Current State of Charge: Assessing Korea's 2023 EV Infrastructure

By

WOO, David

THESIS

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

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Committee in charge:

Professor Kim, Yeong Jae, Supervisor

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Abstract

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Korea's efforts to bolster its burgeoning electric vehicle (EV) industry have predominantly channeled resources into vehicle subsidies, somewhat overlooking the critical development of EV chargers. A thriving EV market requires not only the proliferation of EVs but also readily accessible charging infrastructure, not unlike how gas stations are needed for the operation of internal combustion engine vehicles. As the total number of EV owners grows, so do the genuine inconveniences and concerns related to the accessibility of EV chargers. While various research efforts have recognized this issue and proposed different potential solutions for the future, a significant gap remains in the analysis of chargers already in operation. This study focuses on South Korea's existing EV charging infrastructure, utilizing highly detailed data collected from January 1 to September 30, 2023, to discern various usage patterns and insights of these chargers. The findings of this research can serve as a well-informed foundation for policymakers, researchers, and engineers when contemplating policy and infrastructure decisions to establish a more robust EV charging network.

Keywords: electric vehicles; EV chargers; output; facility types; charging speed; congestion; Korea

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1.0 Introduction

Electric vehicles (EVs) have gained ever-growing importance in recent years for a variety of reasons, including technological advancement and the need for a 'cleaner' option in terms of greenhouse gas emissions. Korea is no exception to this change, and the country has seen significant growth in the EV arena within just the past few years alone – the government has played a significant role in their emergence domestically, and have recently announced that they plan to increase total electric vehicle numbers to 4.2 million by the year 2030, with at least 1.23 million EV chargers installed by that same timeframe (Ministry of Environment, 2023).

To understand what this goal means, as well as the potential issues involved, context through recent data must first be understood. For comparison purposes, 2022 closed out with total EV registrations reaching 389,855 and installed chargers at 191,515, while the most recent numbers as of the end of September 2023 revealed a registration count of 501,485 vehicles with 249,594 chargers installed (Ministry of Public Administration and Security, n.d.; Ministry of Land, Infrastructure, and Transport, n.d.). This change represented an increase of 28.6% and 30.3%, respectively, over the course of nine months. While this growth could be seen as impressive, it is still quite far away from the aforementioned goals that the Korean Government had announced; the current EV count only accounts for 1.94% of the country's total 25,845,648 vehicle fleet (Ministry of Land, Infrastructure, and Transport, n.d.). In addition to this, there has been numerous issues that have hampered the velocity of Korea's EV rollout efforts, including but not limited to the actual electric vehicle costs, the reduction of subsidies, the rapid rise in interest rates and cost of living, the rising costs of charging, and the key focus of this study, the availability and usage of EV chargers.

These problems, despite Korea's sub-2% penetration rate of EVs in their total automobile markets, has been represented through online EV communities and public media outlets both continually and consistently in recent times, with little signs of abating in at least the near future (Shin, 2023; OBS News, 2023; Noh, 2022; Jeonbuk Jungang, 2022; Park, 2022). Given Korea's goal of reaching 4.2 million EVs by 2030, a number that is 8.4 times larger what it is today, the potential for the EV charger availability problem worsening is well within the realm of expectations. As previously mentioned, EV adoption is a strategy currently being employed by many nations around the world to reduce greenhouse emissions and to respond to technological developments, and such an adoption effort hinges on the relative ease that one vehicle can be substituted for another (EEA, 2023; Hausfather, 2019). Putting aside the financial burdens of EV acquisition, EV charging can be a significant barrier to this adoption effort, and this is true in the Korean context, as well (Hodge, 2023; Lee, 2022).

A simple answer to addressing the charger availability concern is to simply install more chargers. Indeed, this is generally a valid strategy, which has already been explored in numerous studies to identify optimal locations for new charger placement using a variety of different techniques (Lam, Leung, & Chu, 2014; Kim & Koo, 2020). However, one of the criticisms that could be made against these studies is that their efforts were focused on a particular geographical area, and without notable consideration for the true usage patterns of already-installed chargers in their analysis. Furthermore, the widespread expansion of electric vehicle (EV) charging infrastructure in South Korea encounters notable challenges across multiple fronts. From an engineering standpoint, it necessitates extensive construction and charger installation, upgrades to the grid infrastructure, and effective management of charging loads (Bryden, Hilton, Cruden, & Holton, 2018). On a financial level, there are substantial upfront expenses linked to charger deployment, ongoing maintenance, and necessary upgrades. These costs underscore the importance of government subsidies to stimulate the adoption of this evolving technology (Kim Y. , 2023). Additionally, political considerations come into play, encompassing issues related to land use, zoning regulations, and the imperative development of policies that both encourage EV adoption and guarantee equitable access to the charging network (Kim Y. , 2023). Lastly, as of 2022, Korea had more chargers installed than any other nation in the world except for China (IEA, 2023), with the highest ratio of charging capacity per electric vehicle at 7 kW/EV (IEA, 2023). This last point suggests that there may be other and more meaningful options than just focused infrastructure expansion.

To explore these potential options and enhance the effectiveness of policies related to EV charging infrastructure in South Korea, it is imperative to first gain insights into the utilization of the already-installed infrastructure. This research aims to narrow the knowledge gap existing in the domain of South Korea's EV infrastructure landscape by offering a detailed analysis of EV charger status and utilization in 2023. The analysis is based on a comprehensive dataset collected between January and September 2023. The patterns identified in this study can serve as valuable guidance for policymakers, engineers, and relevant stakeholders in their endeavors to optimize the use of EV chargers, not only through expansion efforts but also by enhancing the management of existing chargers nationwide.

1.1 Background Information – Electric Charging vs. Gas Fueling

To grasp the apprehension surrounding charger availability and utilization, it's essential to first identify the contrasts between electric vehicles (EVs) and their internal combustion engine vehicle (ICEV) counterparts. While refueling an ICEV is typically a brief affair, taking only just a few minutes irrespective of the car's size or fuel tank capacity, the story is notably different for EVs. Unlike the quick transfer of fuel in ICEVs, EVs rely on batteries that accumulate energy at a relatively slower pace via an 'electric charge', measured in kilowatts (kW). Depending on numerous conditions, an EV might need anywhere from an hour to a full day to charge from empty to full.

Several nuances affect this charging time: there's the 'charging curve', which indicates that as an EV's battery nears its full capacity, the pace of energy absorption diminishes. Additionally, the rate of charging can vary depending on the charger's capacity, the ambient temperature affecting both the charger and battery, the specific design and tech specifications of the receiving vehicle, and other factors.

Despite any knowledge one might have about these intricacies, a fundamental reality stands: recharging an EV is markedly longer than refueling an ICEV. The conventional gas station model, where a few pumps cater to a high volume of cars, isn't directly transferable to the EV realm. It's not feasible for someone to wait for an EV charger to free up, given the unpredictable and prolonged durations required for charging. Moreover, unlike the centralized nature of gas stations, EV chargers are scattered across various businesses, zones, and regions, making the accessibility landscape vastly different. One may be able to charge their car in the comfort of their own apartment residence, but that charger may be used for

12 or more hours in a given day, with no other chargers available, as an example. Thus, charger placements, types, and utilization rate become a critical concern with respect to the maturation of any country's EV market – including that of Korea.

1.2 Special Note – Plug-in Hybrid Vehicles

A number of different vehicle types exist in Korea, including electric vehicles that are powered by energy stored in a battery, in addition to gasoline, liquified petroleum gas (LPG), diesel, and hydrogen. Of particular note are hybrid vehicles, which utilize a combination of electricity stored in a smaller battery compared to EVs, and generally, gasoline as their energy sources. Hybrid vehicles are also available in two types: plug-in and traditional (non-plug-in).

Within the context of EV charger utilization, only EVs and plug-in hybrid vehicles (PHEVs) are considered, as no other vehicles are able to access, store, and utilize external sources of electricity. EVs are generally able to access all types of chargers, including slow, fast, and ultrafast chargers, whereas PHEVs are limited to only slow chargers. This is due to the connector types that are available in these types of vehicles – the DC Combo connector present in EVs allow for the use of both fast+ (DC Combo) and slow (AC) connectors, because of their design. PHEVs are only equipped to accept AC connectors, which limits them to slow chargers only. In other words, PHEVs can compete with EVs for slow chargers, but not for fast chargers. PHEVs also have the option of specifically focusing on gasoline as their fuel type, as the battery can still be charged using the internal combustion engine and/or through regenerative braking. The current data is unable to make a distinction between PHEVs and traditional hybrid vehicles, nor can charging sessions from slow chargers be discernable between these two vehicle types. Furthermore, there is no available data on consumer behavior regarding PHEV owners' preferences to fueling vs. charging.

This disclaimer is pre-emptively provided to acknowledge the limitations and complexities that exist with regards to fully understanding the available charger data.

1.3 Definitions and Terms

Commonly used terms are defined as follows, and will be used in this paper:

- Slow Charger: Any charger with an output capacity of less than 50 kW (often 3.5kW – 11kW)
- Fast Charger: Any charger with an output capacity of 50 kW or higher.
- Ultrafast Charger: Any charger with an output capacity of 300 kW or higher.

  *** Definitions of Slow, Fast, and Ultrafast Chargers are based on the generally accepted standards in the charging industry in Korea* (Korea Environment Corporation, 2023).
- Charger Congestion: Defining a state of charger being actively used, thus preventing a different vehicle from charging at that point in time. Also sometimes referred to as *charger utilization*.
- Charger: Refers to a charging point. Most chargers can only serve one vehicle, but some can serve two vehicles at once.
- Electric Vehicles (EVs): Vehicles that are purely operated via energy stored in a battery. EVs, in the context of this paper, do not include fuel cell/hydrogen vehicles, nor do they consider hybrid vehicles.

1.4 Research Questions

This study aims to answer one broad question: "How is the existing EV infrastructure being utilized?" The general quality of this question leaves it open to a great deal of interpretation, to which this analysis focuses on the following areas: [1] Where are these chargers located? [2] What speeds are these chargers? [3] When are they being used? [4] Which areas have the highest usages? The attributes needed to answer these questions are combined in various manners for a more detailed level of analysis.

2.0 Literature Review

Due to the recency and timeliness of the data being analyzed, in combination with the emerging stage of EVs within the context of South Korea, there is a distinct limit to the potential data that could be acquired through purely academic sources. For example, at the time of this paper being written, very few studies could be identified that provided an analysis of Korea's charger situation nationwide based on the usage of direct and detailed charger data.

To address these limitations, subject-adjacent topic matters were identified and reviewed, such as the optimal expansion and installation of EV chargers, electricity demand load-balancing efforts, and models to predict future usage patterns – concepts found in these literatures were translated into potential variables to measure in this research. Further included in the review are a number of Korean Government reports and announcements regarding EV chargers, as well as tertiary sources such as news publications.

2.1 Factors for Demand and Usage Modeling

Academic researchers have acknowledged that the current EV infrastructure situation is insufficient relative to the EV plans of the future. Expectedly, and with good reason, other researchers have attempted to create models to predict future usage by employing a variety of different techniques – including ARIMA and its variations (ARIMAX, SARIMA, etc.), TBATS, LSTM, artificial neural networks (ANN), DIETER, and more (Choi, Sohn, & Kim, 2018; Choi & Moon, 2023; Kim & Kim, 2021). In all of these cases, the models were driven heavily by assumptions, without consideration of real-world data. Of particular note is from Kim & Kim (2021), where they explicitly stated that "due to the lack of real-world data… some simulation studies substitute current road traffic data." Their specific study utilized a small subset of real-world data provided by the Ministry of Environment, limited to 1916 chargers at the national level – their specific research verified the importance of the analysis of true data, based on their own modeling efforts as well as their comparison with past research (Kim & Kim, 2021).

The previous work conducted has shown that some of the key variables used in modeling including the total charging amount in kilowatt (kW) on various time intervals, aggregation on station, city, provincial, and country levels, and the isolation of when charging activities have taken place (Choi, Sohn, & Kim, 2018; Choi & Moon, 2023; Kim & Kim, 2021). Also of particular note is the model proposed by Choi & Moon (2023), where demand is focused towards the daytime hours due to the purposes of their model – the coupling of the renewable energy sector. In other words, their model proposed a peak approximately around noon and troughs in the late night and early hours of the morning in a given day.

2.2 Factors for Identifying Charging Decisions

Another potential approach for addressing potential concerns of EV charger usage is to identify what causes people to choose one given charger over the other. Some of the obvious choices include proximity and charging speed – both are factors that directly affect time and convenience. Scholars have approached this consideration from the context of different nations, which can offer a multifaceted view to decide which factors might be important within the Korean context.

Chargers, once installed, have a number of inherent characteristics – output speed, physical (geographical) location, and facility or business location, to name a few. Aspen Underwood (2021, 2022) wrote two papers that had a particular focus on these factors to the effect of speed, location, and business types had an effect on the usage of chargers – to which it does, in certain contexts. Additional factors were considered which are not part of the available dataset in this study, including charging prices, which may be an interesting factor to consider for future research. Underwood's research looked at chargers within Kansas and Missouri, in the United States. Two key qualitative advantages that Underwood's dataset in both her 2021 and 2022 are that hers has total Kilowatt charged information and can identify individual drivers.

2.3 Factors for Determining Charger Installation

An attempt at finding additional variables and methods for analysis was sought through research that identified optimal charging locations – a common theme found with literature designed to address an expanding EV market. However, the most commonly used data involved traffic vs. population by region (density) to try and predict where vehicles may be, based on assumed ownership by average population. There were little research attempting to extrapolate optimal placements based on already existing infrastructure, particularly that of a timely nature. Thus, the key takeaway from the literature from this section is that analysis must be first completed on already-existing infrastructure, given that these populations are now already being served by the almost 250,000 chargers now active in Korea.

2.4 Other Considerations – Battery Capacity and Charging Curve

Though not explicitly indicated or calculated in the analyses, understanding the current status of EVs and the effect the various charging devices have on these vehicles is critical to understanding the larger EV and charging infrastructure context.

