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Consumer Preferences for Smart Energy Services Based on AMI Data in the Power Sector

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Abstract: Advanced metering infrastructure (AMI) is becoming increasingly popular as an efficient means of energy demand management. By collecting energy data through AMI, it is possible to provide users with information that can induce them to change their behavior. To ensure that AMI continues to expand and to encourage the use of energy data, it is important to increase consumer participation and analyze their preferred service attributes. This study utilized a choice experiment to analyze consumer preferences for and acceptance of smart energy services based on AMI data. The results of a mixed logit model estimation show that consumers prefer the electricity information service for individual households and the social safety-net service among convergence services. A scenario analysis confirms that monetary compensation to offset any additional charges is important to maintain the level of consumer acceptance. These empirical findings offer insights for policymakers and companies seeking to develop policies and similar services.

Keywords: smart energy service; willingness to pay; stated preference techniques; choice experiment

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1. Introduction

Energy demand management and the active participation of the public are required to promote carbon neutrality. However, energy consumption is increasing yearly, and it is impossible to force only energy savings accompanied by a decrease in utility. In addition, the power consumption environment is changing due to business closures and increased telecommuting following the COVID-19 pandemic. In the United States, residential electricity use increased by 10% and commercial use decreased by 12% in the second quarter of 2020, while in Canada, the average household's daily electricity consumption in 2020 increased by 12% compared to the previous year [1,2]. According to a report by the International Energy Agency (IEA), due to the COVID-19 pandemic, electricity consumption in services and industries has declined sharply, whereas residential use has increased [3].

In order to respond to the changing energy environment, the goal should be high efficiency with less energy through demand efficiency. In terms of cost-effectiveness, demand management through efficiency improvements would be more effective than an expanded supply. In addition, improved energy efficiency is one of the most strongly prioritized policy measures to achieve carbon neutrality [4]. Various methods can be tested as a way to improve energy efficiency and stabilize supply and demand. Ways to increase energy efficiency include building renovations, electrification of transportation, using high-efficiency electronic products, and demand management. This study focused on demand management to change consumption patterns so as to optimize the use of the energy supply. Demand management is an important method to improve energy efficiency because it increases the utilization of power plants and grids and uses the power system more efficiently and flexibly [5,6].

Demand management can be divided into demand management by price function (e.g., time-of-use tariff, real-time pricing tariffs, seasonal rate tariffs) and by non-price function (e.g., personal, company, smart metering) [5,7–9]. Energy data are important for both the price and non-price functions of demand management. Energy data on power consumption, rates, and real-time demand serve as basic data for establishing rate systems and incentives. Such data also serve to induce energy consumers to participate in active and flexible demand management programs. In order to collect and utilize energy data, real-time energy information collection, stable metering data transmission, and a proper system configuration for efficient energy management are essential prerequisites, and the technology that supports these requirements is known as advanced metering infrastructure (AMI) [10].

AMI refers to an intelligent remote meter-reading system that measures electricity consumption in real time using a digitized automatic meter-reading facility instead of manpower meter reading, providing electricity data in both directions. Energy data collected through AMI can be used for energy demand management (e.g., power consumption management, power usage proposal, consumer behavior change management, distributed power management). They can also be used to inform energy conversion policies and energy efficiency policies. Energy data can help consumers reduce their electricity bills through efficient electricity use and can help power companies contribute to the balance and stabilization of power supply and demand levels by predicting power consumption and improving the operational efficiency of their power facilities. Therefore, energy data can make a great contribution to electricity demand management at the national level [11–13].

Many countries are interested in creating an environment in which consumers can voluntarily participate in demand management by providing energy services to consumers by utilizing and processing power data collected through AMI [14]. In addition, as residential electricity demand increased due to lockdown measures and given the increased telecommuting during the recent COVID-19 pandemic, interest in the impact of post-pandemic electricity consumption load and residential electricity demand management is increasing in many countries [1,15]. Therefore, this study focuses on residential AMI and conducts research on smart energy data services.

Various companies, such as ENNET in Japan and Opower, SDG&E, and Green Button in the US, use AMI data to provide services (e.g., real-time usage, real-time electricity rates, estimated electricity usage and rates, comparisons of power consumption patterns between neighbors) to consumers (Japan's ENNET provides electricity information (electricity consumption, electricity rate, etc.) through the web so that customers can check based on AMI data. In addition, the 'InfoEnnet' service is operated to help customers set specific energy-saving goals [16]. Opower, an American company, is an energy management solutions company that provides utilities with a data management and analytics software platform. Opower encourages customers to reduce energy based on behavioral science, not forced control. Information on optimal energy use is provided to consumers by comprehensively considering the weather and power consumption patterns [17]. SDG&E not only provides customer-tailored Internet rate information using AMI-based control, but also operates customer power consumption consulting [18]. The Green Button initiative is a program that allows consumers to easily check their electricity, gas, and water consumption online and, if desired, share their data with a trusted third party to create new value-added services [19]). This leads to a reduction in power consumption. In the case of South Korea, KEPCO's Power Planner is currently a representative energy data service. The Power Planner service also induces customers to save power voluntarily by providing notification services such as power usage information, advanced notifications when entering a progressive stage, notifications of target usage/charge arrival rates, and notifications of emergency situations related to power supply and demand [20]. It is difficult to obtain data showing the cost of each service, though Power Planner in South Korea is a free service. Despite the difficulty in comparing service costs, such services create new added value while also safely utilizing consumers' energy data and help to reduce energy costs by encouraging consumers to reduce their energy consumption voluntarily. Energy companies in major countries include energy data services among their main services.

Most current energy data services simply provide information on usage, and there is no compensation for the amount of electricity saved. Nor are there trading services between users or energy convergence services (a service that combines energy data and unstructured living information). In particular, for South Korea, consumers' interest in services related to energy data is currently very low, and the establishment of a data collection platform and/or AMI penetration rate is lagging. As of 2021, the nationwide AMI penetration rate in South Korea is 48%, which is relatively low considering that it was 100% in Italy, 52% in the United States, and 48% in Japan in 2017 [21]. Therefore, it is urgent to prepare countermeasures to expand household AMI distribution and increase consumer participation in smart energy data services.

