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Predicting Future Energy Demand from Electric Vehicles in Seoul

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ABSTRACT

Along with the increasing popularity of Electric Vehicles (EV) and the expansion of the charging infrastructure, energy demand from EVs is expected to grow substantially in cities. The aging population, as one of the main concerns in South Korea, should also be taken into consideration in future EV energy demand prediction, because the elderly population, defined as those over the age of 65, are found to travel less in general but are more likely to rely on private vehicles in their trips. How will energy demand and charging loads as the driver population continues to age, the number of EVs, and charging infrastructure continue to grow? The study aims to answer this question by simulating future energy demand and charging loads in Seoul under future scenarios with different population estimation, EV penetration percentages, and charging infrastructure development schemes. The study utilizes an agent-based modeling software called BEAM (Behavior, Energy, Autonomy, and Mobility) which is an extension of MATSim, an open-source transportation simulation tool, to simulate within-day travel behavior in Seoul on a typical weekday in Spring. The two main datasets used are the 2016 national household travel survey data and road network data of Seoul from the open street map. The energy demand results from scenario-based simulation for Seoul in 2030 and 2047 concludes that total energy demand will increase with charger availability and decrease in overall charging demand as population ages.

Keywords: electric vehicle (EV), aging society, agent-based modeling (ABM), future energy demand, travel behavior

1. INTRODUCTION

1.1 Electric Vehicles (EV) Energy Use under EV Development Plans in Seoul

Global efforts to deploy Electric Vehicles (EVs) to mitigate global warming have led to the ambitious EV and EV infrastructure goal of the Korean government to achieve almost 85% EV share of a total number of all vehicles by 2050. The carbon-neutral plan for 2050 proposed to prohibit petroleum-fueled vehicles registration in the city of Seoul by 2035 [1]. By the end of 2022, the Seoul government plans to have 65,000 EVs which is more than double the number of EVs which was at 31,029 in 2020 [2]. Along with the growth of EVs, the Seoul government recognizes the need for sufficient charging infrastructure. The infrastructure supply plans are stated in absolute numbers and have been differing each year but ultimately plans to supply EV chargers half the number of existing EVs to promote sustainable transportation [3].

The previous studies for EV deployment in Seoul mostly have been focused on market perspectives such as examining the factors influencing the purchase of EVs [4, 5]. The Seoul Institute has published a report on predictions of future EVs and subsequent energy demand [6]. The mathematical model used for the study considers the average distance traveled, the predicted number of EVs. However, the provided EV energy demand prediction does not consider the stochastic charging behavior and travel behavior of the drivers. [7] has developed time-spatial EV charging power demand forecast model using real-time closed-circuit television

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data and Markov-chain traffic model. The study area was limited to a road network in the area size of 1.28km^2. Despite the popularity of agent-based modeling (ABM) in many research fields, ABM transportation energy simulations considering demographic change of drivers in the entire Seoul is yet to be studied.

1.2 EV Energy Use in 'Actively' Aging Society in Seoul

UN reported in 2020 that there are 727 million persons over the age of 65 worldwide and globally, they will account for around 16%, one in six people, in 2050 [8]. South Korea is not an exception. South Korea has officially entered the 'Aged Society' in 2017 and is continuing to grow old, as 16.5% of the population is already aged over 65 as of 2021 [9, 10]. Korean Baby boomers, the people born between 1955 and 1963, accounts for 14.6% of the population and it is projected that all of them will be seniors by 2030, contributing to a large share of elderly population near future [11].

In recent years, there has been continual growth in global elderly mobility as new successive cohorts entered the old age. The upcoming cohorts are expected to be healthier and have more economic resources that could further affect the elderly mobility [12, 13]. [9] analyzed the changes in the elderly mobility using the household travel survey data in Seoul, an increasing trend in both the number of trips and the total travelled distance were confirmed. This is supported by [14], the population over the age of 65 who did not make any trips on the day of survey was 61% in 2000 and which decreased to 39.5% in 2010.

