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Social acceptance and willingness to pay for a smart Eco-toilet system producing a Community-based bioenergy in Korea

Young Sook Eom [a,*], Hyungna Oh [b], Jaeweon Cho [c], Jaai Kim [c]

[a] Department of Economics, Jeon Buk National University, Jeonju-si 54896, Republic of Korea
[b] College of International Studies, Kyung Hee University, Yongin-si 17104, Republic of Korea
[c] Department of Urban and Environmental Engineering, Ulsan National Institute of Science and Technology (UNIST), Ulsan-si 44919, Republic of Korea

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ABSTRACT

This study investigates residents' social acceptance and their willingness to pay for the community-based smart Eco-toilet system (SETS) project developed by Science Walden in UNIST, Korea. As an alternative to the flushing toilets and the centralized sewage treatment system, the SETS project strives to save water and recover bioenergy and fertilizer on a community basis as well as operate with a health check-up service. A nation-wide, web-based contingent valuation survey was implemented for the sample of 1,613 households in 2018. Nearly 80 percent of respondents expressed their intentions to use the Eco-toilet at home. About 70 percent of the sample stated a positive willingness to pay for the construction of a bioenergy facility inside their community. Furthermore, about 41 percent of the sample expressed their willingness to pay for adding a health monitoring sensor. The respondents' stated preference for the SETS project was influenced by their perceptions and attitudes toward human feces, water usage of flushing toilets, and efficiency of bioenergy and renewable energy. The willingness to pay for constructing the Eco-toilet system was estimated to be around $12 USD per month. The willingness to pay for the smart health services was estimated to be about $3.45 USD per month.

Introduction

Human wastes are a major part of the bio-cycle. They are rich in nutrients and organic matter, which can be used as agricultural fertilizers and transformed into an energy source in a form of biogas [1,2]. Yet, human wastes are not viewed as resources but objects to be safely removed from the perspectives of personal sanitation and public health risks. Therefore, most of the urban households in developed countries use flushing toilets where the human wastes are flushed with a significant amount of potable water and transported to centralized sewage treatment plants, in which sewage water is treated while the residual sewage sludge is landfilled or incinerated.[1] That is, the current flushing toilet system in developed countries is inefficient in managing water and energy resources [5]. To cope with climate changes and to promote sustainable development, there has been global efforts which brought a paradigm shift in waste management polices from' treatment and removal' to 'circulation and recovery' [6,7].[2]

In line with these efforts, there have been increasing researches on alternative toilet systems that can save water in flushing and transporting the human feces, and close the loop of the material flows of the human wastes either by converting into bioenergy or utilizing as fertilizers. A urine separating toilets with less water use have been experimented in Sweden since 1990s [8], and are now commercially available in the name of "NoMix toilet" by Wostman in Sweden [9] and by Eawag as part of the Novaquatis project in Swiss [10,11]. There are also emerging marketed applications of alternative toilets such as the Dry Flush© in camper vans

* Corresponding author.
E-mail addresses: yeom@jbnu.ac.kr (Y.S. Eom), h.oh@khu.ac.kr (H. Oh), jaeweoncho@unist.ac.kr (J. Cho), jaai@unist.ac.kr (J. Kim).

[1] Of course, in developing countries, about 2.4 billion people suffer from a lack of basic sanitation and fecal sludge management, which may impose environmental threats and potential health risks [3–4]. This research is focused on developed countries that already have flushing toilets installed at homes and have centralized sewage treatment facilities at the local government level.

[2] Especially, South Korea has implemented the Framework Act of Resource Circulation from January of 2018, which sets out the importance of energy recovery from waste, taking a step further from the existing waste management policies that emphasize to reduce, reuse or recycle waste in the production and consumption stages [7]. Under such a policy direction, R&D efforts on eco-friendly renewable energy technologies to recover scarce resources from wastes are expected to be vitalized in the future. This study is part of those efforts.

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or cottages, which is designed to seal up the feces in consumable materials [12]. Also, nanomembrane toilets that can convert human feces into biogas at home neither using water nor sending it to sewage treatment plants was introduced [13]. The NoMix toilets with the on-site blackwater treatment to recover composts or energy have been implemented in several countries such as Germany [14], Netherlands [15], Australia [16], Singapore [17], and Canada [18]. However, most of these attempts in 'new sanitation [19]' have implemented at the on-site treatment of laboratories or small scales of semi-public facilities or individual houses so that the installations of alternative toilets have not been generalized to urban households in developed countries yet. Moreover, discussions about these water-saving NoMix toilets did not move far enough to be systematically linked to an alternative sanitation system in small or large decentralized communities [20].

On the other hand, there has been ongoing research efforts of developing 'smart toilets.' This allows monitored health information such as basic health data (e.g. diet, body fat and weight) and signs of disease (e.g. colorectal or urologic cancers) to be extracted using the automated urine and stool analysis [21]. The smart toilet automatically sends the health monitoring data to a cloud-based system, which could be integrated into any health care system in the future [22]. However, there has not been any attempts to combine the alternative toilets with the smart health check-up services yet.

Science Walden of the Ulsan National Institute of Science and Technology (UNIST) in South Korea have conducted a three-stage research project that integrates an alternative Eco-toilet system and a smart service since 2015. In the first stage, Science Walden researchers conducted an experiment of a NoMix toilet in the campus laboratory called Sa-wol-dang pavilion [23]. Taking one step further, it has built and operated a living lab called Science Cabin on the UNIST campus, where feces separated from urine is sucked through a vacuum pump and directly sent to a bioenergy facility in the basement [24]. To enhance the economic feasibility and explore potential business opportunities [25], Science Walden has initiated experiments of attaching a biosensor to the alternative toilet to analyze user's urines. Thereby, residents can receive personalized analysis of their basic health status on their mobile phones [24]. In other words, the living lab in UNIST, Korea has developed a Smart Eco-Toilet System (SETS) that can save water, recover bioenergy, and check user's health conditions.[3] Science Walden envisions applying the living lab experiments of the SETS to a community-based decentralized treatment system that promotes water-saving and energy recovery at the urban community levels. Shifting from the centralized treatment system with conventional flushing toilets to a more environmentally friendly but unfamiliar smart Eco-toilet system (SETS) may require residents' acceptance for both the smart Eco-toilet and the Eco-toilet system (ETS). The shift may challenge residents to change their attitudes and behaviors regarding toilet use as well as incur additional costs for the replacement of conventional toilets and construction of bioenergy facilities in the communities.

Previous studies on user acceptance on the alternative toilets adopted either the theory of planned behavior model [10,11] or technology acceptance model [27,28] or value-belief-norm theory [19] to identify factors affecting users' perceptions in accepting environmentally friendly sanitary technology or smart toilets [21]. On the other hand, there are increasing applications of the contingent valuation method (CVM) to measure residents' demand and willingness to pay (WTP) for the improved sanitation services (i.e., installing flushing toilets) as part of *ex ante* economic feasibility studies of public projects in developing countries [29–31].