As mentioned earlier, a smart energy data service using residential AMI is very important to increase the consumer participation rate because consumers are the service target. Existing services do not have the capabilities to provide customized services such as compensation for the amount of electricity saved, transactions between users, and energy convergence services. Therefore, this study aims to investigate the degree of preference for each service by presenting these new services to consumers and to find factors that can motivate consumers to participate in energy data services, with conversion into monetary value. Finally, this study aims to contribute to the vitalization of the energy data utilization service market and to the establishment of laws and systems related to energy data utilization.

In a situation where the importance and necessity of utilizing energy data has increased, it is very important to identify market needs for services using energy data and set a service development direction that meets these needs. From this point of view, it is necessary to conduct an ex ante evaluation of consumer preferences and their potential acceptance of AMI data-based energy services. Revealed preference data for the target service cannot be actually obtained at this point and thus this study uses the stated preference technique of collecting data by conducting a survey. To analyze consumer acceptance, a choice experiment (CE), a representative stated preference technique, was applied to analyze consumer preferences as well as their levels of acceptance and willingness to pay (WTP) for energy services based on AMI data in the electric power sector in monetary units.

This paper is structured as follows. Section 2 summarizes previous studies related to the topic at hand and explains the current status and future plans in relation to smart energy services in South Korea, which is the subject of this study. Section 3 designs a questionnaire for this study and introduces the methodology and analysis model applied. Section 4 presents the analysis results and scenarios, and Section 5 presents the summary and describes the resulting policy implications.

2. Background

2.1. Review of Previous Studies

In this paper, when energy services are provided to consumers by utilizing and processing electricity data collected through AMI, the preference structure for the service and the WTP for the service attributes are analyzed. To this end, this section summarizes previous studies related to the topic and seeks implications for this thesis. Several related previous studies are summarized and presented in Table 1.

Table 1. Summary of previous related studies.

Source	Country	Methodology	Main Results
Fettermann et al. [22]	Brazil	CE	A study of consumer preferences for smart meter configuration based on residential characteristics. Attributes: electricity, water, gas, display, mobile applications.
Fettermann et al. [23]	Brazil	CE	A study of consumer preferences for the configuration of smart household meters. Attributes: electricity, water, and gas control, smart meter pricing, energy bills, real estate.
Pepermans [24]	Belgium	CE	A survey of consumer preferences for smart meters. Attributes: comfort, functionality, complementarity, aesthetics, cost savings, investment cost.
Daziano [25]	United States	CE	A survey of consumer preferences for energy data services. Attributes: billing forecast, electricity usage, update, approach, system price.
Richer and Pollitt [26]	United Kingdom	CE	A survey of consumer evaluation of residential power services provided in the platform market. Attributes: power usage monitoring, electric device control, technical support, information security, electricity savings.
Huh et al. [27]	South Korea	CE	A study of preferences of residential electrical services. Attributes: presence or absence of smart meters, number and duration of outages, electricity mix.
Ida et al. [28]	Japan	CE	A survey of consumer preferences for home smart meters. Attributes: usage fee, power consumption visualization, off-peak discount, peak surcharge, remote control, greenhouse gas reduction.
Kaufmann et al. [29]	Switzerland	CE	A survey of consumer preferences for smart metering services. Attributes: tariff, monthly base rate, remote meter reading, real-time consumption feedback, programming and adjustment services, home security and surveillance services.

Notes: CE is an abbreviation for choice experiment.

Looking at the studies in Table 1, Fettermann et al. [22,23] and Pepermans [24] examined consumer preferences regarding the application of smart meters and the composition, use, and security of smart meters. Daziano [25], Rucher and Pollitt [26], Huh et al. [27], Ida et al. [28], and Kaufumann et al. [29] investigated consumer preferences for services using smart meters. The services presented in these preceding studies are simple services such as billing prediction, the provision of information on usage, monitoring, and energy charges. In other words, many existing studies have focused on technical design methods, physical locations, convenience of use, security, and simple information provision by smart meters.

Few studies have investigated preferences for services that provide customized information such as comparisons between neighbors and standby power, as explored in this study. In addition, there are no studies examining preferences for services that can be profitable through trading saved energy or using it for new services (i.e., social safety net, transportation, building safety). This study can be said to be academically differentiated from existing studies because the purposes here are to develop a new service that is differentiated from existing services, to identify consumer acceptance, and to identify energy data services that can attract consumers' attention. In addition, the results of this study are designed to contribute to the preparation of legal and institutional standards for designing new energy data services and energy data utilization schemes.

Consumer acceptance has a significant impact on smart meter implementation and service sustainability [30]. Thus, it is important to develop new services that can attract consumers and increase their acceptance. In particular, if consumers are provided with a service that saves energy and generates profits at the same time, their interest and participation in smart energy services based on AMI data will increase. Therefore, this study analyzes consumer preferences for new services (e.g., services that provide incentives equal to the amount of electricity saved, help with profit activities through electricity trading, services that combine electricity data and atypical life information) as well as existing services. Finally, this study intends to suggest a direction for increasing consumer acceptance through the research results.

2.2. Smart Power Platform Business: Plan and Status in South Korea

In July of 2020, the South Korean government announced the Korean version of the Green New Deal policy to prepare for the future energy paradigm shift by creating a sustainable renewable energy society through active R&D and facility investments to become a leading country in the low-carbon economy [31]. As part of this policy, the 'home smart power platform project' was promoted. The project promised to supply five million apartment units by 2022 with 'smart meters' that provide real-time electricity consumption information in 15 min increments to apartment household members, in place of the existing outdated electricity meters. Participants in this project include the Ministry of Trade, Industry and Energy (MOTIE, a power-based center), and private businesses. The government announced that it would invest 50% of the AMI installation cost, or KRW 352.5 billion out of the total project cost of KRW 705 billion, through the Korea Electrical Industry Foundation Fund [32].