Mobility of elderly citizens is becoming increasingly important as they are considered as a significant measure for quality of life and social inclusion [15, 16]. The idea of an aging society posing challenges to transportation planning has been discussed from early on [12]. Past studies revealed that life-cycle stages, primarily age, affect travel behavior of an individual [11, 17, 18]. The elderly population actively participates in non-work activities during the week, such as shopping, leisure, and for social purposes, unlike other age groups where their weekday activity mainly comprises of work and school [9, 16]. Taking private vehicles, both as a driver and passenger, as travel mode for the elderly has went up from 17.2% in 2002 to up to 57.6% in 2016 for Seoul elderly[19]. It can be concluded that 'actively aging' Seoul seniors are becoming car-reliant with high licensing rates, car access and higher frequency of inner-city trips [11, 16, 20, 21].

As for the policy to expand the supply of eco-friendly automobiles, [5, 22] indicate that the older the age group, the higher the support for this policy. In this sense, it becomes necessary to outlook the effect of major socio-demographic change on future EV energy demand as the elderly will shortly comprise nearly 40% of the total population along with the promotion of EV. EV deployment plan in such large-scale proposed by the Seoul government will have a strong impact on the capacity of the power system in the future. This study aims to forecast the future energy demand from EV with growing number of EV infrastructure, and elderly drivers that take intra-city trips under the assumptions that the travel behavior of individuals in certain life-cycle stage would remain relatively the same.

2. STUDY AREA AND DATA COLLECTION

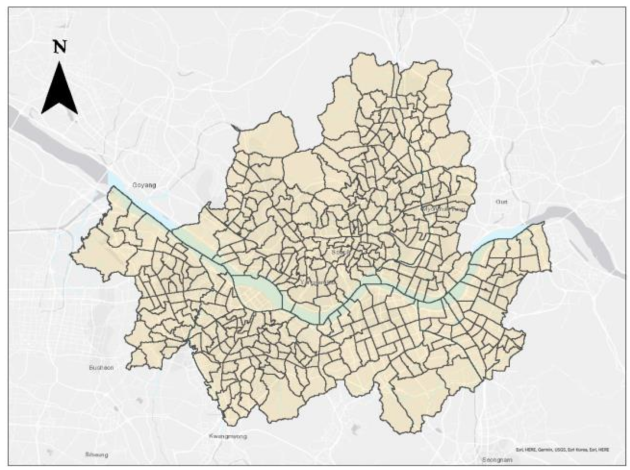

Figure 1. GIS map of Seoul and 424 TAZs.

Seoul, the capital city of South Korea, is the study area. The city is divided into 25 districts (Gu), and 424 sub-units (Dong) also known as traffic analysis zones (TAZs) as seen in figure 1. Approximately, 32,122,000 trips are made per day on average with 22% of travel mode as private cars [23]. 73.5% of the total trips are intra-city trips [19]. According to [6, 19], the average driving distance of a vehicle within Seoul is 7km per day. Considering the mileage limit of a current models EV after a single charge, there is a high possibility of replacing conventional vehicles with EVs.

The data collection for EV energy simulation has two parts (Figure 2). For network data, Seoul road network in .osm file was obtained from Open Street Map [24]. Geographic information of TAZs is obtained from Seoul open data [25]. EV charger locations of Seoul are obtained from EV nuri-jip [26]. For agent data, the latest available household travel behavior survey data of 2016 from Gyeonggi transportation information center [27] is used, the travel diaries of individuals on a typical weekday in Spring. Population projection of Seoul in both low and high scenario obtained from KOSIS [28].

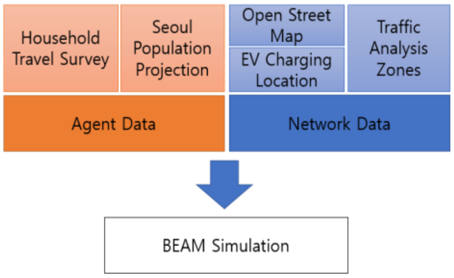

Figure 2. Illustration of data used for simulation.

3. METHODOLOGY

3.1 Definition of Scenarios

Scenario #	1	2	3	4	5	6	7	8
Year	2030		2047		2030		2047	
EV share (%)	10	14	53	98	10	14	53	98
Population projection	Low scenario				High scenario			
Elderly increase from 2016 (%)	176.22		234.13		181.97		257.12	
Elderly proportion (%)	27.5		41.9		23.8		35.3	
Charging Stalls	50% of the existing number of EV							
Scenario #	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Year	2030		2047		2030		2047	
EV share (%)	10	14	53	98	10	14	53	98
Population Projection	Low scenario				High scenario			
Elderly increase from 2016 (%)	176.22		234.13		181.97		257.12	
Elderly proportion (%)	27.5		41.9		23.8		35.3	
Charging Stalls	Unlimited							

Table 1. Scenario descriptions for BEAM.