To the best of our knowledge, this study is the first application of the contingent valuation method (CVM) to investigate residents' acceptance of the innovative smart Eco-toilet and their willingness to pay (WTP) for constructing a community-based bioenergy facility in developed countries. The CVM, a survey-based economic valuation method, extends the technology acceptance model or planned behavior model to elicit individuals' willingness to pay (WTP) for not yet provided services or projects as well as explain factors influencing their behavioral intentions [32,33]. We presented the two CV scenarios of constructing bioenergy facilities connected Eco-toilets inside an urban community and adding health monitoring biosensors to Eco-toilets in a national web-based survey of 1,613 households at the end of 2018. Then, the responses to the two CV questions were jointly estimated using bivariate probit models to elicit respondents' WTP for both the ETS and the futuristic smart Eco-toilet, which may be aggregated to measure *ex ante* benefits of the SETS project.

Materials and methods

A community-based SETS project by UNIST, Korea

This section presents a part of the current research projects that Science Walden of UNIST[4], South Korea, named after Thoreau's essay and Skinner's novel, is working on establishing a community that embodies humanistic values while positively embracing the technological advancement of modern civilization [23]. That is, we introduce a three-stage research project called a smart Eco-toilet system (SETS), that has been ongoing since 2015 by Science Walden.

No-Mix toilet experiments in Science Walden

Science Walden designed and built a pavilion, called "Sa-wol-dang", meaning in Chinese for "a place to think about what is beyond" on the campus of UNIST, Korea. In the pavilion lab, researchers manufactured a prototype of the waterless and urine-diverting toilet dubbed it "BeeVi toilet".[5] A dryer and grinder were installed under the toilet to turn feces into powder. The dried form of feces generated by the BeeVi toilet was delivered to an anaerobic digestion bioreactor. Then, the bioreactor produces biogas, from which methane and carbon dioxide are separated using either the hydrophobic membrane gas separation or the semi-clathrate method [23].[6] About 2,600 visitors including college students used the non-flushing toilet for a year after its opening in May 2016.

A living lab experiment on the SETS by Science Walden.

To carry out the second stage of the BeeVi toilet experiments, Science Walden researchers built a Science Cabin, a lifestyle laboratory, in a two-story building ($198m^2$ in its size) on the UNIST campus. The Science

[3] The concept of Eco-toilet is not new at all. Wostman (2020), a Swedish toilet company, is already commercializing the alternative toilet called Eco-toilet, which combines the classic design with ultra-low-flush capabilities and hygiene standards. The EcoFlush saves water up to 90% by using less than 1 L of water per flush. EcoVac expands EcoFlush by adding a vacuum to transport feces to septic tanks or bio-collectors. The smart eco-toilet in this paper may be viewed as an advancement of Wostman's Eco-toilet with a biosensor. However, the urine-feces separating type of ecological sanitation (EcoSan) in the rural areas of developing countries such as Philippines and Indonesia are differentiated from the eco-toilet presented in this paper in that EcoSan does not require connection to a septic tank or sewer systems. Instead, dry toilets (or composting toilets) are installed in homes and human wastes are used as fertilizer after destroying pathogens [26].

[4] Ulsan National Institute of Science & Technology (UNIST) is one of Korea's leading engineering universities. Science Walden, funded by the National Research Foundation of Korea as a Convergence Research Center project, consists of researchers in various fields, including philosophy, art, economics, design, and urban engineering as well as environmental engineering.

[5] The BeeVi toilet was named after a vision for the future of creating something precious as bees do.

[6] Taking a step further from saving water and converting human feces to bioenergy, the UNIST research team has aimed to establish a Feces Standard Money system where a cyber-money called "Ggool (Honey in Korean)" is paid to users that use the BeeVi toilet, whose payment standards are based on the value of energy converted from human feces [23].

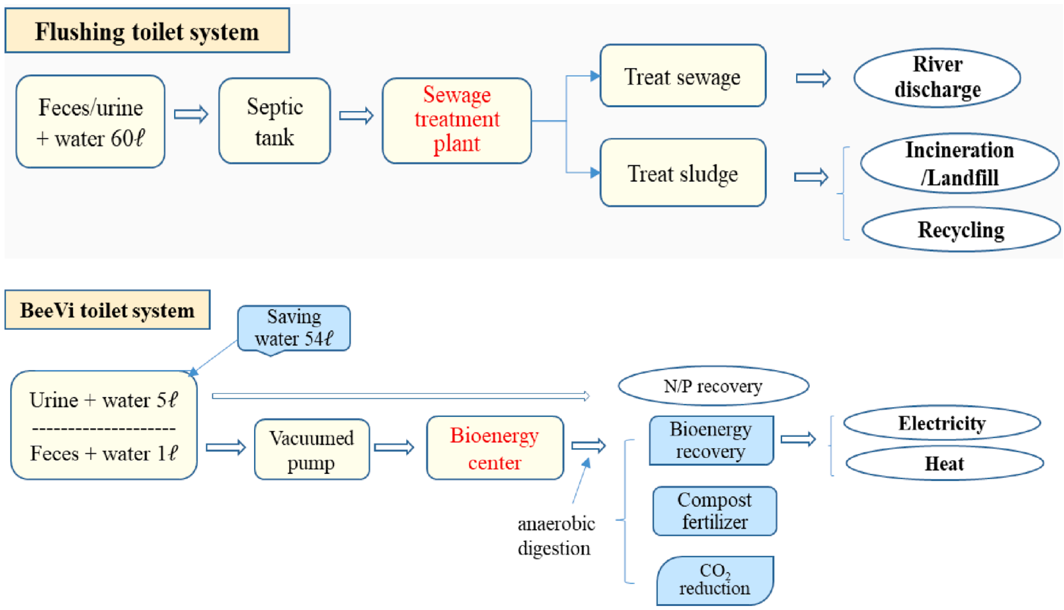

Fig. 1. Residents' easy-to-understand explanations of the two toilet systems.

Cabin is composed of a living space called 'Place Lab' and an experimental space called 'Engineering Lab'. To improve the efficiency of bioenergy production, the BeeVi toilets, which were placed in bathrooms in the Science Cabin, use only one-tenth of the water (about 1 ℓ per use) consumed by the conventional flushing toilets. The BeeVi toilets are directly connected to vacuum suction pumps to transport the feces separated from urine to the basement storage tank. The feces stored in the tank are then combined with food wastes crushed in sinks, and moved to an anaerobic digester in the engineering lab of the basement to be converted into biogas using microorganisms. After purification, the biogas is used as fuel for gas stoves or boilers inside the Science Cabin. The compost fertilizers are used to grow crops in the backyard of the living lab [23,34]. Along with conducting scientific experiments, the researchers collaborated with like-minded artists and social scientists on various workshops and events for the interdisciplinary Science Walden project.