As of September 2021, a penetration rate of only 31.3% was achieved, and only 120,000 contracts were completed among the originally planned 400,000 households. Resident consent is required to install an AMI device. However, as it is difficult to obtain consent from residents due to the lack of publicity, the AMI dissemination project is not proceeding smoothly [33]. In this regard, opinions were raised that MOTIE's plan to expand consumer participation in connection with the national demand response (DR) program (in order to induce business participation, a system in which consumers receive compensation when they reduce their electricity use during times when electricity use is concentrated) did not work properly due to a lack of publicity for the DR system.

As mentioned earlier, given that considerable amounts of public funding are required to carry out a platform business, it is necessary to confirm the existence of social benefits and to increase consumer acceptance in order to secure the legitimacy of the investment and proceed smoothly with the future business. As promoting the smart power platform is important, it is essential to develop services that can attract consumers' attention. It is necessary to identify which parts of the electricity service currently received by consumers are preferred and which parts need to be improved. In addition, it is necessary to investigate in advance the preferences for certain services to be added in the future and reflect these findings in the service plan.

There are currently few studies that have analyzed the value of these services and consumer attitudes. Moreover, in South Korea, the subject of this study, current consumer perspectives, remains relatively unknown. Therefore, it is necessary to select core services among various platform services and to analyze consumer preferences. Furthermore, by converting this preference into monetary value through an economic approach to derive tangible results, this study can contribute to the establishment and revision of plans and goals by public and private companies related to AMI and energy data.

3. Materials and Methods

3.1. Survey Design and Data Collection: A Choice Experiment

The AMI data market has not yet been activated, and the smart energy data service provided based on the data has not yet been released. At this point, there is a limit to collecting related preference data. Therefore, the value of the smart energy data service is estimated by collecting the stated preference data of respondents through a survey. This study explained the AMI data-based energy service to the respondents. In addition, the respondents' preferences for the service were investigated by explaining in detail the service currently being provided and the service to be provided in the future. The selected service attributes are 'electricity information service for apartment complexes', 'electricity information service for individual households', 'household demand response service', 'electricity trading service', and 'data convergence service'. Table 2 shows the five attributes and levels included in the CE questionnaire.

Currently, the service provides only information pertaining to the amount of power used, such as the power consumption of individual households, rates, and a comparison with the previous month's usage. It does not provide consultations about used power or services for efficient energy use management. Therefore, by adding personalized services to the existing services, new energy data services such as an 'electricity information service for apartment complexes' and an 'electricity information service for individual households' can be added. Consumers can receive consulting services on rate contract methods that can reduce electricity charges jointly borne through the 'electricity information service for apartment complexes'. The 'electricity information service for individual households' provides customized information (e.g., basic customer information, power consumption (kWh) and rates, power demand levels (kW), the current rate (KRW), time-based rates (KRW) and the predicted electricity rate for this month, access to a rate table, comparisons among neighbors, message transmission (e.g., notices, peak notifications), advance notifications when entering a progressive stage, access to standby power information) to consumers and provides efficient energy management services.

DR programs are an important strategy for controlling and optimizing energy consumption at the end-user level [34,35]. There should be two-way information between the DR aggregator and the consumers participating in the DR market, and the installation of AMI devices that can read power consumption in real time should precede the start of the program. The AMI-based energy data service provides notifications to the public through the platform when electricity use is concentrated or particulate matter is 'bad'. Through AMI, it is possible to check how much electricity consumption has been reduced, and through the platform, national DR participants can receive incentives according to how much they reduced their electricity consumption [36]. The South Korean government is making efforts to maximize public participation in DR along with the supply of AMI to manage electricity demand. For example, a 'household demand response service' is provided to allow consumers to directly reduce their power consumption and to provide incentives according to the level of consumer participation (approximately KRW 1300 per kWh). However, the 'household demand response service' has been piloted since 2016, but there is still no data to present proper performance due to low awareness. Therefore, the 'household demand response service' was selected as an attribute in this study to investigate consumers' awareness of DR.

Table 2. Descriptions and levels of the attributes used in this study.

Attribute	Description	Level
Electricity information service for apartment complexes.	(1) Provides key numerical information useful for managing electric energy and power facilities in apartment complexes. (2) Provides specific consulting services by analyzing relevant figures.	Level 1: No service provided. Level 2: Service provided.
Electricity information service for individual households.	(1) Provides information so that households can conveniently receive intuitive and useful power information by analyzing power usage patterns based on the amount of electricity used and the electricity rates of individual households. (2) Provision of appropriate energy management services to induce efficient electricity use in individual households.	Level 1: No service provided. Level 2: Service provided.
Household demand response service.	A service in which consumers are compensated in cash or gift certificates for the amount of electricity saved when they reduce their own electricity use after receiving a request that they reduce their electricity use.	Level 1: Non-participation. Level 2: Participated five times a month. Level 3: Participated 10 times a month.
Electricity trading service.	A service that generates sales revenue from electricity transactions between households with different progressive stages or lowers electricity rates with purchased electricity.	Level 1: Non-participation. Level 2: Participation.
Data convergence service.	A service that provides user convenience by merging energy data with data from other fields. (1) Social safety-net service: a service that remotely monitors the electricity consumption of households where a person lives alone or is in a welfare blind spot to check their safety. (2) Transportation-related convergence service: provides information such as the locations of electric vehicle charging stations in an apartment complex, the current status, the availability of charging, and the required time. (3) Building safety management service: provides a service that detects and diagnoses facility abnormalities and abnormal energy consumption due to leaks, short circuits, malfunctions, and other issues.	Level 1: No service provided. Level 2: Social safety-net service. Level 3: Transportation-related convergence service. Level 4: Building safety management service.
Additional electricity bill.	This refers to the monthly additional charge in addition to the existing electricity rate by receiving the AMI data-based smart energy service and refers to the actual price increase rate excluding the increase due to a price level change (unit: Korean won).	Level 1: KRW 1000/month. Level 2: KRW 2000/month. Level 3: KRW 3000/month.

Notes: USD 1.0 was approximately equal to KRW 1112 at the time of the survey.

Recently, in order to improve the utilization of AMI and develop related new energy businesses, a service by which users of small amounts of electricity can trade is being planned through an AMI-based energy data platform [37]. The energy data service is a real-time rate system based on big data that helps to match sellers and buyers in the electricity market by identifying their progress levels. By comparing and showing expected profits after a transaction, consumers can engage in profitable activities. Therefore, in order to attract consumers' attention, this study aims to review consumers' acceptance by adding an ‘electricity trading service’ that not only reduces electricity use but also facilitates profitable activities as an attribute.

