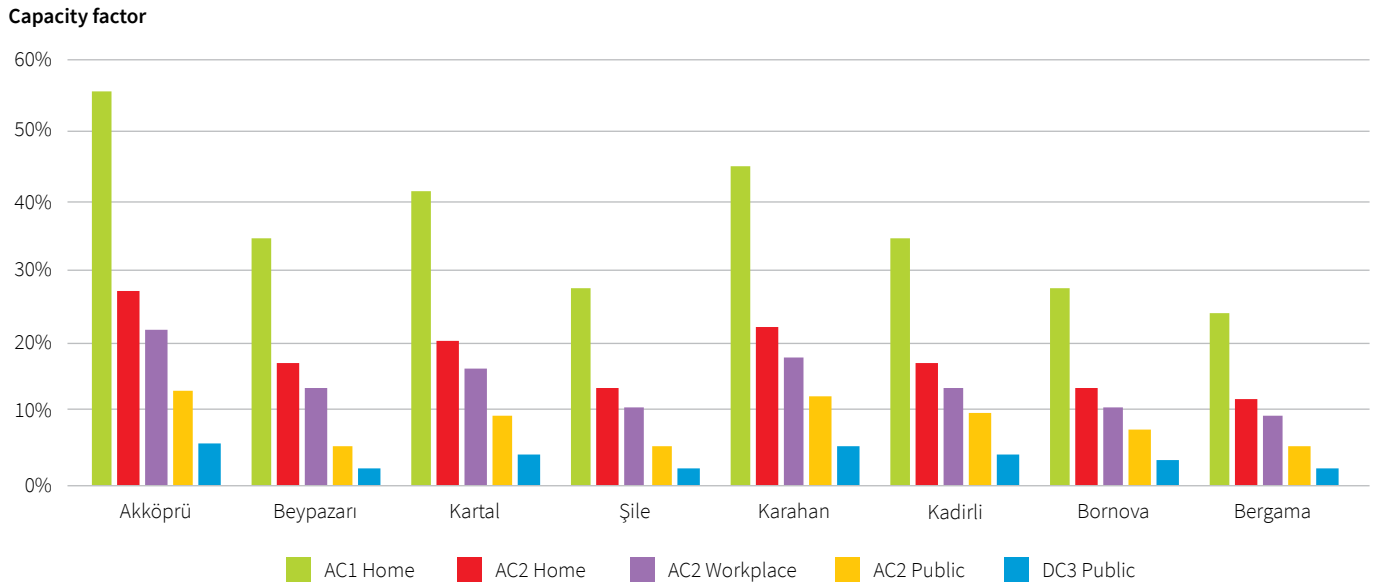


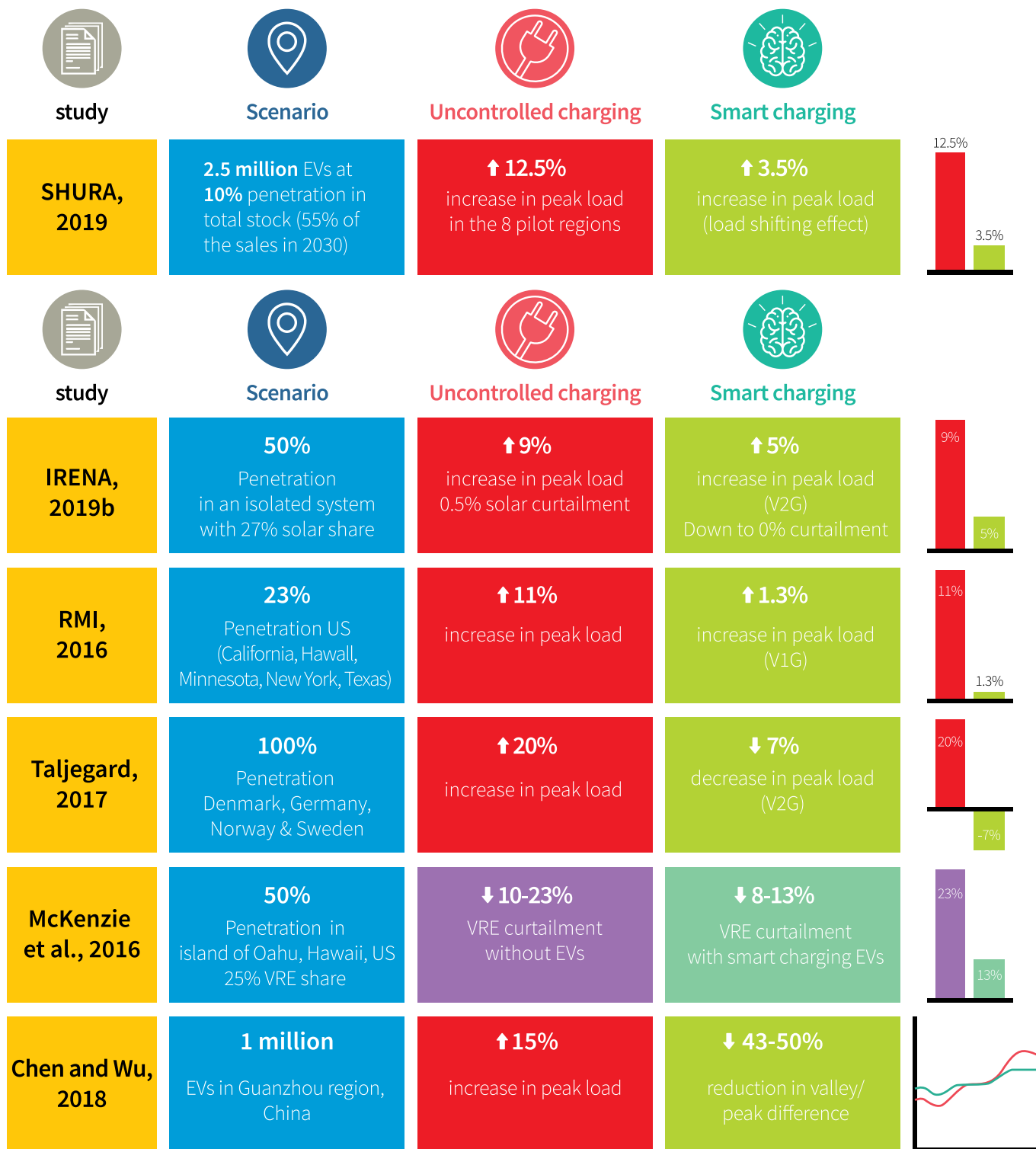
Figure 38: Capacity factor of charging infrastructures - Home Charging Support



The peak load in pilot regions increases by up to 12.5%. However, the peak load increase is only 3.5% in the High Growth scenario with home charging support case, when midnight shifting is considered a smart mechanism at homes.

According to Figure 39, which compares the findings of this study with those of other studies that assess the impacts in other world regions, the increase at the peak load of pilot regions seems inevitable when EVs are charged in an uncontrolled manner. However, smart charging can substantially reduce the increase in the peak load. Uncontrolled charging in our study (i.e., the first study in Figure 26) corresponds to the High Growth scenario with public charging support case where there is no smart charging mechanism (except for uniform daily charging at workplaces, as indicated in Figure 2). In this case, the peak load in pilot regions increases by up to 12.5%, as illustrated in Figure 39. However, the peak load increase is only 3.5% in the High Growth scenario with home charging support case, when midnight shifting is considered a smart mechanism at homes. These results show that home charging support, along with smart charging mechanisms, is the key strategy for EV integration to grid.

Figure 39: Summary of comparison between current study and similar studies results based on High Growth Scenario, Public Charging Support



Source: IRENA (2019b) and authors

5.4. Sensitivity analysis

Five different sensitivity cases have been investigated to estimate the impact of changing several key assumptions that impact the results of this study. These assumptions are the annual increase in electricity demand, public charging behaviour, distribution of charging points on MV feeders, as well as the integration of renewables

and energy storage. Note that the results of the studies for the target year 2030 presented above are based on the very limited current level (2018) of renewable energy sources in the pilot regions (no renewables in metropolitan pilot regions indeed). Also, no storage device is included in the studies. In this regard, their effects on the results were intended to be investigated through sensitivity analysis. The sensitivity analysis was carried out for the Kartal pilot region and the results are summarised across the following two indicators: total number of violation (voltage violation and overloadings), and the increment in MV/LV transformers capacity factor.

In Figure 40 and Figure 41, the last bar, namely “Normal Public (5% load growth)”, corresponds to expected public charging behaviour (shown in Figure 24) where 5% annual load growth was assumed. The results for “Normal Public (5% load growth)” are the same as those indicated in Figure 26, and are considered the base case for the sake of comparison in this sensitivity analysis. The second bar in Figure 40 and Figure 41, entitled “Normal Public (3% load growth)”, corresponds to normal public charging behaviour (shown in Figure 24); however, in this case, 3% annual load growth is assumed instead. In Figure 40, the comparison between “Normal Public (5% load growth)” and “Normal Public (3% load growth)” shows that the total number of violations in case of 3% load growth is increased (from 6 in 5% growth case to 13 in 3% growth case). The main reason is that lower load growth (i.e., 3%) results in lower amount of grid investments in the Reference Model. Less investment means less idle grid capacity to integrate EVs. The average capacity factor increment of MV/LV transformers is around 7% in the case where electricity demand grows by 5%. By comparison, integration of the same number of EVs results in a higher number of violations, causing the average capacity factor increment to double to 15% in the case of 3% growth in electricity demand.

This is due to the change in the charging pattern and shifting EV load. This change relieves the grid elements which were overloaded at Normal Public charging pattern and returned to the permissible loading level at Extreme Public Charging pattern.

In the “Extreme Public Charging (5% Load Growth)” case, public charging pattern during the day is narrowed to few hours resulting in more public charging during peak load time. The number of violations are decreased compared to the “Normal Public (5% load growth)”, as indicated in Figure 40. This might be surprising at first glance, however, this is due to the change in the charging pattern and shifting EV load. This change relieves the grid elements which were overloaded at Normal Public charging pattern and returned to the permissible loading level at Extreme Public Charging pattern. Despite this reduction, transformer capacity factors are increased compared to Normal Public Charging pattern, as expected (see Figure 41).

To estimate the impacts of installing more chargers on fewer number of feeders, 17 public charging points are reduced to 9 while maintaining the same number of EVs. In Figure 40 and Figure 41, total violations and the average of capacity factor increment increase. The underlying reason is that, by concentrating more chargers on fewer number feeders, the load profile of the feeder is changed, and adding more load increases the usage of the corresponding feeder.

Figure 40: Total number of violations (voltage violation plus overloadings) for each case of the sensitivity analysis