According to Statistia (2023), the bestselling EVs in Korea for 2022 included the Ioniq 5, EV6, Porter 2, Bongo 3, Niro EV, Model 3, Model Y, and GV6, in that order. Taking into consideration newer models that have been released in 2023, including the Ioniq 6, EV9, and the Torres EVX, the general battery capacity for these vehicles falls between 55 kW to 100 kW, with most long-range models averaging about 75 kW (Korea Environment Corportation, 2023). Most battery types, including those used in EVs, but also everyday devices like tablets and mobile phones, are only able to receive a certain amount of charge at any given time, based on a number of factors, including the temperature of what is being charged, and how charge is already retained relative to the maximum capacity of the charger – this concept is known as a charging curve.

In Korea, 'super' fast chargers exist, rated at 300 kWh and higher (Korea Environment Corporation, 2023). A simple math calculation might show that a 75-kW long range EV model could be charged in 15 minutes from 0 to 100%, but this assumption would only be true in the case that the full speed of the charger could be maintained from start to end (Whaling, 2022). Batteries are only able to receive charges at such high speeds of the vehicle itself is designed to do so, and only under certain conditions, such as the current battery charge being in between the 20% to 80% range rather than the extreme ends of empty or full, and if the temperature is 'normal' enough to do so (Whaling, 2022). If these conditions are not well-met, then even these fast chargers will output energy at a much lower rate, such as 10 kWh or even less, despite what their designed speed might indicate. This is especially true as a vehicle approaches full charge, and this same concept is also applicable to the aforementioned mobile devices like phones and tablets as well (Whaling, 2022).

In the case of slow chargers, there is significantly less 'stress' in the form of heat generation and resistance from the charge-receiving vehicle, so the full or near-full charging ability of these chargers are usually maintained regardless of the battery's current charge state. Considering a realistic case of a 75-kW long range EV using a 7-kW charger, it would take approximately 11 hours to charge it from 0% to full. Changes to charge times are still susceptible to excessive heat, such as when charging in direct sunlight on a clear sunny day in the summertime, when the output is reduced to avoid potential dangers and risks to the battery and car.

The charging session data include these characteristics, though they are entangled among other known and unknown (latent) factors at the time of each charging session taking place.

2.5 Identification of Research and Policy Gap

Review of previous work has revealed that there exists a notable gap in contemporary research focused on the Korean EV charger landscape. While numerous studies have delved into various aspects of EV charger matters, such as predicting future demands or identifying optimal charger placements, the key foundational data of these analyses stems from variables like traffic, population density, and geography. However, very few of these studies employed authentic, historical data relevant to their research timelines. Such an oversight runs the risk on assumptions, potentially limiting the practical application and accuracy of their findings and models.

The focus of this research lies in its commitment to address this gap by analyzing and interpreting real-world EV charger usage patterns within the context of 2023. By examining these patterns, the objective is to assess the trajectory and effectiveness of Korea's ongoing EV infrastructure enhancement initiatives. This study will also illuminate areas ripe for strategic management or intervention, bolstering the momentum of EV adoption and guide future policies. Furthermore, offering a tangible evidence base on charger usage patterns will offer a data-hardened foundation for future research endeavors and model creations alike. Ultimately, this initiative hopes to bridge the existing research and policy lacuna and chart a more informed path forward for Korea's EV ecosystem.

3.0 Data

In this analysis, high-frequency charger data collected from the Korea Environment Corporation (K-ECO) via Korea's Public Data Portal, as well as the car registration information from the Ministry of Land, Infrastructure, and Transportation, were utilized. The charger data spans from January 1, 2023 through to September 30, 2023, and includes approximately 91,000 files at a raw stored volume of 7.3 terabytes. This was consolidated into two files with a total raw volume of approximately 25.6 gigabytes. These consolidated files were then used as the point of basis for all subsequent analyses conducted. The car registration data is vastly simpler by comparison, based on just 9 files totaling to approximately 3.5 megabytes. The simplicity of the car registration data removes the need for in-depth explanation – vehicle numbers are reported once a month at the end of the month, and required no special consideration or processes prior to its inclusion in this analysis.

All data collection, cleaning and processing, analysis, and visualization tasks were completed using Python (programming language) and publicly available packages.

3.1 EV Charger Data

The Korea Environment Corporation provides real-time electric vehicle charger data across Korea through Korea's Public Data Portal website. This provided data is wholly considered *transient*, in that it is only true and available at the time of querying and is not saved by K-ECO or the Public Data Portal service (personal communication, July 13, 2023). Despite the data's *transient* nature, some information can be considered *static* as it will remain unchanged over time, such as its geographical coordinates and station numbers.

However, when comparing whole rows of information, each subsequent query may yield different (transient) information for the same charger (static), as should be the case since chargers are intended to be utilized (used for charging). Thus, if the data is not saved at the time of querying, it is considered permanently lost. Excluding the dataset compiled for this research, a separate publicly available repository of this information, or datasets similar in nature for research and analysis purposes, was not.

3.1.1 Data Acquisition Process

The data source also implements a practice called ‘pagination’, where there is a fixed limit to the amount of data (rows) that can be retrieved with each API call. This means that all of Korea cannot be queried at once, and that multiple queries must be conducted in series to be able to poll and retrieve the charger information across the country. With this pagination trait and the described data transience in mind, a perpetual routine script was written where API calls would be continually conducted until a full set of nationwide charger data was collected, saved to a unique filename, and then repeated ad infinitum. Each API call required several seconds to complete, and a full set of charger data across Korea necessitated approximately 5 to 8 minutes to create 80-100 megabytes of raw data. Korea continues to install more chargers over time, increasing the total number of API calls needed to retrieve all available data, which then leads to a natural increase in the time required to create one full set of charger data across Korea.

In general, concurrent (parallel) calls were not conducted due to technical limitations on the client side as well as API call quotas set on the server side. Concurrent calls were only employed intermittently when a full set of data required a period of time longer than 10 minutes due to server-side delays, in which case one data collection script would run staggered to the second script, and potentially a third script if needed. The total number of scripts operated concurrently depended solely on the amount of time one set of data required to create. The goal in doing so was to maintain a relatively steady stream of data querying and storage to create a consistent and comprehensive dataset over time, despite any potential delays that were encountered.

3.1.2 Variables of Interest & Raw Data Dictionary

The raw data contained the following information, with the variables of interest for this paper indicated as follows:

Variable Name	Explanation	Required	Interest
statNm	Station Name	O	O
statId	Station ID	O	O
chgerId	Charger ID	O	O
chgerType	Charger Type	O	O
addr	Address	O	X
location	Specific Charger Location	X	X
lat	Latitude	O	O
lng	Longitude	O	O
useTime	Hours of Accessibility	O	X
busiId	Business Code	O	O
bnm	Business Name	O	X
busiNm	Operating Business Name	O	X
busiCall	Operating Business Contact Number	O	X
stat	Charger Status	O	X
statUpdDt	Status Last Updated	X	X
lastTsdt	Last Session Start Timestamp	X	O
lastTedt	Last Session End Timestamp	X	O
nowTsdt	Current Session Start Timestamp	X	X
powerType	*Unused*	X	X
output	Maximum Power Output in Kilowatts (kW)	X	O
method	Charger Point Type	X	X
zcode	Province/Metropolitan City Code	O	O
zscode	City/County Code	X	O
kind	Facility Type	X	O
kindDetail	Detailed Facility Type	X	O
parkingFree	Free Parking Indicator	X	X
note	Additional Information	X	X
limitYn	Limited Access Indicator	O	O

The variables of interests are consolidated and aggregated in different manners depending on the scope that is being considered (ex. National, Provincial/Metropolitan, Regional), however, any and all data processing and refinements originates from the same raw dataset collected and consolidated.

3.2 Consolidation

The described method of querying storing the data naturally results in significant amounts of duplicate data. For example, if a given charger is used once on February 1, 2023 and left alone until it is used again on February 20, 2023, every single querying of that charger will show the same session start and end time, among other variables. Assuming an average of 7-minute intervals for each nationwide data file being created, this situation represents a potential 4115 count (20 days * 24 hours * 60 minutes / 7, rounded up) of duplicate data, as the charger will report the last used session start and end timestamp each time it is queried.

Dataset consolidation takes two forms: [1] charger focused, and [2] session focused. As the names might suggest, these two consolidation efforts focus on different variables – one which looks at the charging devices themselves, and one which looks at the charging session information. Referring to the raw data table, the session information is considered optional, which means there will be chargers that have this data missing (and thereby dropped in the dataset). However, the actual device information, such as the station name and geographical location, is considered mandatory, thus offering a different facet to analyze compared to the former. These two consolidated datasets are complementary to one another and form a comprehensive foundation where further aggregation and descriptive analysis can be conducted.

3.2.1 Charger-Focused Consolidation

The vast amount of data that is generated is consolidated into a daily level of observation. This is considered consolidation and not aggregation, as information is simply truncated to yield the necessary final dataset. Before this truncation occurs, a new variable is created to indicate the date in which the data was queried. Based on this date, as well as the columns of station ID, charger ID, business ID, charger type, output, geographic information, and other variables that are considered *static*, a daily 'snapshot' containing the technical and geographical information of the chargers can be acquired. This dataset will contain a unique combination of query date, station ID, and charger ID, while other information may be duplicated.

The daily level is selected as it offers a consistent way to show change over time, and to take into consideration that charger installations and their registration into the national database happens at various points throughout the day. Information more detailed than the daily level, while possible, is not considered meaningful within the scope of this paper.

3.2.2 Session-Focused Consolidation

Unlike the charger-focused dataset, the session-focused variety is characterized by a high level of temporal granularity, with the session-related variables measured down to the second level. The lastTedt and lastTsdt are timestamps for when the last session started and ended, and the initial consolidation step only retains rows where both of these variables are present, regardless of their value. The importance of lastTedt and lastTsdt is that their difference becomes the duration of the charging session in seconds, which is calculated as a part of this consolidation step. Consequently, the session-focused dataset permits the ability to acquire a fine-grained temporal perspective while retaining the flexibility to aggregate (or bin) the data into broader intervals, such as hours or days. Other data features that are static to a given charging station, such as its business type, output, and geographic location, are retained as well.

3.3 Aggregation

Aggregation of the data takes multiple forms, and is based on the consolidated dataset indicated in the previous section. For example, the two datasets can be aggregated by charger speeds (output in kilowatt hours), by geographic assignments (major regions such as provinces, or smaller regions such as cities), and/or to a daily, weekly, or monthly level, to name a few examples. Aggregation was also employed as a strategy to address the computational cost of analyzing this sizeable dataset. The specific method utilized will be explained with the respective data that is presented, where appropriate.

3.4 Data Quality Considerations

The data acquired is considered the highest quality possible that could be obtained regarding charger utilization across Korea, given that it polls all registered chargers across Korea and that information is reported in real-time to the querying system. There exists a number of issues with the data that must be acknowledged, and will be explained on a point-by-point basis below:

1. Null Values in the Variables of Interest

   The columns for [session start time], [session end time], and [output wattage] are missing in some observations. This is due to a number of different reasons, most commonly because the charging device simply doesn't have the technical ability to record and transmit this data, and another reason being that the operating company has not registered this information. Consider a situation where one simply uses a cable to charge their car, connecting it from a wall socket to their vehicle – such a device may not have the ability to connect to the internet, or even measure the details of a given charging session. However, the current dataset includes a great number of valid (information existing) observations disbursed nationwide, even when excluding these null values – thus, while the information being analyzed is not perfect, it can still be considered representative of the true status in Korea.

2. Unregistered Charging Sessions and 'Stations'

   In line with the example provided above, it is very possible to charge an EV without using a dedicated outlet intended for vehicle charging. While this is possible, it can be considered rare in Korea as the current legal context classifies such an action as theft, and the relatively few numbers of sockets available that would be suitable to EV charging (proximity, cost, etc.). Even in the case where an individual may reside in a single detached home instead of a high-density residence, it is often preferred to have a dedicated charging station installed due to preferential electricity rates for EVs. With these considerations in mind, the unregistered charging sessions and stations are considered a non-issue.

3. API Calling Process

   As described in the Data Acquisition Process, multiple API calls are conducted in sequence to one another to create a single file containing the information of all polled charging stations in Korea. This process takes several (5-7) minutes, thus if multiple activities took place between two adjacent API calls, only the most recent activity of those conducted be retrieved at the time of the next call – all other activities would not be recorded and subsequently lost. This is not considered a major issue, given that the analysis revealed that an average session greatly exceeded the amount of time needed between API calls to a given station, and that the generally idle nature of most chargers nationwide means that there is no real change in status to be reported between those minutes, anyways. Some data is expected to be lost due to the polling time gap, but this is considered to be inconsequential when considering the breadth of data that was actively captured.

4. System Outages and Connection Issues

Over the course of 9 months, there have been a number of system outages on the side of the Open Data Portal, as well as errors in calling the API. These issues result in data gaps (loss) and a reduction in the observed chronological granularity of the data, respectively. For the issue of system outages, these have lasted approximately 12-24 hours, and have only occurred a total of approximately 7 days in total across that entire timeframe. This gap was left missing as-is. In the case of connection issues, concurrent API calls were conducted within the limit of the monthly API quota permitted by the server, timed to be staggered with the main script. Any API calls that resulted in an error triggered the code to repeat that exact same call, which usually resulted in success. This meant that a full set of data could take longer than the aforementioned 5-7 minute average. With the concurrent calling strategy, even if that set of data took 10 or 15 minutes in total due to connection errors, two files could be produced within that timeframe with chargers polled at points in time long enough to provide similar coverage to what would have been possible in a business-as-usual (no error, stable) scenario.

To exclude user error for this particular point, various EV charger information companies were contacted to see if they experienced the same issue – which they confirmed, and direct observation was conducted at charging stations in Sejong to see if the true active occupancy (usage) or availability of chargers aligned with the information reported in these companies' applications, which they did not.