Moreover, based on the comments from a focus group discussion on adding health care features to futuristic toilets, researchers of Science Walden designed experiments installing RGB sensor in the urine storage section of urine-diverting toilets. After a resident uses the toilet, the urine is collected and analyzed immediately using a spectrophotometric analysis on the individual's basic health status, for instance, blood sugar levels for diabetics. The health information is collected through the gateway, LoRa that is connected to the toilet, and stored in the cloud server. The information is then sent to the resident's mobile phone through a transmission device using Bluetooth Low Energy (BLE) in real time [24]

A scenario of a community-based bioenergy production project

The final objective of the SETS project by Science Walden is to install the BeeVi toilets, beyond the campus living lab, in households of urban communities and construct a community-based decentralized bioenergy production system. This requires the replacement of flushing toilets currently in use as well as the transition from the current centralized sewage treatment system into a decentralized treatment system. How to treat human wastes is a sensitive issue, which is strongly connected to emotions about sanitation. Thus, it is crucial to understand what is required for residents to accept changes from the "flush-and gone" system to this innovative and self-sustaining SETS [11]. Based on the research experience in the living lab, the researchers from Science Walden constructed a scenario establishing the SETS in an urban community as follows and elicited stated preferences for the SETS using CVM.

CVM research design

Contingent valuation method (CVM)

CVM is a survey-based economic method frequently used for placing monetary values on environmental goods and services not bought and sold in the marketplace. A CV survey constructs a hypothetical scenario for non-marketed goods or options being valued in a similar manner to the situations in actual markets. The design and implementation of a CV study consist of the following six main steps [33,35,36]. The first step is to define the valuation problem at hand – what services are being valued, who are the relevant beneficiaries (i.e., the target population), sampling and data collection method, and sample sizes, and so on. The second step is to design a hypothetical scenario for the CV survey, which should specify at least the following three basic components: description of alternatives being valued, how it will be provided (i.e., payment vehicle), and the way it is paid for (i.e., elicitation method). The third step is to implement the actual survey design, after going through various efforts such as focus group interviews and pre-tests to reduce potential biases of responses to the hypothetical CV scenarios. The fourth step is to randomly select a sample of the relevant population and implement the survey using a method to yield the highest possible response rate. The fifth step is to understand the data and to analyze the CV responses using various econometric models. Then, the final step is to calculate sample means (or median) of the WTP for the services being valued using parameter estimates of the econometric models. This study carefully followed these procedures required for conducting a CVM research and is described in detail below.

Defining population, sample and survey method

The target population of our survey may be the entire population of a country, because mostly everyone uses toilets every day. However, we supposed a hypothetical community of 1000 households of three-person families to embody the decentralized alternative sewage treatment system near their current residential regions. The sample unit of the CV survey was set on a household basis, considering that toilets are installed in each household. Thus, the sampling frame was defined as heads of the households or their spouses, and was stratified based on respondents' gender, age, and their residential provinces. Incorporating the recent development of survey mode,[7] we adopted a web-based survey method, in which respondents answered the survey using their cell phones.

Designing the CV scenario

Prior to the CV questions, respondents were asked about their perceptions of human feces and conventional flush toilets as well as their bathroom habits. They were then asked how much their household paid for water, electricity, and city gas in the month just before the survey. Those who did not remember the exact amount of utility bills were presented with the national average monthly fees of 2017. The CV scenario is consisted of three sections. The first section describes two different types of toilets and treatment systems. The second section describes a hypothetical situation of constructing of a community-based bioenergy facility connected to Eco-toilets at apartments in the community. The final section illustrates a health monitoring sensor that will be attached to the Eco-toilets at home. The CV scenarios and questions are attached in Appendix A.

A scenario of the two toilet systems

In the first stage of CV scenarios as shown in the description C1-0 in Appendix A, respondents were informed that a flush toilet at a typical household uses 10 ℓ of tap water per flush, and thus about 60 ℓ per day/per person.[8] The sewage mixed with urine and feces is transported from a septic tank to a sewage treatment plant and then discharged after a treatment process. On the other hand, the remaining sludge would be dehydrated and recycled (as composts or energy) or incinerated. The flushing toilet system was illustrated along with a simplified flow diagram in Fig. 1.[9] Subsequently, respondents were informed that the Eco-toilet designed by UNIST (i.e. BeeVi toilet) separates urine and feces and consumes only one liter of water, 1/10 of the average. With another simplified flow chart in Fig. 1, we explained the Eco-toilet system in that the organic matters included in the separated feces are converted into methane gas through anaerobic digestion in the decentralized bioenergy facilities, producing gas and electricity, and composting residues are used as fertilizers for urban farming.

After presenting the two types of toilet systems, respondents were asked if they understood the difference between the two. We explained the two toilet systems again for those who expressed difficulties in understanding them. Then, respondents were asked which type of toilets, between the flushing toilet and the Eco-toilet (BeeVi toilet), they would use if the two types of toilet were available at their home, given that there was no difference in the design of toilets and smell and amenity of bathrooms. They were then asked to provide reasons for their choices.

A CV scenario of constructing a community-based Eco toilet system

Right after expressing types of toilets to use at home, respondents were presented with a hypothetical situation that they are considering to move in a newly constructed apartment complex of 1000 households of three-person families, as shown in the description C2-0 in Appendix A. Every house in the complex would have the Eco-toilet installed, each using only 1 ℓ of water per flush. Now, the local government has a plan to build a bioenergy producing center inside the apartment complex, which can produce electricity and recover heat by applying the anaerobic digester to feces (and food waste) that are collected through vacuum pumps connected to the Eco-toilet of each household.

According to the calculation, based on [39,40], the Science Walden researchers found that the 1,000 households in the community can save up to 162 tons of tap water every day by installing the Eco-toilets, assuming that an adult defecates about six times a day. Moreover, the recovered heat per day can be used to heat shower water for 310 people (about 10% of the apartment residents), and the electricity produced per day can be used to power an electric bus for 900 km. The 450 kg of residues left after producing bioenergy can be utilized as compost for urban farming. Moreover, it can contribute to reducing CO_2 emission, as it does not require fossil fuel to generate electricity. We implied to the respondents that the tap water, saved by using the Eco-toilets, and the bioenergy, recovered from the anaerobic digester, can collectively save multiple utility bills including water, electricity, and gas or food waste collection fees.

Followed by the description of the ETS scenario, the respondents were asked if they would be willing to pay the suggested amount for the construction of the bioenergy production center for the next 5 years, taking into accounts their current household income and expenses including utility bills.[10] As being currently in charge of the municipal wastewater treatment system, the local government is also supposed to construct the bioenergy facility in the apartment complex. Considering this scenario, a natural choice of the payment vehicle for the facility may be an objective local tax – a charge. The tax revenue collected will be deposited into a public fund called a 'bioenergy fund', and solely be used for the construction of the bioenergy facility.