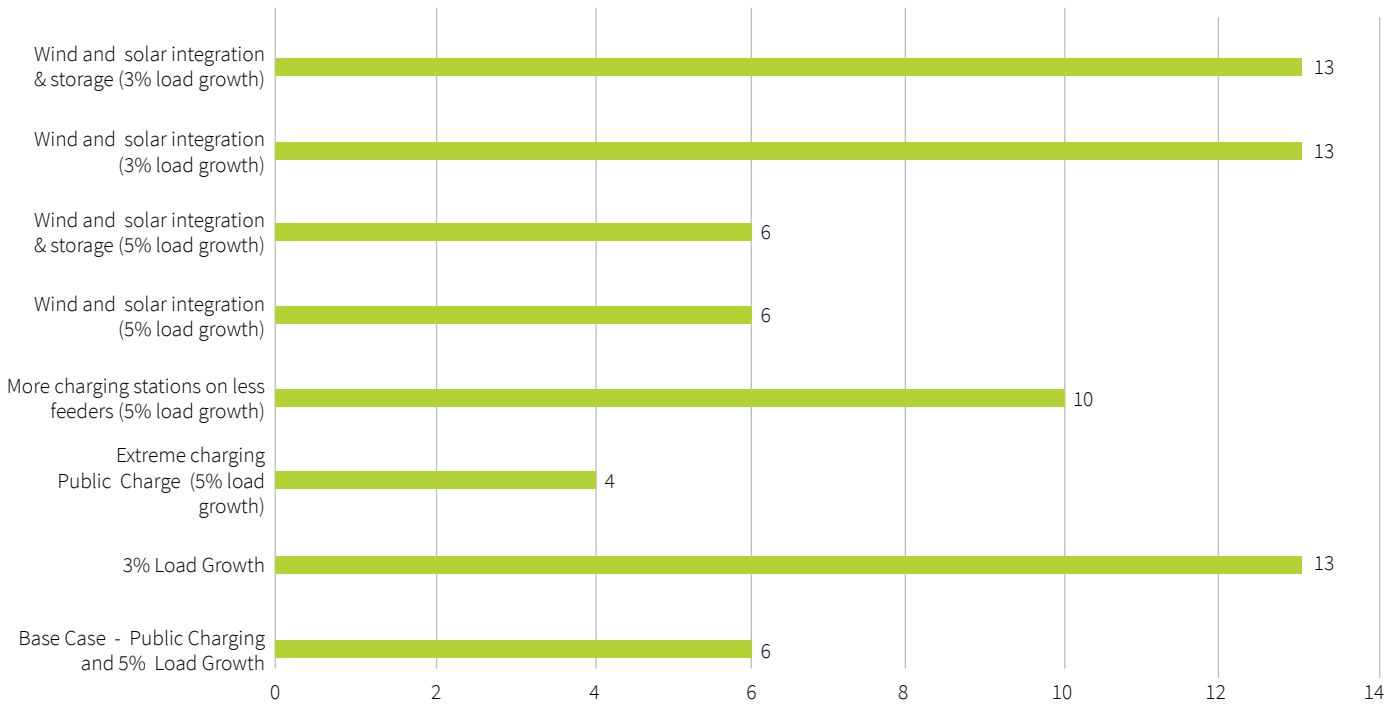
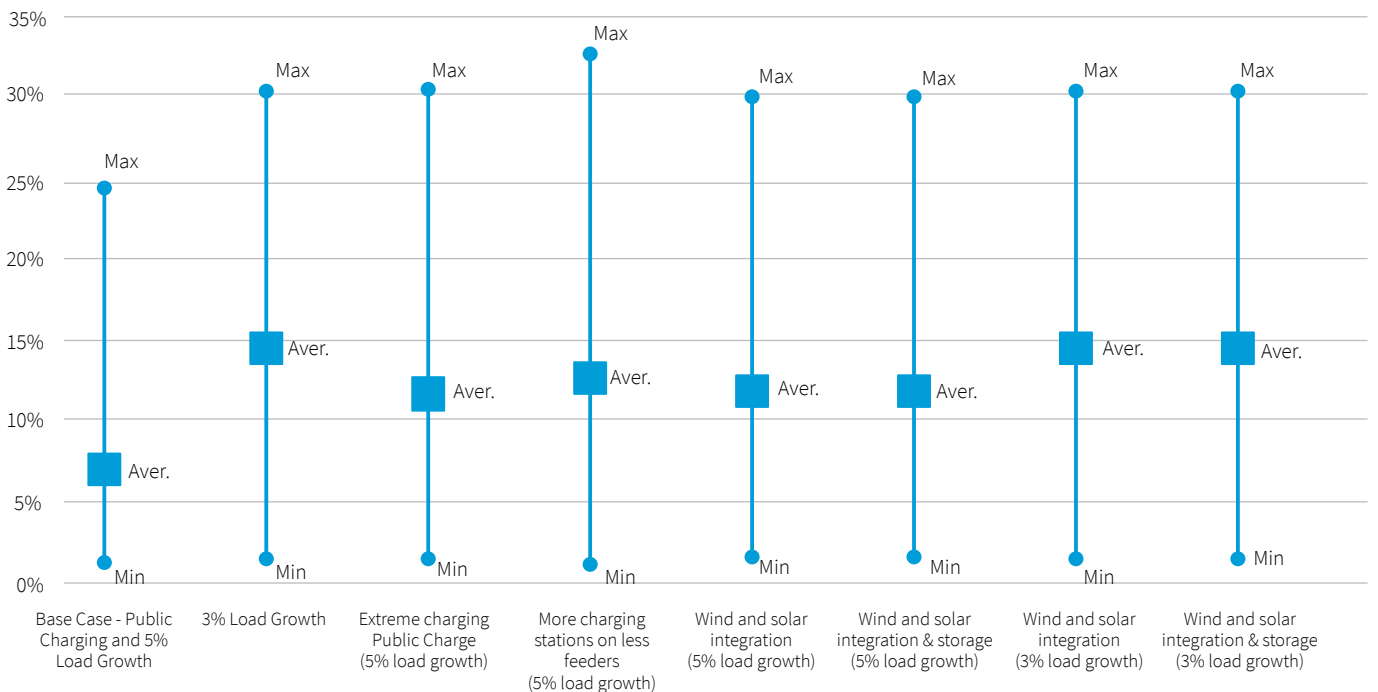


Figure 41: Medium voltage/Low voltage transformers capacity factor increment after electric vehicle introduction for each case of the sensitivity analysis

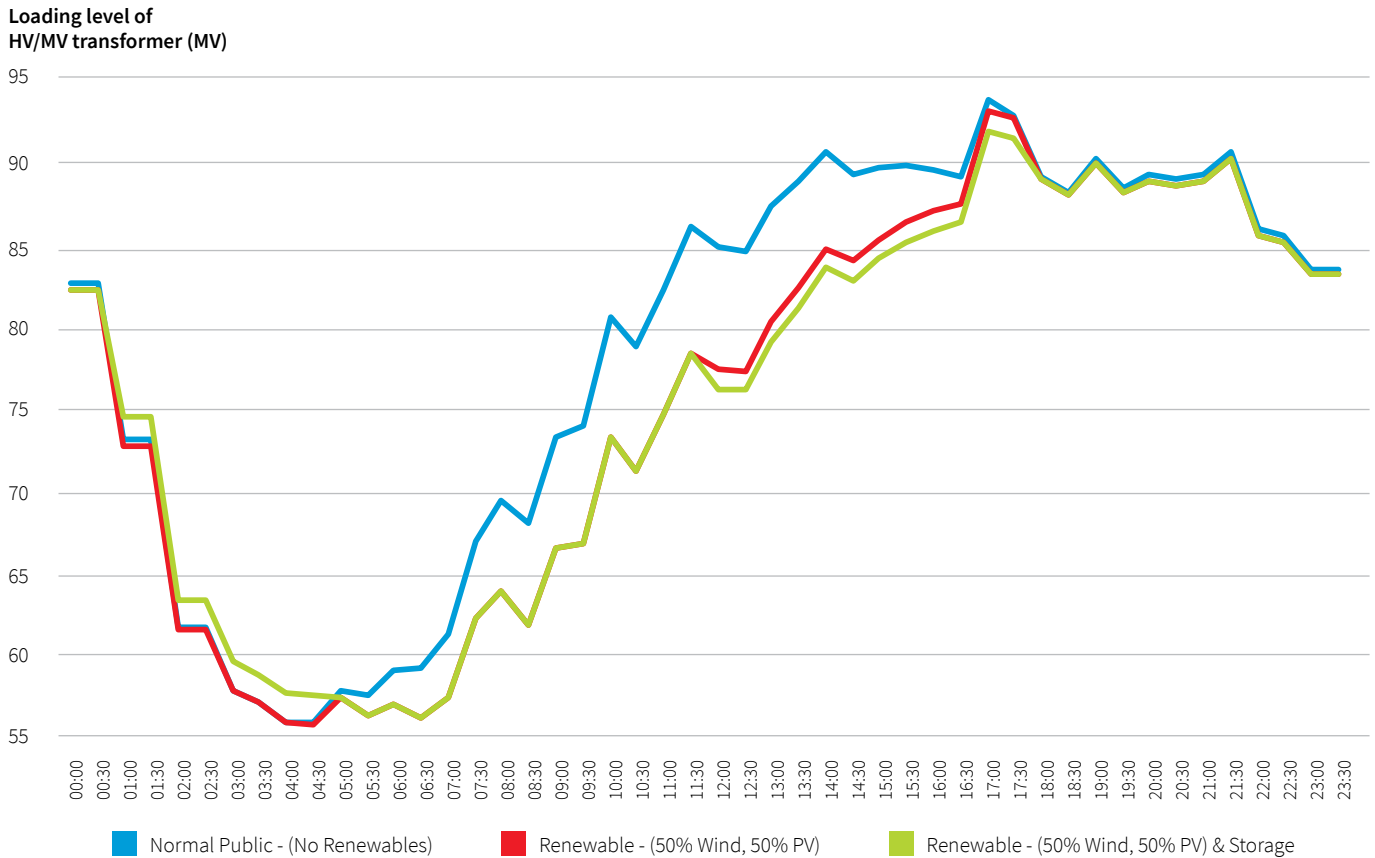
Transformer capacity factor increment



When renewable energy is integrated to the system, the total number of violations remain the same, indicating that the renewables and storage integration may have ignorable effect. While this could be the case for the entire year, it does not hold true for all seasons. Figure 42 depicts the loading level of the HV/MV transformer in Kartal on a typical summer day. As can be seen, renewable energy and battery storage systems reduce the HV/MV transformer loading level. However, since the availability of

renewables does not coincide with the peak load at Kartal (hour 17:00 in Figure 42), the effect of renewables and storage system cannot be observed clearly in removing the violations (overloadings and voltage violations) at peak loading hour. In other words, positive effects of renewables and storage devices at peak loading hour are not as obvious as those at the other hours, as illustrated in Figure 42.

Figure 42: Loading level of High voltage/Medium voltage transformer in the Kartal pilot region – Typical summer day



Note that violations usually happen during peak times. In other words, renewables and battery storage systems have their positive effect on relieving the system, but their availability might not always coincide with the peak load time when violations happen. This result indeed supports the results of a research from a more mature EV market, namely Norway, indicating that without any incentives or signals, EV owners tend to charge during existing peaks.

Another reason for this result is that charging and discharging patterns of storage devices are assumed to follow a price-based scheme where storage charging is realised during midnight (when the prices are the lowest) and discharging is realised during peak hours (daytime).

Finally, it is worth emphasising that this study does not involve/assume a charging incentive mechanism, which directs, as an example, EV charging during a typical summer daytime when generation from solar renewable energy is high. Such mechanisms would provide benefits not only to EV owners but also to the distribution grid in terms of relieving technical constraints.

5.5 Discussion of findings

This chapter discusses the findings of the study and puts them into the context of European and global developments.

5.5.1 Distribution grid impacts

Based on the analysis of data from four grids that represent around one-third of Turkey's total population and electricity demand, the results of the analysis show that 2.5 million EVs (representing 10% of the vehicle stock in 2030) can be integrated to Turkey's distribution grid with almost no additional investments and limited impact on the operation of the distribution grids.

Based on the analysis of data from four grids that represent around one-third of Turkey's total population and electricity demand, the results of the analysis show that 2.5 million EVs (representing 10% of the vehicle stock in 2030) can be integrated to Turkey's distribution grid with almost no additional investments and limited impact on the operation of the distribution grids (measured by maximum loading increment and voltage violations). The additional capacity needed in transmission lines and the MV/LV transformers for limiting the voltage violations and maximum loading increment resulting from EV integration is estimated to be between 1% and 10%, compared to the Reference Model where no EV penetration was assumed. For example, the estimated value for the Kartal region is 1.66% and in economic terms, this corresponds to less than 1% of the total investment needed for the Kartal pilot region (see Figure 37). Achieving this will require grid investments between now and 2030 in line with the 5% annual demand growth for buildings and industrial processes. Maintaining this investment speed will also be crucial for EV integration. Therefore, it will be crucial for DSOs to monitor the level of grid investments along with key performance indices, such as the capacity factor of the distribution grid assets.

In the extreme public charging case during peak hours, the capacity factors of the assessed distribution grids have increased while the total number of voltage violations and maximum load increments has decreased. It is worth emphasising that this study focuses mainly on DC fast charging with a capacity of 100 kW. With the advancements in charging technology, however, fast DC chargers with higher capacities (such as 350 kW) might be integrated in the 2030 outlook. Under such circumstances, more voltage violations and overloadings might be observed. In this regard, the result points to the importance of planning for location and of the technology type of charging points. This is also highlighted by the capacity factors of different charging infrastructure technologies across the selected pilot regions in this study.

The analysis is confined to passenger vehicles and excludes several other modes of electric mobility. These are taxis, light duty vehicles, two/three wheelers, trucks and buses, which are the segments where the transformation to electric mobility could happen much faster with major fleet changes. For instance, in several cities of Turkey, public transportation system is shifting towards the use of e-buses following the global trend where the e-bus stock has increased by 25% in 2018 compared to the year before (IEA, 2019b). Rented car fleets and light duty vehicles can go through rapid changes if the companies that rent or use these cars make business choices to this effect. These fleets have large numbers of vehicles, and if they become fully electrified, they could lead to considerable grid impacts, particularly in highly populated regions with major economic activity, including those selected for the purposes of this analysis. Taxis operate full day in big cities like Istanbul and will not be entirely following the charging patterns of passenger vehicles that have been examined in this analysis. In addition, the battery size of some of these vehicle types is significantly larger than that of passenger vehicles and could have much larger impact on the grids despite fewer vehicle numbers. An e-bus has a battery size of more than 200 kWh. An e-truck

The additional capacity needed in transmission lines and the MV/LV transformers for limiting the voltage violations and maximum loading increment resulting from EV integration is estimated to be between 1% and 10%, compared to the Reference Model where no EV penetration was assumed.