5. Absolute Charger Count Fluctuations

   Between January and September, the total charger count ranged from approximately 190,000 to 250,000. However, these numbers were sometimes not uniformly presented within each nationwide set of chargers that were queried – for example, a number may fluctuate from 249,594 to 249,582, then back to 249,594, then averaging upwards to 249,601, and so forth. This is attributed to a combination of observed errors from the Open Data Portal servers (confirmed by their own API Call test page via the 'total records' count at the time of querying), natural differences in charger operations (some may break and/or become disconnected, thus being removed from the total pool of chargers), technical testing of chargers, new chargers that are brought online and permanently added to the total pool, and so forth. These variances were simply observed and noted, but no action was taken to address them as it was deemed both unnecessary and exceptionally difficult to rectify.

Despite these aforementioned issues, this dataset was still assessed to be representative of Korea's utilization of EVs due to the majority percentage of observations that had the relevant data available, as well as the approximately even distribution of missing and available charger locations when plotted on a map and observed geographically. Analysis has also revealed that usage patterns in a given area generally stayed consistent over time, suggesting that in areas where some charger information is missing, the people located in those areas generally use the same chargers they have always been using, making these patterns observable when aggregated to a sufficiently broad level (in time, geographic location, business types, etc., or a combination thereof).

3.5 Initial Session-focused Data Cleansing

Due to the nature of the charger-focused dataset, it was left as-is after the consolidation work was conducted. The session-focused dataset dropped all observations where at least one of the following was true:

1. There is no data available for the session start or end session variable, thus session time cannot be calculated
2. The start or end session time indicated a year value earlier than 2023, to focus on chargers that were used within the 2023 year within the timeframe of the data collected
3. Session times were less than 30 seconds, as even the most powerful chargers, which are very few in number as-is, need time to 'ramp up' to a high level of charging for vehicles that can accept it. This also indicates that all other vehicles cannot be meaningfully charged in such a timeframe, thus this exclusion criteria removes incidences of charger errors, sudden change of driver plans that would not be considered contributive to understanding the total charger behavior, and other unexpected scenarios that may take place within the first few moments of initiating a charging session.
4. Session times were more than 1 week. A very small number of sessions (approx. 2000 out of 26 million) were identified that qualified for this criterion, and upon manual inspection, many of them were due to apparent data-reporting error (ex. session starts in January, ends in August). Such cases might actually be within the actual realm of possibilities, as it is possible to leave a vehicle idle for weeks or months at a time. However, these sessions were removed as they could have significant skewing effects towards higher-than-actual utilization rates,

Once the dataset was sufficiently truncated, analysis was conducted.

3.6 Methods of Analysis and Calculation

Many of the calculations employed were not based on specific references of past work, but rather, by simple definition of what is being measured and through the compounding of simple arithmetic works.

For example, for one charger that can provide power for one vehicle at any given time, the maximum potential charging time in one day, in seconds, is calculated as follows:

24 hours / day x 60 minutes / hour x 60 seconds / hour = 86,400 seconds/day

From there, the total usage time in a given day can be calculated and summed together given the available information, divided by 86400 to find a percentage value of utilization for a given day by charger. Complexity increases when aggregating to a charging station (different from charging device) or larger geographic level, and/or different times – but the rationale for the calculations employed remains distinctly sound and rational.

In cases where the analysis process goes beyond what could be described as 'simple', details of the process taken will be indicated in their respective analysis results found in Sections 4.0 and 5.0. Inspirations on which variables to measure and to what level to aggregate originated, in part, from the literature review conducted.

4.0 General Analysis and Findings

Given the large amounts of data, some findings were produced using ‘snapshots’ of the data, such as in the case of maps or when it was appropriate to report in set periods or intervals.

4.1 Missing Data Check

As mentioned in Section 3.1.5., missing session data was a weakness in this dataset. The number of observations that were not fully complete (with session data) were not insignificant. However, the large number of valid observations that were captured (~30 million) over the 9-month time period, as well as manual inspection of the physical placements of chargers on a map to see where chargers with and without session data were located showed that they did not concentrate in just a handful of areas, but were rather distributed across the nation. Furthermore, the share of missing session chargers decreased significantly over time, and despite this total increase in available data, the trends and patterns that were analyzed were kept intact. This is revealed in the following sections of this paper.

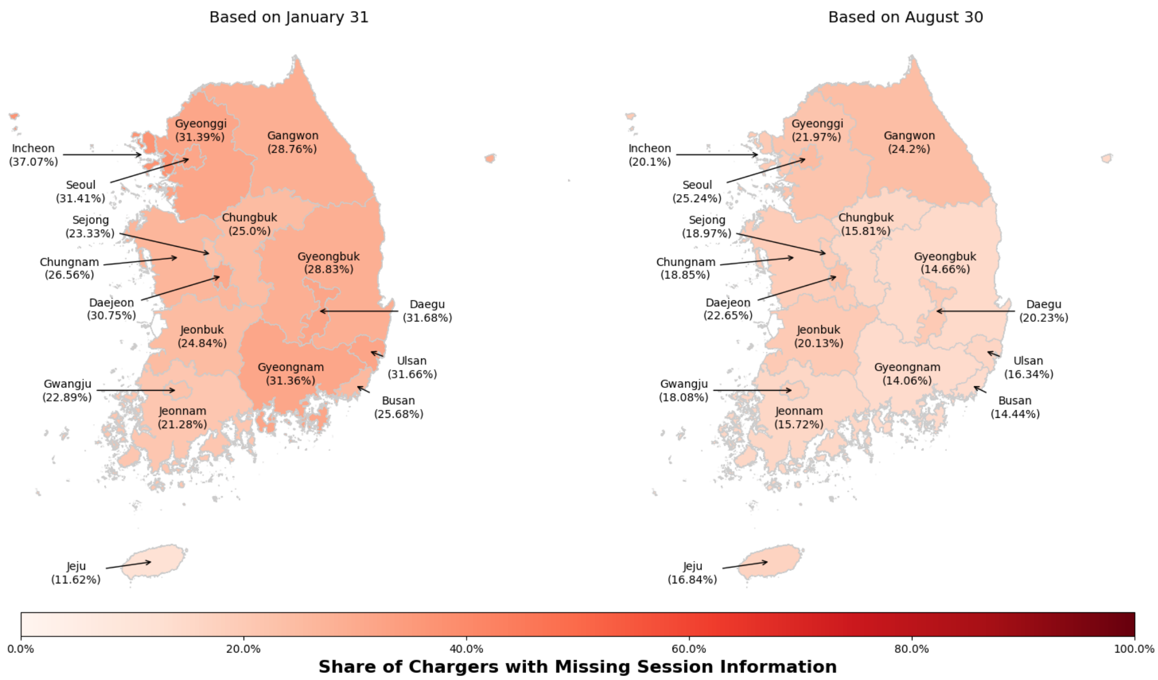
The following figure (screen capture) shows a truncated sample of the data that was used to calculate missing percentages:

Figure 1. Sample Session Data (Truncated)

	statId	zcode	lastTsdt	lastTedt
75265	HM000244	27	NaN	NaN
110302	KP002075	41	2.023013e+13	2.023013e+13
190793	SF002404	47	NaN	2.023013e+13
2818	ME19B163	45	2.023013e+13	2.023013e+13
67986	GN100164	44	2.023013e+13	2.023013e+13

Any observations where lastTsdt and/or lastTedt was empty (ex. NaN, Not a Number, null, NA, empty strings “”) were dropped from the dataset. A separate dataset, identifying all EV charging stations, was then inserted with a new variable (column) to identify if the charger, based on statId, existed in the session dataset. If yes, the value of 1 was assigned, and if not, then 0. This was conducted twice, using the data from January 31 and September 30, specifically. These values were then aggregated by region and then plotted on a map.

Figure 2. Percentage of Chargers with Missing Session Data



As missing data is undesirable, the 'reds' gradient color scheme was selected represent the proportion of chargers that had missing data by major geographical regions (metropolitan cities and provinces). With the exception of Jeju Island, all other locations have reduced their percentage of missing session data significantly over time – while there is much room left to further increase the quality of available data, these efforts are certainly crucial in better understanding the EV infrastructure situation in Korea.

For January 31, 2023, the total share of missing data was at 29.25% across the nation. As of September 30, this number dropped down to 20.22%. A significant increase in the total number of installed chargers (~ 50,000 units) as well as the reduction of chargers that had missing data (~8,000 units) were the drivers of this change.

4.2 Charger Installations Over Time

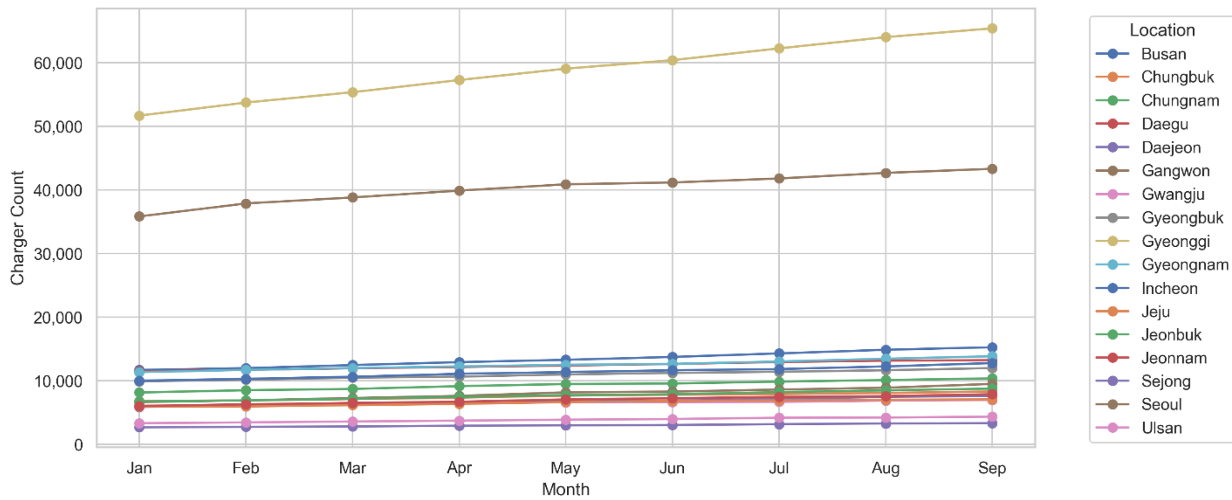
This rudimentary analysis shows the change in charger count by month (based on the last day of each month) and the major administrative regions in Korea. While the total charger summary can be found below, a more detailed breakdown of chargers by speed types (slow, fast, superfast, unknown) is available in the following sections. Please note that the data is based on the information available as of the last day of each indicated month.

Table 1. Total Charger Count by Region and Month

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Busan	11,664	11,961	12,437	12,896	13,265	13,715	14,270	14,843	15,238
Chungbuk	6,757	6,884	7,097	7,321	7,630	7,770	7,881	8,060	8,286
Chungnam	8,128	8,483	8,685	9,126	9,454	9,542	9,827	10,088	10,348
Daegu	11,463	11,687	11,929	12,132	12,367	12,609	12,918	13,125	13,217
Daejeon	5,857	6,080	6,377	6,495	6,726	6,843	7,140	7,431	7,591
Gangwon	6,614	6,895	7,250	7,597	8,153	8,268	8,587	8,875	9,475
Gwangju	5,955	6,127	6,242	6,420	6,576	6,603	6,647	6,841	6,958
Gyeongbuk	9,887	10,116	10,457	10,618	10,961	11,206	11,385	11,623	11,964
Gyeonggi	51,647	53,704	55,332	57,247	59,036	60,367	62,223	63,988	65,386
Gyeongnam	11,323	11,682	11,970	12,229	12,484	12,621	13,001	13,433	13,823
Incheon	9,987	10,277	10,599	11,066	11,339	11,617	11,806	12,225	12,754
Jeju	5,919	5,935	6,140	6,328	6,638	6,787	6,902	6,981	7,049
Jeonbuk	6,716	6,885	7,130	7,436	7,717	7,854	8,185	8,463	8,734
Jeonnam	6,021	6,260	6,484	6,684	7,037	7,220	7,430	7,567	7,865
Sejong	2,657	2,729	2,788	2,897	2,968	3,018	3,147	3,259	3,310
Seoul	35,805	37,844	38,789	39,860	40,858	41,138	41,774	42,649	43,292
Ulsan	3,301	3,423	3,576	3,704	3,856	3,953	4,158	4,192	4,322
Total	199,701	206,972	213,282	220,056	227,065	231,131	237,281	243,643	249,612

Table 1 reveals very quicky that Korea has invested significant amounts of efforts in increasing their charger count, regardless of region. Figure 3 is provided below to illustrate this increasing trend, based on the same numbers.

Figure 3. Total Chargers by Region and Month



4.3 Charger Installations by Facility Types

Facility types are another important aspect with it comes to charger placements and their utilization. Considering that most vehicles are parked and idle throughout a given day, it would make logical sense to install large amounts of low-cost slow chargers compared to the more expensive and power-demanding fast chargers. Conversely, areas that are subject to high levels of traffic that are not final destination locations may be better served by rapid chargers, due to the comparatively transient nature of the cars that visit those areas. For the sake of simplicity, the facility types for the end of January and September were selected, and the total charger count by speed was then tallied.