A CV scenario of attaching a health monitoring sensor on the Eco-toilet

Subsequently, as shown in the description C3-0 in Appendix A, a short description followed that Eco-toilets at home will add an advanced function to sterilize the inside and the seat of the toilet by installing UV lamps. In addition, respondents were informed that the Eco toilet could also attach a health monitoring sensor (HMS) to analyze urine separated from feces, and the health analysis data is sent to residents' mobile phones. They were then asked if they were willing to pay the suggested amount of monthly fees in a form of additional phone bills for the smart health check-up function.

Payment vehicle and elicitation format

Reflecting on the potential difficulties of expressing the exact amount of money that respondents are willing to pay, a single-bounded dichotomous choice of WTP question was adopted [41]. That is, they were asked to state either 'yes' or 'no' to the suggested monthly amounts

[7] The in-person survey method was recommended as a good practice of CVM [33,36]. However, internet-based survey modes are getting popular in CV research, partly due to the low survey costs. Studies comparing the two survey modes are fairly encouraging for the use of the internet survey in implementing the CVM because stated preferences or WTP derived from the internet survey modes don't seem to be significantly different from those derived from the in-person survey modes. don't seem to be significantly different from those to the in-person survey modes [37].

[8] In Korea, the amount of water used in the bathroom including taking showers as well as flushing toilets accounts for about 30% of household daily water consumption based in a three-person family [38].

[9] The draft questionnaires schematized a flow chart of the human waste treatment process in a more engineering aspect as show in Figs. 1 and 2 of the Appendix B. The process starts chronologically from flushing toilets, septic tanks, sewerage pipes, to sewage treatment facilities, which subsequently illustrates the technical process of treating the sewage sludge. However, participants of a focus group interview (FGI) with 10 potential consumers pointed out that the engineering flow chart was too complex for the general public to understand. Based on the feedback, we revised the questionnaire with a simplified flow chart as shown in Fig. 1 (and in Appendix A) with verbal explanations. Participants of the FGI understood it without much difficulty and over 90 percent of the respondents in the main survey answered that they understood the description C1-0 of alternative toilet systems as shown in Appendix A without difficulty.

[10] If the CV scenario specified a community cooperative as the entity of carrying out the community energy project, water fee, electricity fee or city gas fee could be chosen as payment methods. However, we selected a bioenergy fund, which is a type of objective tax used as a payment vehicle, because the local government was assumed to provide the community bioenergy center, which is a type of decentralized power supply system. Participants in the FGI discussions judged that the payment method in the form of a bioenergy fund was appropriate.

for both establishing the Eco-toilet system and attaching a health monitoring sensor. It is important to provide incentive-compatible payment vehicles so that respondents may reveal their true values for the SETS project [33,36]. Based on this ground, we selected an objective tax of charge for the ETS scenario and an additional fee for the HMS service as mentioned earlier. The payment frequency is designed to be monthly in accordance with the payment scheme for both charges of utility and mobile phone bills. Based on the open-ended WTP amounts obtained from a pretest survey, the six different monthly bid amounts ranging from the US $1.3 to $12.8[11] per household were randomly assigned to respondents in the main survey. Table 1 presents the experimental design of assigning bid amounts to the potential sample. The number of respondents distributed to each bid amount in the second and fifth columns of Table 1 reflected the WTP distributions elicited from the pre-test. The percentage that respondents are willing to pay for different bid amounts is determined in much the same way as in a dose–response experiment in biology or medicine, or in responses to market prices in demand theory of economics [41,42].

A CVM survey and data

After thorough reviews by Science Walden researchers, the CV survey questions were further examined by a focus group interview. The questions were also pretested with 100 potential respondents, whose responses provided the expected distribution of WTP by applying an open-ended question format. A national web-based survey of 1613 households, responded by the heads or spouses, was conducted from mid-December 2018 to mid-January 2019 using household panels of a leading professional research firm in South Korea with substantial experience with CV surveys.

Considering a potential sample selection bias from implementing an internet-based survey, the sample means of demographic variables were compared with those of the national averages for 2019 [43]. The sample means of age, household income, and higher education level were similar to the national population means. The mean age is 47 years old for the sample and 49 years old for the national statistics. The mean monthly household income is $4,490 for the sample and $4,530 for the national statistics. The proportion of college and higher education levels is 70 percent for the sample and 67 percent for the national statistics. On the other hand, the average of household members in the sample (2.9 persons) was a bit higher than that of the national level (2.4 persons). And the proportion of female respondents in the sample (61 percent) was higher than that of the national population (49 percent).

Table 2 defines selected attitude and perception variables as well as individual characteristics that were included as covariates in the empirical analysis. Respondents seemed to have some knowledge that feces consist of organic matter, as implied in the average of 4.7 on a 1 to 7 linear scale. On the other hand, respondents appeared to have less knowledge that human wastes are resources with the average of 4.0 on a 1 to 7 scale. Most respondents seemed to perceive South Korea as a water stressed country and conventional flushing toilets as using excessive water, indicating the average of 4.0 and 4.1 on the 1 to 5 linear scale respectively. However, respondents seemed to have less confidence in the thermal efficiency of bioenergy as being good and the renewable energy as a good alternative to nuclear power plants, indicating the average of 3.6 and 3.7 on a 1 to 5 scale. The distributions of the CV responses for the SETS project were presented in the fourth and eighth column Table 1. As expected based on the economic theory, respondents were less incline to answer 'yes' to both ETS and HMS service as the bid amounts presented got larger. Compared with the responses to the ETS project, the proportion of positive responses to the HMS service was overall lower and seemed to have reduced evidently as the bid amounts got larger.

[11] The Korean won was converted to US dollars at a rate of $1,174:1 in December 2018 and January 2019.

Results and discussions

Factors affecting residents' intentions to use the Eco-toilet

For the question of which type of toilets between flushing toilets and Eco-toilets would one use, given a hypothetical situation that both types of toilets are available at home, as described in QC1 of Appendix A, 1,270 (79%) out of the total 1,613 respondents expressed that they would use the alternative Eco-toilet as long as sanitation condition including smell and hygienic status is similar to the current flushing toilet.[12] That is, the majority of respondents were willing to use the Eco-toilet even though they can continue to use the current flushing toilet. This high acceptance of Eco-toilet is consistent with the findings from previous works. More than 80 percent of the survey respondents in Switzerland showed interests in moving into apartments with NoMix toilets [10]. Around 80 percent of the respondents in 7 European countries liked the idea of urine-feces separating toilets and were willing to purchase agricultural products grown using compost fertilizers [11]. Over 80% of university students in the USA were favorable to the urine separating toilet being installed in their residence halls [27]. Also, 64% of online survey respondents in the Netherlands indicated their acceptance of new sanitation of source separation with on-site treatment [19].

