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Economic Valuation of Vehicle-Grid Integration (VGI) in a Demand Response Application from Each Stakeholder's Perspective

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Abstract: Recently, the use of electric vehicles in a power grid has been attracting attention. The success of vehicle-grid integration (VGI) requires the active participation of not only VGI service providers but also electric vehicle owners, utility companies, and the government in the VGI service. However, until now, such research has not been sufficiently discussed. Thus, we propose a framework for analyzing the economic environment in which each stakeholder can participate, especially in the application of a demand response, and derive its economic value in Korea. Also, through the proposed framework, we suggest optimal scenarios and policy directions for each participant's successful business. Our results show that government and a utility company need to share their benefits with a VGI service provider to make VGI a success.

Keywords: vehicle-grid integration (VGI); stakeholder; demand response; economic analysis

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1. Introduction

With the recent rapid increase in electric vehicles (EVs), various ways to use the EVs and the business models are emerging. Among these, the interest in vehicle-grid integration (VGI), which is used in the power grid while the vehicle is connected to the charger, is also increasing. In addition, since the capacity of vehicle batteries is gradually increasing and the number of batteries in an idle state that are plugged into a charger but not in use are increasing, the ways to use the batteries for other purposes are being considered. For example, it is representative to use them for an ancillary service in connection with the grid while they are not being charged. Some research projects, such as the Parker project, have verified the technical issues through a stage of demonstration and estimated the economic benefits [1]. Besides, VGI can be applied to other areas, such as peak shaving, renewable energy integration, and spinning reserve [2]. For example, the batteries of EVs can be used to suppress high power consumption during peak times and stabilize the unstable output of renewable energy by feeding stored energy back into the grid [3,4].

While many studies regarding VGI have mostly discussed profits that an EV owner can make when the EV gets to participate in a regulation program, economic analyses for other purposes are barely studied. Among many different applications of VGI, we want to study the demand response, which is a program to respond to shed peak demand. When the demand becomes too high and is not expected to be met by supply, a utility company might want to shut down some equipment of high-use industrial consumers to prevent blackouts. For this demand response, EVs can be used by either turning off charging or transferring the stored energy in the EV battery into a grid. However, thus far, economic analysis for this demand response application has received little attention.

Therefore, we would like to study whether VGI service is profitable from the demand response perspective.

More importantly, in order for VGI service to be successfully launched and executed, the service needs to attract all participants who are involved in the VGI service, such as EV owners, a VGI service provider, a utility company, and government, and should guarantee a certain level of profits for each stakeholder. For example, if EV owners expect profits and want to participate, but the service provider does not expect profits, the VGI service may fail. Therefore, we would like to study the economic feasibility from each stakeholder's perspective under a demand response program. Also, based on the suggested analysis framework, we provide optimal scenarios in which all stakeholders can make profits and we propose policy directions, including a governmental subsidy structure.

The structure of this paper is as follows: In Section 2, we investigate the literature regarding VGI investment and discuss backgrounds of the demand response, especially in the Korean electricity market. Then, we suggest a framework and an algorithm for VGI investment evaluation in demand response application from each stakeholder's perspective in Section 3. Based on the proposed framework, simulation and analysis are executed to analyze the economic feasibility of VGI for different scenarios in Section 4. Section 5 summarizes the major results and provides implications for policy makers and government.

2. Background and Literature Review

2.1. Demand Response Program in Korea

A demand response (DR) provides an opportunity for consumers to play an important role in the operations of the electric grid by reducing or shifting their electricity usage during peak periods throughout time-based charges or other forms of financial incentives. The demand response program is being used by some electric system planners and operators as resource options for balancing supply and demand.

Currently, it forms a 4.3 GW demand response market in Korea. This compares the operation cost of an LNG power plant with a 4.3 GW scale, and the demand response has the effect of saving about 164 billion KRW from the capacity charge of an LNG power plant. Also, the demand response is more economical considering that more than 4 trillion KRW is required to build 4.3 GW power plants.

In Korea, there are two types of demand response. First, DR type I is defined as a method that contributes to supply stabilization by asking companies to reduce electricity when the power supply and demand situation changes rapidly. This is a curtailable load program. This DR type I program addresses medium and large consumers. The participants in this program receive incentives in order to turn off specific loads or even to interrupt their energy usage, responding to calls emitted by the utility. Contracts should specify the maximum number and the duration of calls. The participants can participate for a maximum of 60 h per year on weekdays and participate from 9:00 to 20:00, excluding 12:00 to 13:00. In addition, the reduction call is issued one hour in advance. This program is mandatory, i.e., customers may face penalties in case they fail to respond to a demand response event. The utility may call the consumer to respond to reliability events [5,6].

Second, DR type II is called a demand-side bidding program. The option of demand-side bidding provides the opportunity to consumers to actively participate in the electricity market by submitting load reduction offers. Large customers may participate in the market directly and usually employ sophisticated load management tools and strategies, while relatively small consumers can participate indirectly through third-party aggregators. This type of DR program is designed to aim at lowering the electricity market price by encouraging more customers' involvement and making a market more competitive, so it is called an economic DR program. This program runs into the one-day-ahead market. The participation in Type II DR is possible 24 h a day, but only on weekdays. The compensation for participation is a system marginal price (SMP). The participants must participate in the reduction at a fixed time the next day, by as much as the amount that was won in the one-day-ahead market. As with DR type I, a penalty is imposed for failure to implement. The participants can participate in both DR type I and DR type II, but if a reduction call is issued at the same time, they must first participate in DR type I [5,6].

2.2. Economic Valuation Literature for VGI

There are a few studies on the economic analysis of VGI. In the NREL 2017 report, bulk energy storage, operating reserves, and frequency regulation were considered as use case models of V2G (Vehicle-to-Grid), and the main factors of cost and benefit for economic analysis were presented [7]. Other research suggested regulation service as a V2G model for delivery fleets and conducted an economic analysis for this [8]. Similar research analyzed the costs and revenues of plug-in electric vehicles using unidirectional and bidirectional V2G technologies, and the simulation results showed that electric vehicles would gain economic benefit if they participated in the grid ancillary service [9]. Pilot studies have shown potential to support frequency regulation in the PJM market, focusing on the short response time of EVs as the main profit over traditional regulation mechanisms. The papers have estimated annual revenues ranging between USD 1200 and USD 2400 per vehicle [10,11]. A V2G EV school bus was economically compared with conventional diesel vehicles, showing that savings are approximately USD 230,000 per bus [12]. A business model was analyzed using real data set in the German market for frequency regulation and evaluated to make revenues from EUR 274,992 to EUR 510,656 for 10,000 EVs [13]. Most recently, a project for frequency regulation in Denmark showed that a single car participating in the service for 13,000 h out of two years can make an average revenue of 1860 EUR per year [1].