The ‘data convergence service’ refers to the provision of a new service by combining two or more types of energy data or combining energy data and non-energy data. In this study, the ‘social safety-net service’, ‘transportation-related convergence service’, and ‘building safety management service’ were selected as major services and applied to the level of the convergence service. The data convergence services are now in the formative stage. Currently in South Korea, the ‘social safety-net service’, which detects abnormalities for the elderly living alone or for the socially underprivileged through electricity consumption, is a representative example of a convergence service [38]. However, the ‘social safety-net service’ was selected as an attribute level to re-evaluate the value of the service due to low public awareness.

Next, the government’s plans to expand the supply of electric vehicles and the increase in consumer demand for electric vehicles are both factors that are accelerating the construction of charging station infrastructure in residential areas [39]. Reflecting the current market, the ‘transportation-related convergence service’ was added at the attribute level to attract consumer demand by providing information such as the locations of electric vehicle charging stations and charging availability.

In an apartment complex where many people live in one building, casualties may occur in the event of a fire. Therefore, safety management to prevent accidents is very important. AMI can detect building anomalies by identifying power consumption patterns [40]. However, there is no service that provides information by diagnosing building safety and detecting anomalies. Therefore, the ‘building safety management service’, which detects and diagnoses abnormal power consumption through AMI to check the safety of buildings, was selected as a new convergence service business and was included as an attribute level.

The last attribute, the payment vehicle, was selected as an ‘additional electricity bill’. Several existing studies of electric power services also set the payment vehicle as the electricity bill [22,23,27]. Therefore, this study also considered the electricity bill as a payment vehicle. To explain this in detail, this refers to a service usage fee that is added to the existing electricity bill every month when using a smart energy service. The established attribute levels of the payment vehicle were KRW 1000, KRW 2000, and KRW 3000 to reflect the recent increase in electricity rates. In South Korea, household electricity bills increased by KRW 7.4 per kWh, representing approximately a 6% increase [41]. The average monthly electricity bill per household is about KRW 50,000 [42], which is an increase of KRW 3000 considering the rate of increase of 6%. After setting KRW 3000 as the maximum amount, the remaining level was set by decreasing this fee at a constant rate.

In this study, we set the number of attributes to six, considering the essential characteristics of the CE survey. While determining the appropriate number of attributes in a CE should be based on research objectives and the trade-offs between the complexity of the survey design and the quality of the data, it is generally recommended to limit the number of attributes to six or fewer [43]. Increasing the number of attributes can result in survey fatigue and response errors. However, there are other crucial attributes that energy services based on AMI data can have. For instance, a strategy that can enhance consumer engagement in the energy service, such as gamification, is an important attribute. Recently, research has reported that gamification, which involves using game elements in non-game contexts to improve the user experience and user engagement, can increase consumer participation and effectively induce behavioral changes and energy efficiency improvements [44–46]. In the future, it is essential to examine the effects of such consumer engagement techniques on consumer choice. The levels of all potential attributes not included in this CE survey were considered to be equal for each alternative; these were fully recognized by the respondents.

As shown in Figure 1, alternatives consist of a combination of the attribute level and the price level. A total of 288 possible alternatives for the proposed attributes can be selected.

Suggesting all 288 alternatives is time-consuming, costly, and inefficient. Therefore, it is necessary to derive a minimum set of alternatives among the 288 options. The minimum set of alternatives in each case was obtained using an orthogonal main effects design created with the SPSS 12.0 package. Finally, twenty-four selected alternatives were obtained, and the randomly mixed alternative sets were divided into a total of eight sets by merging three alternatives into one set, as shown in Figure 1. Then, four sets were randomly assigned to each respondent. In the CE survey, respondents were shown questions consisting of three alternatives, as shown in Figure 1, and were asked to choose their preferred alternative.

	Alternative A	Alternative B	Alternative C
Electricity information service for apartment complexes.	Service provided.	Service provided.	No service provided.
Electricity information service for individual households.	Service provided.	No service provided.	No service provided.
Household demand response service.	Non-participation.	Participated five times a month.	Participated five times a month.
Electricity trading service.	Non-participation.	Participation.	Participation.
Data convergence service.	Building safety management service.	No service provided.	Social safety-net service.
Additional electricity bill.	KRW 2000/month.	KRW 1000/month.	KRW 2000/month.
Check with √ only the one alternative that you prefer among A, B or C (the status quo).	□ A	□ B	□ C

Figure 1. An example of the choice experiment.

This survey was conducted for about a month in June of 2022 by a specialized survey agency (Gallup) targeting 17 major cities. An online survey was conducted by randomly selecting 1021 households nationwide. Respondents to the survey were limited to household heads or spouses of household heads between the ages of 20 and 68 with income. A total of 1021 data instances was obtained, and the representativeness of the sample was reviewed by comparing the characteristics of each respondent with the entire set of households (population). Table 3 compares the characteristics of the respondents and the population.

Table 3. Characteristics of the survey respondents.

Characteristic	Sample	General Population [a]
Sample size	1021	51,829,136
Female	47.2%	50.0%
Education level		
High school and less	8.7%	39.0%
College and higher	91.3%	61.0%
Age [b]		
20–29	7.3%	7.1%
30–39	19.7%	18.0%
40–49	29.0%	25.6%
50–59	26.7%	27.9%
60–68 (60–64 for general population)	17.2%	21.4%

Table 3. *Cont.*

Characteristic	Sample	General Population [a]
Region		
Seoul	21.8%	18.5%
Busan	6.5%	6.5%
Daegu	4.6%	4.7%
Incheon	7.1%	5.7%
Gwangju	2.6%	2.9%
Daejeon	3.4%	2.9%
Ulsan	1.8%	2.2%
Sejong	0.9%	0.7%
Gyeonggi-do	29.9%	26.1%
Gangwon-do	2.6%	2.9%
Chungcheongbuk-do	2.0%	3.1%
Chungcheongnam-do	3.5%	4.2%
Jeollabuk-do	2.4%	3.5%
Jeollanam-do	2.0%	3.5%
Gyeongsangbuk-do	3.3%	5.1%
Gyeongsangnam-do	5.4%	6.4%
Jeju Island	0.2%	1.3%
Monthly household income		
Less than KRW 3 million	14.3%	n/a [c]
KRW 3–4 million	31.2%	
KRW 5–6 million	25.9%	
More than KRW 7 million	28.6%	

Notes: [a] General population stats were extracted from the Korea Statistical Information Service [47]. [b] Age distribution for the general population was limited to heads of households for a better comparison. [c] Only average monthly income per household could be found: KRW 4.5 million in 2021.