Table 2. Chargers by Speed and Facility Types
(January vs. September, 2023)

Facility Type	January					September				
	Fast	Slow	Super	Unknown	Total	Fast	Slow	Super	Unknown	Total
Public	3,995	3,130	5	4,906	12,036	5,443	4,667	28	4,250	14,388
Residential	1,130	111,346	2	36,697	149,175	1,559	142,929	0	32,529	177,017
Tourist	1,035	423	2	318	1,778	1,341	774	24	288	2,427
Education & Culture	855	2,028	1	742	3,626	1,065	4,544	22	632	6,263
Community	788	1,265	0	540	2,593	1,033	2,249	16	433	3,731
Other	1,257	6,491	24	1,782	9,554	2,860	11,595	62	1,632	16,149
Commercial	2,195	5,787	10	4,137	12,129	3,589	9,725	46	3,328	16,688

Parking	2,936	1,799	4	932	5,671	4,433	3,664	23	855	8,975
Vehicle Maintenance	382	508	0	698	1,588	531	675	37	544	1,787
Highway Rest Areas	903	42	33	53	1,031	1,300	48	110	41	1,499
Unknown	3	11	0	506	520	12	257	0	419	688
Total	15,479	132,830	81	51,311	199,701	23,166	181,127	368	44,951	249,612

Interestingly, the total number of 'unknown' chargers have decreased over time despite the total number of chargers installed. This indicates that previously unregistered information for these chargers have updated over time, and is now represented one of the descriptive categories rather than simply being left as 'unknown'. This data also reveals that the vast majority of slow chargers are assigned to residential areas, while fast and superfast chargers are assigned to areas where people may be 'passing through', in general. A particular note is the concentration of superfast (300 kw+) chargers assigned to highway rest areas, which are located alongside the major roadways throughout Korea. Furthermore, the superfast charger has increased in count by over 450% from its original number in January, indicating that the willingness and infrastructure availability to install these chargers have become more attainable.

4.4 Electric Vehicles and the Charger-to-EV Ratio

The total number of electric vehicles that have changed over time is another simple yet important figure to consider, which can be used as a measure of progress in Korea's efforts to push forward with EV adoption. This number is not intended to be definitive, as true EV charger accessibility is highly dependent on what is available within a reasonable distance of the vehicle owner – but it does assist in the process of forming a comprehensive picture on the infrastructure that exists currently. These values only focus on pure electric vehicles.

Table 3.Total EVs Registered by Region and Month

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Busan	22,114	23,481	24,676	26,191	27,147	28,466	29,037	30,148	31,096
Chungbuk	15,156	15,727	16,765	16,996	17,511	17,903	18,100	18,739	19,095
Chungnam	16,617	16,990	18,832	19,487	20,225	20,677	21,437	21,656	22,065
Daegu	24,100	25,019	25,535	26,092	26,691	27,263	27,911	28,336	28,988

Daejeon	14,450	14,600	14,972	15,301	15,564	15,904	16,138	16,263	16,559
Gangwon	14,065	14,427	14,823	15,218	15,728	16,143	16,459	16,723	17,014
Gwangju	9,118	9,542	9,761	10,028	10,303	10,609	10,853	11,054	11,318
Gyeongbuk	19,150	19,808	21,278	22,349	23,023	23,520	24,347	24,645	25,051
Gyeonggi	77,673	79,880	84,533	87,779	90,624	93,995	97,738	99,925	103,704
Gyeongnam	22,749	23,739	25,495	26,661	27,593	28,799	30,888	31,767	32,763
Incheon	26,342	26,479	27,840	29,464	30,905	32,065	33,248	34,094	35,554
Jeju	32,904	33,573	34,432	35,020	35,619	36,262	36,903	37,342	37,689
Jeonbuk	12,740	13,022	15,070	15,852	16,256	16,668	17,302	17,623	18,187
Jeonnam	15,449	16,505	18,041	19,169	19,966	20,874	21,368	21,708	22,317
Sejong	3,081	3,153	3,343	3,444	3,562	3,674	3,778	3,882	4,073
Seoul	59,624	59,584	61,123	62,385	63,807	65,614	66,528	67,351	68,892
Ulsan	5,071	5,682	5,864	6,050	6,207	6,492	6,813	6,960	7,120
Total	390,403	401,211	422,383	437,486	450,731	464,928	478,848	488,216	501,485

Over the course of 9 months, Korea has added over 110,000 new EV vehicles to the total national count. The unweighted mean of increases by provinces was found to be at 30.15%, with Jeonnam Province leading the biggest change at 44.46%, and Jeju Island at the lowest at 14.54%.

Intuitively, the differences in these numbers may be attributed to a number of factors including the availability of EV purchasing subsidies, which differ greatly in amount (Seoul: 8.6 million KRW vs. Gyeongnam Geochang County: 18.3 million KRW) and eligible vehicle counts (Seoul: 11,668 EVs vs. Geochang County: 103 EVs), as well as the total population, income, infrastructure availability, and the saturation level of EVs within each of these respective regions.

Table 4. EV Statistics
(January vs. September)

Region	Change	Increase
Busan	40.62%	8,982
Chungbuk	25.99%	3,939
Chungnam	32.79%	5,448
Daegu	20.28%	4,888
Daejeon	14.60%	2,109
Gangwon	20.97%	2,949
Gwangju	24.13%	2,200
Gyeongbuk	30.81%	5,901
Gyeonggi	33.51%	26,031
Gyeongnam	44.02%	10,014
Incheon	34.97%	9,212
Jeju	14.54%	4,785
Jeonbuk	42.76%	5,447
Jeonnam	44.46%	6,868
Sejong	32.20%	992
Seoul	15.54%	9,268
Ulsan	40.41%	2,049
	Total	111,082
Average	30.15%	6,534
Std. Dev.	10.15%	5,585.19

Using the total number of registered EVs over time, as well as the total number of chargers registered across Korea, the availability of chargers per EV can then be calculated, as shown in Table 5 below.

Table 5. Ratio of Installed Chargers to Registered EVs

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Busan	0.53	0.51	0.50	0.49	0.49	0.48	0.49	0.49	0.49
Chungbuk	0.45	0.44	0.42	0.43	0.44	0.43	0.44	0.43	0.43
Chungnam	0.49	0.50	0.46	0.47	0.47	0.46	0.46	0.47	0.47
Daegu	0.48	0.47	0.47	0.46	0.46	0.46	0.46	0.46	0.46
Daejeon	0.41	0.42	0.43	0.42	0.43	0.43	0.44	0.46	0.46
Gangwon	0.47	0.48	0.49	0.50	0.52	0.51	0.52	0.53	0.56
Gwangju	0.65	0.64	0.64	0.64	0.64	0.62	0.61	0.62	0.61
Gyeongbuk	0.52	0.51	0.49	0.48	0.48	0.48	0.47	0.47	0.48
Gyeonggi	0.66	0.67	0.65	0.65	0.65	0.64	0.64	0.64	0.63
Gyeongnam	0.50	0.49	0.47	0.46	0.45	0.44	0.42	0.42	0.42
Incheon	0.38	0.39	0.38	0.38	0.37	0.36	0.36	0.36	0.36
Jeju	0.18	0.18	0.18	0.18	0.19	0.19	0.19	0.19	0.19
Jeonbuk	0.53	0.53	0.47	0.47	0.47	0.47	0.47	0.48	0.48
Jeonnam	0.39	0.38	0.36	0.35	0.35	0.35	0.35	0.35	0.35
Sejong	0.86	0.87	0.83	0.84	0.83	0.82	0.83	0.84	0.81
Seoul	0.60	0.64	0.63	0.64	0.64	0.63	0.63	0.63	0.63
Ulsan	0.65	0.60	0.61	0.61	0.62	0.61	0.61	0.60	0.61
Average	0.51	0.51	0.50	0.50	0.50	0.49	0.49	0.50	0.50

These numbers do not include plug-in hybrid vehicles, which would cause the ratio to drop further than it is now. These numbers also illustrate an assumption that all chargers are considered equal, and that everyone as similar access to these across the nation – which is obviously not the case. However, these same figures show that Korea has been consistent in maintaining roughly the same ratio of chargers to EVs over time, both nationwide as a total average, and by regions as well.

Interestingly, Norway, which has been recognized as a representative 'EV Success Story' (Bekes, et al., 2023), was able to achieve their high rates of EV penetration and sales despite having a vastly lower charger-to-EV ratio of 0.03 (IEA, 2023), or about 17 times less than Korea's current stance. China, which has the highest number of chargers installed in the world, has a reported charger-to-EV ratio of about 0.14 – a number about 3.5 times less than Korea.

To place this into a different context, if Korea were to achieve its announced goal of 4.2 million registered EVs by 2030, but did not install any additional chargers (~ 250,000 ct.) from the end of September onward, the total charger-to-EV ratio nationwide would be approximately 0.06, or still twice as high as that of Norway. While there are clear differences in these and other countries in the form of population density, geography, culture, and familiarity with EVs, the fundamental process of charging and using such a vehicle remains the same – this suggests that Korea may have unexplored options to help achieve a similar level of success (defined by satisfaction of EV drivers' ease of use, including charging), given their current advantage of having a very high charger-to-EV ratio to build from. In other words, a concerted focus towards charger infrastructure expansion may not be completely necessary.

5.0 Charger Utilization Analysis and Findings

5.1 Session Times (By Charging Speed)

One full session is defined by the time when a vehicle successfully engages in charging their vehicle for at least 30 seconds, as reported by the charger. Noting from the general analysis that slow chargers vastly outnumber fast chargers, and that slow chargers require significantly more time to charge a vehicle than their quicker counterparts, the session calculations below were conducted based on charger speed types of slow, fast, and superfast, and unknown, across the entirety of the dataset from January through to September. The session data used to calculate these statistics was not aggregated.

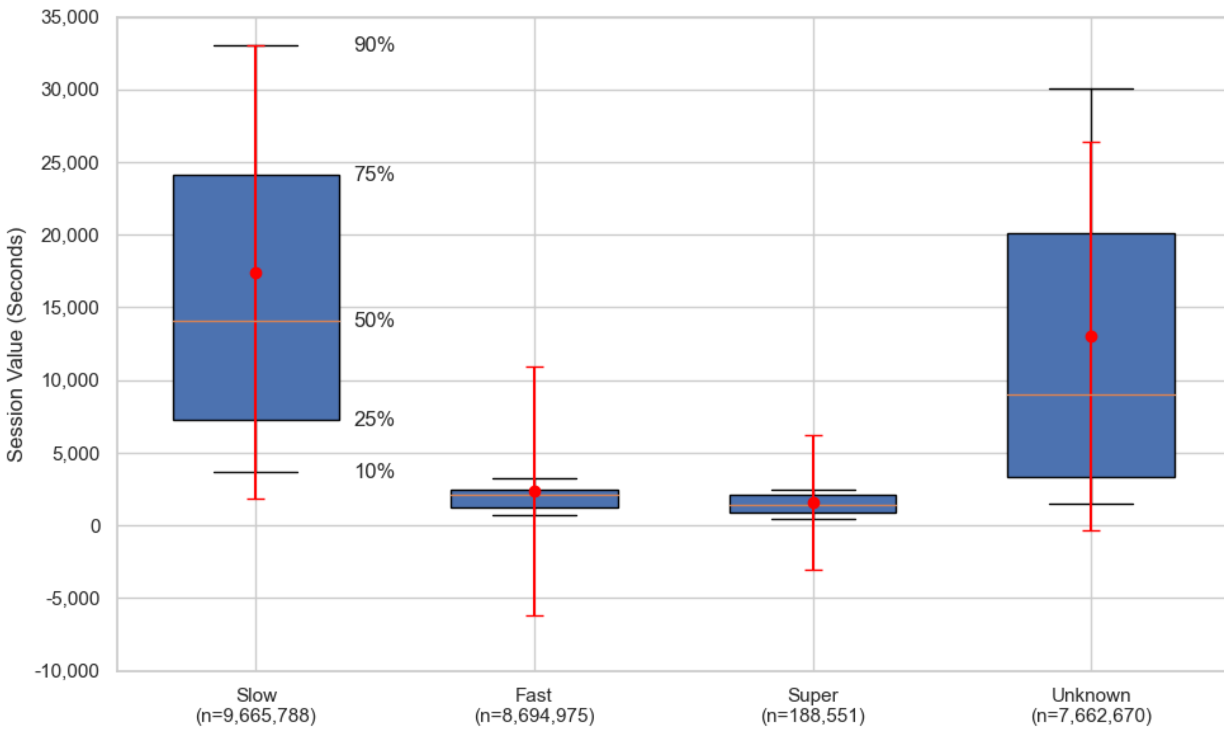
Table 6. Charger Session Statistics
(In Seconds, Nationwide, January - September)

Output	Count	Mean	Std	10%	25%	50%	75%	90%
Slow	9,665,788	17,415.75	15,602.22	3,664	7,229	14,037	24,110	32,995
Fast	8,694,975	2,337.36	8,551.46	701	1,275	2,078	2,458	3,285
Super	188,551	1,585.50	4,607.92	463	870	1,437	2,123	2,437
Unknown	7,662,670	13,025.02	13,359.17	1,471	3,341	9,022	20,110	30,063

Table 7. Charger Session Statistics
(In hours:minutes, Nationwide, January - September)

Output	Count	Mean	Std	10%	25%	50%	75%	90%
Slow	9,665,788	4:50	4:20	1:01	2:00	3:54	6:42	9:10
Fast	8,694,975	0:39	2:23	0:12	0:21	0:35	0:41	0:55
Super	188,551	0:26	1:17	0:08	0:15	0:24	0:35	0:41
Unknown	7,662,670	3:37	3:43	0:25	0:56	2:30	5:35	8:21

Figure 4. Boxplot of Charger Session Statistics
(Nationwide, January - September)

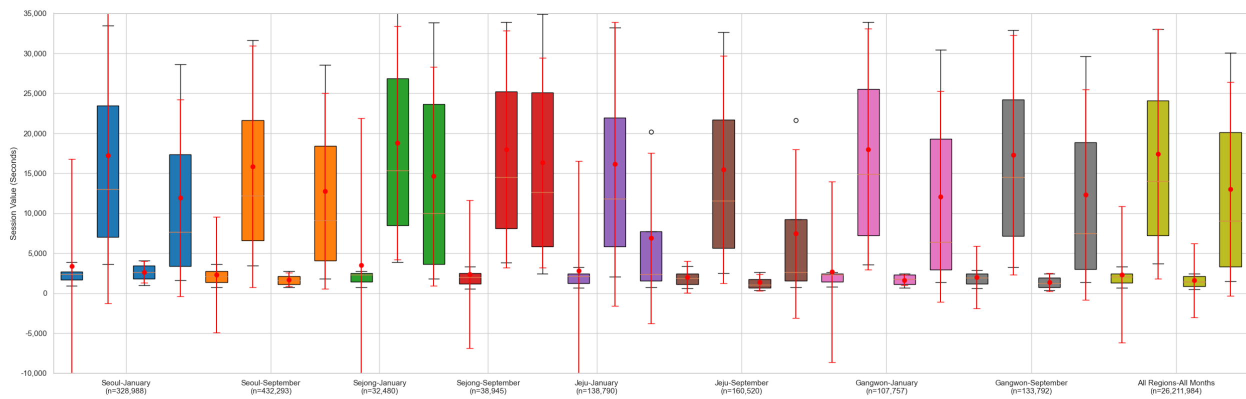


To note, the minimum and maximum values were excluded from the summary statistics as they defaulted to the criterion originally set as a part of data filtering, excluding all sessions under 30 seconds or over 7 days. The large number of observations (sessions) allowed for a full spectrum of charging times. Instead, a 10% and 90% interquartile range was added to observe the change in total length of time these 'edge' cases expanded to. The red line represents the standard deviation range.