For renewable energy, VGI is also considered as a way participation could stabilize power generation [14]. In this paper, the allocation approach is proposed to maximize the annual profits by properly combining EV chargers, PV (Photovoltaic) panel location, and panel size. Another research shows that a private household with integrated PV storage is also estimated to increase net profit by 4% per year [15]. Similarly, the VGI service for wind power smoothing is estimated [16]. Likewise, applications for renewable energy integration with EV have begun to get attention.

Most of the research on VGI economic analysis has been focused on frequency regulation and renewable energy and limited to bulk energy storage and operating reserves [17–19]. As a new application of VGI service, peak shaving is also being considered and the cost benefit analysis has recently begun to be studied [20]. Like arbitrage trading in finance, an EV owner can purchase electricity from the power grid when the electricity price is low and sell it to the power grid when the electricity price is high, which leads to a peak shaving effect. Researchers analyzed the economic feasibility under the time-of-use electricity pricing scheme in a regular electricity market where the electricity price is different for peak load, basic load, and valley load.

However, in the Korean DR market, we can consider a case where a service provider could not only play a role in peak shaving but also play a role in load reduction, like a generator, inducing the effect of lowering the market price. In this respect, little research on the DR market application has been done. When the demand is expected to be so high that blackout is likely, a utility company may want to reduce the excess demand by turning off highly consuming equipment. Also, at regular times, the stored energy can be used for decreasing the system marginal price, as a generator does, when the price is high. For these two DR purposes, VGI service can be considered. Furthermore, in the VGI service for DR application, the roles of participants and their interests are very important. Depending on the financial compensation and subsidy, each stakeholder might want to participate or not. From this viewpoint, a research study investigates user acceptance of such smart charging schemes with financial compensation to improve grid stability and renewable energy integration [21]. Reference [20] analyzed the costs and benefits of stakeholder participating in VGI services according to battery prices and peak-time prices at a regular market. In this research, the possibility of each stakeholder's participation in the VGI service was reviewed but Li et al. [20] failed to consider the possibility of interaction and financial transaction that may occur among stakeholders. However, in this paper, each cost and benefit was analyzed in consideration of the interactions that may occur among utility, service provider, government, and EV owner. Among stakeholders in the VGI service, one needs to pay settlement fee and/or subsidy to the other stakeholder, such as service provider or EV owner, which implies that the relationship among participants is very important for the service's success. Therefore, in this paper, we propose a framework that can economically evaluate businesses of all stakeholders while considering their financial relationships.

In short, unlike most of these studies, which focus only on revenue or do not consider cost-effectiveness and influence on other stakeholders, we consider demand response and stakeholders who are able to influence each other by settlement fee and subsidy. Furthermore, this study attempts to derive a scenario in which all stakeholders can succeed from the economic feasibility perspective.

3. Methodology

This section estimates the costs and benefits for each stakeholder participating in the VGI service under the assumption that VGI resources can participate in the DR application. First, the capacity of resources available to VGI was estimated using the actual charger usage data. After that, benefit-cost ratio (BCR) analysis for each stakeholder was performed by defining the stakeholders of the VGI service and estimating the costs and benefits for each stakeholder. Finally, sensitivity analysis according to the change in government subsidies for the service provider and the change in the available VGI capacity was conducted to examine the change in BCR.

3.1. Estimated Available Capacity of VGI

In this study, we used the 2019 charger usage data provided by Korea Electric Power Corporation (KEPCO) to estimate the available VGI capacity. These data were obtained from chargers installed in apartments and workplaces, i.e., chargers that can be used for the public rather than personal chargers. This can show the usage of public chargers. Among the various chargers included in the data, the analysis was conducted only on the data of the 7 kW charger. This is because only chargers less than 7 kW can perform VGI due to the technical characteristics of the VGI currently being studied in Korea. In addition, since the data do not represent the actual capacity used for VGI, several assumptions were made to estimate the available VGI capacity. The main assumptions are as follows: (1) Electric vehicles remain capable of charging and discharging while connected to a charger. (2) To ensure the stability of the demand response resource, the DR capacity is registered at the minimum of the available capacity per time period. (3) The consumer participation rate for VGI service is 10%. (4) The efficiency of charging and discharging is 95%. Based on these assumptions, the available VGI capacity was estimated using the following equation. In the equation, p represents the probability of charger availability and the capacity of the total supplied chargers is $7q$ kW, where q is the total number of chargers.

$$Cap_t = 0.1 \times 0.95 \times \underset{\forall i}{\text{mean}} p_{it} \times 7q(\text{kW}) \quad (1)$$

The probability of the availability of charger i at t (p_{it}) was estimated as the ratio of the connected cases among the total observations n. This was calculated as follows:

$$\begin{gathered} p_{it} = \left(\sum_{d=1}^{n} I_{it} \right) \times \frac{1}{n} \\ where\ I_i = \begin{cases} 1,\ if\ an\ EV\ is\ connected\ to\ a\ charger\ i\ at\ t \\ 0,\ others \end{cases} \\ n = the\ number\ of\ observed\ days \end{gathered} \quad (2)$$

Figure 1 shows the mean probability of charger availability for each time period estimated using the above equation.