For EV scenarios, as seen in table 1, EV share rate predictions were obtained from [6]. The two target years, 2030 to reflect the upcoming surge of the baby boomers into the elderly population, and 2047 instead of 2050 to reflect government proposed EV goal, due to population projection for Seoul being available up to that point. Mean battery level for EV parameter is set at 40%, it is randomly assigned to EVs during simulation, ranging from 0 to 80%. The current recommended charging range for EV battery is 20% to 80% [29]. The battery capacity is set at 72kWh, mileage set at 0.2kWh/km to reflect those of the popular Hyundai Ioniq model [30].

3.2 *BEAM*

The study incorporates an ABM software called BEAM. Two interactive simulators are present in BEAM. AgentSim models daily travel behavior of the agents and plan routes to destination. PhySim replicates traffic flow of vehicles and optimizes the commute times [31]. When evaluating energy consumption, characteristics including speed of travel, street type, inclination, and congestion are used [32]. An agent beginning their day enters traveling state then once they arrive at their destination, arrival decision is executed to look for a charger. If there is no charger available, they expand search distance for the next closest charger. When charged successfully, the session ends, and the process is repeated until the agent finishes the trip plan [32].

The household travel behavior survey was used to create synthetic population to represent future Seoul. Population was selected based on the following criteria: Seoul residents who are 20 and over, has a driver license, owns a vehicle, answered their primary travel mode as road traffic, and take intra-city trips on a weekday. As a result, 35,061 agents and plans were generated for simulation. Then random sampling was performed to produce the within-day intra-city travel plans of the future population which involves the following stages: (1) Division of population of each TAZ into life-cycle stages (20-34, 35-64, 65+), assuming that different life-cycle stages leads to different travel behaviors [13, 18], (2) Calculated the percentage increase of each age group from 2016 survey population to population projection for 2030 and 2047, both high and low, from KOSIS [28], (3) Random sampling with replacement performed for each age group from (1) using python coding language based on the predicted population scenarios from (2). Important to note that low and high projections in table 1 by KOSIS [28], essentially means low birth rate and high birth rate, respectively, the elderly population proportion is higher in low projection.

4. RESULTS

Figure 3 shows the total energy demand for 16 scenarios. It is apparent that the overall energy demand increases with the availability of charging stalls. The average energy demand per driver increases by 10.8 per cent when the charger is set to unlimited compared to the number of chargers being half the number of existing EVs. Assuming agents charge when charger is available and their battery level starts with the mean of 0.4, at 28.8 kWh, the results shown in table 2 are seen as reasonable.

Comparing the EV shares of each year, 10 and 14, 53 and 98, as EV share increases energy demand per capita decreases. When comparing different elderly proportion, the energy demand is relatively lower overall for low population projections which has high elderly

Population Projection	Scenario	Year	EV share (%)	Charging Stalls	Charging Energy Demand/Per driver
Low	1	2030	10		33.4 kWh
	2		14		32.9 kWh
	3	2047	53		32.94 kWh
	4		98	EV:Charger 2:1	32.7 kWh
High	5	2030	10		33.2 kWh
	6		14		32.6 kWh
	7	2047	53		37.7 kWh
	8		98		34.9 kWh
Low	9	2030	10		36.16 kWh
	10		14		36.3 kWh
	11	2047	53		36 kWh
	12		98	Unlimited	35.9 kWh
High	13	2030	10		36.26 kWh
	14		14		36.13 kWh
	15	2047	53		41.56 kWh
	16		98		41.36 kWh

Table 2. BEAM results.

proportion. The energy demands per driver with low and high projections in 2030, they stay relatively similar. This difference is magnified in 2047. With unlimited charging and high projection in 2047, the energy demand per driver is the highest and shows largest difference compared to unlimited and low projection of 2047. This can be attributed to the difference in number of populations in age groups (elderly and non-elderly) is intensified after 17-year period from 2030 to 2047.