In addition to maintaining the rate of grid investments, the results point to the importance of smart charging mechanisms that can enable optimisation of EV charging by schedule in public and commercial charging points.

Shopping centres are also assumed to be equipped with such smart mechanisms, which contribute to achieving such favourable results. These strategies will gain more importance as the share of EVs increase compared to the initial assessment of this study, which was 10% of the total vehicle stock by 2030.

typically has a battery size of 300 kWh. Announced heavy weight e-truck models with gross vehicle weight of over 15 tonnes will be driving at least 200 kms per trip and the size of batteries could be triple for such trucks (IEA, 2019b). Other potential factors that can adversely impact the grid integration of EVs are the growing capacity of batteries in passenger vehicles and the potential customer choices towards fast charging equipment. Increasing complexity and growing expectations in service demand from vehicles create additional energy demand, thus increasing battery capacity. In addition, to drive longer distances, the battery capacity of vehicles will be increasing. These will contribute to higher loads at charging points. As the number of vehicles in the fleet that require more electricity grows and battery sizes increase, there could be a greater need for fast charging and this could potentially shift the trends towards charging at DC level. When these are accounted for in the next stages of grid modelling, as indicated by the results of the current study, there could be grid integration challenges if strategies fail to involve additional hardware and smart approaches, thus increasing investment needs strongly.

5.5.2 Smart charging

In addition to maintaining the rate of grid investments, the results point to the importance of smart charging mechanisms that can enable optimisation of EV charging by schedule in public and commercial charging points.

This can be managed by either limiting the number of charging points spatially or introducing charging by schedule optimisation mechanisms (i.e., charging EVs in turn). In both charging-support cases where either public or home-based charging was supported (and where EV owners still have access to other charging options), it was assumed that there will be the necessary electricity price signals and charging infrastructure located in preferable areas to incentivise EV owners to charge at close-to-optimal hours that have the least impact on the grid. In addition, in the public charging scenario, EVs are charged more during the day in public places at AC level 2 or DC level 3 points. These hours typically represent the off-peak times of the day during which the electricity prices could be the cheapest, provided that tariffs reflect the high penetration of zero-cost renewables, such as wind and solar PV. The home charging support scenario follows a similar analogy where charging takes place within off-peak sleeping hours during the night, but at a slower pace than in public places. The electricity needed for charging EVs could be supplied either from the grid mix or from distributed energy storage at homes, which is filled with electricity from rooftop solar PV systems. It is also assumed that EVs at workplaces will not be charged at the same time, and smart mechanisms will exist to optimise EV charging by schedule. Shopping centres are also assumed to be equipped with such smart mechanisms, which contribute to achieving such favourable results. These strategies will gain more importance as the share of EVs increase compared to the initial assessment of this study, which was 10% of the total vehicle stock by 2030. For instance, in a recent study regarding the case of Germany, smart charging becomes crucial in the event that the EV share reaches one-third of the total vehicle stock by 2030 (with the two-thirds of the total electricity demand supplied from renewables, predominantly wind and solar energy) (Agora Energiewende, 2019).

A precondition for smart charging is cost-reflective pricing. The model adopted in this study implicitly assumed the presence of pricing signals to encourage consumers to smart charge. Without detailing the assumed tariffs, it can be noted that the EV

While the simplest form of time-varying tariffs, namely ToUT, incentivises EV owners to charge at specific hours, it is important to take into consideration that charging behaviour could differ by season (similar to energy consumption in general), and this needs to be reflected in the design of such tariffs by, for example defining different summer and winter prices.

uptake towards the higher growth scenario makes the presence of smart charging mechanisms, such as the widely-available time-varying prices, more important. Real-world experience also shows that the ratio between on- and off-peak periods that tends to produce a shift in consumer behaviour is about 3:1 to 4:1. While the simplest form of time-varying tariffs, namely ToUT, incentivises EV owners to charge at specific hours, it is important to take into consideration that charging behaviour could differ by season (similar to energy consumption in general), and this needs to be reflected in the design of such tariffs by, for example defining different summer and winter prices. As more decentralised renewable energy production is added to the grid and the charging behaviour scenarios further differentiate with the EV uptake (for example, more fleet and commercial use), more dynamic tariff strategies may be needed to address such changing patterns. In certain tariff applications, CO₂ emissions of the grid mix are also considered in the pricing structure to encourage charging at times of the day with the least CO₂ emission intensity, for instance, through increased share of renewable energy resources. The more granular and complex the tariff designs are, the more reflective the prices of energy production and grid use need to be. This can be achieved through a reform of wholesale and retail market prices, which is further detailed in the policy recommendation section.

Both charging support cases point to the benefits to be gained from the synergies between renewable energy & storage and EV charging. The benefits would be more prominent from a grid integration perspective during summer times when additional load from EVs increases the already existing high load due to air condition use for space cooling. Distributed energy and battery storage creates significant benefits for meeting the additional EV load at times when the load on the distribution grid is high from demand sources other than EVs, thereby reducing the operational and investment impact on distribution grids.

Even in the High Growth scenario, capacity factors for EV charging remain at or below 50%, indicating the flexibility to absorb high shares of electricity generation from renewable energy sources.

The analysis investigated the concept of smart charging defined as managed, optimised unidirectional charging from grid to vehicle with the aim of reaping the benefits the EVs' flexibility presents for the grid, as well as the potential to reduce consumer cost through off-peak charging and to increase renewables use at the same time. The public charging scenario illustrates the value that EVs can add to the grid if their charging is aligned to hours that can allow for grid integration of variable renewable energy sources, including wind and solar PV: Even in the High Growth scenario, capacity factors for EV charging remain at or below 50%, indicating the flexibility to absorb high shares of electricity generation from renewable energy sources.

Smart charging can benefit from batteries with second life, which would be collected from EVs that reach the end of their lives. These batteries would provide stationary energy storage capacity for renewable energy deployment (Transport & Environment, 2019), thereby also easing the grid integration of EVs. If price reductions in logistics and modification techniques to make them suitable for reuse in new EVs are successful, they can also replace the production of new battery systems.

5.5.3 Charging infrastructure

At homes and workplaces, the capacity factors of the charging infrastructure are estimated to be at least 15%-20%, and can reach more than 50% in some of the pilot regions, indicating that much of the charging capacity is sufficiently utilised. This

DC level charging points are estimated to have capacity factors that range from as low as 2% to as high as 10%.

Such issues are being currently experienced in markets where the EV use is rapidly growing. At early stages of building charging infrastructure in public places, states initially provide incentives to investors, and there is often little business case for these chargers. Subsequently, as markets reach a sufficiently large size, market-based approaches are phased-in.

In addition, there are significant differences between individual regions in terms of the capacity factors estimated in this study. Grid-specific planning would be needed to determine the number and location of the charging infrastructure.

The analysis foresees the ambitious deployment of between 1 million and 2.5 million EVs and of the related charging infrastructure with a total of 1 million charging points by 2030 in Turkey.

was, however, not the case for charging at public places. DC level charging points are estimated to have capacity factors that range from as low as 2% to as high as 10%. This points to possible issues about the potential business case of these stations. Such issues are being currently experienced in markets where the EV use is rapidly growing. At early stages of building charging infrastructure in public places, states initially provide incentives to investors, and there is often little business case for these chargers. Subsequently, as markets reach a sufficiently large size, market-based approaches are phased-in. By comparison, from the perspective of EV drivers, good coverage of charging stations will be crucial in public areas (after accounting for the availability of stations at homes and workplaces). Hence, a balanced approach will be needed to create a business case for charging station investors and to ensure that EV drivers always have sufficient charging for batteries.

As a best practice example, in Norway, government support programmes for co-financing publicly accessible fast charging stations to be built on its main roads are limited to installation and exclude operation costs. As a result, all installed fast charging stations today are commercially run. Norway is gradually phasing out public financing for fast charging infrastructure, especially in and around cities, as well as along major highways. At the same time, the number of fast charging stations being installed without public support has been increasing. This suggests that demand is high enough to support a business case for EVSE suppliers. However, phasing in commercial charging in remote rural regions proves more difficult.

Another issue concerns the lack of data on and monitoring of the use of public charging stations. This is often in the hand of investors, and therefore it is challenging for planners to craft effective incentive mechanisms. The Netherlands represents a best practice case for the monitoring of charging point utilisation, and the sharing of the collected data publicly.

Evidence from the Netherlands shows that utilisation factors of charging infrastructure remain low even in dense markets, and that monitoring demand is needed to further develop the charging services market. For example, Amsterdam's public charging points have an average utilisation of 35%, which is high compared to other Dutch cities and locations in Europe. The fact that EVs use only 20% of their parking time for actual charging implies a further optimisation potential (Wolbertus et al., 2016). More generally, there is a lack of publicly available data on the usage of charging points that would facilitate a targeted policy design.

In addition, there are significant differences between individual regions in terms of the capacity factors estimated in this study. Grid-specific planning would be needed to determine the number and location of the charging infrastructure. Finally, it will also be important to understand the complementary role different charging points can offer to each other in utilising their capacities in the most effective way. This will also be important for enabling smart charging to receive flexibility services from EVs since EV batteries are connected for longer hours at homes as opposed to in public places.

5.5.4 Creation of the EV market

The analysis foresees the ambitious deployment of between 1 million and 2.5 million EVs and of the related charging infrastructure with a total of 1 million charging points by 2030 in Turkey. Given that Turkey is currently at a very low base in terms of both the

number of its EVs and charging infrastructure, these numbers could seem challenging to realise. When compared with the estimates of global EV stock by 2030 that range between 120 and 250 million, the total stock in Turkey would represent around 1% of the global total, which is along the same lines as the share of Turkish transport sector's total energy use compared to the global total. Hence, the assumptions of this study are in line with the estimates that pertain to the rest of the world. Moreover, Turkey's car ownership is expected to increase in the coming years to reach levels that are closer to developed countries, creating a significant opportunity to accelerate electrification of its vehicle stock. In addition, as the second hand EV market grows quickly and the prices stabilise, a quicker fleet turnover can be expected. In this situation, the lack of EV charging infrastructure for broader use groups, and high purchase prices are typically the main barriers that need to be addressed with a supportive policy framework (purchase rebates, scrapping schemes for older combustion vehicles), as well as by introducing minimum requirements for infrastructure rollout.

5.5.5 Benefits of EVs

These include growth in economic activity, creation of new jobs, improvements in the energy trade balance, increased energy efficiency, as well as the grid integration of higher shares of wind and solar energy through the flexibility services provided by EVs.

Creation of a domestic EV market in Turkey will bring multiple benefits. These include growth in economic activity, creation of new jobs, improvements in the energy trade balance, increased energy efficiency, as well as the grid integration of higher shares of wind and solar energy through the flexibility services provided by EVs. As the grid integration benefits of EVs through various smart charging concepts have been discussed elsewhere in the report, this section will discuss the other benefits .

It is expected that within two years of local production, Turkey can start exporting EVs, and within a period of 15 years, the sector could provide the following estimated benefits: an additional GDP growth of 50 billion TL , a reduction of 7 billion TL in the current account deficit, and the creation of 20,000 new jobs (Yeşil Ekonomi, 2019b). 2.5 million passenger vehicles with internal combustion engines have an estimated total fuel cost of around 11.5 billion TL per year (assuming that half of these vehicles run with diesel and the other half with petrol). By comparison, 2.5 million EVs would have an estimated total electricity consumption of 4.3 TWh per year, and depending on whether they are charged at homes or at commercial/industrial places, the total cost of electricity for charging would range between 2.7 and 3.6 billion TL (excluding any cost that could accrue from charging companies), resulting in savings of 8-8.8 billion TL per year.²²

2.5 million EVs would have an estimated total electricity consumption of 4.3 TWh per year, and depending on whether they are charged at homes or at commercial/ industrial places, the total cost of electricity for charging would range between 2.7 and 3.6 billion TL, resulting in savings of 8-8.8 billion TL per year.

With the current electricity generation mix, total annual electricity demand of EVs of 4.25 TWh is supplied in roughly equal amounts from local resources and from imported fuels. If the trajectory of the electricity generation mix up until 2030 confirms SHURA's estimates of 50% renewables and 14% local lignite, the amount of electricity supplied from imported fuels would decline to 1.6 TWh per year, pointing to a total saving on energy imports of 0.6 TWh per year. This suggests another synergy between the use of local renewable energy sources and EVs.

²² The assumed prices of diesel and petrol are 6.31 and 6.75 TL per litre, respectively. The price of electricity is assumed to be 0.4986 TL/kWh for households, and 0.6589 TL/kWh for commercial users. The following tax items have been included in the electricity tariffs: energy funds 1%, TRT (Turkish Radio and Television Corporation) funds 2%, municipality consumption tax 5%, and value added tax 18%.