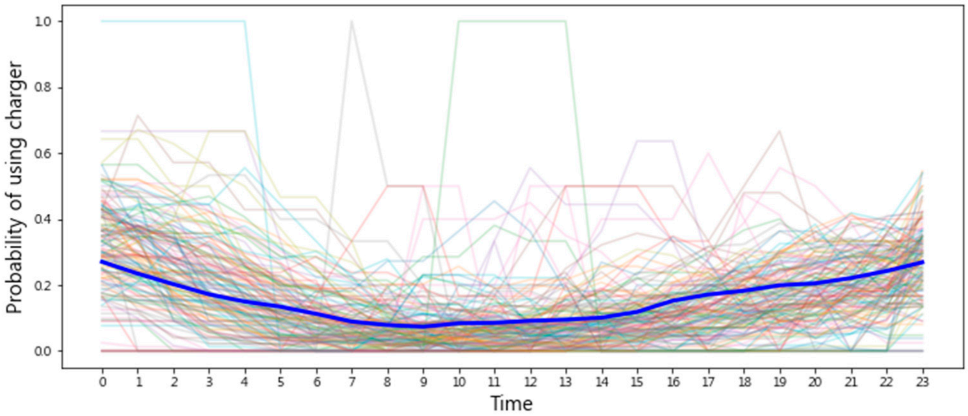


Figure 1. The estimated probability of the charge availability.

The number of deployed chargers (q) was calculated based on the EV deployment plan in Korea and the number of 7 kW chargers per EV. As of October 2019, the number of EVs in Korea was 83,407 and the number of 7kW chargers was 13,704 [22]. Therefore, the number of 7 kW chargers per EV was 0.16. The EV deployment plan from 2020 to 2030 is shown in the table below. The cumulative supply plan by 2030 is 3 million units. In 2020, 2022, 2025, and 2030, the plan is to supply 78,000, 153,000, 270,000, and 440,000 units, respectively. Based on the above plan and as of October 2019, the cumulative number of EVs supplied by 83,407 and the cumulative supply of 3 million in 2030, we estimated the cumulative number of EVs from 2020 to 2030 [23]. Based on the plan above and the charger-EV ratio (0.16), the total number of chargers (q) was estimated. In addition, considering the above assumption that the DR capacity is registered at the minimum of the available capacity per time period, the available VGI capacity was estimated as shown in Table 1.

Table 1. The estimated number of 7 kW chargers and available VGI capacity in 2020–2030 (in thousands, MW).

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
# EVs	197	313	466	656	881	1143	1442	1777	2148	2556	3000
# Chargers (q)	32	51	77	108	145	188	237	292	353	420	493
Capacity (MW)	1.77	2.82	4.19	5.90	7.93	10.29	12.97	15.99	19.33	23.00	26.99

3.2. Description of Stakeholders and Business Model

Stakeholders of VGI service are classified into VGI service provider (aggregator), utility company, EV owner, and government. A VGI service provider is an aggregator that provides charging services and VGI programs to EV owners and acts as an intermediary between EV owners and utility companies in the DR market. A service provider participates in the DR market using the collected resources of customers who have subscribed to the service and, in return, pays compensation to EV owners who participated in the VGI program. Utility, as a system operator, pays settlement fees and subsidies to service providers participating in the DR market. Finally, the government participates in the VGI service by paying subsidies. The structure of VGI service is displayed in Figure 2.

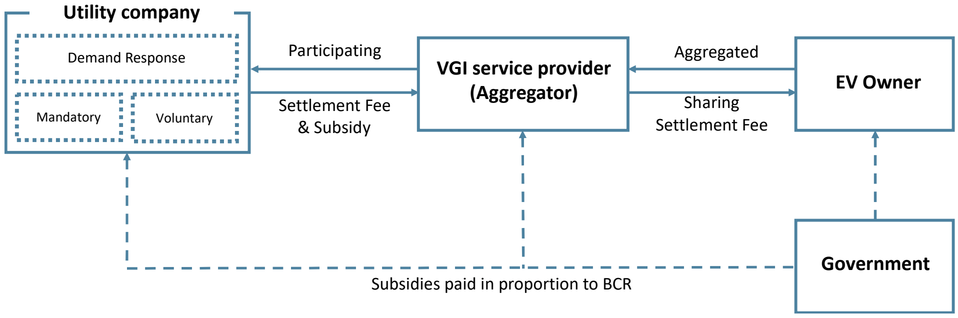


Figure 2. Stakeholders and business model.

3.3. Factors of Benefit and Cost for Each Stakeholder

All factors for each stakeholder are summarized in Table 2, which displays the details of the benefits and costs for each stakeholder. Based on the items in the table, we evaluated the economic feasibility of VGI service from the perspective of each stakeholder.

Table 2. The benefits and costs for each stakeholder.

Stakeholders		Code	Factors	Description
Service provider	B	SB1	Settlement for Type I DR	60 h/year, fixed + performance based (SMP)
		SB2	Settlement for Type II DR	5-year average, 1670 h/year, payment based on SMP
		SB3	Utility subsidy	Compensation for DSM and reserve
		SB4	Government subsidy	Subsidy for capital expenditure (CAPEX) and operating expenditure (OPEX)
	C	SC1	Payment for EV owners	90% of (SB1 + SB2 + SB3)
		SC2	VGI operating system	EMS investment for V1G/V2G
		SC3	Chargers installation	In proportion to consumer participation and access
		SC4	Operation/management	15% of (SC2 + SC3)
		SC5	Recharging	Cost of recharging to the initial SOC
Utility	B	KB1	DSM cost reduction	Benefits due to increased reserve
		KB2	Blackout compensation	The expected reduction in blackout time
		KB3	Government subsidy	Subsidy for CAPEX and OPEX
	C	KC1	T&D investment	Cost for T&D investment for V2G
		KC2	Subsidy for service providers	50% of KB1 allocated for subsidy
		KC3	VGI operating systems	EMS investment for V1G/V2G
EV owner	B	EB1	Reward for VGI participation	(=SC1) payment from service provider
		EB2	Government subsidy	For investment in OBC and EV for VGI participation
	C	EC1	Battery degradation	30 KRW/kWh
		EC2	VCMS	PLC communication and control
		EC3	Bidirectional OBC	AC charge/discharge
Government	B	GB1	Grid investment deferral	Investment deferral on generation, T&D facilities
		GB2	Blackout compensation	(=KB2) the expected reduction in outage time
		GB3	DSM cost reduction	(=KB1) due to increased reserve capacity
		GB4	CO_2 emission reduction	CO_2 emission reduction due to fossil fuel reduction
		GB5	Value-added creation	Economic-value-added creation
		GB6	Production inducement	Production inducement in adjacent industries
	C	GC1	Subsidy	Commensurate with other stakeholders BCR