Intuitively, the findings are not unexpected – slow chargers are used for longer periods because their energy output is low, necessitating more time to acquire the same amount of energy that a fast charger may provide. Also somewhat expected was characteristics described for 'unknown speed' chargers being similar to that of slow chargers – referring back to the share of chargers installed by speed and residence type, the majority of unknown speed chargers were categorized within the residential facility type. These types are generally equipped with slow chargers because of its relatively low technical (power grid) requirements, installation time, and costs. These chargers, because of their technical simplicity and widespread installation, may not necessarily have received the attention or possess the capability needed to transmit specific specification details such as their rated output amount.

To ensure that these findings are consistent and generalizable across regions and time, similar summary statistics were calculated using Seoul and Sejong Cities, as well as Gangwon and Jeju Provinces for the months of January and September. These regions were selected because of obvious heterogeneity in their characteristics (population size, development, income, charger infrastructure, EV ownership, and other latent factors), and the dates were selected as the opposite ends of the available data used in this study. For the sake of simplicity, the information has been directly visualized into a boxplot. The statistical data in numeric format used to create this visualization can be referred to in the appendix.

Figure 5. Boxplot Comparison of Charger Session Statistics
(Select Regions, January and September)

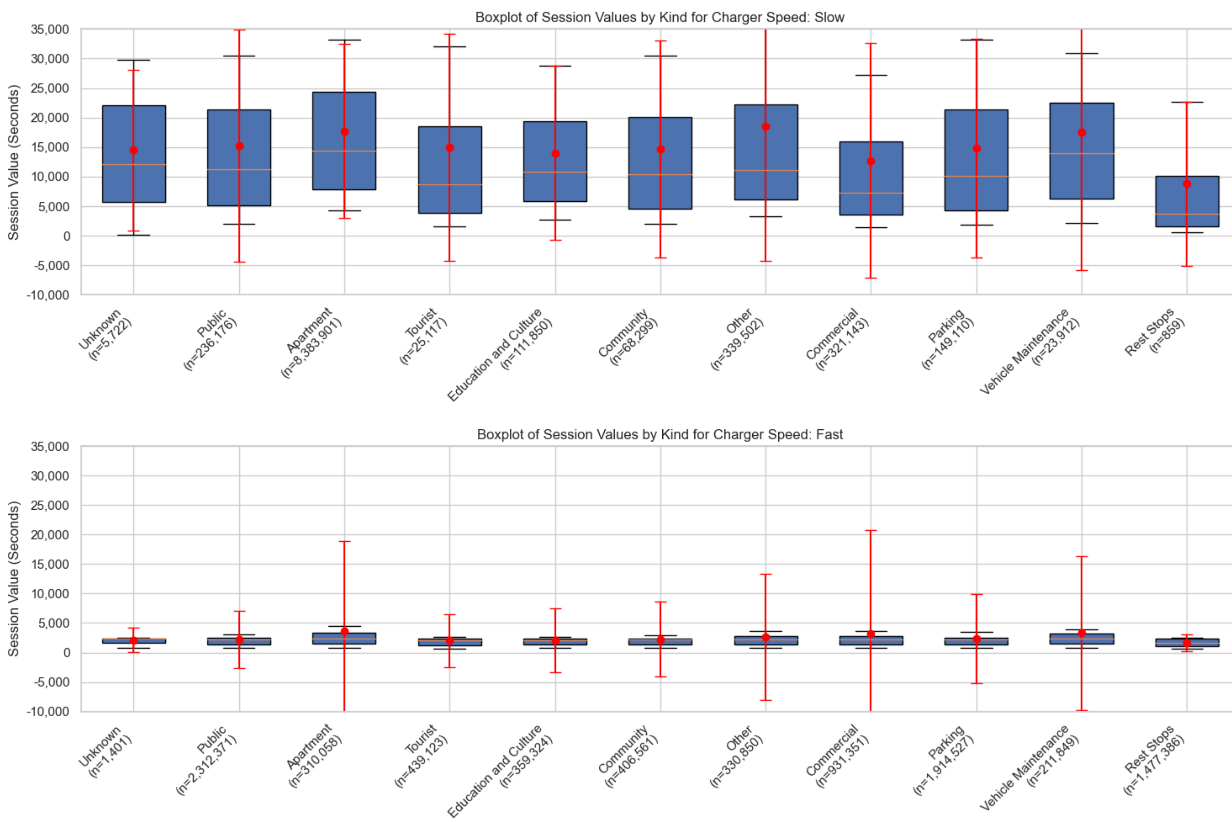


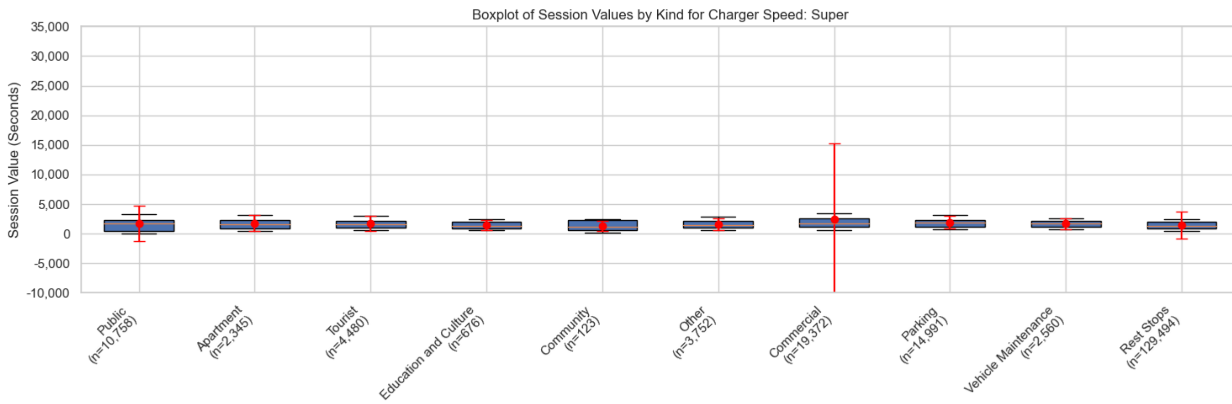
This visualization suggests that the original findings, located on the far right of Figure 5, is generally held true across different regions and times (months), though some differences do exist as well. However, these differences do not appear to detract significantly from the national-level full-timeframe findings. A special note is that region-time combinations with only three (3) boxplots instead of four (4) is due to the absence of a superfast charger in that specific region, thus statistics could not be calculated.

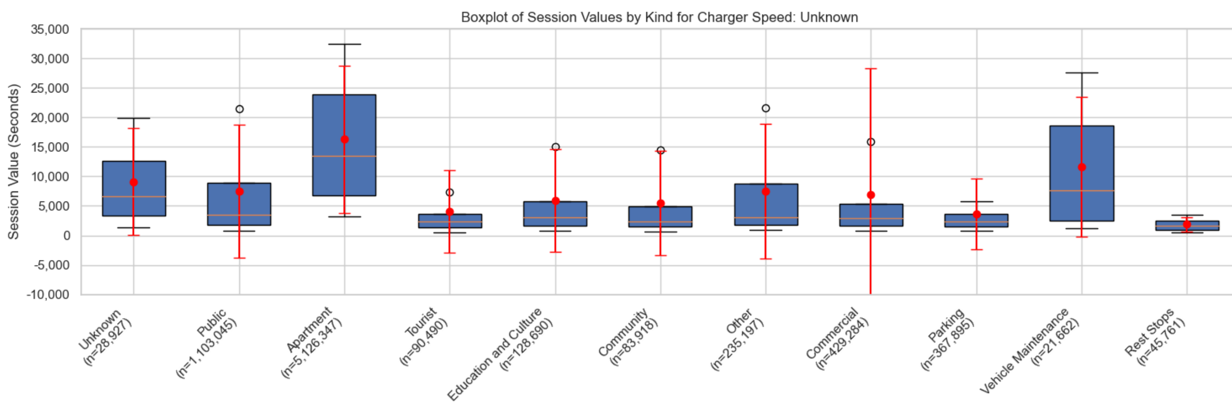
5.2 Session Times (By Charging Speed & Facility Type)

This next section adds in further details to the previous 5.1 Session Times (By Charging Speed) section, by separating the data into specific facility types, while retaining the charger speed distinctiveness. The scope was set to include all regions of Korea over the full timeframe of the data available, January 1 through to September 30, 2023. Due to the volume of data and the size of the figures necessary to create a by-region and by-time-period analysis to compare these parameters, and considering that a general session trend was established in Figure 5, this breakdown analysis was omitted from this paper. The summary statistics used to calculate this figure has been made available in the appendix.

Figure 6. Boxplot Comparison of Charger Session Statistics
(All Regions, All Periods, By Facility Type)







Similar to Section 5.1, this figure excluded the min and max session values for the same reason that its inclusion would automatically set the range to 30 seconds and 7 days, respectively – the minimum and maximum set values for the dataset being analyzed. It also included a 10% and 90% interquartile range to provide additional information on how these charging sessions take place.

The fast and superfast chargers appear to stay within a very tight area, and this is likely due to the fact that fast-charging sessions are limited to a maximum of 1 hour (or less) by law or company regulations, and also because vehicles generally receive sufficient amounts of energy within this timeframe. Thus, the findings represented here are not considered out of the ordinary. In general, this is also true for the slow chargers as well. However, the slow chargers may potentially be an avenue for change and enhancement as facilities of a transitory nature, with respect to the people that visit or pass through it, are unable to acquire sufficient amounts of energy in a short period of time. This is particularly true for the Tourist and Rest Stops categories.

When considering the last facet for unknown speed charging sessions, we can begin to see a degree of session characteristic heterogeneity between certain facility types. For example, the Apartment and Vehicle Maintenance Facility type reveals a pattern similar to what was noticed for the slow charger category, while Tourist and Rest Stops category types are much closer to fast and superfast charger types. Other categories, such as Unknown, Public, and Other, appear to possess a combination of both slow and fast chargers – that is, they are not necessarily dominated by one type or another. This information can provide new avenues for testing, such as mass installation of slow chargers in shopping areas or a focused cluster of rapid chargers for very high-density residences – possibly to challenge the apparent ‘survivorship bias’ characteristic of this analysis result.

5.3 Hourly Usage Patterns (By Charging Speed)

The information available in the dataset allows us to visualize *when* the chargers are being used, particularly when separated into different categories such as charging speed. Hypothetically speaking, it is very possible for chargers to have very low utilization rates in a given day, but be used to full capacity for an hour or two. In such a case, the daily utilization rate might be 4%, despite there being an accessibility issue at some point in the day.

To shed light on this consideration, two visualizations have been created: one using the absolute active session count values, and another that has been standardized into a percentage scale. The active session count was calculated by first subsetting the dataset into various speed types, then noting the specific day and hour of the session start and end times, and then incrementing the appropriate bins for when the session was active. This was conducted for each session observation, unaggregated, in the entire dataset. The relative scale version is calculated by taking the value in each already-calculated hourly bin and dividing it by the sum of all values for that specific speed time. This means that all of the combined percentage values, by charger speed, will add to 100%. Caution is to be taken as this visualization does not indicate the total utilization percentage of all chargers at a given time, but is relative to the total number of sessions that have been logged.