6. Priority areas for transforming Turkey's transport sector

Based on the results of this analysis, this section proposes seven priority areas for energy policy makers, the market regulator, distribution grid companies, the automotive industry, charging technology developers and investors, urban planners, and the academia. The proposed areas for policy action are not ranked in order of priority or importance, and are rather categorised depending on which stakeholder groups or part of the energy sector they impact.

A well-designed policy-mix through government leadership that supports both EV sales and charging infrastructure, as well as electricity grid integration, is necessary to ensure that EVs become cost-competitive vis-à-vis combustion-based vehicles.

1) Accelerate the market for EVs and charging services in parallel

Experience from the first mover markets in the EU, the United States and China has shown that a well-designed policy-mix through government leadership that supports both EV sales and charging infrastructure, as well as electricity grid integration, is necessary to ensure that EVs become cost-competitive vis-à-vis combustion-based vehicles. Purchase incentives, such as price rebates or tax deductions, are beneficial when combined with targeted incentives to phase-out internal combustion vehicles (such as the 'Bonus-Malus' Scheme in France, for instance, where the purchase reduction on low-emitting vehicles is financed through a levy on higher-polluting vehicles), as well as with scrapping schemes that also encourage lower income groups to purchase less polluting vehicles. Local governments also need to be proactive and take initiatives for the creation of an EV market, as experienced in most advanced markets worldwide.

These measures need to be designed at an early market phase to help accelerate the electrification of the fleet, but should be phased out gradually to establish a competitive market. In parallel, measures to electrify public vehicles (e.g. buses) and fleets (e.g. delivery/logistics, taxi) are effective in replacing combustion-driven kilometres with electric drive. EV charging infrastructure needs to be rolled-out to reassure early adopters that charging EVs is available when needed, while allowing the broader population access to using EVs.

2) Develop and implement smart charging mechanisms for load management

When more EVs will enter Turkey's vehicle market in the medium term, optimisation of charging times as assumed in this study is crucial to avoid peak exacerbation, and should be considered for all charging points with the aim of optimising additional load at homes, workplaces and in public areas. Optimisation by timing requires using EVs flexibility. This can be achieved by pricing strategies (recommendation A), further optimised by the use of load management technologies, such as the automation of charging times according to price signals and, charging schedules (relevant for fleet applications, e.g. charging electric buses in turn) (recommendation B), and spatial optimisation (i.e., siting charging points optimally where the grid reinforcement costs are the least and at the same time mobility demand is met along with integrated planning, as discussed in recommendation C.) Since the Turkish EV market is still at an early development stage, it is important to already start preparing for smart and cost-efficient EV grid integration. As more EVs will enter the market and will need to be integrated into the grid, optimisation strategies will matter more.

Time-varying tariffs that reflect as closely as possible the costs of producing and delivering electricity can direct charging towards the lower cost hours of the day, benefiting both the EV-owners and the system.

A. Development of time-varying electricity tariffs and pricing strategies to integrate higher shares of electric vehicles to the grid

Experience from advanced EV markets in the US and Europe has confirmed electricity pricing as a powerful lever to enable smart charging, i.e. cost-efficient, consumer- and grid-friendly EV charging when grid load is low, or when renewable energy sources are abundant. Time-varying tariffs that reflect as closely as possible the costs of producing and delivering electricity can direct charging towards the lower cost hours of the day, benefiting both the EV-owners and the system.

In the medium and long term, in order to allow for more time-varying pricing, it will be important to further develop the wholesale markets, including the day-ahead, intra-day and balancing markets, so that the markets work seamlessly across all timeframes. Faster and shorter wholesale markets (e.g. moving towards shorter imbalance periods), and electricity prices driven by the dynamics of supply and demand for energy and balancing services, will better reflect the value of flexibility. These wholesale prices could then be reflected on consumer bills through time-varying prices.

In the short-term, as the liberalisation of the retail market advances, it could be beneficial to develop dedicated ToUT for EVs in order to exploit the inherent flexibility of EVs. Turkey has ToUTs already in place as part of its regulated prices, and these EV dedicated tariffs could be considered an extension of them.²³ As the renewable energy and EV penetration increases, and the market itself becomes more competitive, it can be expected that more dynamic pricing designs would emerge naturally in the market. If this is not the case, the regulator could intervene by setting a more dynamic EV tariff further in the future, one that could help trigger a market by incentivising suppliers to develop their own offers. In any event, regulators should monitor the effectiveness of any EV tariffs in place in integrating EVs at low-cost.

Earlier pricing pilots show that smart technology, combined with time-varying or more dynamic pricing schemes, can maximise the benefits of EV integration for the power system.

B. Deployment of intelligent technologies to support grid-friendly charging

Earlier pricing pilots show that smart technology, combined with time-varying or more dynamic pricing schemes, can maximise the benefits of EV integration for the power system. Smart technology to optimise charging ranges from smart meters, which measure and communicate a charging point's consumption, to solutions such as automated charging that can be operated in response to price or other signals. This means that the charging technology to be put in place now and in the years to come must have smart functionality built into it (or an alternative should be available), even if it is not used immediately. Policy makers should require this minimum intelligence for all charging infrastructure, particularly at workplaces (where larger numbers of EVs are likely to plug in for about 8 hours in an effort to use the potential of optimised charging) and at public charging stations to be able to control for peak hours usage. Lessons learnt from pricing pilots in the United States also show that opt-out schemes are successful. That is, if customers are put on a dynamic tariff, they can be given the option to opt-out to the standard tariff, although few of them do so. For Turkey, pilot projects for the introduction of time-varying tariffs to encourage cost-effective, grid-friendly EV charging will be useful. Opt-in/-out options can be used.

²³ Prior to the introduction of any tariffs, it would be prudent to develop pilot projects to assess the likely impact of these dedicated tariffs, and if necessary, undertake educational efforts to explain to the consumers the benefits of these tariffs, and how to use them best, as well as to address any other concerns and needs that consumers might have.

EV charging infrastructure roll-out needs to meet mobility and grid demand. Therefore, a coherent planning, including anticipation of future use scenarios and charging needs, is crucial.

C. Optimal cost-efficient infrastructure siting and planning to enable commercial operation: a roll-out plan for Turkey

EV charging infrastructure rollout needs to meet mobility and grid demand. Therefore, a coherent planning, including anticipation of future use scenarios and charging needs, is crucial. Future EV infrastructure is likely to be a combination of:

- residential (home-based) level 2 charging, offering time flexibility mostly overnight to optimise for low-cost hours and make better use of the underutilised network capacity via pricing and technology
- commercial and public charging, with a higher share of fast charging during the day which offers less time-based flexibility, but can be optimised to absorb noon-time solar energy, for example and can also be optimised by location.

Incentives need to be set in a targeted way to prepare for a broader use of EVs among different user segments. The EU, for example, has deployed targeted public-private incentives for establishing high-power charging points along major highways across the continent with a minimum density factor of 1 charging point in every 60 kms (European Commission, 2016) – this and other potential roll-out criteria are currently being evaluated according to the market situation (European Commission, 2019). (In addition, grid operators in some countries, such as National Grid in the United Kingdom, explore how fast charging points for cars, and in the future also for electric coaches and trucks, can be linked to the existing transmission grid at mid-voltage level.) Best practices identified across Europe and the United States (Hildermeier et al., 2019) also suggest the adoption of joint integrated demand-based planning procedures, including transport and energy departments in cities and grid operators to identify cost-effective and grid-optimal charging locations that meet expected mobility demand. Grid impacts of future use cases, including vehicles with larger batteries, larger fleets of electric vans, trucks and buses that are electrified, will have to be further studied and evaluated in planning.

Government should pursue a charging infrastructure plan nation-wide to determine a minimum density criterion for urban/semi-urban/rural areas, but require cities to provide local plans for charging-infrastructure roll-out according to local characteristics.

For Turkey, such a ‘mapping’ exercise should identify the most cost-efficient fast charging needs nationally, along Turkey’s highway infrastructure and grid. Grid investments necessary to support EV infrastructure could be capped and a certain share of charging could be required to be delivered through optimisation mechanisms. EVSE builders should be required to use, where possible, existing network assets (e.g., transformer or network line capacity) and existing public transport or street infrastructure to maximise efficiency gains and avoid additional infrastructure costs. As charging needs and use cases are likely to differ, solutions will vary from normal charging (along with providing parking space) in dense urban areas to fast-charge hubs for taxis and shared EVs. Cities can put in place demand-based rollout, i.e. establish a procedure by which citizens/companies can ask for equipment with charging points, and then choose a supplier via public tender. Financial support should seek the phase in of commercial operation, but may need to sustain funding in less densely populated areas (semi-urban/rural areas). Government should pursue a charging infrastructure plan nation-wide to determine a minimum density criterion for urban/semi-urban/rural areas, but require cities to provide local plans for charging-infrastructure roll-out according to local characteristics.

Workplaces and multi-unit buildings with shared parking lots need to be equipped with EV parking. Building codes are an essential policy area to prepare for the EV roll-out. In the EU, recent building codes were reformed (Platform for Electro-mobility, 2018) to increase the number of charging points in shared parking lots by providing

For Turkey, building codes should include provisions for new builds, and substantial renovations need to anticipate the possibility for EVs to park and charge.

Network violations (namely, line/transformer overloading and voltage drops beyond the established limits) caused by the deployment of EVs can be limited with the implementation of smart charging and the development of distributed generation.

The more flexible the distribution grids are, the more reliable the penetration of renewable energy and EVs becomes. However, introducing such flexibility market mechanisms require locational pricing mechanisms which take into account the cost of relieving the local technical constraints.

minimum targets for equipping charging points. However, more ambitious building provisions are needed, such as those already in place in California, including “make-ready” ducting infrastructure in parking spaces at residential and non-residential buildings; and giving tenants’ and owners’ the “right to charge” by allowing owners of parking spaces in residential buildings to install a smart charging point, or by granting additional incentive programmes for landlords to set up EV charging in buildings; as well as by setting more ambitious minimum requirements for equipping shared parking lots and incentivising companies to equip their workplaces with charging facilities for employees. For Turkey, building codes should include provisions for new builds, and substantial renovations need to anticipate the possibility for EVs to park and charge. For example, shared parking lots should be equipped with pre-cabling (setting ducting infrastructure to install EV charging points) and a minimum number of already existing charging points to facilitate EV adoption.

3) Develop region-specific measures to avoid overloading and voltage violations

The results demonstrate that network violations (namely, line/transformer overloading and voltage drops beyond the established limits) caused by the deployment of EVs can be limited with the implementation of smart charging and the development of distributed generation. Smart charging through, for example, the application of time-varying network tariffs or automated load management technologies can direct EV charging towards the times of the day when there is spare network capacity, thus avoiding overloading the network, and at the same time limiting voltage violations. The parallel development of distributed generation in areas of EV deployment can also limit voltage violations by replacing centralised generation that needs to be transferred over long distances.

Another solution, which is being discussed in developed markets, is to introduce flexibility markets in distribution systems. Flexibility services include aggregated demand response, aggregated renewable energy management, and virtual power plant concepts. The more flexible the distribution grids are, the more reliable the penetration of renewable energy and EVs becomes. However, introducing such flexibility market mechanisms require locational pricing mechanisms which take into account the cost of relieving the local technical constraints. This concept is not even implemented in Turkey at transmission level. That is, congestion costs induced by the balancing market are uniformly distributed to all consumers in the grid. Locational marginal pricing (LMP) at transmission level is common in the United States markets. Although distribution locational marginal pricing (DLMP) at distribution level has not been introduced in the United States, it is being discussed particularly in California, given the high penetration, in this state, of distributed generation (renewable energy and others) in distribution grids (Li et al., 2014). Such international developments in the DLMP concept could be followed.

Beyond the above-mentioned solutions and the statutory obligations of DSOs for quality of supply (Energy Market Distribution Regulation of Turkey, EMRA, 2019a), technical solutions will likely be required, i.e. more interconnection on-load tap changers and better voltage control systems. The regulatory framework should ensure that network companies can develop these solutions in a timely manner, while avoiding any investment excesses.

For Turkey, any support policy for EV charging infrastructure should seek commercial phase in and could be indexed to the number of EVs in use, and should be gradually reduced accordingly.

4) Assess, develop and implement new business models for EV charging

Although EV charging infrastructure is developing across main EV markets, building a sustainable business case remains a challenge for many companies, and public support programmes are needed to establish a market phasing in commercial operation. Utilisation rates remain at around 30% in best cases in Europe, and although commercial operation exists in Norway, charging infrastructure in less mature markets is supported partially by the public sector. More importantly, public sector support is expected to reduce as the EV market grows and should be done in view of establishing a self-sustaining market. For Turkey, any support policy for EV charging infrastructure should seek commercial phase in and could be indexed to the number of EVs in use, and should be gradually reduced accordingly. In addition, separating installation cost subsidy from running costs encourages commercial operation. Utilisation data of charging points should be monitored and be made publicly available.