Treating respondents' binary outcomes of 'yes/no' as the dependent variable, Table 3 reports the probit model results, which are investigating factors affecting the respondents' intentions to use the Eco-toilet. The respondents who intend to use the Eco-toilet seemed to have different perceptions and attitudes toward human feces, flush toilets, and bioenergy compared to those who wish to continue to use flush toilets. Respondents who intended to use the Eco-toilet seemed to be aware that human feces are made up of organic matters, and were less accepting of flush toilets as environmentally friendly. The group more acceptive of the Eco-toilet tended to think that Korea is a water-stressed country and that flushing toilets consume a lot of water. Furthermore, they also seemed to think that the bioenergy is efficient, and that renewable energy is a good alternative to the nuclear power plants.

Among demographic variables, men are more likely to choose the Eco-toilet compared with women. Respondents with higher education are more inclined to use the Eco-toilet than those with less education. On the other hand, home-owners, compared to tenants, indicate a relatively lower acceptance of the Eco-toilet. However, household income level and residential housing types, either apartments or single houses, as well as the metropolitan residential status did not have statistically significant influences on respondents' acceptance of the Eco-toilet.

Residents' stated preferences for the community-based SETS

Bivariate probit model in the random utility framework

In the CV scenario of establishing the Eco-toilet system in a community of 1,000 three-person households, 1,078 (67 percent) out of 1,613 respondents responded positively to the suggested amounts of charges as reported in the last row of Table 1. On the other hands, 656 respondents (41 percent) of the sample expressed their willingness to pay for extra fees on mobile phone bills for adding the HMS to the Eco-toilet. In a user acceptance survey of the smart toilet with disease check-up services, more than 50% of college students in a university in the USA expressed either 'somewhat comfortable' or 'very comfortable' [21]. Considering potential upward bias of the highly educated sample, the acceptance rate of over 40% for the HMS in this study seems to be within a comparable range.

[12] After respondents chose to use either the flushing toilet or the Eco-toilet, they provided reasons for their choices as shown in Appendix A. The reasons for choosing the Eco-toilet (BeeVi toilet) were "It reduces water use", "It is eco-friendly", and "It may produce bio-energy" in order. On the other hand, the reasons for choosing the flush toilet were "it costs money to replace it", "it looks uncomfortable", or "I do not like change".

Table 1
Experimental design of bid amounts and distribution of CV responses.

CV scenario for ETS				CV scenario for HMS			
Bid amount	Assigned in CV survey	'Yes' responses	Proportion of 'Yes' responses	Bid amount	Assigned in CV survey	'Yes' responses	Proportionof 'Yes' responses
1.3	250	198	0.79	1.7	283	173	0.61
2.6	300	209	0.70	4.3	404	181	0.45
4.3	299	202	0.68	6.4	403	153	0.38
6.4	303	203	0.67	8.5	302	95	0.31
8.5	303	187	0.62	12.8	221	54	0.24
12.8	158	79	0.5				
Total	1,613	1,078	0.67	Total	1,613	656	0.41

Table 2
Definitions of variables and sample characteristics.

Variable name		Definitions	Mean (S.D.)[a].
Experimental variables	Bid for ETS	Bid amount suggested for constructing Eco-toilet system (ETS) ($)	6.474 (4.018)
	Bid for HMS	Bid amount suggested for attaching health monitoring sensor (HMS) ($)	7.405 (3.969)
Perceptions/ attitude variables	Feces are organic	Knowledge that feces are organic matter on a 1 to 7 scale	4.7 (1.6)
	Human wastes are Resource	Recognition that human wastes are resources on a 1 to 7 scale	4.0 (1.7)
	FT use lots of water	Attitudes toward water usage of flush toilets (FT) on a 1 to 5 scale	4.1 (0.8)
	FT is environ-mentally friendly	Attitudes toward environmentally friendliness of flushing toilets on a 1 to 5 scale	3.2 (0.86)
	Korea is water stressed country	Awareness that Korea is a water stress country on a 1 to 5 scale	4.0 (0.9)
	BE is efficient	Awareness about the efficiency of bioenergy (BE) on a 1 to 5 scale	3.6 (0.9)
	RE is an alternative to NPP	Attitudes toward renewable energy (RE) as an alternative to nuclear power plants (NPP) on a 1 to 5 scale	3.7 (1.1)
	Buy compost grown products	Attitudes toward purchasing agricultural products grown using composting fertilizer on a 1 to 5 scale	3.6 (0.88)
Socio-economic variables	Household income	Monthly household income ($1,000)	4.489 (2.368)
	Gender	=1 if male; =0 if female	0.39 (0.49)
	Age	Respondent's age (years)	47 (10.1)
	Education	Years of education completed (years)	15.8 (2.41)
	Home owner	=1 if home owner, =0 for else	0.72 (0.45)
	Housing Type	=1 if the resident resides in apartments, =1 for else	0.65 (0.52)
	Metropolitan resident	=1 if the resident resides in one of the 7 metropolitan cities; =0 for else	0.43 (0.49)

Note: [a] S.D. denotes standard deviation.

Table 3
Probit estimates for intentions to use the Eco-toilet.

Variables		Coefficients
Perception/attitude variables	Intercept	−2.45*** (−6.09)
	Feces are organic	0.091*** (3.90)
	FT is environ-mentally friendly	−0.12*** (-2.56)
	FT use lots of water	0.219*** (4.65)
	Korea is water stressed country	0.16*** (4.04)
	BE is efficient	0.103** (2.27)
	RE is an alternative to NPP	0.113*** (3.34)
Socio-economic variables	Household income	−0.001 (−0.04)
	Gender	0.183** (2.26)
	Education	0.059*** (3.55)
	Housing Type	0.05 (0.63)
	House Owner	−0.169** (2.03)
	Metropolitan resident	−0.113 (−1.52)
N		1,613
LR χ^2 statistic		122.5 (0.000)

Note: The numbers in parentheses are the ratios of the coefficients to their estimated asymptotic standard errors (i.e. *t-ratio*).
***. **. * represent significance levels of 1%, 5% and 10% respectively.
LR χ^2 denotes the statistic that the null hypothesis that none of independent variables affects the intentions to use Eco-toilets. The number in the parenthesis is the *p-value* of obtaining the LR χ^2 statistic at least as extreme as the results actually observe under the null hypothesis.