3.3.1. VGI Service Provider (Aggregator)

The main benefits of the service provider are the settlement fee (SB1–SB2) received from participation in the demand response and subsidies paid by the government and utility (system operator). The DR market in Korea is divided into two types. In the Type I DR market, participants are obligated to reduce the contracted DR capacity according to the system operator's instructions. In general, the system operator issues a reduction request 1 h before the reduction day, and participants can participate for a maximum of 60 h per year only on weekdays (9:00 to 20:00, except 12:00 to 13:00). On the other hand, in the Type II DR market, compensation is paid in proportion to the participant's DR capacity. In general, participants bid in the one-day-ahead market (where SMP is determined) and reduce the amount of the winning bid. The participation in Type II DR is possible 24 h a day but only on weekdays [6]. If both types of reduction orders are issued at the same time, the service provider will preferentially participate in the Type I DR with higher compensation [5]. In the last five years (2015–2019), demand has been reduced for an average of 1730 h, which is estimated by the yearly market reports [24].

It is worth noting that the service provider can receive settlement money not only through V2G but also through V1G (one directional Vehicle-to-Grid). Therefore, it is assumed that both V2G profit and V1G profit are generated together with the EV being charged, and the settlement amount is therefore doubled in this case, as described in Figure 3. On the other hand, when the EV is connected to the charger but not charging, only the V2G effect occurs. As a result of analyzing the data provided by Korea Electric Power Corporation (KEPCO), the situation where V1G and V2G are simultaneously possible is 71.7% of the total.

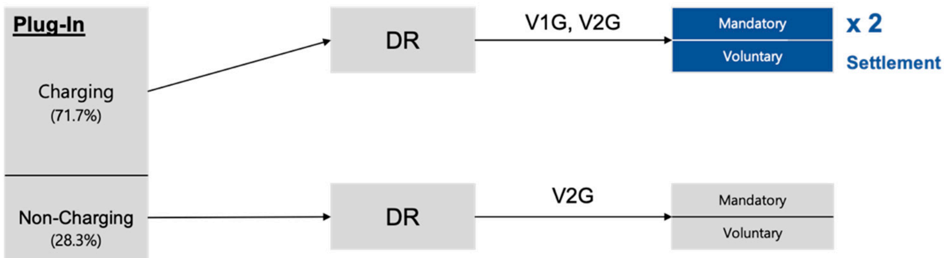


Figure 3. Demand response settlement method.

In addition to the settlement method described so far, the operating scenario for calculating the benefits and costs is assumed as follows: (1) EV owners can participate in demand reduction for up to 1730 h per year depending on the performance of the last five years. (2) EV owners participate in Type I DR for 60 h and Type II DR for 1670 h out of a total of 1730 h. (3) When performing V2G, the service provider recharges to the level of SOC (state of charge) before discharging. (4) All V2G capacity will participate in the DR market.

The formula for calculating the settlement fee for the reduction of obligations by combining these assumptions is as follows: Type I DR pays a fixed basic settlement amount as compensation for the contracted capacity, and the average rate is 35,500 (KRW/kW). The settlement fee based on the amount of reduction is paid based on SMP and 79.65 (KRW/kWh), which is SMP as of May 2018, is used for calculation [6].

$$SB_1 = 35500 \times Cap_t + 0.717 \times (2 \times Cap_t \times 60 \times SMP) + 0.283 \times (Cap_t \times 60 \times SMP) \quad (3)$$

Similarly, the settlement for Type II DR is calculated as follows. Unlike SB1, the settlement for SB2 does not include the basic fixed payment.

$$SB_2 = 0.717 \times (2 \times Cap_t \times 1670 \times SMP) + 0.283 \times (Cap_t \times 1670 \times SMP) \quad (4)$$

In addition, the service provider's benefits include utility subsidies (SB3) and government subsidies (SB4). SB3 is given by a grid operator as a reward for reducing its cost for conducting demand side management (DMS) and securing reserve, and SB4 is a government subsidy for the service provider's investment (capital expenditure (CAPEX)) and operating costs (operating expenditure (OPEX)) required to provide V2G services such as EMS installation, charger installation, maintenance, and recharging costs. In this study, SB3 was assumed to correspond to 50% of the benefit KB1 of the utility and the government subsidy was to pay a certain part of the total cost of the service provider according to the BCR of the service provider.

The service provider's cost is divided into facility investment cost and operation and management cost. The facility investment includes the investment in the energy management system (EMS) for V2G operation, and its cost is assumed to be 900 million KRW. The cost of securing a V2G-capable charging facility also corresponds to the facility investment cost. The investment cost for charging equipment is proportional to the number of chargers available for V2G. Therefore, from Equation (3), the number of chargers required for V2G was obtained by dividing the power of a 7 kW charger and 95% of charge/discharge efficiency. The results are shown in the following Table 3:

Table 3. The number of chargers participating in VGI services.

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
VGI chargers	259	412	613	862	1158	1503	1895	2335	2824	3359	3943

In 2020, the first year of V2G service, investment was required for all chargers participating in VGI, and from 2021, investment will be made only for the increased quantity from the previous year. The investment cost is estimated to be 100,000 KRW per unit as estimated by KEPCO. This can be expressed as the following formula:

$$SC_3 = (E_t - E_{t-1}) \times 100000 \text{ (where, } t = 2020, \ldots, 2030 \text{ and } E_{2019} = 0) \quad (5)$$

Meanwhile, the operation/management cost of the service provider includes the cost (SC1) of paying part of the participation fee to EV owners who participated in V2G. In this analysis, it was assumed that 90% of the sum of SB1 and SB2 is paid to EV owners by referring to the profit-sharing ratio that the current demand management service provider gets when participating in the power market. The cost of operating and managing facilities, including EMS and chargers (SC4), was assumed to be 15% of the sum of the facility investment costs SC2 and SC3. In addition, there was a cost (SC5) to recharge the reduced battery capacity due to participation in V2G. As assumed in the previous section, the recharge cost corresponds to the amount discharged during 1730 h of DR participation. Discharge occurs mostly at peak times and recharge occurs at other times. Taking this into account, the recharging cost was calculated by applying 92.91 (KRW/kWh), which is the average rate during the middle load period [25].

$$SC_5 = 1730 \times Cap_t \times 92.91 \quad (6)$$

3.3.2. Utility Company

Utility has two main benefits. First, by participating in the DR market, the service providers can replace the demand side management (DSM) activities performed by the utility. This means that VGI has the effect of contributing to the reserve capacity as much as the capacity participating in DR. The formula for calculating this benefit is as follows.