3.2. Model Specifications

Consumer preference for smart energy services based on AMI data is analyzed using a discrete choice model (DCM) based on a probability utility model that assumes a decision-maker's utility maximization behavior. Respondents select the alternative that gives them the greatest utility among a plurality of service alternatives. Because CE data have discrete characteristics intrinsically, DCM is suitable as the analysis methodology in this study.

This study analyzed CE data using the mixed logit model, a type of DCM. The mixed logit model is quite flexible and exhibits heterogeneity of preferences because the researcher can directly set the distribution of the coefficients of the attributes [48]. In addition, the mixed logit model can relax the assumptions of the standard logit model because it allows the use of a variance–covariance matrix between the randomized taste parameters [48].

In the mixed logit model, the utility U_{mjc} by which respondent m obtains from one selected alternative j in choice set c can be expressed as Equation (1) [48,49].

$$U_{mjc} = V_{mjc} + \varepsilon_{mjc} = \beta_m{}' X_{mjc} + \varepsilon_{mjc}, \quad \beta_m \sim N(b, W) \quad or \quad \beta_m \sim \ln N(b, W) \tag{1}$$

The utility (U_{mjc}) of each respondent can be divided into V_{mjc}, a deterministic term, and ε_{mjc}, a stochastic term with uncertainty. V_{mjc} can be expressed as the product of a vector (X_{mjc}) of attributes related to the selected alternative j and a vector (β_m) of the coefficients of attributes. It is assumed that β_m follows a normal or log-normal distribution with mean b and variance W and that ε_{mjc} is independent and follows an identity Type I extreme value distribution [48]. In this study, the utility that respondent m feels for the alternative j for the AMI data-based smart energy service can be configured as in Equation (2).

$$\begin{aligned} U_{mj} &= V_{mj} + \varepsilon_{mj} = \beta_m{}' X_{mj} + \varepsilon_{mj} \\ &= \beta_{m1} X_{\text{electricity information service for apartment complex}} + \beta_{m2} X_{\text{electricity information service for individual households}} \\ &\quad + \beta_{m3} X_{\text{households demand response service}} + \beta_{m4} X_{\text{electricity trading service}} + \beta_{m5} X_{\text{social safety-net service}} \\ &\quad + \beta_{m6} X_{\text{transportation-related convergence service}} + \beta_{m7} X_{\text{building safety management service}} \\ &\quad + \beta_{m8} X_{\text{additional electriciry bill}} + \varepsilon_{mj} \end{aligned} \tag{2}$$

Given that respondents choose an alternative that maximizes their utility, the probability that respondent m will choose alternative k can be expressed as Equation (3).

$$\begin{aligned} P_{mj} &= \int \Pr\left(U_{mk} > U_{mj}, \forall k \neq j\right) f(\beta) d\beta \\ &= \int \Pr\left(V_{mk} + \varepsilon_{mk} > V_{mj} + \varepsilon_{mj}, \forall k \neq j\right) f(\beta) d\beta \\ &= \int \Pr\left(\varepsilon_{mj} - \varepsilon_{mk} < V_{mk} - V_{mj}, \forall k \neq j\right) f(\beta) d\beta \\ &= \int \frac{\exp(V_{mk}(\beta))}{\sum\limits_{j} \exp(V_{mj}(\beta))} f(\beta) d\beta \\ &= \int \frac{\exp(\beta_m{}' X_{mk})}{\sum\limits_{j} \exp(\beta_m{}' X_{mj})} f(\beta) d\beta \end{aligned} \tag{3}$$

The mixed logit model used here was estimated by applying the Bayesian approach presented by Train [48]. Compared to the classical approach, the Bayesian approach has been widely applied in various studies because the estimates of respondents' part-worth values are nearly identical [50–53]. The Bayesian approach solves the problem of computational complexity and can overcome the initial value problem because it does not require function maximization calculations [50,54]. Consistency and efficiency can also be obtained under more flexible conditions [48]. Therefore, the Bayesian approach is an appropriate approach for the analysis in this study.

On the other hand, the coefficient values estimated based on the mixed logit model represent the marginal contribution to the utility of each attribute with an arbitrary unit. They do not have any comparable meaning between attributes. Therefore, it is necessary to calculate the marginal willingness to pay (MWTP) for each attribute from the estimation results. The MWTP is the amount consumers are willing to pay to keep their utility unchanged when the quantity or quality of an attribute changes by one unit. This can be interpreted as the amount of change in the consumer's compensated surplus when the attribute changes. The MWTP that respondent m has for the remaining attributes (X_{jn}), except for the attributes ($X_{j,price}$) related to price, can be derived through Equation (4).

$$MWTP_{X_{jn}} = -\frac{\partial U_{mj}/\partial X_{jn}}{\partial U_{mj}/\partial X_{j,price}} = -\frac{\beta_n}{\beta_{price}} \tag{4}$$

Additionally, by analyzing the relative importance (RI) of each attribute, it is possible to compare how much each attribute affects the decision-making step. The RI was calculated using the part-worth of each attribute, and the partial value of each attribute n was derived by multiplying the level difference of the attribute by the coefficient value β_n.

$$RI_n = \frac{part\text{-}worth_n}{\sum\limits_{n} part\text{-}worth_n} \times 100 \tag{5}$$

4. Results and Discussion

4.1. Estimation Results: Public Preferences for Smart Energy Services

Table 4 presents the estimated results based on the mixed logit model using a total of 1021 data points. The median MWTP and RI of 2000 extracted values were calculated based on the mean b and standard deviation $\sqrt{W}$ of the estimate and the distribution of the estimated coefficients. As a result of the estimation, the average and standard deviation of all attribute coefficients except for the estimated coefficients of the 'transportation-related convergence service' and the 'building safety management service' among convergence services were statistically significant at the 1% confidence level.