Figure 7. Active Sessions by Hours, Cumulative
(By Speed, All Regions, January to September)

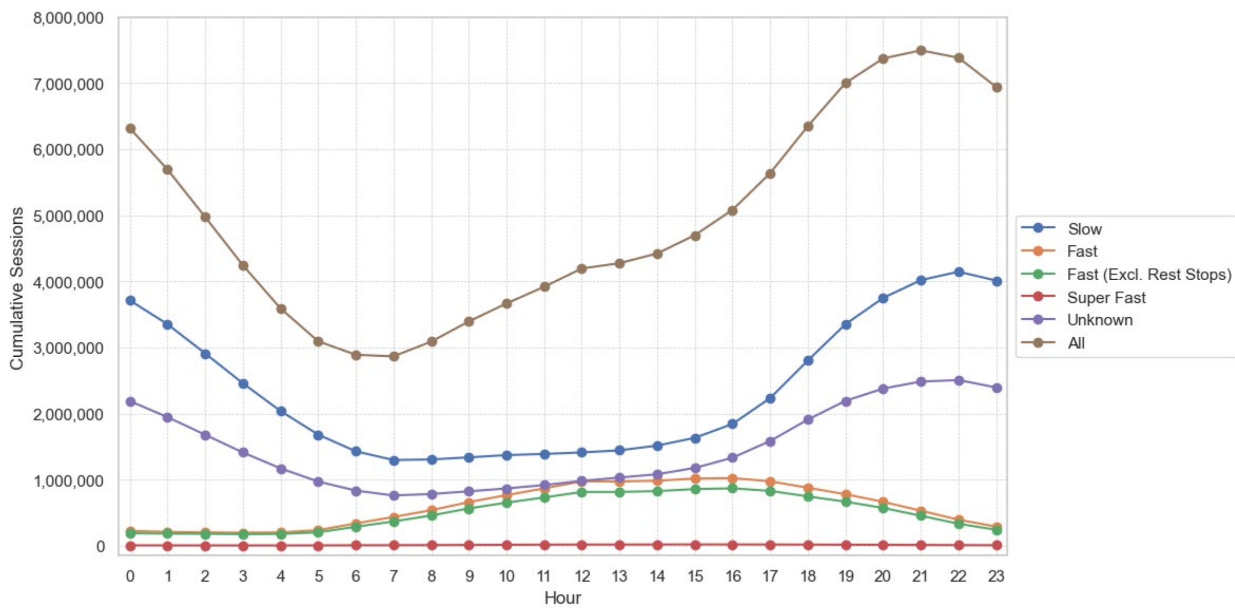
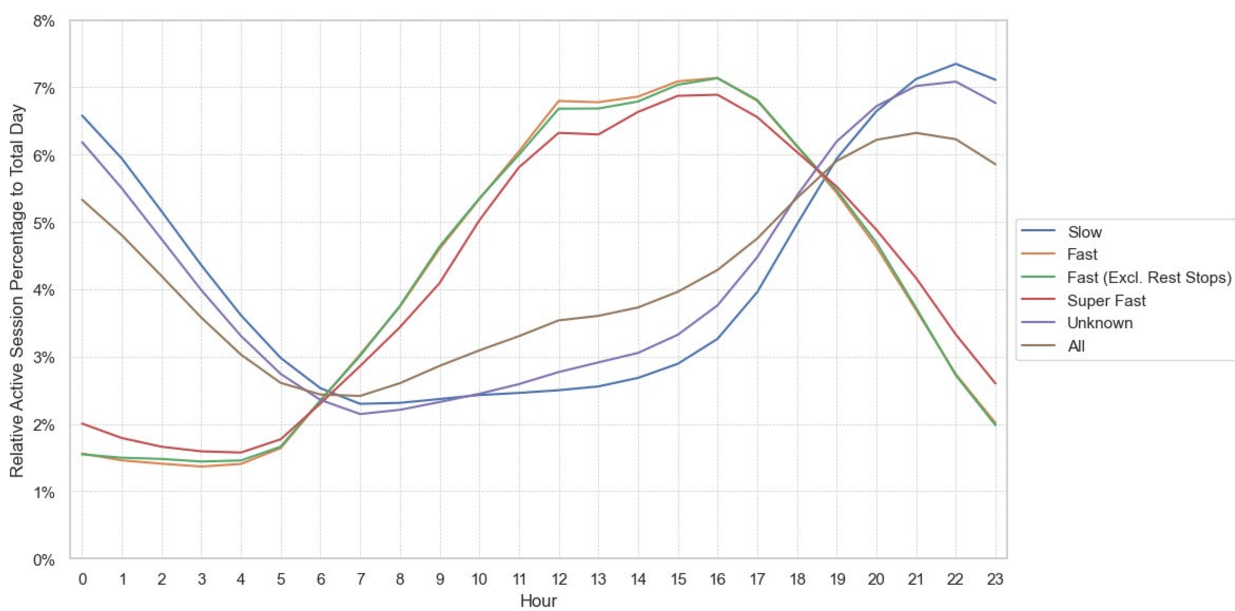


Figure 8. Active Sessions, Relative
(By Speed, All Regions, January to September)

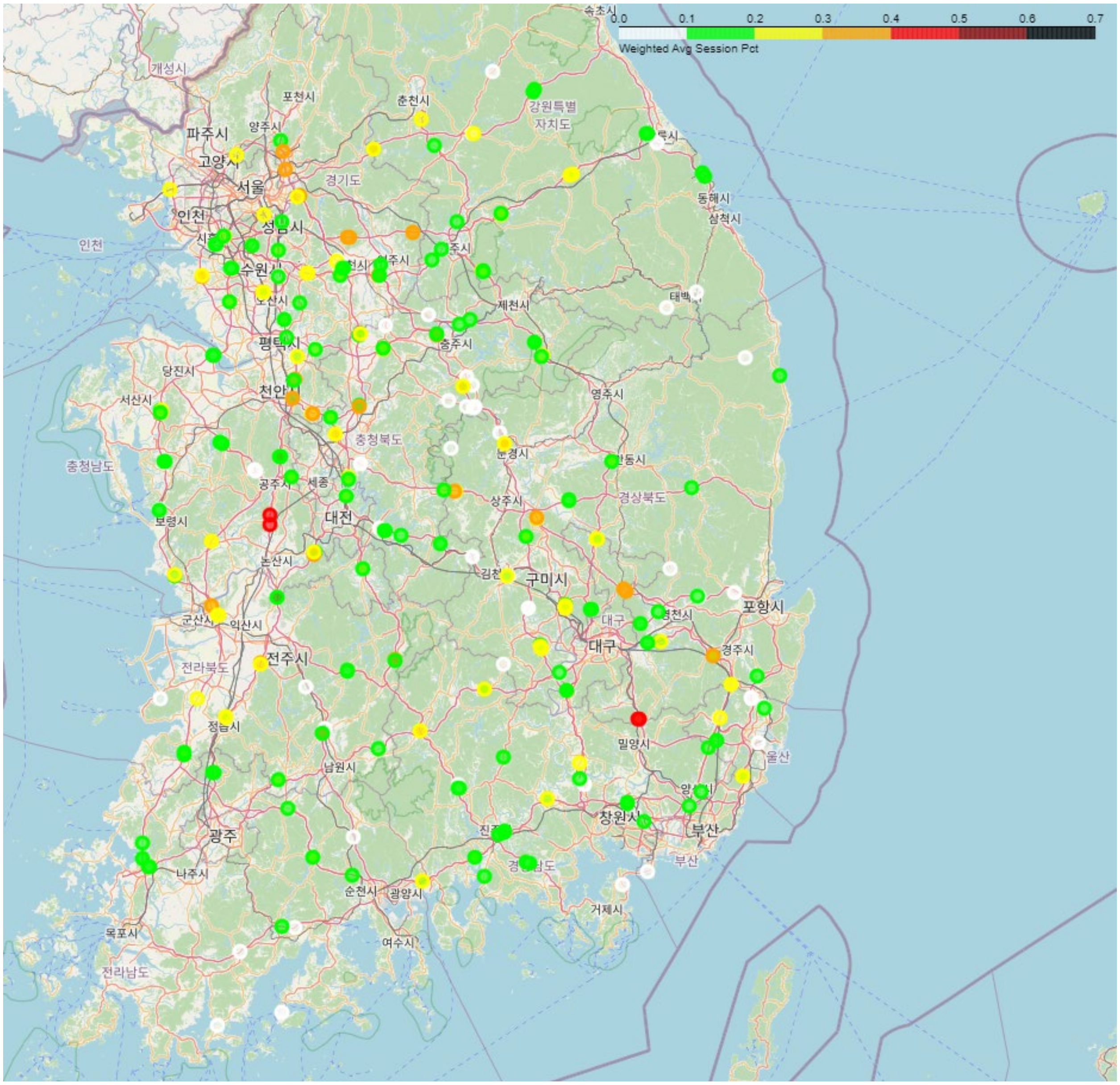


Not surprisingly, the variables of Slow, Unknown, and All exhibited similar patterns of lower usage during waking hours and higher usage during sleeping hours, whereas Fast chargers exhibited the reverse. Superfast chargers were too low in session count by comparison, and appeared flat. By standardizing each charger speed's data to a relative percentage (within the total session count within), effects of dwarfing caused by excessively high and low absolute session counts is removed, revealing the underlying trend that exists in each charger category. As Figure 8 reveals, the three fast charger speeds follow a highly similar pattern to one another, whereas the slow, unknown, and all charge are aligned with an inverse trend, likely lead or dominated by the slow charger type. Of particular interest are fast chargers, showing that the peak tends to happen between 12:00 and 17:00. Different from slow chargers, fast chargers are limited to a session length of 1 hour at most, whereas slow chargers often engage in multi-hour charging sessions due to their relatively low power output. This fast charger pattern provides potential insights into what could be done to shift the curve in either direction, or if the curve should be concentrated more towards the middle (daytime).

5.4 Charger Congestion – Highway Rest Stops

This next section looks specifically at highway rest stops because of their naturally high-traffic characteristics, drawing in vehicles both electric and traditional alike. The dataset was prepared in two major components: [1] Subsetting the charger dataset for all chargers, and then finding the total count by charging station, and [2] Subsetting the session dataset, aggregating by charging station, and summing the total session values together by that charging station. This allowed for a possible utilization percentage to be calculated within a given 24-hour period.

Figure 9. Utilization Map of Rest Stops Across Korea (Weighted Average, January - September)



At first glance, the general rest stop EV charger utilization seems to be fairly stable – there are many spots with white and green, which indicates a utilization ratio of less than 10% and 20%, respectively. The concern begins in that even such a utilization percentage can be considered very high, especially along highly trafficked areas like highway rest stops, where immense numbers of automobiles move through on a regular basis. These numbers are also based on an EV market share of between and 1.7% and 1.8% of the total national fleet over the period of 9 months. Furthermore, in actuality, those who might be moving around are unlikely to do so equally within any given 24-hour period. Rather, an average of 8 hours is allotted to sleep and waking preparation time, which means that a more realistic scope of potential movement would likely occur within a narrower 16-hour period. The scale in Figure 9 reflects this, setting an upper limit to 0.7 or 16.8 hours of a given day. It should be noted that the circle indicators have not been modified to match this 0.7 utilization ceiling on the legend, but the actual markers are still calculated out of a potential maximum value of 1 (i.e., a full 24 hours of utilization).

A general view like the one provided in Figure 9 obscures the potential differences that may exist between different time periods, such as the installation and activation of new chargers, holidays, and other events. To illustrate these differences, similar maps focusing on January, May, and September have been prepared. Note that January 1 saw the Lunar New Year Holiday, and September 2023 hosted Chuseok, Korea’s most significant holidays. These trigger massive nationwide movement as people return to their hometowns and families to celebrate, and two additional maps have been created focusing specifically on the Lunar New Year (January 21 – 24) and Chuseok (September 28 – 30).

Figure 10. Utilization Map, Jan.

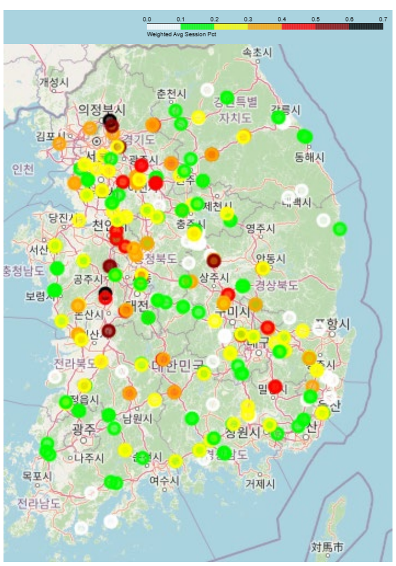


Figure 11. Utilization Map, May

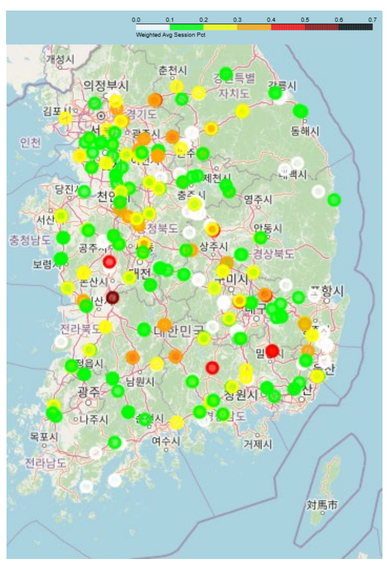


Figure 12. Utilization Map, Sept.