In the equation, the effect of contributing to the reserve capacity (*eff_res*) is calculated as 1331 MW based on the facility standards and the cost of DR is calculated as 167,113 Million KRW [26].

$$KB_1 = \frac{Cap(t)}{eff\_res} \times Cost\ of\ Demand\ Response \quad (7)$$

Another benefit of utility is the reduction in outage compensation cost. When VGI resources participate in the operation of the power system, system instability can be reduced, allowing flexible preparation in case of a power outage. Therefore, the effect of reducing the compensation cost for power failure can be expected. To calculate this, the following parameters in Table 4 and calculation formula are required:

$$KB_2 = EB \times M \times t \times n \times \left(\frac{Cap_t}{TC}\right) \quad (8)$$

Table 4. Parameters for KB2.

Parameter	Value
Average electricity rate (EB)	109 KRW/kWh
Compensation multiplier (M)	3
Power outage time (t)	0.1922 h per household
The number of households (n)	23,501,542
Total generation capacity (TC)	125,338 MW

Source: Electric Power Statistics Information System (EPSIS) in Korea.

On the other hand, utility plays a role in inducing market participation by paying settlement fees and subsidies to service providers. The corresponding cost is KC2, and it is assumed that 50% of KB1 is paid for this. In addition, facility investment is required to provide VGI services, and this cost corresponds to KC1 and KC3. KC1 is the cost required to improve transmission and distribution facilities for VGI services, but according to KEPCO, the cost is very low, so it is assumed to be zero. KC3 assumes that the initial cost of EMS investment is 900 million KRW, as estimated by KEPCO.

3.3.3. EV Owner

The benefit of the EV owner is the reward paid from the service provider in exchange for providing VGI capacity for DR. Currently, participants in the DR market in Korea pay about 90% of their profits to customers. By referring to this, we assumed that 90% of SB1 and SB2 are assigned to the EV owner's benefit (EB1). The EV owner's cost includes the cost of devices installed in the vehicle and the cost of battery degradation due to participation in VGI. The devices for VGI are bidirectional onboard charger and VCMS (Vehicle Control Modules). According to the automaker, the two devices will be installed and released in cars starting in 2023. Therefore, the cost for the two devices will only be incurred between 2020 and 2022, and the cost is 75,000 KRW and 50,000, KRW respectively, according to the automaker. The battery deterioration cost was assumed to be 30 won/kWh, as estimated by KEPCO project [27].

3.3.4. Government

The government's most important benefit is the investment deferral in power generation and transmission and distribution facilities. By securing reserve capacity through VGI-DR, the need for constructing additional power generation facilities is reduced. In this analysis, the benefit was calculated by using the construction cost of the LNG combined-cycle generator, which is responsible for the peak load. The cost was calculated as 663,659 (KRW/kW). This cost was calculated as the average of the construction cost of 20 LNG power plants in 2018 [28]. The transmission and distribution facility cost was assumed to be 98,384 (KRW/kW), as estimated by KERI [26]. Another benefit for government is GB2 and GB3. Each is the same as KB2 and KB1, the benefits incurred by the utility. The reason is that the utility is operated as a public company. In addition, CO_2-related benefits and effects on the industry can be considered. However, since the expected value for this benefit is very small, it was not considered as an important factor in this analysis. Finally, the government's expense is a subsidy paid to each stakeholder. For a subsidy for the service provider, the analysis was performed by changing the total cost of service provider to 0%, 10%, and 23%. The subsidies for utility and for the EV owner are fixed at 0% of the total cost and 5%, respectively.

3.4. Calculation of the Benefit-Cost Ratio

In this study, the benefit/cost (B/C) ratio evaluation method based on the net present value (NPV) has been used, which is widely used to analyze the economic feasibility of large-scale projects. The B/C ratio evaluation method evaluates the economic feasibility for the stakeholder by calculating the net present value of all the benefits and costs for each stakeholder. The net present value of costs and benefits refers to the amount converted into the base year price by applying an appropriate discount rate to the nominal value for each year. In general, if the B/C ratio is ≥ 1, it is considered economical. The equation for calculating the B/C ratio is as follows:

$$B/C\ ratio = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} / \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} \quad (9)$$

In the above equation, B_t is the nominal benefit at time t, C_t is the nominal cost at time t, r is the social discount rate (interest rate or weighted average cost of capital), and n is the analysis period. In this analysis, the analysis period is 10 years, from 2020 to 2030, and 5.5% was applied as the social discount rate reflecting the management guidelines for public enterprises and quasi-governmental organizations.

4. Results and Analysis

This section describes scenarios for different factors and provides analysis results for cases where government subsidized or did not.

4.1. Scenarios

We define scenarios before reviewing the economic values for each stakeholder participating in the VGI service. The goal of scenario analysis is to see if a service provider can make profits by participating in the VGI service and to create a business model in which all stakeholders, including the service provider, can make profits by participating in VGI services. The main content of the scenario is to check the economic feasibility for each stakeholder in the presence and absence of government subsidies. At the same time, we review the economic feasibility of expanding the EV market by increasing the connection rate. In addition, scenario analyses are conducted in consideration of the policies that a utility company can implement by itself in the situation where government subsidies are minimal. The policies that the utility company can implement on its own include a way to open a charging plan exclusively for a service provider and to reorganize the settlement fee for participation in DR. Government subsidies are set to be 0–25% of the total cost of a service provider, and it is assumed that a connection rate is 8–30% and the utility company's support is 50–90% of KB1. A total of 12 scenarios are examined, as follows Table 5.