As is the case in more mature EV markets, some specific locations are likely to retain a low capacity factor. In these cases, models of public-private co-funding should be developed, and/or operation through electricity network companies could be considered for example through public tenders an option to ensure minimum EV charging infrastructure coverage.²⁴ Other technology options, such as battery-assisted chargers, could also be considered. These chargers make a charging point more flexible to be moved to where demand is, and/or avoid high energy prices at peak hours and instead recur on pre-stored energy, thereby allowing operators to establish business-models more flexibly.

5) Continue the planned investments in distribution grids in line with the growth in electricity demand

The additional capacity in transmission lines and the MV/LV transformers required to limit the voltage violations and maximum loading increment resulting from EV integration is estimated to be between 1% and 10% ,compared to the Reference Model where no EV penetration was assumed. In economic terms, it was estimated to be less than 1% of the total investments in the Reference model for the Kartal region as an example (and in terms of physical capacity estimated at 1.66%). These estimates, however, assume that distribution grid investments will continue to meet an annual increase in electricity load by 5% per year. While this is crucial for the four selected distribution grid regions examined in this study, it will be equally important for the other 17 distribution grid regions in Turkey that are beyond the scope of this study, especially for those critical regions where grid losses are high and investments are not always implemented in line with the actual planning. Sensitivity analysis results for 3% annual demand increase show that the total number of voltage violations increase compared to 5% growth in electricity demand, highlighting how important it is to ensure that distribution companies continue their capacity investments along with monitoring key performance indices, such as capacity factor of the distribution grids to align the with the market growth for EVs and location choices of charging infrastructure.

Sensitivity analysis results for 3% annual demand increase show that the total number of voltage violations increase compared to 5% growth in electricity demand, highlighting how important it is to ensure that distribution companies continue their capacity investments along with monitoring key performance indices, such as capacity factor of the distribution grids to align the with the market growth for EVs and location choices of charging infrastructure.

²⁴ This has been a temporary solution adopted, for instance, in California, the United States and in Spain and is allowed as an exception through the European 'Electricity Market Directive' (Art.33 (2)) (European Union, 2019).

Time-varying pricing schemes, which are tied to wholesale market prices that indicate consumers when it is a good time to charge (this can be done either manually by informing consumers or in an automated way by load management technologies), could be a rational step forward as ToUT is already being implemented in Turkey.

Urban transport that relies more on electric mobility will reduce local air pollution, and if electricity needed for charging is sourced from renewables, it will also reduce the emissions of CO₂ and air pollutants from the power sector.

6) Utilise synergies between EV charging and renewable energy integration and energy storage

A holistic approach to energy and transport planning is needed to make the EV grid integration cost-efficient and to fully reap its benefits. To integrate renewables and optimise the use of flexible loads, such as EVs, in the medium to long-term, more granular pricing designs (like the DLMP concept) are needed. For example, during a typical summer daytime when generation from solar renewable energy is high, a price incentive can be given for EV charging. This will provide benefits not only to EV owners but also to distribution grid in terms of relieving technical constraints, such as voltage increase resulting from high local generation from solar PV systems. The more effective implementation of time-varying network pricing and the more efficient use of existing networks are the solutions for deferral of grid investments. Time-varying pricing schemes, which are tied to wholesale market prices that indicate consumers when it is a good time to charge (this can be done either manually by informing consumers or in an automated way by load management technologies), could be a rational step forward as ToUT is already being implemented in Turkey (Energy Market Distribution Regulation of Turkey, EMRA, 2019b).

7) Assess and plan for utilising the benefits of EV development with other sectors

Planning for parking and infrastructure in different types of buildings and integration of charging EVs with their energy supply and demand flows will be crucial. As transportation is electrified, power and transport sectors will need to be increasingly coupled so as to limit grid impacts. This will require the management of energy flows through smart charging methods for integration of EVs by minimising their impacts on the grids, and integration of wind and solar energy to the grid through the battery capacity offered by EVs. In order to integrate the various types and technologies of charging stations, planning for EVs will need to go hand in hand with urban planning. Urban transport that relies more on electric mobility will reduce local air pollution, and if electricity needed for charging is sourced from renewables, it will also reduce the emissions of CO₂ and air pollutants from the power sector. Such environmental and human health benefits should be quantified and taken into account in the broader planning of the EV sector. As EV batteries reach the end-of-life stage, there will arise a need for a regulatory framework to manage the waste of batteries.

It will be important to understand and measure the synergies and trade-offs between Turkey's industrial policies and the social and economic impacts of the efforts for expanding domestic production of EVs and its equipment. While the creation of an EV sector and its supply chain will create new business opportunities and employment, Turkey is already a large hub of equipment manufacturing for internal combustion engines, developing over the years a significant engineering and manufacturing know-how. The creation of a significant local EV manufacturing capacity may impact this existing industry base, though this may not be as obvious as in other large automotive producing countries where the demand for cars is also on the rise (Arnold and Provan, 2019). In addition, it will be essential to understand how the existing tax regimes can be adapted to create a market for EVs (ICCT, 2019b).

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Annex 1: Methodology for estimating the amount of required MV line investment

Nowadays, electrical load growth is inevitable due to the significant dependency levels of modern society on electrical energy. However, load growth is among the key factors which reinforce additional investment at distribution network. Increasing the capacity of MV/LV transformers, reinforcing the available MV and LV lines, and constructing new MV and LV lines are among the common investment methods to cope with load growth in distribution systems. In this study, we started from the current (i.e., 2018) MV grid model of each pilot region and applied an 5% annual load increment up until the target year 2030. For the load forecast for year 2030, grid investment requirements are determined in accordance with the following technical constraints: i) overloadings on the existing branches; ii) voltage drop at the consumer points; and iii) N-1 contingency at the primary distribution network. In the following section, the process of determining the grid investment requirements will be explained.

Figure 43 depicts the schematic of a sample distribution system in year 2018 where the loads at distribution transformer centres (DTC) are supplied from a HV/MV substation. In year 2030, two possible conditions can be realised for demand growth: vertical and horizontal demand increase (see Figure 44). Vertical demand increase refers to demand growth at DTCs which were already available in year 2018, i.e. DTC1 to DTCn. On the contrary, horizontal demand increase originates from the load growth at DTCs which were not available in year 2018 and are constructed in year 2030 due to attendance of new loads. Total investment in a distribution system refers to the summation of investments realised due to the vertical and horizontal load growth.

Figure 43: Schematic of a simple distribution system in year, 2018

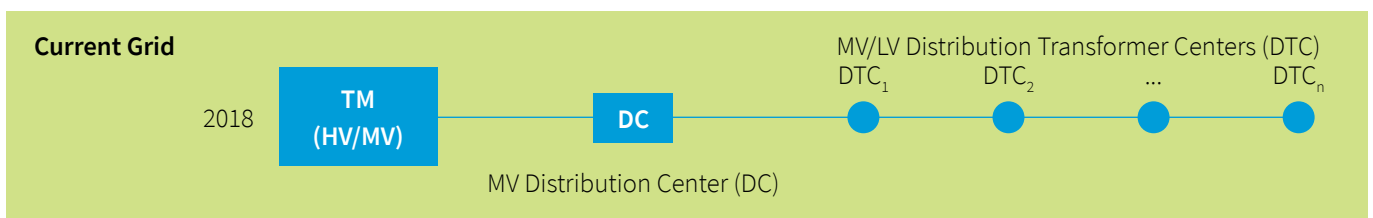
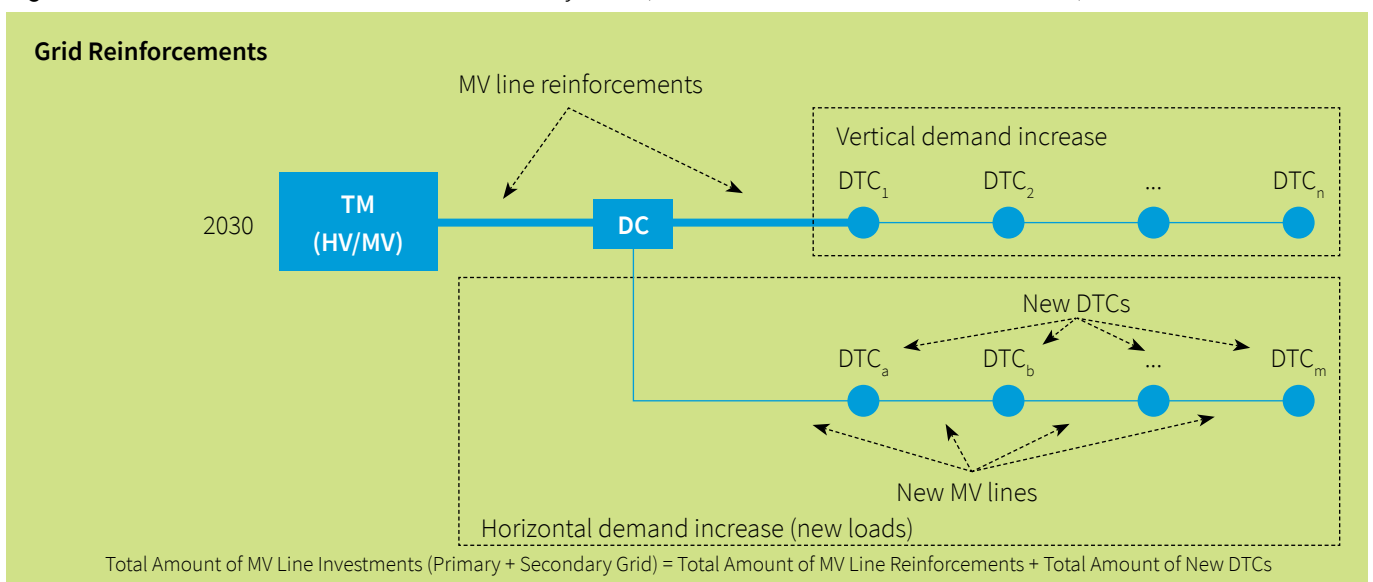
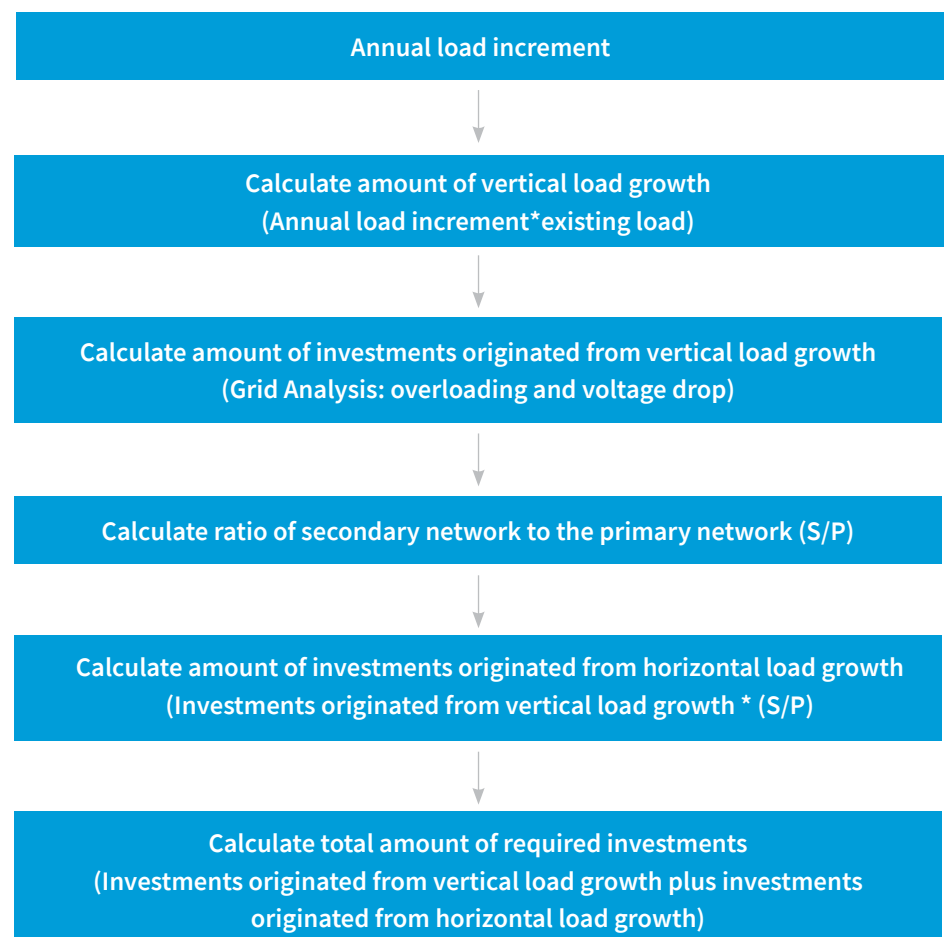