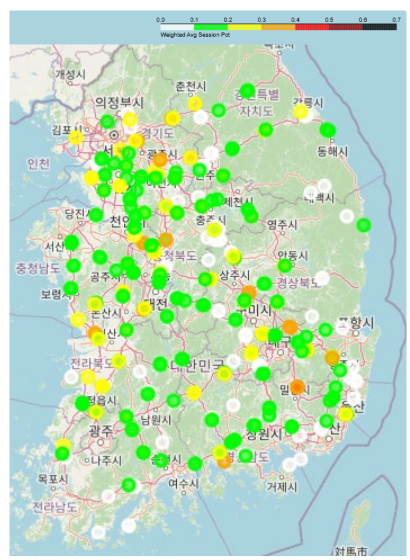


Figure 13. Utilization Map, Seollal 2023

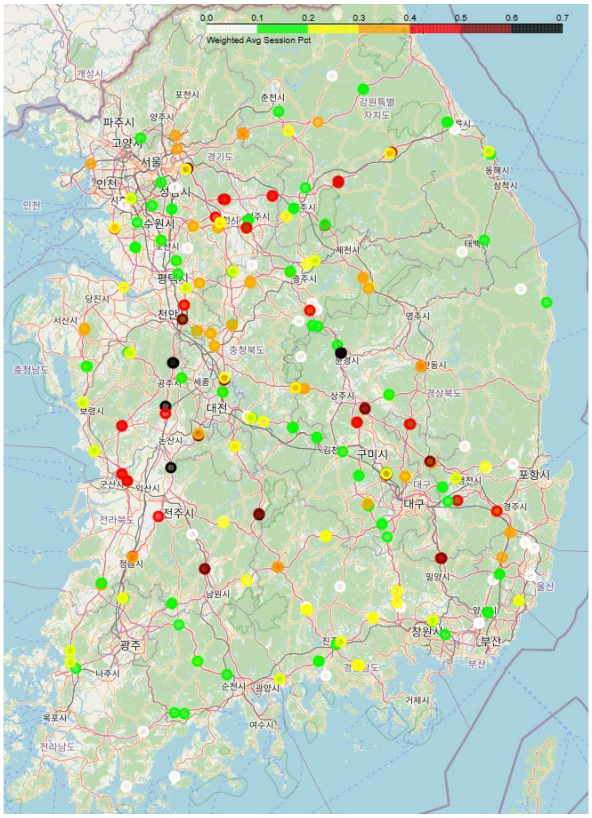
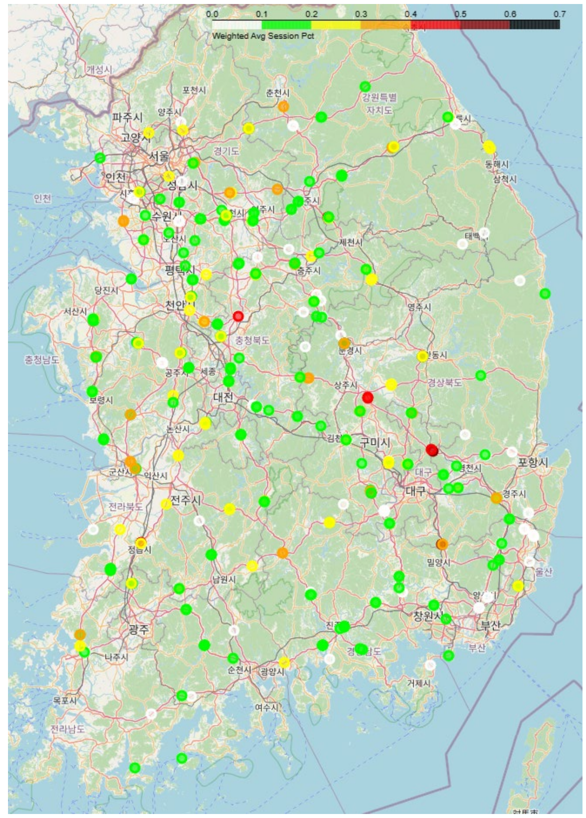


Figure 14. Utilization Map, Chuseok 2023

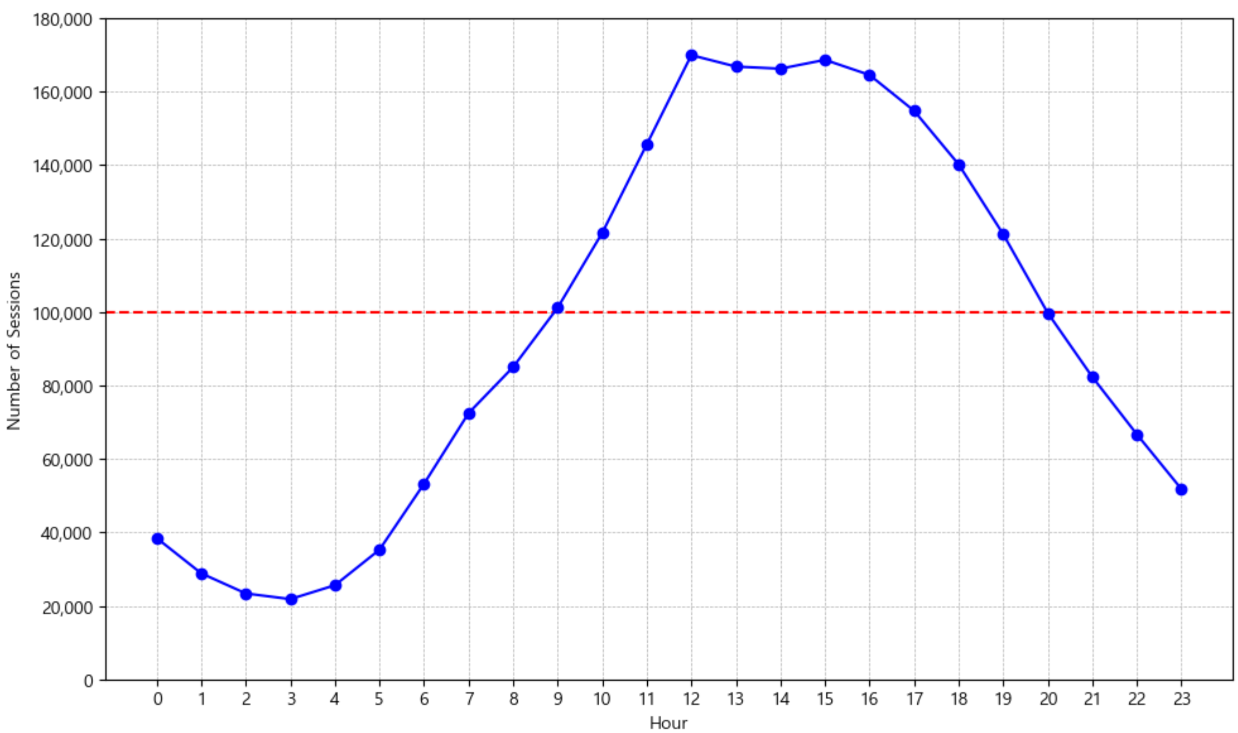


According to Figures 6, 7, and 8, which offer a monthly snapshot with a 3-month gap in between, the overall highway rest stop chargers have improved significantly. While utilization ratios are still considered quite high, the reduction in average utilization percentage is attributed to the installation of additional rapid chargers in these highly-trafficked areas. Reinforcing this fact is the comparison between Figure 9 and Figure 10, which were approximately 9 months apart and focused only on the data for the actual days of Seollal (Lunar New Year) and Chuseok holidays. Significant congestion could be seen at the beginning of 2023, which has been alleviated significantly for Chuseok by comparison.

Another interesting note are the specific locations that have consistently been marked with darker colors, indicating priority locations where much large expansion efforts could be directed towards. Also unmarked on this map are ‘break spots’, or areas that drivers can park aside to go to the bathroom, stretch their legs, or take a break in their vehicle. Aside from small bathrooms, no other amenities exist in these areas, and are much smaller in physical size as well. Despite this comparatively small nature of these break spots, they see the same amount of passing traffic as the major rest stops, making them an interesting target for new EV charger installation sites – particularly around the consistently congested areas, as indicated in the figures prior.

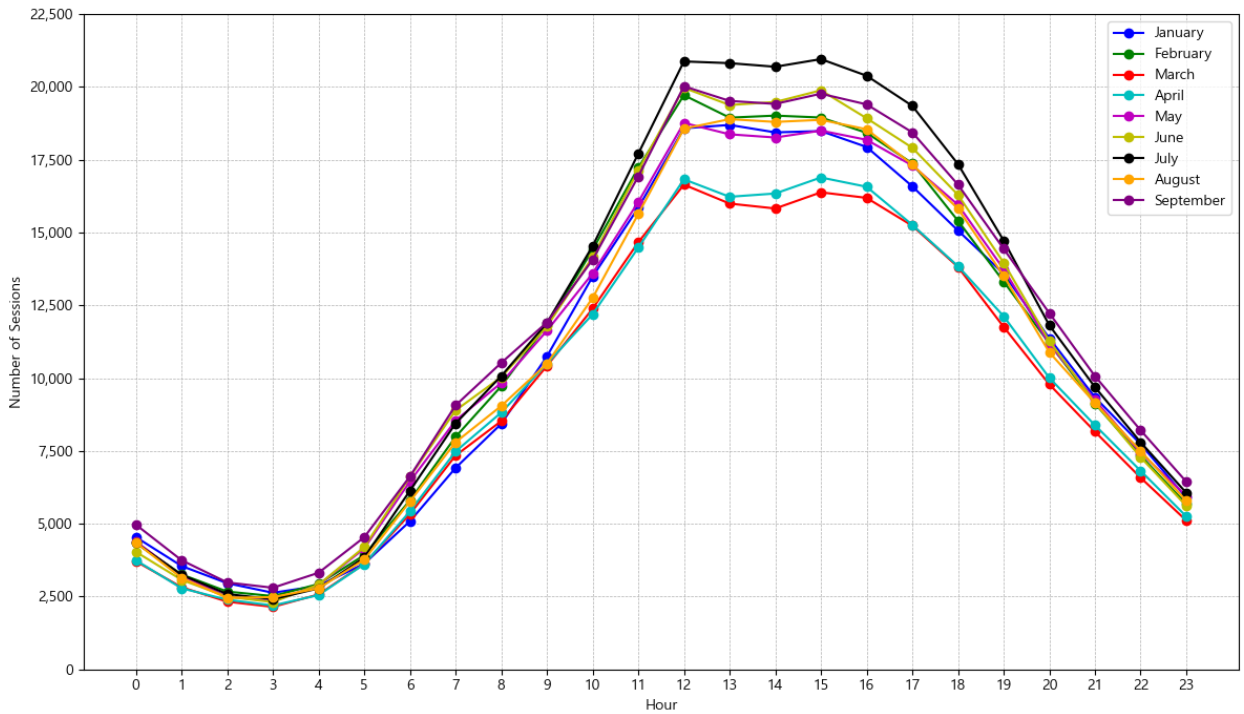
Maps only provide one facet of information, and precludes individuals from understanding *when* these cases of high utilization occurred. To address this, a line-graph representation of the total cumulative number of active sessions that took place over a 24-hour period was created. The time scope for this data is from the full January to September period. For this visualization, each unique session active in the respective hourly bin will cause it to increment by 1.

Figure 15. Cumulative Active Sessions
(Nationwide, Rest Stops Only, Hourly Intervals, January – September 2023)



Much like the fast charger usage patterns found in other, more generalized locations, the ones along the rest stops exhibited similar peaks during the daytime and troughs in the early hours of the morning - though the troughs still show a fair level of usage compared to non-highway locations. Hour 23 connects to the hour 0 (midnight), based on the method used to calculate this data. The red line indicates the approximate middle point between the peak and the trough of this visualization, at 100,000 sessions. To confirm these findings, the same calculations were conducted for each of the months and then overlayed onto a single visualization.

Figure 16. Cumulative Active Sessions
(Nationwide, Rest Stops Only, Hourly Intervals, By Month (2023))



The general trend found in Figure 13 seems to be holding when the data is broken into separate months.

6.0 Conclusion

6.1 Summary of Findings and Discussion

The dataset analyzed contained missing data in some cases, which is a potential limitation to acknowledge. However, despite this consideration, over 30 million valid observations were captured nationwide over a period of nine months lasting from January through to September 2023. By analyzing the geographical placements of the chargers, it appeared that the missing data did not center around any particular regions, but were disbursed among the chargers which did have data (in other words, the two types of missing and non-missing chargers were mixed). Furthermore, by the end of the data period, the national missing session data rate had fallen from about 29% to 20%, despite the 25% increase in total charger count, demonstrating that, nationwide, the overall quality of data has increased significantly.

Within the scope of this data, Korea consistently maintained a high level of charger to EV ratio at approximately 0.5 chargers per EV. This ratio is higher than any other in the world, and Korea's market is considered to be more 'matured' than many other countries, according to the IEA (2023) data. In addition, the heaviest-trafficked locations (highway rest stops) have revealed a measurable improvement in charger accessibility over time, likely owing it to the increase in installations and speed types over time. Of particular note is the rapid increase of superfast (300 kWh+ output) chargers increasing by 450% over this particular time period. This is all the while Korea has increased their EV registration count by over 30% in just a 9-month period – which means that the true year-on-year increase will be higher than this figure.

With respect to the division and count of charger installations across major geographical regions, no particularly unusual results were found, though more in-depth comparisons by more detailed geographic subdivisions may reveal patterns hidden by high-level aggregation. Korea's capital region, consisting of Seoul, Incheon, and Gyeonggi Province collectively held the highest number chargers, owing it to their status as Korea's most populous and commercially active region, whereas other regions with lower populations, such as Sejong and Gangwon Province, were noted to be on the opposite send of the charger count spectrum.

When dividing the total charger pool into ‘speed brackets’ of slow, fast, superfast, and unknown, a number of patterns could be identified: Slow chargers took significantly longer than their fast chargers in terms of session times, slow chargers are more often located in residential locations while fast chargers are more concentrated towards locations that have transience, or the characteristic of having temporary or short-term visitors. These findings themselves are not groundbreaking, however, the numbers themselves open up other possibilities for exploration, such as installing more slow chargers at places of work or fast chargers in residential areas. For the unknown charger types, a high-level aggregation shows the session times or utilization patterns closer to slow charger types rather than fast – however, a more level of aggregation based on facility types shows a more discernable trend of higher session times in residential areas, and lower session times in other areas. This type of pattern gives insights into how data imputation could be performed in the future, identify who operates these chargers along with better understanding why such data might not be available, as examples to potential uses and applications.

Active charging sessions were also identified based on time-of-day, with slow chargers experiencing peak usages during the evening and early morning hours, whereas fast chargers displayed the inverse pattern of high levels of usage during the daytime. When considering that a car requires potential tens of kilowatts of charging to be appreciably re-energized, sessions taking place overnight when the owner is sleeping is a logical consideration. Conversely, fast chargers are able to supply a large amount of energy in a much shorter timeframe, which makes them ideal for people to use while they are ‘on-the-go’, which typically happens during the waking hours. This is further reinforced by the fact that Korea’s legal regulations limit the amount of time a single fast charging session can take up to a maximum of 1 hour for most chargers, and up to 40 minutes for some chargers operated by the Ministry of Environment. This type of information can be useful in identifying peaks and troughs of electricity demand (usage), which can then be coupled with other efforts for behavior modulation or to take advantage of additional sources of energy, such as that from solar generation.

The value of such data and analysis is clear, particularly in the general absence of it as identified in past works. The work done in this research lays out a rudimentary but important foundation for future efforts to build upon, as well as a point of reference for all past models to refer to in order to determine the accuracy of their calculations to true, on-the-ground results. Similarly, the implications such data and research can be staggering for academics, engineers, and policymakers alike – though their respective applications and goals may not align perfectly with one another.