All attributes followed a normal distribution, and the sign of the additional electricity bill, which was the payment vehicle used here, was analyzed as negative, while the signs of the other statistically significant attributes were analyzed as positive. The sign of the estimation coefficient indicates the direction of consumers' preferences for the corresponding attribute. Given that higher suggested amounts are linked to a lower WTP, a negative sign is consistent with general perceptions [53]. In addition, because the remaining attributes provide services to consumers, the estimated result with a positive sign coincides with universal perceptions and explains the general direction well.

Because the standard deviation of each coefficient varies according to consumer preferences, it represents the heterogeneity of the respondents' preferences. The ratio of consumers' attitudes (positive or negative) to attributes can be confirmed using the mean and standard deviation of the attributes while assuming a normal distribution. By calculating the probability of above zero and below zero, it is possible to visualize the public's preference for the corresponding attribute. As presented in Table 5, preference heterogeneity was found to be significant for all attributes, except for 'additional electricity bill'. Among attributes other than price, the heterogeneity of the 'electricity information service for individual households' and the 'household demand response service' is relatively low.

Table 4. Estimation results of the mixed logit model.

Variables [a]	Assumed Distribution	Mean of the Estimate, b	Standard Deviation of Estimate, $\sqrt{W}$	Median MWTP [b]	RI (%) [c]
Electricity information service for apartment complexes	Normal	1.8942 *	17.7736 *	266.91	5.09
Electricity information service for individual households	Normal	3.7739 *	8.4518 *	510.06	5.83
Household demand response service	Normal	0.2105 *	0.4097 *	34.85	3.73
Electricity trading service	Normal	1.2436 *	11.0943 *	199.92	4.0
Social safety-net service	Normal	1.6411 *	69.5055 *	148.82	9.28
Transportation-related convergence service	Normal	−0.2325	22.0953 *	−22.10	5.22
Building safety management service	Normal	0.296	36.9855 *	−55.77	6.69
Additional electricity bill	Normal	−0.4949 *	0.2551 *	-	60.16

Notes: [a] The variables are explained in Table 2. Here, * indicates statistical significance at the 1% level. [b] MWTP was calculated based on 2000 values drawn from the distribution of the estimated coefficient, and the median of the 2000 MWTP observations is presented. [c] The RI of each attribute was calculated based on 2000 values drawn from the distribution of the estimated coefficient, and the mean of the 2000 RI observations is presented.

Table 5. Share of the population showing a positive or negative value for the attributes.

Variables	Percentage of the Distribution (%)	
	Above Zero	Below Zero
Electricity information service for apartment complexes	54.4	45.6
Electricity information service for individual households	67.4	32.6
Household demand response service	69.5	30.5
Electricity trading service	54.4	45.6
Social safety-net service	50.8	49.2
Additional electricity bill	97.4	2.6

The mean and standard deviation of the coefficient estimates of the mixed logit model provide information about the direction of the preference and the degree of heterogeneity, but it is practically impossible to compare the relative values of the attributes due to the use of different units. In this case, the MWTP can demonstrate both the relative value of the attribute and the actual monetary value that consumers place on it. It was found that consumers are willing to pay the following amounts in addition to the monthly electricity bill when receiving an AMI data-based smart energy service: 'electricity information service for apartment complex': KRW 266.91/month; 'electricity information service for individual households': KRW 510.06/month; 'household demand response service': KRW 34.85/month; 'electricity trading service': KRW 199.92/month; 'social safety-net service': KRW 148.82/month.

With regard to whether or not the attributes included on the questionnaire are providing the services, MWTP can be directly compared because the units are the same. Therefore, because the MWTP is high in the order of the 'electricity information service for individual households', 'electricity information service for apartment complexes', and 'electricity trading service', it can be seen that consumers prefer the 'electricity information service for individual households' relatively more. In order to attract consumers' interest in smart energy services, it is necessary to emphasize the provision of customized power information and energy management services for individual households. If personal service is provided according to the individual's power usage pattern, and information is provided so that a customized electricity bill plan can be selected, it will be a key service that will attract consumers' attention.

The 'electricity trading service' is a new service that is not yet available in South Korea and is at the stage of demonstration and pilot projects, but it is found that consumers are showing some interest. Currently, South Korea has an electricity trading system between neighbors, but the area is limited to Jeju Island, and this system is different from the 'electricity trading service' because it deals with directly produced electricity. The 'electricity trading service' is a hypothetical service that is not yet provided, but consumers are showing interest. Therefore, if the related infrastructure and legal system are systematically prepared, it will become a service that can attract consumers.

As mentioned earlier, MWTP can assign consumer utility as an economic value, but a direct comparison may be difficult for some attributes because the units for each attribute are different. Therefore, this study compared the importance of attributes by analyzing RI. It can be seen that consumers prefer these services in the order of the 'social safety-net service (9.28%)', 'electricity information service for individual households (5.83%)', 'electricity information service for apartment complexes (5.09%)', 'electricity trading service (4.0%)', and 'household demand response service (3.73%)'.

AMI technology is emerging as an alternative to solve social issues, such as the increasing number of people living alone due to an aging society and the increasing number of elderly people with dementia, and it is improving the welfare of the energy underprivileged. Given that consumers prefer the 'social safety-net service' among all of the presented services, it is expected that the 'social safety-net service' will be able to establish itself as a new service model that solves social problems and secures public acceptance. In addition, if publicity for the 'social safety-net service' and its importance are actively provided to consumers, a social safety net will be quickly established, as will participation in smart energy services.

There is a range of technological and other options that can lead to energy efficiency improvements. For example, Blok and Nieuwlaar [55] categorized options for improving energy efficiency into reduction of losses, energy recovery, more efficient conversions, and completely new technologies. In the building sector, measures such as better insulation, the prevention of leakages, lighting upgrades, the improvement of appliance efficiency rates, and the building of energy management systems are widely adopted to improve energy efficiency. The energy service presented in this study, which uses AMI data, is just one of several measures that can improve energy efficiency and change users' behaviors.