A random utility model, which includes the portion of respondents' preferences that are known to themselves but unknown to researchers as error terms, was applied to analyze factors influencing stated preferences for both the Eco-toilet system and the smart health service [42,44]. In the scenario of ETS project where respondents were asked to choose between two alternative toilet systems, the indirect utility for respondent i is written as Eq. (1)

$$u_{ij} = u_j(M_i, z_i, \varepsilon_{ij}) \tag{1}$$

where $j = 0$ is for the status quo, the state of maintaining the current flushing toilet system, and $j = 1$ is the alternative situation that switches to the Eco-toilet system. The determinants of utility are M_i, i^{th} respondent's income, and z_i, various perceptions or attitudes and socio-demographic characteristics of the respondent. The error term (ε_{ij}) represents components of preferences known to the respondent but not observed by the researcher, so that one can only make probability statements about the respondent's choice of alternatives. Based on this random utility framework, respondent i would express 'yes' to a suggested charge of t_i if the utility with the Eco-toilet system, net of the suggested payment, exceeds the utility of the status quo.

$$u_1(M_i - t_i, z_i, \varepsilon_{i1}) > u_0(M_i, z_i, \varepsilon_{i0}) \tag{2}$$

Following the convention of random utility framework [42,44], the indirect utility function is assumed to be additively separable in deterministic, $v_j(M_i, z_i,)$, and stochastic preferences, ε_{ij}. If the deterministic portion of the indirect utility function, $v_j(M_i, z_i,)$, for each toilet type is approximated to take a linear functional form, then the probability of 'yes' response can be written as Eq. (3).

$$\Pr(yes_i forETS) = \Pr[v_1(M_i - t_i, z_i) + \varepsilon_{i1} > v_0(M_i, z_i) + \varepsilon_{i0}]$$

$$= \Pr(\Delta v_i^E > \varepsilon_{i0} - \varepsilon_{i1}) = \Pr[(\beta_0 - \beta_1 t_i + \beta_2 z_i) > \varepsilon_i^E] \quad (3)$$

Assuming that the error term $\varepsilon_i^E(\varepsilon_{i0} - \varepsilon_{i1})$ is independent and identically distributed (*iid*) with a standard normal distribution, a probit model for Eq. (3) describes the respondent's stated preference for the Eco-toilet system. The main hypothesis in the probit model is whether respondents are less likely to answer 'yes' as the bid amounts (t_i) get larger (i.e., $-\beta_1$ in Eq. (3)), because the bid amounts play a similar role as the market prices in the demand theory of economics [32,44].

Similarly, we can specify a probit model that describes the respondent's stated preference for the (HMS) in a random utility framework, as followed in Eq. (4).

$$\Pr(yes_i forHMS) = \Pr[v_1(M_i - r_i, z_i) + \varepsilon_{i1} > v_0(M_i, z_i) + \varepsilon_{i0}]$$

$$= \Pr(\Delta v_i^H > \varepsilon_{i0} - \varepsilon_{i1}) = \Pr[(\gamma_0 - \gamma_1 r_i + \gamma_2 z_i) > \varepsilon_i^H] \quad (4)$$

where r_i designates the additional fee for HMS service that is assigned to each respondent in the CV survey. Again, the hypothesis in Eq. (4) is that the coefficient for the bid amount in the form of additional fee would have a negative sign ($-\gamma_1$), implying that the respondents would hesitate to express 'yes' as the bid amount gets larger. The error term ε_i^H is again assumed to be *iid* with a standard normal distribution. Because the two CV questions are asked to the same respondents, the error terms in both probit equations (Eqs. (3) and (4)) might contain some common omitted variables. That is, the correlation coefficient ρ between ε_i^E and ε_i^H may not be equal to zero. If then, respondents' stated preferences for the ETS project and HMS services can be specified with a bivariate probit model in which the log likelihood function can be expressed as Eq. (5) [45].

$$\ln L = \sum_{i=1}^{n}[I_1 I_2 ln\Phi(-\Delta v^E, -\Delta v^H, \rho) + I_1(1 - I_2)) ln\Phi(-\Delta v^E, \Delta v^H, -\rho) + (1 - I_1) I_2 ln\Phi(\Delta v^E, -\Delta v^H, -\rho) + (1 - I_1)(1 - I_2)) ln\Phi_{\varepsilon,\eta}(\Delta v^E, \Delta v^H, \rho) \quad (5)$$

where the variable I_1 and I_2 are binary indicators for the two discrete CV responses of ETS project and HMS services respectively. $\Phi(\cdot, \cdot, \rho)$ is the bivariate standard normal cumulative distribution function.

Bivariate probit estimation results

Table 4 reports parameter estimates of the bivariate probit model, Eq. (5), that were estimated via the maximum likelihood method using STATA. Model 1 is a simple model that includes only two covariates. The first is randomly assigned bid amounts for the two CV questions (Bid for ETS and Bid for HMS). The second variable is the predicted probability of respondents' intentions to use the Eco-toilet (Pr(use ET)), which was calculated using parameter estimates of the probit model in Table 3. Since respondents' intentions to use the Eco-toilet were affected by their attitudes and perceptions, as shown in Table 3, those variables were not separately included as covariates in Model 1 to avoid the potential endogeneity problems. Model 2 includes respondents' attitude and perception variables separately, and their socioeconomic variables as well as bid amounts. Based on Wald χ^2 (=174.3 for Model 1 and = 302.2 for Model 2) with *p-value* of 0.000, the overall goodness of fit of the bivariate probit models reported in Table 4 judged to be good, suggesting that covariates included in Model 1 and 2 are appropriate.

Residents' social acceptance of constructing the ETS

First of all, the bid amounts presented to the respondents in a form of charges to construct the ETS (Bid for ETS) exhibited negative signs with statistical significance regardless of model specifications, indicating that the tendency expressing 'yes' diminishes as the bid amounts get higher. Fig. 2 depicts box plots of predicted probabilities of positive responses to the amounts of charges suggested to respondents. Predicted probabilities of 'yes' responses are reduced as bid amounts get larger, which is expected from the demand theory of economics. However, even for the highest charge suggested, $12.8 per month, the predicted probability of positive response is greater than 0.5, which implies that respondents may have high social acceptance of the Eco-toilet system.

In Model 1 of Table 4, respondents who had intentions to use the Eco-toilet were more likely to respond positively to the community-based Eco-toilet system (ETS) project. Most covariates in Model 2, which reflect respondents' attitudes and perceptions, had statistically significant effects on the social acceptance to support the ETS project with expected signs. Respondents who think that Korea is a water stress country and flushing toilets consume a lot of water were more likely to respond positively to the transition to the ETS. The respondents who perceive that human wastes are resources, thermal efficiency of bioenergy is good, and renewable energy is a good alternative to nuclear power plants were more likely to support the ETS project. Moreover, respondents who expressed their inclination to purchase agricultural produce grown from using the compost after bioenergy recovery were more positive about the transition to the ETS. Equally important, older respondents and female respondents were more likely to respond positively to the ETS project. However, respondents' household income, education level, and residential housing type did not have a significant influence on the CV response to the proposed ETS project.

Residents' stated preference for the smart toilet

Similar to the responses to the ETS project, the bid amounts presented to the respondents in a form of additional fees for the smart services (Bid for HMS) exhibited negative signs with statistical significance regardless of model specifications. Fig. 3 depicts box plots of predicted probabilities of positive responses to the amounts of fees suggested to respondents. As expected from economic theory, the tendency of expressing 'yes' diminishes as the additional fees get higher. Compared with the box plots of Fig. 2, the proportion of positive responses to the HMS service in Fig. 3 is overall lower and seem to reduce more clearly as the bid amounts get larger.