Figure 44: Possible demand increase at distribution systems (Vertical and Horizontal demand increase)



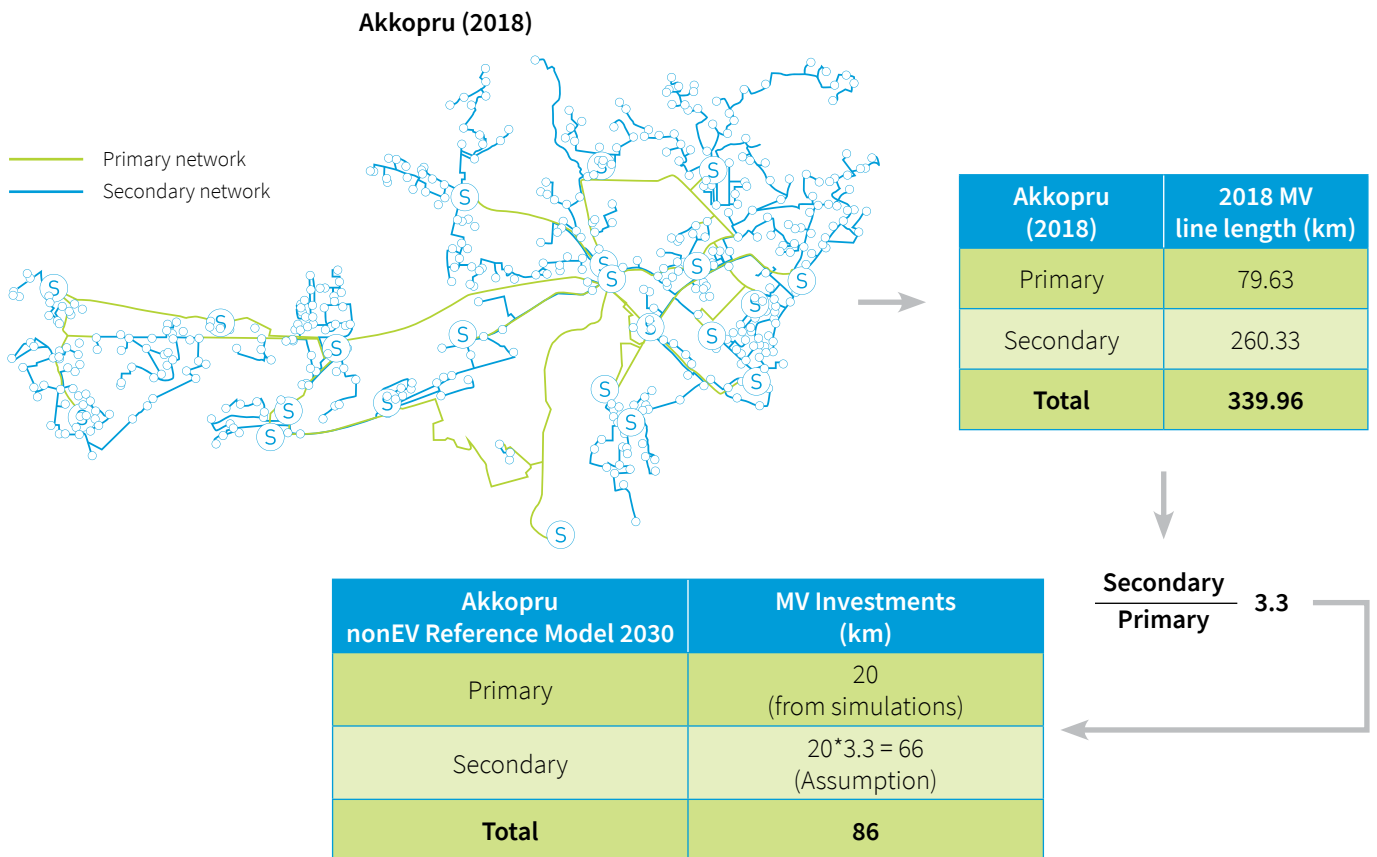
Calculation of vertical load growth is trivial where the existing load is multiplied by annual load increment factor (5% in this study). However, horizontal load growth is dependant on different factors, such as policies of municipalities, issuance of new residence permits, etc. Therefore, forecasting horizontal load growth is a difficult task which requires a master plan study. In this study, vertical load growth is considered and the amount of horizontal load is estimated. To do so, the concepts of primary and secondary networks are defined here to provide a better understanding of the proposed methodology. Primary network refers to the branches between the main substations. For instance, in Figure 44, the thick lines connecting TM to DC, and DC to DTC_1 are primary networks. The laterals feeding DTCs (for instance, the thin line connecting DTC_1 to DTC_2) are called secondary networks. Vertical load increase mostly affects the main branches in distribution network; however, secondary network remains almost unchanged for vertical load growth. On the other hand, horizontal load growth mostly influences both secondary networks. Therefore, the relationship between primary and secondary networks can somehow represent the relationship between vertical and horizontal load growth. For instance, consider that the total length of primary and secondary MV networks in a sample distribution system is “X” km and “Y” km, respectively. In addition, total investment originating from vertical load growth is “Z” km. Therefore, the representative amount of investment originating from horizontal load growth would be “ $Z \cdot (Y/X)$ ”. Finally, the total amount of required investments is “ $Z + Z \cdot (Y/X)$ ”. The flow chart of calculating total amount of required MV line investment is depicted in Figure 45.

Figure 45: Flowchart of calculating the total amount of required medium voltage line investment



Primary and secondary networks in the pilot region of Akköprü, Ankara, in 2018 are illustrated in Figure 46-. As can be seen from the figure, primary network refers to the branches between the main substations and the laterals. However, secondary network includes only laterals feeding the distribution transformers. The ratio of the total length of secondary MV branches to that of primary branches is 3.25 in 2018, as presented in . For example, the total amount of investment requirements for the target year 2030 is calculated as 20 km at the primary network of Akköprü pilot distribution region. This corresponds to 65 km secondary network branch investment under the current secondary / primary ratio as presented in Figure 46.

Figure 46: Primary and secondary networks in the pilot region of Akköprü



Annex 2: Locational distribution of the EV charging points in the pilot distribution regions

Locational distribution of the EV charging points in the pilot distribution regions are as follows:

Figure 47: Locational distribution of the electric vehicle charging points in the pilot distribution region of Akköprü, Ankara

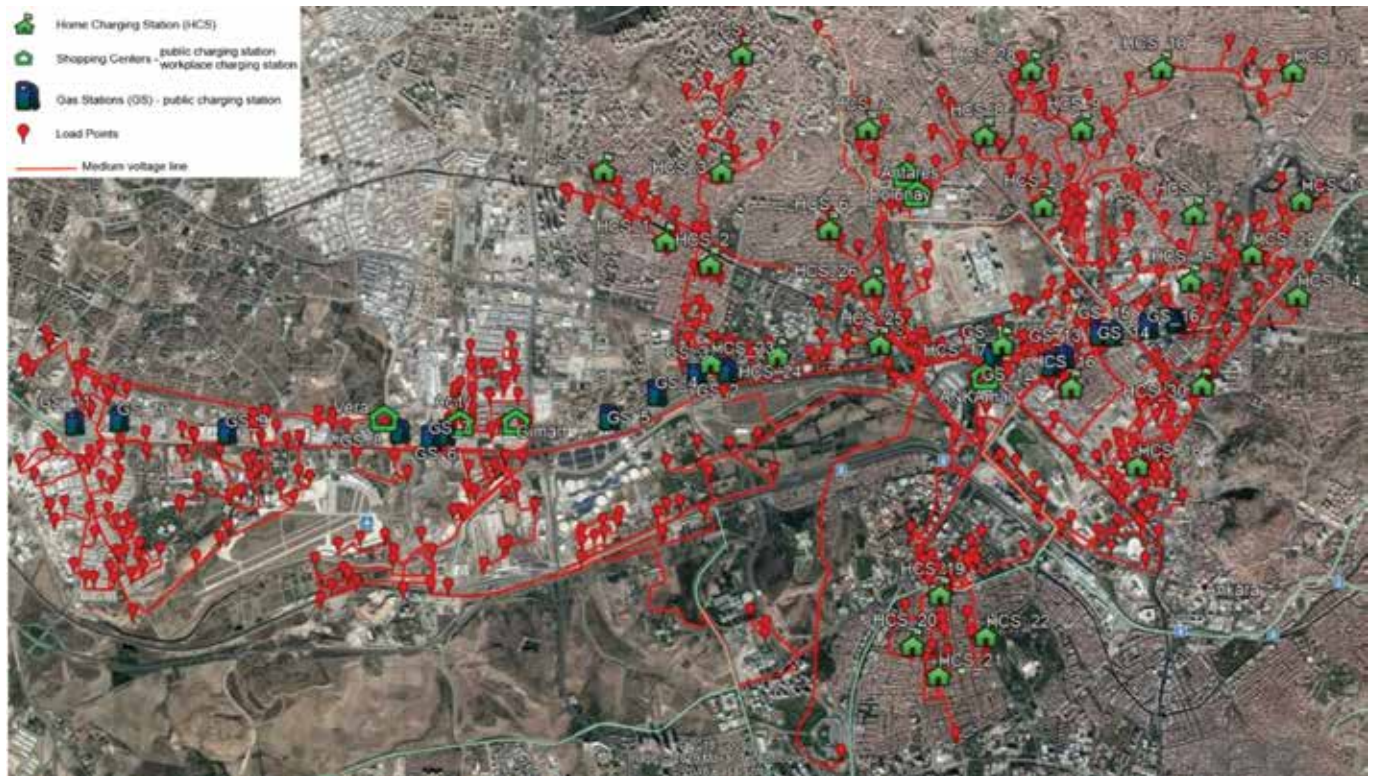


Figure 48: Locational distribution of the electric vehicle charging points in the pilot distribution region of Beypazarı, Ankara

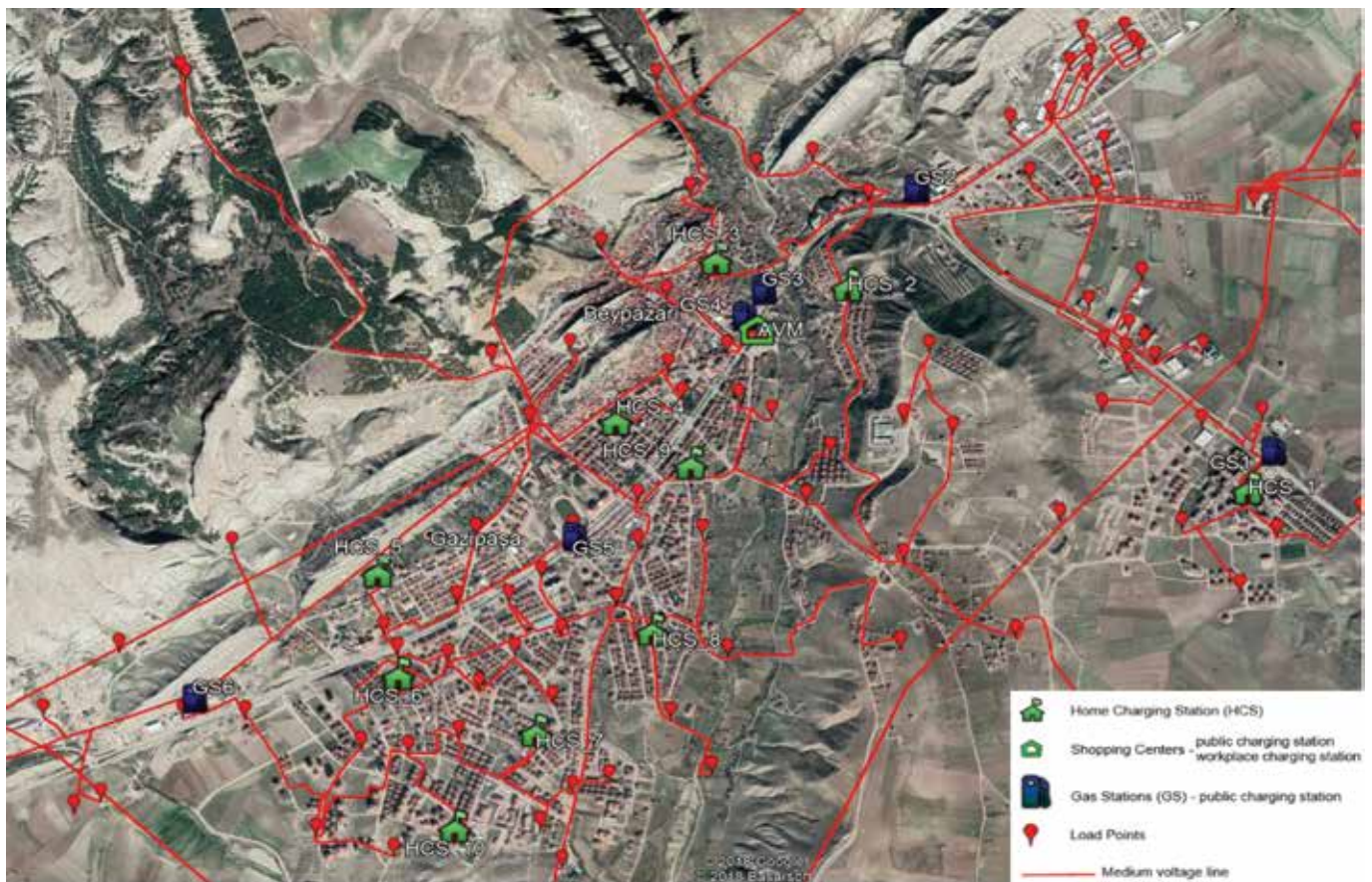


Figure 49: Locational distribution of the electric vehicle charging points in the pilot distribution region of Kartal, Istanbul