5. DISCUSSION

Despite the 'active aging' of Seoul seniors, lower EV energy demand is discernible with higher elderly proportion. Even though the elderly population is increasing, their travel distances are relatively shorter than the younger generation [19, 20]. It has been revealed that elderly population primarily participate in leisure, shopping, and social activities freely at their own will whereas trips of younger population are mostly restricted with work and school [20]. Younger population would tend to travel during rush hours due to their time schedule with work and school. Traffic congestions during rush hours could have a significant effect on charging demand of younger generations, resulting in higher charging energy. Future road network of Seoul could have a potential shift in rush hours as the driving trips made by the elderly would have stochastic characteristics throughout the midday without constraints on time schedule. Recognizing that higher EV share leads to lower energy demand from the result, the future Seoul with nearly 100 per cent of EVs and the drivers are likely to require high availability of chargers. Nevertheless, more charger availability leads to more energy demand as the result shows, its impact on the power system is also to be further understood when planning.

6. CONCLUSION

The study conducted scenario-based EV energy demands simulations for Seoul for 2030 and 2047 to provide a general picture of the future energy impacts from increased EV usage and aging population. The study reveals that changing demographics of road users will influence EV energy demand. With population aging, the overall energy demand will tend to decrease. For 2047 scenarios, energy demand per driver decreases by 9.59 and 13.29 per cent when elderly population increases (low projection), with half parking, and unlimited parking, respectively. The results also show that the availability of charging infrastructure in locations can also alter the charging behavior of individuals, resulting in higher demand. The average of 10.8 per cent increase in charging energy per driver when the charging is available in any parking stalls. The effect of different EV shares for each year is to be further examined as the

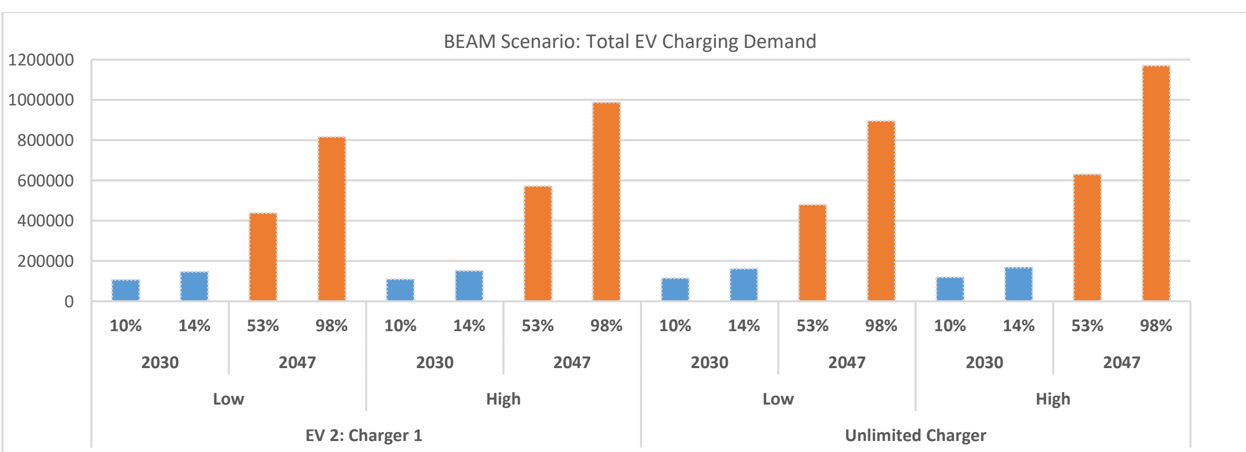

Fig 3. Total EV Charging Demand for 16 scenarios for BEAM (Unit: kWh).

energy per driver tends to decrease when EV share increases. The current charger supply plan of Seoul is only considered in absolute number, however, future infrastructure planning should consider the demographic changes, hence the shift in travel behavior, of the citizens. It is necessary to better understand these changes with aging population and shift in travel purposes and behavior of future EV drivers to carefully plan the relevant charging locations for sustainable energy system of Seoul.

The study has limitations in that it assumes travel behavior would depend on age (life-cycle stages) and each age group would have similar traveling behavior and it is applied for the future Seoul population. The model assumes that drivers would charge whenever they park, which does not take in to account the stochasticity of human behaviors. Also, compared to the real-world with diversified travel mode choice, the model only considers the driver population, the travel mode is restricted to walk or private vehicle.

In conclusion, the arising concerns with decrease in birth rates and the subsequent aging society aside, it can be concluded that such phenomenon could lower the total energy demanded with transportation energy of the future Seoul.

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