For the HMS service to check respondents' health status, older respondents residing in apartments were inclined to give positive answers to the bid amounts presented in a form of extra phone bills. Respondents with higher household income were more likely to indicate their support for the smart toilet, which implies that the smart function of the toilet is a normal good. Furthermore, respondents' attitudes toward the efficiency of bioenergy, the effectiveness of renewable energy as an alternative, and the agricultural produce grown from using composts had a significant influence on the intentions to attach the HMS to the Eco-toilet. The correlation coefficient of the bivariate probit model was estimated to be over 0.6, which indicates that random components unknown to the analyst were moved in the same direction when respondents answered the two CV questions.

Measuring willingness to pay for a community-based SETS

The ultimate goal of CV studies is to measure the amount of willingness to pay (WTP) that makes the respondent indifferent between the status quo and the proposed CV scenario [36]. In other words, WTP is the amount that makes expected value of utility from the two states the same in Eq. (2) (i.e. $E[u_1(M_i - WTP_i, z_i)] = E[u_0(M_i, z_i)]$). Thus, the mean WTP for constructing a community-based SETS was calculated

Table 4
Bivariate probit estimates for the Eco-toilet system and health monitoring service.

Variables		Model 1		Model 2	
		Eco-toilet system (ETS)	Health monitoring service (HMS)	Eco-toilet system (ETS)	Health monitoring service (HMS)
Experimental design variables	Intercept	−0.545 (−2.79)	0.303 (4.77)	−2.7 (−7.32)	−1.86 (−7.32)
	Bid for ETS	−0.0699*** (−8.04)		−0.0734*** (−8.03)	
	Bid for HMS		−0.0875*** (−9.37)		−0.0923*** (−9.42)
Perception and attitude variables	Pr(Use ET)	1.759*** (7.19)			
	Human wastes are Resource			0.041* (1.91)	
	FT use lots of water			0.103** (2.37)	
	Korea is water stressed country			0.081** (2.19)	
	BE is Efficient			0.189*** (4.19)	0.152*** (3.53)
	RE is an alternative to NPP			0.173*** (5.41)	0.09*** (2.80)
	Buy compost grown products			0.164*** (3.75)	0.173*** (4.13)
Socio-economic variables	Housing type			0.024 (0.33)	0.137** (1.95)
	Household income			0.007 (0.42)	0.027* (1.83)
	Age			0.013*** (3.51)	0.012*** (3.43)
	Gender			−0.15** (−1.99)	−0.14 (−1.56)
	Education			0.013 (0.93)	
Correlation coefficient, ρ		0.65 (20.97)		0.62 (18.3)	
N		1,613		1,613	
Wald χ^2 statistic		174.3		302.5	

Note: The numbers in parentheses are the ratios of the coefficients to their estimated asymptotic standard errors (i.e. *t-ratio*).
***. **. * represent significance levels of 1%, 5% and 10% respectively.
Wald χ^2 denotes the statistic that the null hypothesis that none of independent variables affects the responses to the two CV discrete choices.

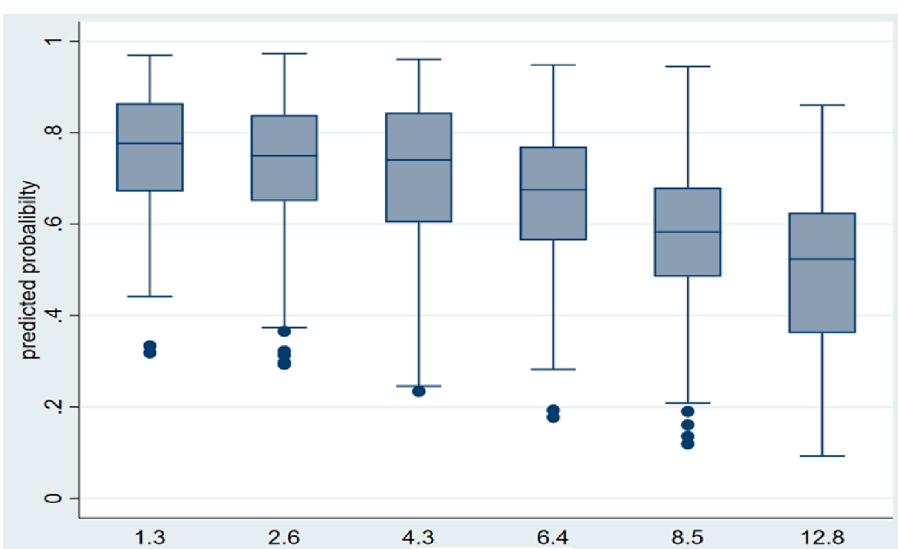

Fig. 2. Box plot of predicted probability of "yes' responses for the ETS by bid amounts.

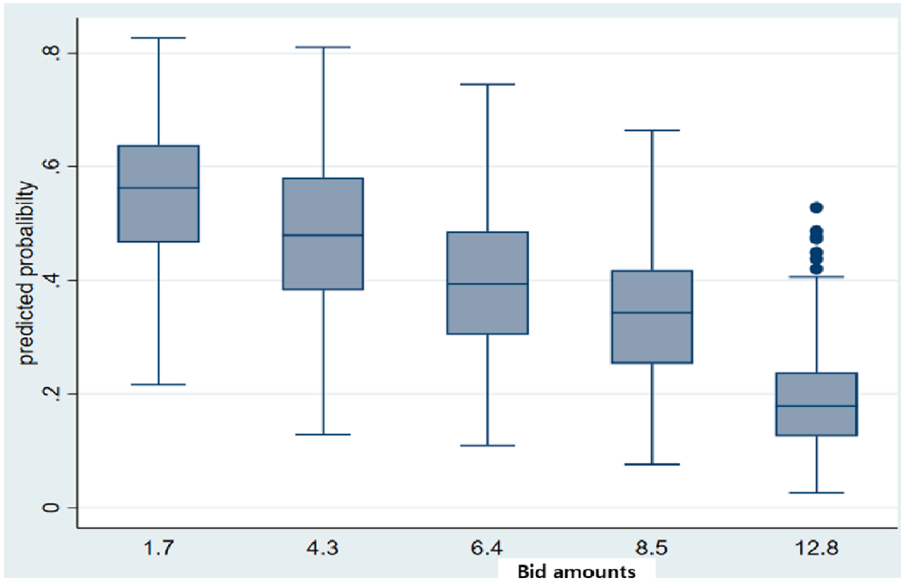

Fig. 3. Box plot of predicted probability of "yes' responses for the HMS service by bid amounts.

using the parameter estimates of the bivariate probit model shown in Table 4 [42,44]. Table 5 reports the sample means of WTP and 95% confidence intervals for the ETS and HMS scenarios, which were evaluated at the mean of covariates. The monthly mean WTP for constructing a community-based ETS was stable around the US $12 per household, and the 95% confidence interval of WTP ranged from $10.3 to $14. Likewise, the monthly mean WTP for the smart health service from attaching a biosensor to the Eco-toilet was also estimated to be around the US $3.5 per household, and the 95% confidence interval of WTP ranged from $2.6 to $4.4.