6.2 For Research (Academics)

Much of the literature that was reviewed focused on attempting to estimate demands based on set assumptions and proxy data, rather than the inclusion or extrapolation of true real-world charger usage information. The simple inclusion of real-life data can help create vastly more accurate and applicable models, as was in the case of the research work conducted by Kim and Kim (2021) that looked charger data from less than 1% of what is available today. That same publication, as well as the literature review conducted as a part of this research, has indicated that models based on proxy data and assumptions often end up detracting significantly from truly accurate estimations, reducing the applicability and effectiveness of those efforts. There is a limitation to the amount of guidance that even such amounts of micro-data can provide, as there can be any number of unexpected factors that shape the future landscape of electric vehicles and their needed charging infrastructure. However, the inclusion of such data can serve to make much more reliable models, particularly in the short term.

The results from this study are considered non-exhaustive by any means, leaving significant room for further exploration. However, these same results have shed a formative light in understanding the EV infrastructure status of Korea in 2023, and have further revealed the abundant possibility of further research in various arenas stemming from these analyses.

6.3 For Data Availability (Open Government Data)

The system currently operated by the Korean Government, while its stellar in its breadth and provision of information, can be greatly improved. During the course of this study, numerous calls to various government organizations were made to find out if [1] past data was available, and [2] to find out about the possibility of government systems collecting and retaining this data themselves. In every single communication instance, negative responses were received – data was not available, and it would be too hard to collect the data.

In reality, this information was relatively easily collected and stored using basic programming skills on a general (non-specialized) computer system. For the purposes of understanding and evaluating the efforts of the past, to adjust to current happenings in the present, and to create new development plans for the future, information such as the charger usage data is vital to collect and retain for analysis purposes. A much deeper analysis could be conducted if there were fewer missing values, and if additional information, such as session charging amount or some sort of anonymized vehicle identification, could be collected. In many cases, this information is already collected by the individual companies, especially as usage fees are based on the amount of electricity used, not the time connected to a charger. Negotiating the release of this information into the public domain, or at least in a repository that researchers and policymakers can access for the purposes of analysis, understanding, and future planning, could be another critical step to take for the sake of transparency and guided development.

As both the Open Data Portal and the EV initiatives for the past several years have been funded by taxpayer money, this author challenges the Korean Government to enhance their efforts in the area of system stability, data collection, and data retention.

6.4 For Policymaking (Policymakers)

Policymakers are strongly advised to consider the findings in this paper to understand the importance of EV chargers in the context of vehicle electrification, regardless of its purpose – be it to reduce greenhouse gas emissions, boost the economy, reduce noise, or for other sociopolitical goals. The current strategy of focusing on the subsidy of electric vehicles rather than equalizing it or even prioritizing the charging infrastructure can cause significant issues in the future. While Korea has done exceptionally well in maintaining the general 0.5 charger-to-EV ratio within this year, this number does not draw an accurate image of the charging situation at a more granular level. Consider Seoul City’s Gangnam District. It is well known that this district is one of the richest districts in Seoul City, and is also very high in population density and is highly developed as well. This means that while EV adoptions may be higher in this area, the expansion of charging infrastructures may not be able to follow at the same rate of increase as well – instead, Seoul’s numbers may be pulled upwards because of other regions, despite their comparatively lower potential for EV adoption.

There is also the importance of effective usage of taxpayer money when it comes to the subsidization of charging stations. For example, there has been criticism from the media where vast amounts of money has put towards only fast charger installations, which only serves a particular segment of the population. Another example includes older and more dated buildings, which are required to have a set percentage of chargers installed within this year – however, there are potential costs issues involved in such efforts. The data can show which areas have a higher probability or necessity of being expanded upon compared to other areas, which can help more efficiently allocate taxpayer funds. There are also cases where chargers have been installed but completely unused in elementary, middle, and high-school areas in the Jeonnam Province, as was reported recently in September 2023.

The data provided by the same government these policymakers represent is a vital tool that must be collected, analyzed, disseminated, and utilized to help inform and guide policy and development decisions.

6.4 Further Research

Many of the findings of this paper can be considered relatively rudimentary in terms of the technical processes used in analyzing the data. However, the findings here allowed for the models created in the past, including those from more recent times, to be evaluated for their alignment with real data based on the progression and evolution of the EV industry over time. The simplicity of the calculations employed in this research lends strength to the credibility of its findings, as it is a more direct means of establishing factual numbers with comparatively little to context rather than more complex methods. Unlike models, this simplicity also provides a higher degree of clarity compared the extrapolations of potential outcomes primarily using assumptions and proxy data, as has been found in previous works. This is not to criticize previous works, as thus author genuinely acknowledges the efforts the researchers have contributed to the greater knowledge body; rather, the data and analysis presented here is suggested as an addition to their work, to serve as a strong basis for supplementation, augmentation, development, and refinement.

The future of mobility electrification is an exciting, and arguably a necessary development for the future. EVs themselves do not solve the problem of pollution and climate change, however, in sufficient numbers, they can a critical platform for a cleaner future. The electricity currently powering EVs in Korea come, in large part, from fossil fuel sources like coal and gas – however, the country has made significant efforts to move towards green and lower-emission alternatives. Even if this all came to pass, and Korea was able to operate fully on truly clean power, it could only affect the mobility market if there were enough EVs to charge, and for those EVs, enough chargers available to service them. This work contributes knowledge and information towards that niched, but still-important area.

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Appendix

A. Charger Session Summary Statistics

(by charging speed, region, and for the months of January and September vs. all regions and dates)

Region	Months	Charger Speed	Session Count	Mean Session Time	Session Time Std. Dev.	10% IQR	25% IQR	Median	75% IQR	90% IQR
Seoul	January	fast	89,089	3,349.31	13,412.48	906	1,672	2,400	2,667	3,886
Seoul	January	slow	110,966	17,253.69	18,543.85	3,604	7,047	13,026	23,429	33,442
Seoul	January	super	1,413	2,648.86	1,347.80	1,003	1,782	2,602	3,411	4,083
Seoul	January	unknown	127,520	11,907.18	12,290.10	1,597	3,358	7,632	17,365	28,635
Seoul	September	fast	115,610	2,307.66	7,212.95	755	1,376	2,127	2,737	3,600
Seoul	September	slow	201,362	15,850.26	15,121.26	3,462	6,602	12,189	21,637	31,639
Seoul	September	super	2,866	1,707.83	863.22	717	1,125	1,646	2,137	2,721
Seoul	September	unknown	112,455	12,771.30	12,226.09	1,831	4,063	9,101	18,423	28,557
Sejong	January	fast	3,519	3,494.81	18,394.28	745	1,453	2,334	2,519	2,768
Sejong	January	slow	13,273	18,802.53	14,580.03	3,903	8,470	15,321	26,863	35,154
Sejong	January	unknown	15,688	14,626.67	13,681.40	1,797	3,601	9,965	23,632	33,815
Sejong	September	fast	3,882	2,345.93	9,249.46	541	1,153	1,979	2,523	3,286
Sejong	September	slow	22,911	17,999.07	14,819.23	3,844	8,084	14,522	25,230	33,913
Sejong	September	unknown	12,152	16,327.25	13,120.71	2,438	5,820	12,647	25,085	34,913
Jeju	January	fast	47,209	2,823.70	13,676.54	683	1,237	2,091	2,439	3,226
Jeju	January	slow	10,914	16,130.18	17,739.89	2,076	5,814	11,814	21,928	33,180
Jeju	January	unknown	80,667	6,896.31	10,672.20	760	1,569	2,403	7,714	20,166
Jeju	September	fast	61,878	2,007.06	1,971.53	607	1,090	1,861	2,422	3,365
Jeju	September	slow	23,432	15,451.86	14,202.69	2,521	5,665	11,550	21,669	32,627
Jeju	September	super	300	1,334.09	1,028.52	343	642	1,071	1,760	2,613
Jeju	September	unknown	74,910	7,454.89	10,547.24	719	1,562	2,627	9,246	21,615
Gangwon	January	fast	52,899	2,681.27	11,290.80	780	1,448	2,330	2,445	2,639
Gangwon	January	slow	26,712	18,002.64	15,073.65	3,593	7,221	14,881	25,523	33,889
Gangwon	January	super	778	1,636.53	657.78	668	1,141	1,728	2,291	2,406
Gangwon	January	unknown	27,368	12,074.58	13,182.76	1,395	2,923	6,427	19,285	30,414
Gangwon	September	fast	55,500	1,993.78	3,929.58	622	1,161	1,925	2,408	2,903
Gangwon	September	slow	50,407	17,291.05	14,993.44	3,277	7,125	14,519	24,222	32,914
Gangwon	September	super	3,166	1,356.04	1,119.68	361	757	1,219	1,903	2,405
Gangwon	September	unknown	24,719	12,313.18	13,149.81	1,374	2,985	7,499	18,884	29,597
All Regions	All Months	fast	8,694,975	2,337.36	8,551.46	701	1,275	2,078	2,458	3,285
All Regions	All Months	slow	9,665,788	17,415.75	15,602.22	3,664	7,229	14,037	24,110	32,995
All Regions	All Months	super	188,551	1,585.50	4,607.92	463	870	1,437	2,123	2,437
All Regions	All Months	unknown	7,662,670	13,025.02	13,359.17	1,471	3,341	9,022	20,110	30,063

B. Charger Session Summary Statistics

(by charging speed and facility type, combined January – September 2023 period)

Charger Speed	Facility Type	Session Count	Mean Session Time	Session Time Std. Dev.	10% IQR	25% IQR	Median	75% IQR	90% IQR
fast	Unknown	1,401	2,120.62	2,013.50	733	1,571	2,407	2,408	2,565
fast	Public	2,312,371	2,184.24	4,818.84	735	1,333	2,175	2,453	3,130
fast	Apartment	310,058	3,601.03	15,330.89	769	1,488	2,365	3,410	4,534
fast	Tourist	439,123	2,010.10	4,445.81	678	1,245	2,048	2,406	2,598
fast	Education and Culture	359,324	2,113.32	5,436.87	730	1,309	2,111	2,406	2,641
fast	Community	406,561	2,263.56	6,302.07	731	1,322	2,151	2,406	2,974
fast	Other	330,850	2,673.60	10,668.72	743	1,348	2,193	2,815	3,645
fast	Commercial	931,351	3,251.76	17,480.54	728	1,355	2,187	2,773	3,602
fast	Parking	1,914,527	2,364.56	7,589.29	743	1,362	2,191	2,519	3,431
fast	Vehicle Maintenance	211,849	3,302.84	13,070.02	834	1,505	2,291	3,278	3,938
fast	Rest Stops	1,477,386	1,658.69	1,375.42	608	1,026	1,660	2,400	2,490
slow	Unknown	5,722	14,496.90	13,645.34	182	5,752	12,147	22,070	29,776
slow	Public	236,176	15,200.37	19,645.00	1,954	5,131	11,246	21,352	30,555
slow	Apartment	8,383,901	17,739.02	14,755.32	4,233	7,823	14,445	24,407	33,154
slow	Tourist	25,117	14,980.90	19,209.36	1,629	3,864	8,720	18,533	32,093
slow	Education and Culture	111,850	14,006.74	14,729.77	2,638	5,835	10,784	19,363	28,779
slow	Community	68,299	14,683.61	18,316.80	1,938	4,576	10,348	20,085	30,542
slow	Other	339,502	18,471.69	22,736.84	3,226	6,066	11,162	22,187	41,169
slow	Commercial	321,143	12,728.20	19,839.13	1,472	3,585	7,246	15,963	27,260
slow	Parking	149,110	14,814.41	18,529.18	1,881	4,323	10,188	21,432	33,248
slow	Vehicle Maintenance	23,912	17,520.10	23,390.49	2,148	6,283	13,935	22,467	30,921
slow	Rest Stops	859	8,831.86	13,899.34	618	1,578	3,766	10,110	22,654
super	Public	10,758	1,696.35	2,953.46	57	463	1,657	2,328	3,250
super	Apartment	2,345	1,755.73	1,377.09	408	855	1,576	2,317	3,181
super	Tourist	4,480	1,748.31	1,279.16	630	986	1,537	2,195	3,025
super	Education and Culture	676	1,397.53	829.10	514	788	1,224	1,970	2,405
super	Community	123	1,339.80	859.75	166	597	1,200	2,323	2,405
super	Other	3,752	1,584.31	1,028.47	512	933	1,429	2,133	2,857
super	Commercial	19,372	2,370.74	12,826.59	597	1,081	1,779	2,506	3,453
super	Parking	14,991	1,892.13	1,052.88	763	1,177	1,783	2,351	3,169
super	Vehicle Maintenance	2,560	1,684.14	927.08	723	1,167	1,683	2,151	2,597
super	Rest Stops	129,494	1,413.91	2,274.72	458	822	1,331	2,004	2,406

unknown	Unknown	28,927	9,083.77	9,061.41	1,406	3,289	6,659	12,638	19,924
unknown	Public	1,103,045	7,486.39	11,204.64	768	1,783	3,500	8,908	21,504
unknown	Apartment	5,126,347	16,248.66	12,448.85	3,234	6,827	13,520	23,871	32,443
unknown	Tourist	90,490	4,071.18	6,963.17	564	1,355	2,420	3,616	7,301
unknown	Education and Culture	128,690	5,890.71	8,656.23	742	1,673	3,051	5,830	15,045
unknown	Community	83,918	5,495.65	8,784.12	700	1,510	2,404	4,988	14,471
unknown	Other	235,197	7,496.51	11,456.95	911	1,825	3,131	8,706	21,591
unknown	Commercial	429,284	6,871.22	21,388.16	775	1,655	2,985	5,410	15,915
unknown	Parking	367,895	3,634.66	6,037.28	763	1,532	2,405	3,609	5,747
unknown	Vehicle Maintenance	21,662	11,636.11	11,795.05	1,225	2,527	7,679	18,543	27,612
unknown	Rest Stops	45,761	1,856.45	1,255.30	516	971	1,642	2,483	3,481