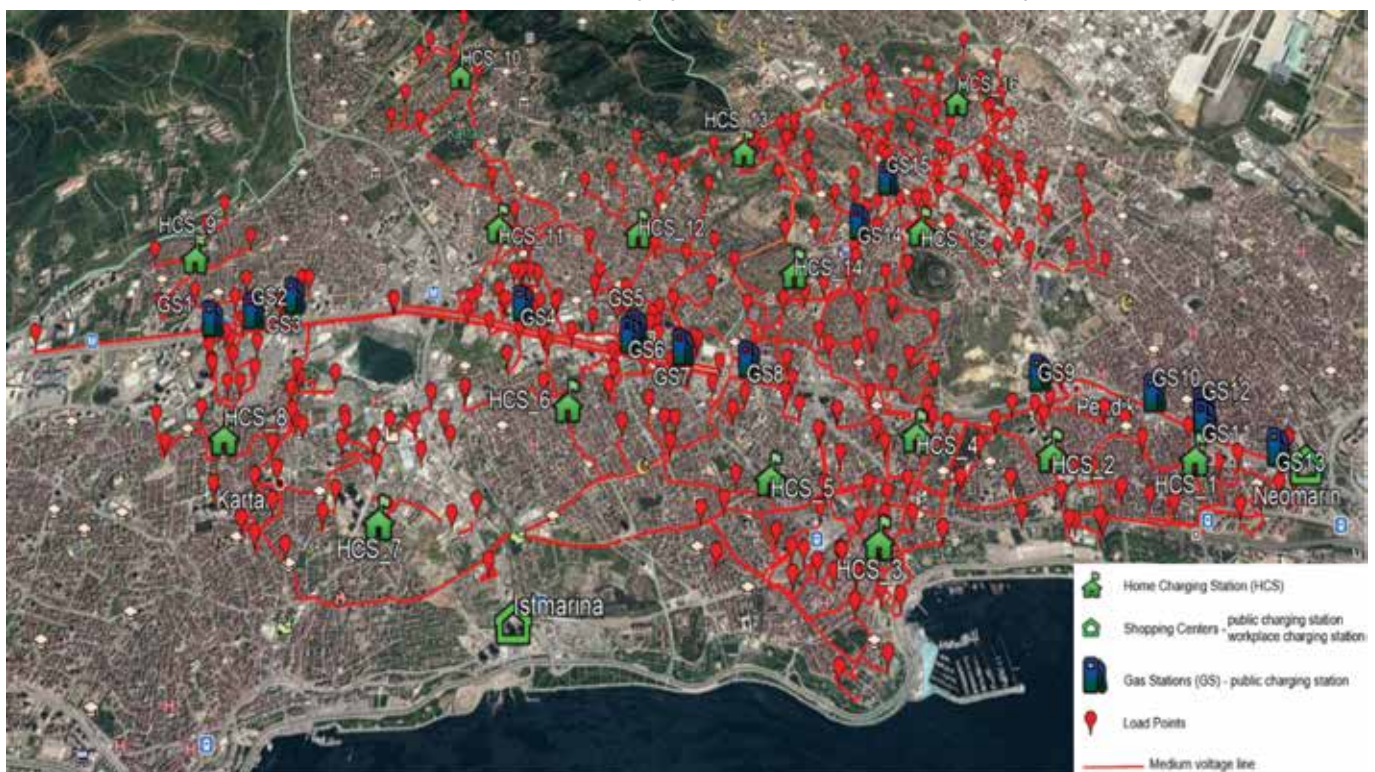


Figure 50: Locational distribution of the electric vehicle charging points in the pilot distribution region of Şile, Istanbul



Figure 51: Locational distribution of the electric vehicle charging points in the pilot distribution region of Karahan, Adana

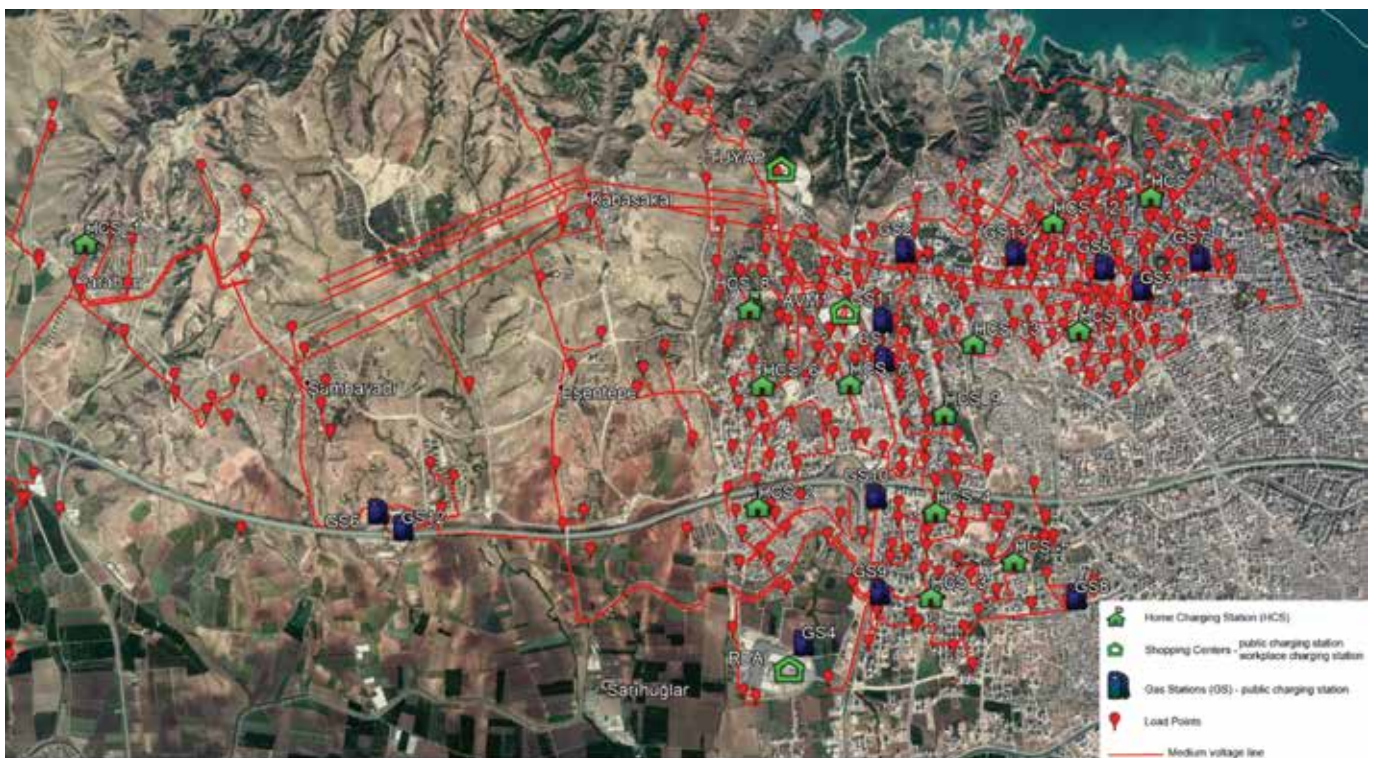


Figure 52: Locational distribution of the electric vehicle charging points in the pilot distribution region of Kadiri, Osmaniye

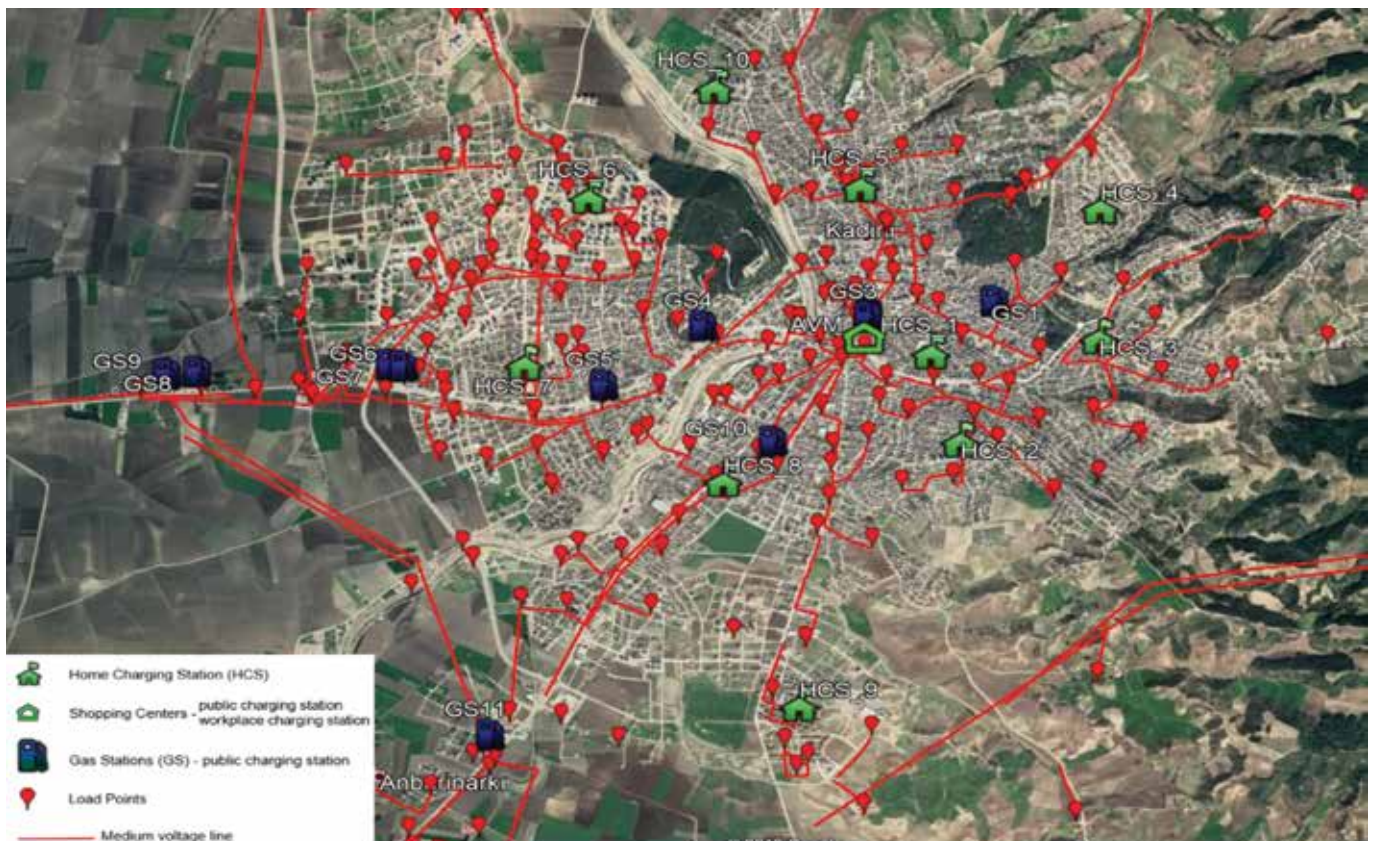


Figure 53: Locational distribution of the electric vehicle charging points in the pilot distribution region of Bornova, Izmir