When combined with such various technical means for energy efficiency improvements as mentioned above, the smart energy service is expected to spread rapidly in the market and generate demand management effects.

Incorporating AMI data-based energy services that align with consumer preferences, alongside different energy supply facilities, can significantly enhance energy efficiency and system operation stability levels. The utilization of AMI data can also provide valuable insights to balance the supply and demand of renewable energy and assist in determining the appropriate sizing of heat networks, energy storage options, heat pump installations, and EV infrastructure [56]. By integrating the operation of home solar power plants, which is gaining popularity at present, with AMI data-based energy services, it is possible to satisfy diverse consumer needs, such as identifying and providing notifications about optimal power generation and storage times that align with consumer preferences. This integration can lead to more effective uses of energy and an improved consumer experience.

4.2. Simulations: Scenario Analysis of Smart Energy Services

One of the advantages of various discrete choice models is that they can calculate the selection probability for hypothetical alternatives. In this section, simulations are performed based on the estimation results of the mixed logit model. Several hypothetical AMI data-based smart energy services can be released in the future and these simulations quantitatively analyze consumers' potential preferences for such possible services. A scenario analysis was conducted while considering the following two aspects: (1) the difference in selection probability between the launch of a new service and the current state, and (2) changes in consumer acceptance rates according to the frequency of participation in DR.

First, Scenario 1 compares Service 0 (not providing all services), which is in its current state, and Service 1, which provides all services (the convergence service provides only the statistically significant 'social safety-net service'), as presented in Table 6. The probability of selection between the new service and the current status was analyzed while changing the service fee to be paid when receiving a new service. Changes in consumer acceptance between services were estimated and are presented in Table 7. As a result, consumers were found to prefer a hypothetical scenario that provides services as opposed to the current state. However, even a small increase in the service fee drastically reduced consumer acceptance. Consumer acceptance, which was approximately 63% when this fee was KRW 10, decreased by half to 32% when the fee was raised to KRW 40. Consumer acceptance decreased by less than 50% when the service charge was raised to KRW 19 or more. Consumers are very sensitive to this type of fee, but it was confirmed that about 15% of consumers could be secured even if the price was raised to the maximum amount of KRW 1000. In other words, 15% of customers will continue to use the service even if the price is raised. Therefore, when providing hypothetical services, it appears to be necessary to create an environment in which customers can diversify their choices and provide customized services by subdividing services into premium services, mid-level services, and basic services.

Scenario 2 assesses changes in consumer acceptance rates according to how many times they have participated in DR. Other attributes were fixed as in Scenario 1, and the number of DR participations was increased from 1 to 10. The service fee was fixed at KRW 10. The difference in selection probability was analyzed by comparing the difference in service according to the number of DR participations with Service 0 (status quo). Table 8 presents an explanation of the service and Table 9 presents the changes in the selection probability. It was found that consumer acceptance increased as the number of DR participations increased. In addition, it was confirmed that consumer acceptance remained above 50%. Because consumers are provided with incentives corresponding to the amount of electricity saved through their DR service participation, the increase in DR participation appears to have affected consumer acceptance. Therefore, setting the frequency of DR participation as high as possible can be seen as one of the ways to bolster consumer acceptance when designing energy services. When designing a differentiated service in connection with the results of Scenario 1, one feasible means of inducing consumer choice is to change the number of DR participations.

Table 6. Scenario 1: comparing Service 1 and Service 0 (status quo).

Variable	Service 1	Service 0 (Status Quo)
Electricity information service for apartment complexes	Service provided	No service provided
Electricity information service for individual households	Service provided	No service provided
Household demand response service	Participated five times a month	Non-participation
Electricity trading service	Participation	Non-participation
Social safety-net service	Service provided	No service provided
Additional electricity bill	KRW 10/month ~ KRW 1000/month	KRW 0/month

Table 7. Scenario 1: difference in selection probabilities between Service 1 and Service 0 (status quo).

Additional Electricity Bill (KRW/month)	Customer Acceptance (%)	
	Service 1	Service 0 (Status Quo)
10	62.78%	37.22%
15	55.07%	44.93%
19	49.95%	50.05%
30	39.18%	60.82%
40	32.32%	67.68%
50	28.02%	71.98%
100	19.96%	80.04%
500	16.03%	83.97%
1000	14.86%	85.14%

Table 8. Scenario 2: comparing Service 2 and Service 0 (status quo).

Variable	Service 2	Service 0 (Status Quo)
Electricity information service for apartment complexes	Service provided	No service provided
Electricity information service for individual households	Service provided	No service provided
Household demand response service	Participated 1~10 times a month	Non-participation
Electricity trading service	Participation	Non-participation
Social safety-net service	Service provided	No service provided
Additional electricity bill	KRW 10/month	KRW 0/month

Table 9. Scenario 2: difference in selection probabilities between Service 2 and Service 0 (status quo).

Participation in Household Demand Response Service (Times/Month)	Customer Acceptance (%)	
	Service 2	Service 0 (Status Quo)
1	61.13%	38.87%
2	61.53%	38.47%
3	61.91%	38.09%
4	62.34%	37.66%
5	62.78%	37.22%
6	63.15%	36.85%
7	63.44%	36.56%
8	63.72%	36.28%
9	64.04%	35.96%
10	64.38%	35.62%

When comprehensively considering the various selection probability simulations mentioned above, consumer acceptance (selection probability) tends to drop rapidly even if a low level of fee is charged for the service. In South Korea, smart energy services based on AMI data are not active, and most of them are free even if only simple electricity information is provided. Therefore, it can be seen that consumers show a very sensitive response to an increase in their electricity bills, even if the increase is a small amount. However, for some consumers, in this case approximately 10 to 15%, it was confirmed that they would continue to choose the service even if the service fee is considerably higher. As mentioned above, because consumer acceptance has a significant impact on smart meter implementation and service sustainability [30], it is necessary to enhance consumer acceptance by providing the services preferred by consumers. In addition, given that approximately 15% of consumers are willing to use energy services even if they have to pay a relatively high usage fee, it is necessary to provide differentiated services (e.g., premium, standard) tailored to consumer preferences, such as changing the frequency of DR participation according to the price. Therefore, diversifying the range of choices offered to consumers can contribute to activating the smart energy service business based on AMI data.