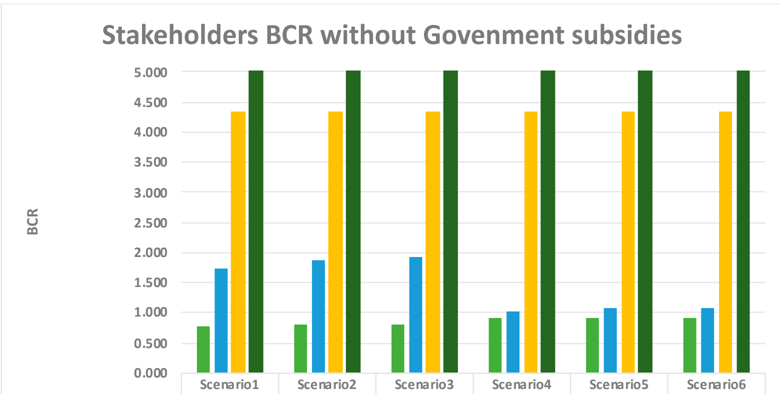
Table 5. Scenarios for analysis.

Scenario	Government Subsidies	Utility Company Policy	Plug-in Rate	Scenario	Government Subsidies	Utility Company Policy	Plug-in Rate
1	$\sum_{i=1}^{10} SC_i \times 0$	KB1 × 0.5	0.08	1–1	$\sum_{i=1}^{10} SC_i \times 0.23$	KB1 × 0.5	0.08
2	$\sum_{i=1}^{10} SC_i \times 0$	KB1 × 0.5	0.2	2–1	$\sum_{i=1}^{10} SC_i \times 0.23$	KB1 × 0.5	0.1
3	$\sum_{i=1}^{10} SC_i \times 0$	KB1 × 0.5	0.3	3–1	$\sum_{i=1}^{10} SC_i \times 0.23$	KB1 × 0.5	0.15
4	$\sum_{i=1}^{10} SC_i \times 0$	KB1 × 0.9	0.08	4–1	$\sum_{i=1}^{10} SC_i \times 0.1$	KB1 × 0.9	0.2
5	$\sum_{i=1}^{10} SC_i \times 0$	KB1 × 0.9	0.2	5–1	$\sum_{i=1}^{10} SC_i \times 0.1$	KB1 × 0.9	0.08
6	$\sum_{i=1}^{10} SC_i \times 0$	KB1 × 0.9	0.3	6–1	$\sum_{i=1}^{10} SC_i \times 0.1$	KB1 × 0.9	0.1

4.2. VGI without Subsidies

Scenarios for the absence of government subsidies are scenarios 1–6. Scenarios 1 to 3 are, in turn, scenarios in which the connection rate increases as the EV market expands with the policy support of the utility company, which is fixed at 50% of KB1. And scenarios 4–6 are scenarios in which the connection rate increases with the policy support of the utility company, fixed at 90% of KB1 in turn. The reason for increasing the policy support of the utility company to 90% of KB1 is to review the business model in which the VGI service can be operated by a service provider, a utility company, and EV owners without government subsidies.

In scenarios 1 to 3, all stakeholders except a VGI service provider have a BCR of 1 or more. This shows the possibility of earning profits through participation in the service. The BCR of the service provider is from 0.77 to 0.79 in scenarios 1 to 3 as in Figure 4, implying that there is no motivation to induce participation in the VGI services. Therefore, the stakeholders other than the service provider might want to find a way to increase the incentives for encouraging the service provider, because VGI service cannot be launched without the service provider and the others cannot make profits. Since this analysis assumes that there are no government subsidies, we review the possibility of policy support from the utility company, which operates the power market. In scenarios 1 to 3, the BCRs of the utility company are 1.77 to 1.91, which shows the possibility of increasing the participation incentives of the service provider through policy support. According to this possibility, we analyze scenarios 4 to 6, which expand the policy support of the utility company to 90% of KB1. When reviewing the analysis results, it can be seen that the BCRs of the service provider are 0.90–0.92, which is still less than 1. But compared to scenarios 1 to 3, it can be seen that there is the possibility for a service provider to earn profits. Therefore, in the absence of government subsidies, policy support from the utility company is expected to play a leading role in VGI services.



	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6
Aggregator (VGI service provider)	0.778	0.791	0.794	0.904	0.919	0.923
Utility company	1.727	1.878	1.917	1.021	1.072	1.085
Ev Owner	4.328	4.329	4.329	4.328	4.329	4.329
Government	63.857	64.540	64.700	63.857	64.540	64.700

Figure 4. Stakeholders' BCR without government subsidies.

4.3. VGI with Government Subsidies

In the case of the Korean power market, a utility company is a public enterprise and has a close relationship with the government's activities. In particular, investments in power generation facilities and accompanying transmission and distribution facilities tend to be led by the government rather than a utility company. As mentioned in Section 3.3.4, through VGI services, the government can take advantage of deferring investment in power generation facilities and transmission and distribution facilities. That is why the government also has an incentive to create a business model in which all stakeholders required for VGI services participate. As reviewed in Section 4.2, in the scenarios without government subsidies, the BCRs of a service provider are less than 1 regardless of the policy support of the utility company. Therefore, the government needs to induce participation in VGI services by providing subsidies to the service provider.

It is necessary to determine the minimum level of subsidies required by a service provider for subsidies and the maximum level of subsidies that the government can pay. In scenarios 1–1 to 3–1, the minimum subsidy level is set at 20% to 23% of the total cost of the service provider for 10 years, and in scenarios 4–1 to 6–1, it is at 8 to 10% of the total cost for 10 years as shown in Figure 5. However, at the start of the business, we need to note that it is about 35–70% of the total investment cost of the service provider in 2020. Meanwhile, the level of government subsidies that the government can pay to the maximum was determined at the level where the benefits and costs for the government were the same. On a 10-year basis, in scenarios 1–1 to 6–1, the government can provide maximum subsidies of up to 41–43% of the total cost of VGI operators. However, in 2020, which is the beginning of the business, the government can pay up to about 15–30% of the total cost of a VGI service provider depending on the connection rate of 8–30%. At the beginning of VGI services, the maximum level of subsidies that the government can pay to the service provider does not reach the level required by the provider. Considering this, it can be seen that subsidy by the government should be paid over a period of time but not for the initial investment.

Scenario analyses with government subsidies assume a period of 10 years. Accordingly, it is assumed that scenarios 1–1 to 3–1 pay 23% of the total cost of the aggregator and scenarios 4–1 to 6–1 pay 10%. The analysis result is shown in Figure 6. Scenarios 1–1 to 6–1 have BCR values of 1 or more for all stakeholders, unlike scenarios 1–6 without government subsidies. This means that if a certain percentage of government subsidies is paid, all stakeholders will be able to profit from VGI services.