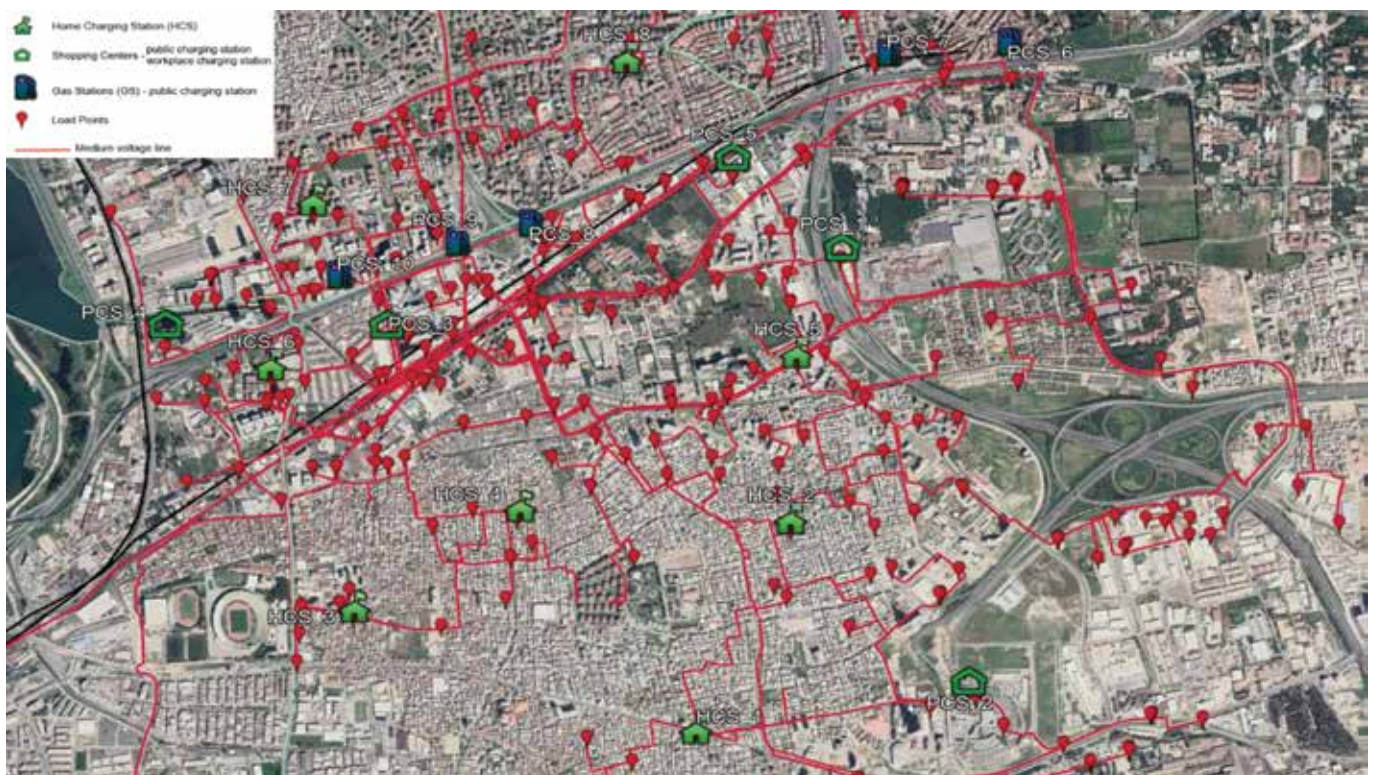
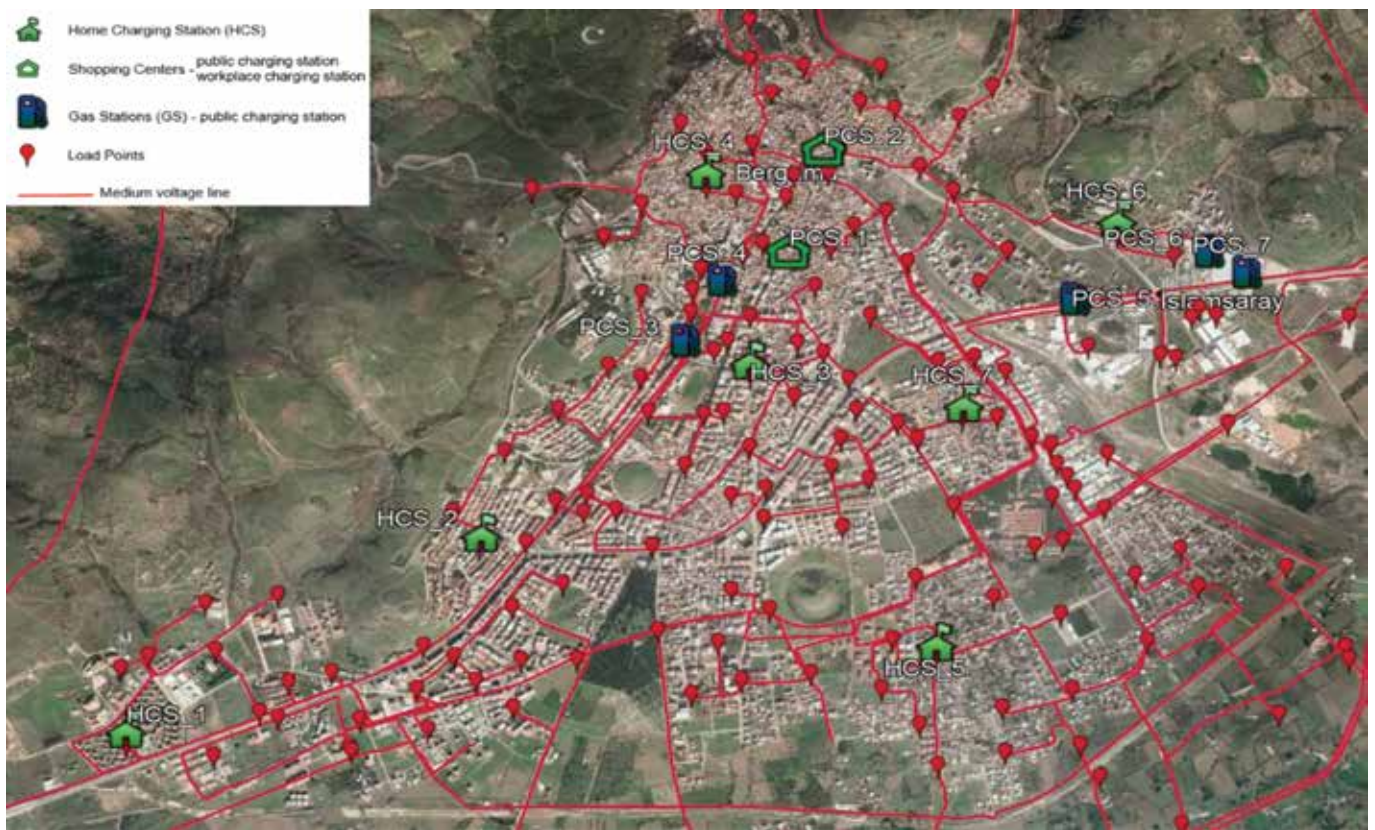


Figure 54: Locational distribution of the electric vehicle charging points in the pilot distribution region of Bergama, Izmir



Annex 3: Summary of the stakeholder consultation meeting

On August 8, 2019, a stakeholder consultation meeting was held at the premises of the Ministry of Energy and Natural Resources, where the draft results of the study were evaluated. Meeting notes are shared in Annex 3.

Questions and suggestions

- Are 2.5 and 1 million electric vehicles predicted in the “Rapid Development” and “Medium Development” scenarios, respectively, based on domestic production? Are electric vehicles included in the scenarios foreseeing an average annual 5% peak increase? Or, was it considered a general increase? Will electric vehicles be charged at home via special equipment or is it possible to use a regular cable?
- For safety reasons, it may be dangerous to connect the plug socket directly to the battery. Instead, there are more simple AC products in the form of household boxes.
- What is the battery capacity of the vehicles?
- In public areas, the “state-of-charge” probability distribution function is considered to be between 5% and 40%. Could the probability ratio be low considering our habits? Is there a probability of 80% for home charging support cases?
- The integration of renewable energy with charging stations in a distributed way reduces the negative impact on the grid by allowing electricity to be consumed at the generated site. In this way, the strategic use of renewable energy can provide an advantage.
- In addition, assessing impacts on the public and sociological implications while developing the simulations may provide an alternative perspective.
- Although the need for charging is not much in a regular day, it may require a planning for infrastructure, such as peak charging needs in some areas, especially for religious holidays.
- Incentives can be provided through dynamic pricing to set up infrastructure in areas where there is normally no need for recharging, but peak recharging is needed during holidays such as religious holidays. With smart charging technologies, power restrictions may be another method. As the new trends in fast charging are emerging in the world, there is a need for making more accurate calculations on this matter.
- Sensitivity analyses can be performed by taking the different consumption patterns of EVs into consideration. Especially, electricity consumption will increase in the summer months due to use of air conditioners. In general, the pricing practices in the World take into accounts CO2 emission effects.
- Joint implementation of renewable energy, energy storage and charging stations can be considered as an option to reduce grid integration problems. If a central control system for renewable energy integration is included, additional investments may not be necessary. Various investment mechanisms (e.g for highways and parking lots) may be devised. The study performed reveals that charging stations connected at the medium voltage (MV) level may be beneficial.
- It does not seem possible to reach the projected level of 1 million electrical vehicles by 2030. Similarly, 1 million charging stations by 2030 does not seem possible. While there are trends toward fast charging and EV battery capacities are approaching 50-50 KWh, careful analysis of consumer preferences is necessary. Emphasis should be placed on EVs feeding the grid.

- The projections for number of EVs seem high. Charging stations on public streets may be implemented with municipalities taking the lead.
- High projections of electrical vehicles are useful to better analyse the possible effects on the grid. It is important to take a 360-degree approach to the study. The approach should be based on consumer rights, tax issues and energy.
- The study should include a detailed analysis of battery storage and its effects on renewable energy. Battery storage costs are constantly declining. Neighbourhood and building level applications for battery storage should be taken into account. Smart charging systems and their effects should be assessed.
- EVs are part of the solution, not the problem. Investments in the distribution grid may be delayed due to financial problems faced by distribution companies. EVs may increase their benefits by providing auxiliary services to the grid.
- Heavy vehicles like buses and trucks will cause the maximum effect on the grid due to high load factors. They should be included in the analysis.
- Does the study include the picture on harmonization of the distribution grids? Has a problem on this issue been encountered?
- A rapid transformation is underway. Aside from renewable energy and energy storage, focus should be placed on manufacturing and domestic production.
- What was the assumption of the driving distance of EVs in the calculations? Was a possible increase in the distance in the future taken into account?
- Changes in life-style and preferences should be taken into account in the context of the transformation.
- Wider use of fast charging in the World and increases in the driving distance should be taken into account in the study. Grid feeding by EVs can help reduce costs and negative effects.
- This is an optimisation and all stakeholders should take responsibility. How to determine emission values and targets should be studied. It is unacceptable to reduce employment in order to achieve a zero-carbon target. A work plan focusing on increasing local content and preventing capital flight, assessing the effects of EVs, batteries for EVs and charging stations should be prepared.

Assessment of questions and suggestions and next steps

- Adopting EU tariff structure may bring opportunities for auxiliary services.
- Predictability, the sharing economy, standardisation of charging stations through regulation, assessment of EU building codes, increasing distributed generation, incentives for highways and parking lots, tariff structures, auxiliary services, energy efficiency, grid flexibility and management, infrastructure for smart charging systems, automation and telecommunication systems, emerging issues such as block chains should be taken into account.
- Questions and suggestions brought up by all stakeholders and alternative viewpoints will be considered before finalising the report.
- The report will be finalised and shared with all stakeholders by the end of October.

About Istanbul Policy Center at the Sabanci University

Istanbul Policy Center (IPC) is a global policy research institution that specializes in key social and political issues ranging from democratization to climate change, transatlantic relations to conflict resolution and mediation. IPC organizes and conducts its research under three main clusters: The Istanbul Policy Center–Sabancı University–Stiftung Mercator Initiative, Democratization and Institutional Reform, and Conflict Resolution and Mediation. Since 2001, IPC has provided decision makers, opinion leaders, and other major stakeholders with objective analyses and innovative policy recommendations.

About European Climate Foundation

The European Climate Foundation (ECF) was established as a major philanthropic initiative to help Europe foster the development of a low-carbon society and play an even stronger international leadership role to mitigate climate change. The ECF seeks to address the “how” of the low-carbon transition in a non-ideological manner. In collaboration with its partners, the ECF contributes to the debate by highlighting key path dependencies and the implications of different options in this transition.

About Agora Energiewende

Agora Energiewende develops evidence-based and politically viable strategies for ensuring the success of the clean energy transition in Germany, Europe and the rest of the world. As a think tank and policy laboratory, Agora aims to share knowledge with stakeholders in the worlds of politics, business and academia while enabling a productive exchange of ideas. As a non-profit foundation primarily financed through philanthropic donations, Agora is not beholden to narrow corporate or political interests, but rather to its commitment to confronting climate change.



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