5. Conclusions

South Korea is preparing a policy and institutional foundation to provide smart energy services based on AMI data in the electric power sector, and research is underway to introduce an optional rate system for housing. In this situation, the results of this study can provide directions for policy and institutional arrangements related to smart energy services. In addition, it is thought that the type of service preferred by consumers can be used as evidence when designing an optional rate plan.

This study identified the types of services that could enhance consumer acceptance through intuitive figures. It was found that consumers are not highly indifferent to smart energy services. However, it was also found that consumers were very sensitive to an increase in the service charge, and consumer acceptance rapidly declined when faced with such an increase. Because smart energy services are in their early stages in South Korea, consumer acceptance is a very important part of the continuity of these services. Therefore, it is necessary to plan energy services that will induce consumer preferences and further strengthen the awareness and promotion of the services described here to ensure rational energy consumption and to create demand management effects in the housing sector.

As mentioned above, as a result of the scenario here, it was found that acceptance decreases rapidly from about 63% when the usage fee is KRW 10 to about 50% when the usage fee is KRW 19, falling further to approximately 28% when the usage fee is KRW 50. South Korea showed a sensitive response to additional usage charges because smart energy services have not yet become popular and basic information is provided free of charge. Therefore, it is necessary to induce consumer participation by providing monetary compensation that can offset the additional charge. Among the services planned in this study, the 'household demand response service' and the 'electricity trading service' are services that provide incentives for energy saving and enable profit activities through electricity trading between neighbors. In the scenario analysis results, it was confirmed that consumer acceptance increased as DR participation increased. If institutional help and measures are prepared so that these financial rewards exceed the usage fee and if the aspect is actively used and publicized to consumers, such efforts will help to increase awareness and interest in the service.

There are studies that show that people's trustworthiness and competition with others affect their willingness to pay [57,58]. In particular, one study found that visualizing a reduction of one's electricity bill through comparisons between neighbors showed positive results in attracting participation in energy data services [57]. Like these previous studies, in this scenario study, consumers most strongly preferred the 'electricity information service for individual households', which compares usage between neighbors. Therefore, by stimulating a competitive spirit among consumers, it will be possible to induce action such that they participate in the service and reduce their energy consumption at the same time. In addition, if data storage, supplementation, and management are thoroughly and systematically carried out to increase the reliability of energy services, it will have a positive effect on attracting consumer participation.

This study can contribute to the academic, policy, and energy service industries. First, from an academic aspect, this study proposes a new energy data service that differs from those in previous studies. It is academically meaningful in that it adds new research findings to existing research. Because there is no study of consumer preferences for the new energy data service presented in this study, a diversity of studies on AMI-related smart energy data service is presented. In addition, the study contributes academically in that it can suggest directions for a smart energy data service at a time when the government's interest in services that enable consumers to trade energy equal to their savings or to receive incentives is high and consumer preference research is lacking.

While South Korea is preparing laws and systems for energy data services, there are no standards regarding the number of DR participation instances or energy transaction services, and these services are not yet provided. By examining consumer preferences and their willingness to pay for the provision of these services, this study can be used as evidence of the viability of a service charge system and for setting directions for service provision and preparing legal systems to activate the services. In a situation where it is difficult to find domestic and foreign cases for this study, the results of this study can contribute to the establishment of laws and systems. Hence, it can be said to be an important study in terms of policy.

Because smart energy data services are in their infancy, there are few data on consumer preferences in terms of services. The services presented in this study were designed considering the services in which the government and energy companies are interested. Therefore, the results of this study can be used as evidence for power generation or platform companies planning smart energy services. In addition, given that this study presented the patterns of changes in consumer preferences and price acceptance according to services, it can contribute to planning services that attract consumers' attention by considering the promotional direction of smart energy data services and service price-setting categories.

As of 2021, South Korea is at a very low level when comparing household and industrial electricity rates by OECD countries ((household electricity rate level) OECD average: USD 180.3/MWh; Germany: USD 380/MWh (1st); Denmark: USD 340.3/MWh (2nd); Belgium: USD 338.3/MWh (3rd); Korea: USD 108.4/MWh (34th); (industrial electricity rate level) OECD average: USD 115.5/MWh; UK: USD 187.5/MWh (1st); Germany: USD 185.9/MWh (2nd); Ireland: USD 173.4/MWh (3rd); Korea: USD 95.6/MWh (29th)), but it is a country with high electricity consumption, ranking seventh out of ten countries in terms of electricity consumption as of 2019 [59,60]. There are studies that show that feedback on electricity consumption has a positive effect on energy consumption [61,62].

Accordingly, South Korea is preparing a system to expand energy data services through AMI to efficiently manage energy consumption. This study can contribute to the building of a legal system or service system by identifying how much consumers are willing to pay when receiving customized services tailored to their energy consumption activities and what level of service they prefer. In addition, analyzing hourly consumption patterns through data on daily electricity rates and daily consumption schedules by country and reflecting them in the results of this study will be of great help in calculating data service usage fees. However, in this study, it was difficult to obtain such data, and this situation is presented as a limitation of the progress of this study.

Reductions of carbon use in the global energy sector rely heavily on the adoption of measures such as consumer behavior changes and energy efficiency improvements, particularly in the short term [63]. In order to implement these measures effectively, it is crucial to digitize the energy sector and to ensure the optimal use of energy data [64–66]. Smart meter data can offer the opportunity to understand consumer load profiles and consumption behaviors on a near real-time basis [67]. Thus, data analytics can be used to identify opportunities for programs related to energy efficiency, which incentivize customers to reduce their energy usage. There are numerous examples of service developments related to AMI and smart metering data around the world, such as Green Button and Opower. While this study primarily focuses on a consumer preference analysis in the South Korean context, its empirical findings can provide valuable insights for policymakers and companies seeking to develop similar services and policies in other countries.

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