A brief analysis of economic feasibility and limitations

Based on the CV scenario of constructing SETS for the community of 1,000 households of three-person families, researchers in the Science Walden of UNIST calculated expected amounts of the household-based monthly water savings and the community-based electricity, gas recovery, and compost residues. Assuming that these household and community savings are distributed to each household, expected monthly savings in utility bills were estimated at $6.64 to $16.01 per household according to the scenarios of water, electricity and gas usage. The monthly average WTP for the ETS project in this study was estimated to be the US $12, which fell within the range of savings of utility bills per household. Moreover, considering that each member of households in Korea appeared to pay $30~$40 of phone bills on a monthly average in 2018 [43], the respondents' monthly WTP of $3.45 for adding a smart health check-up service seemed to account for about 10 percent of their monthly mobile phone bills.

Results of this study consistently suggest that residents in urban communities of Korea are willing to replace the conventional flushing toilets with the environmentally friendly Eco-toilet, as well as convert from the centralized municipal sewage treatment system to a decentralized one linking with bioenergy producing facilities. However, it is equally important to find out whether implementing the SETS project is economically feasible. The total annual WTP, that are aggregated to the community of 1,000 households, can be viewed as the annual benefits that residents can expect to enjoy from constructing a bioenergy facility within their community. Therefore, The present value of total benefits of constructing the community-based ETS, based on the monthly WTP of $12 (i.e., annually about $144) per household and discounted at an annual discount rate of 4.5%, is about 660 thousand dollars. The present value of the cost of constructing the bioenergy facility was approximately estimated to be around 640 thousand dollars by an engineering company in Korea. This means that the total benefits residents place on the ETS project just exceeds the total cost of constructing the bioenergy facility. The annual operating costs of the bioenergy facility may be also covered by savings of sewage treatment costs, and electricity and gas, and compost sales by the community.

However, the installation costs of the Eco-toilet are far greater than those of the current flushing toilets. For example, the EcoVac toilet by Wostman Co., which is most similar to the Eco-toilet with vacuum pipes that Science Walden is envisioning, is roughly $2000.[13] The price of flushing toilets in Korea currently ranges from $200 to $300, so the cost of replacing the Eco-toilet may cost more than 7 times of installing the flushing toilets. However, it is optimistic that residents' considerable amounts of WTP for the HMS services added to the Eco-toilet (about $40 annually) may increase the price competitiveness of the Eco-toilet.

Technologies for NoMix vacuumed Eco-toilets and construction of the community-based bioenergy facilities are currently available. However, the costs to install Eco-toilets are yet expensive to be adopted in general urban households. Moreover, to become the SETS project more feasible in urban communities, the technologies associated with the ETS need to be more energy-efficient (e.g. anaerobic co-digestion with food wastes), to demand little maintenance, and to fulfill the personal and urban hygienic requirements [46]. Even with these efforts, the diffusion of SETS project in the urban communities may take quite some time partly because the centralized wastewater treatment

Table 5
Sample mean of WTP estimates for constructing ETS and adding HMS service.

	CV scenario for constructing ETS		CV scenario for adding HMS service	
	Model 1	Model 2	Model 1	Model 2
Mean of monthly WTP	$12.29 (12.26)	$12.14 (7.71)	$3.47 (7.71)	$3.45 (7.86)
95% confidence interval of WTP	$10.32 ~ 14.26	$10.33 ~ 13.96	$2.59 ~ 4.35	$2.59 ~ 4.31

Note: The numbers in parentheses are the ratios of the coefficients to their estimated asymptotic standard errors *(t-ratio)*.

[13] The description and prices of the EcoVac toilet can be found in the website of Wostman (https://www.wostman.se/en/ ecovac).

system has been developed and invested over decades. Switching to an innovative decentralized system would mean abandoning these investments, and applying new decentralized infrastructure requires new investments, resulting in a lock-in [19]. Moreover, implementing a decentralized sanitation system may require a systematic approach with a cluster of technologies embedded in a highly complex network of diverse stakeholders including property developers, engineers and architects, local governments, legal requirements, and users of recovered resources as well as the general public's acceptance.

Conclusions

This study is to investigate individual households' acceptance of smart Eco-toilets as an alternative to flushing toilets and the community acceptance of the Eco-toilet system as an alternative to the centralized municipal waste treatment system. The main findings are summarized as below:

Residents as individual households in Korea seemed to have a high acceptance to use the alternative Eco-toilets at homes, and households as a community also stated a high social acceptance for the Eco-toilet system which constructs a bioenergy facility inside an urban community. Equally important, residents were fairly acceptive of innovative addition of smart health service on the Eco-toilet. One may be critical of the hypothetical nature of CVM in eliciting a social acceptance of the community-based SETS project at this early stage of development. Nonetheless, the findings of high acceptance for SETS in both individual and community levels may be partly attributed to the expectations that the saved water, improved health information, and gas and electricity produced may in return bring financial benefits to the community as well as individual household.

Residents ' social acceptance of the community-based SETS project was not random, but influenced by their perceptions of feces or flushing toilets and attitudes toward renewable energy, rather than their demographic factors. Especially, respondents who were receptive to both the use of Eco-toilet at home and the construction of a bioenergy facility inside the community tended to think that human feces can be used as resources, Korea is a water-stressed country and flush toilets use excessive water. Moreover, those who think that thermal efficiency of bioenergy is good and renewable energy is a good alternative to nuclear power plants were more inclined to support the SETS project as well as the use of Eco-toilet. These results provide valuable insights that, when promoting the commercialization of renewable energy technologies including the SETS, it is important to trigger residents' perceptions or attitudes through education or publicity about the environmental background or expected effects of related technologies.

Residents were willing to pay for considerable amounts for developing the innovative SETS project. The average willingness to pay for constructing a community-based ETS was estimated to be around $12 per month. The average willingness to pay for the smart service of health check-ups was estimated to be about $3.45 per month, which can positively contribute to the price competitiveness of the Eco-toilet. The present value of total benefits measured by annualizing the monthly WTP over the five years matches with the present value of costs of constructing the decentralized bioenergy facility inside a 1,000 households community. Nonetheless, the cost of purchasing Eco-toilet at home is much higher than the cost of purchasing the current flushing toilet yet.

Aside from public acceptance and economic feasibility issues, there are several potential challenges of diffusing the decentralized SETS projects to urban communities from the perspective of energy efficiency, maintenance, and hygienic. While resolving issues associated with new investments for ETS infrastructure and interacting with diverse stakeholders, pilot projects in public buildings, not in private homes, may facilitate the development of the SETS project. At this early stage of development, the findings of the high social acceptance of and WTP for the SETS project by Korean households may provide important signals to researchers and policymakers in that the R&D efforts of finding values from previously disposed of human wastes may unlock new business opportunities in the upcoming circular economy.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.seta.2021.101400.

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