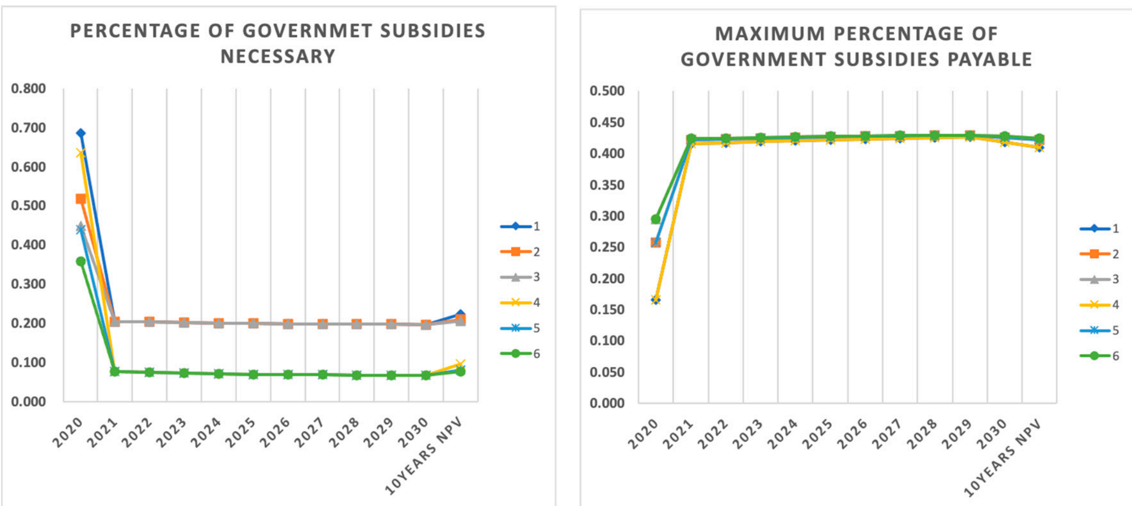
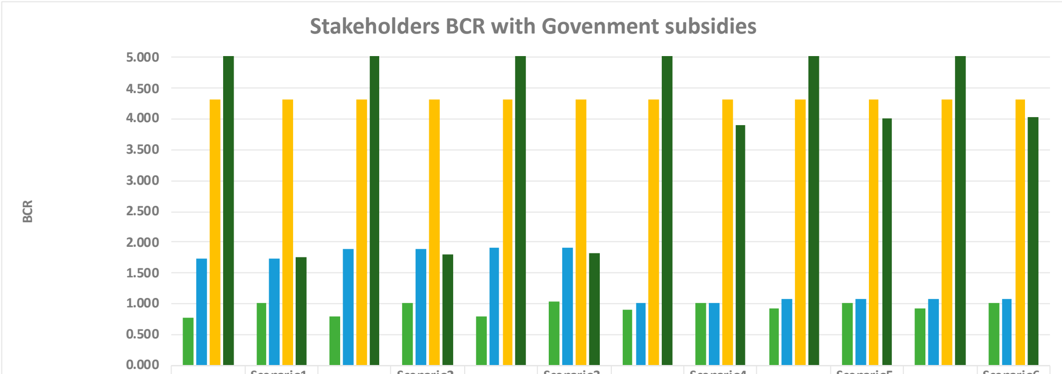


Figure 5. The range of government subsidies.

The main difference between a scenario group from 1–1 to 3–1 and a scenario group from 4–1 to 6–1 is how much the government will invest to increase participation incentives for a service provider.

In scenarios 1–1 to 3–1, where government invests more, both a utility company and government will have BCR values of 1.7 or higher. On the other hand, in scenarios 4–1 to 6–1, the utility's BCR values are close to 1 and the government's BCR values are very high, above 4. From a utility company's point of view, even if additional financial support is provided to induce the service provider to participate in VGI services without the government, the profitability of the utility company is not easy to guarantee. Therefore, the utility company may expect the role of the government.



	Scenario1	Scenario1-1	Scenario2	Scenario2-1	Scenario3	Scenario3-1	Scenario4	Scenario4-1	Scenario5	Scenario5-1	Scenario6	Scenario6-1
Aggregator (VGI service provider)	0.778	1.008	0.791	1.021	0.794	1.024	0.904	1.004	0.919	1.019	0.923	1.023
Utility company	1.727	1.727	1.878	1.878	1.917	1.917	1.021	1.021	1.072	1.072	1.085	1.085
Ev Owner	4.328	4.328	4.329	4.329	4.329	4.329	4.328	4.328	4.329	4.329	4.329	4.329
Government	63.857	1.761	64.540	1.809	64.700	1.821	63.857	3.910	64.540	4.014	64.700	4.039

Figure 6. Stakeholders' BCR with government subsidies.

In summary, VGI service can be defined as the necessary business for generating new revenues of both the government and utility. However, from the point view of the VGI service provider, it is very hard to find any drivers to participate in the VGI service without subsidies from government. Therefore, the government and utility should develop policies or incentive programs like subsidies to make VGI service providers participate. The levels of subsidies paid by government or utility should be determined within the range that the BCRs of both the government and utility can be greater than at least 1.

From scenario analyses, it has been also found that the overall benefit of the stakeholders increases as the plug-in rate increases. This means that it is relatively important to increase the charger access rate in order to activate the VGI service. It is possible to increase the plug-in rate by increasing the number of chargers or motivating EV owners to participate in the VGI service. In a different way, the compensation structure for the EV owners needs to be designed to attract more owners using a marketing strategy.

5. Conclusions and Implications

Although it is well known that VGI has attractive technological features for regulation application, relatively less attention has been paid to the economic valuation for DR. Thus, we discussed the economic value of the VGI service in a DR application in the Korean market. More importantly, our valuation logic includes the relationship among stakeholders who are able to influence each other by a settlement fee and subsidy. Furthermore, based on the suggested framework, this study derived scenarios in which all stakeholders can succeed from the economic feasibility perspective.

Our analysis results show that the VGI service might not be economically viable without governmental subsidy because the profitability of a VGI service provider is not easy to guarantee. It was also shown that all stakeholders can make positive profits only when both government and utility financially support the service provider at a certain level. Moreover, we found that the overall benefits for each stakeholder increase as the plug-in rate increases, which implies it could be a key factor of success. Thus, government needs to design a structure where compensation for the EV owners can attract more EV owners with appropriate marketing strategy to encourage active VGI service program participation.

This paper addresses the challenge for policy change to make VGI service a success in Korea and derive all stakeholders' proactive participation. According to our analysis results, deployment of VGI could raise a conflict of interest among stakeholders. Sophisticated government policy measures and direction are necessary to deal with such subtle relation of gain and loss among stakeholders. As suggested by the results, if a utility company appropriates excessive benefits from its market position, the benefits must be shared among other shareholders in some way.

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References

1. Andersen, P.B.; Toghroljerdi, S.H.; Sørensen, T.M.; Christensen, B.E.; Høj, J.C.M.L.; Zecchino, A. *The Parker Project*; Final Report; DTU Library: Lyngby, Denmark, 2019.
2. EPRI. *Open Vehicle-Grid Integration Platform—Unified Approach to Grid/Vehicle Integration*; EPRI: Washington, DC, USA, 2015.
3. Kempton, W.; Tomić, J. Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. *J. Power Sources* **2005**, *144*, 280–294. [CrossRef]
4. Kempton, W.; Kubo, T. Electric-drive vehicles for peak power in Japan. *Energy Policy* **2000**, *28*, 9–18. [CrossRef]
5. KPX. *Power Market Operation Rules*; KPX: Naju, Korea, 2020.
6. Korea Power Exchange Electricity Market Trading System DR. Available online: https://dr.kmos.kr/nx/nxIndex.do (accessed on 1 October 2020).
7. Steward, D.M. *Critical Elements of Vehicle-to-Grid (V2G) Economics*; NREL: Golden, CO, USA, 2017.
8. De Los Ríos, A.; Goentzel, J.; Nordstrom, K.E.; Siegert, C.W. Siegert Economic analysis of vehicle-to-grid (V2G)-enabled fleets participating in the regulation service market. In Proceedings of the 2012 IEEE PES Innovative Smart Grid Technologies (ISGT) 2012, Washington, DC, USA, 16–20 January 2012; pp. 1–8.
9. Zeng, W.; Gibeau, J.; Chow, M. Economic benefits of plug-in electric vehicles using V2G for grid performance-based regulation service. In Proceedings of the IECON 2015-41st Annual Conference of the IEEE Industrial Electronics Society, Yokohama, Japan, 9–12 November 2015.
10. Kamboj, S.; Kempton, W.; Decker, K.S. Deploying power grid-integrated electric vehicles as a multi-agent system. In Proceedings of the 10th International Conference on Autonomous Agents and Multiagent Systems, Taiwan, China, 2–6 May 2011; pp. 13–20.
11. Kempton, W.; Tomić, J. Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. *J. Power Sources* **2005**, *144*, 268–279. [CrossRef]
12. Noel, L.; McCormack, R. A cost benefit analysis of a V2G-capable electric school bus compared to a traditional diesel school bus. *Appl. Energy* **2014**, *126*, 246–255. [CrossRef]
13. Brandt, T.; Wagner, S.; Neumann, D. Evaluating a business model for vehicle-grid integration: Evidence from Germany. *Transp. Res. Part D Transp. Environ.* **2017**, *50*, 488–504. [CrossRef]
14. Abdelwahab, O.M.; Shaaban, M.F. PV and EV charger allocation with V2G capabilities. In Proceedings of the 2019 IEEE 13th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG) 2019, V2G capabilities, Sonderborg, Denmark, 23–25 April 2019; pp. 1–5.
15. Madlener, R.; Kirmas, A. Economic Viability of Second Use Electric Vehicle Batteries for Energy Storage in Residential Applications. *Energy Procedia* **2017**, *105*, 3806–3815. [CrossRef]
16. Raoofat, M.; Saad, M.; Lefebvre, S.; Asber, D.; Mehrjedri, H.; Lenoir, L. Wind power smoothing using demand response of electric vehicles. *Int. J. Electr. Power Energy Syst.* **2018**, *99*, 164–174. [CrossRef]
17. Mullan, J.; Harries, D.; Bräunl, T.; Whitely, S. The technical, economic and commercial viability of the vehicle-to-grid concept. *Energy Policy* **2012**, *48*, 394–406. [CrossRef]
18. *Oliver Warweg Achievable Revenues for Electric Vehicles According to Current and Future Energy Market Conditions*; IEEE: New York, NY, USA, 2016.
19. Agarwal, L.; Peng, W.; Goel, L. Using EV battery packs for vehicle-to-grid applications: An economic analysis. In Proceedings of the 2014 IEEE Innovative Smart Grid Technologies-Asia (ISGT ASIA), Kuala Lumpur, Malaysia, 20–23 May 2014; pp. 663–668.
20. Li, X.; Tan, Y.; Liu, X.; Liao, Q.; Sun, B.; Cao, G.; Li, C.; Yang, X.; Wang, Z. A cost-benefit analysis of V2G electric vehicles supporting peak shaving in Shanghai. *Electr. Power Syst. Res.* **2020**, *179*, 106058. [CrossRef]
21. Will, C.; Schuller, A. Understanding user acceptance factors of electric vehicle smart charging. *Transp. Res. Part C Emerg. Technol.* **2016**, *71*, 198–214. [CrossRef]

22. Power Data Open Portal System. Available online: https://bigdata.kepco.co.kr/cmsmain.do?scode=S01&pcode=main&redirect=Y (accessed on 1 November 2019).
23. Korean Government. *Future Automotive Industry Development Strategy (National Roadmap for 2030)*; Korean Government: Seoul, Korea, 2019.
24. KPX. *Korea Power Exchange Market Statistics for 2019*; KPX: Naju, Korea, 2020.
25. KEPCO Electricity Tariff. Available online: Cyber.kepco.co.kr (accessed on 1 September 2019).
26. KERI. *Demand Management Project Evaluation Report*; KEPCO: Naju, Korea, 2012.
27. KEPCO. EV-Grid Integration(VGI) and control technology development and wide area V2G field demonstration for EV as a fast-DR resource). Unpublished work, in progress.
28. KPX. *Power Generation Facility Status in 2018*; KPX: Naju, Korea, 2018.