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The Impact of Electric Bidet Diffusion on Municipal Water Infrastructure

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Abstract: Electric bidets have become widespread in Japan and are now rapidly being installed across the rest of Asia, the United States, and the European Union. However, the impact on water infrastructure has not yet been sufficiently evaluated. Using Japan as an example, we assess the impact of the spread of electric bidets on the existing water infrastructure and use the results to predict the impact in countries in which the spread of electric bidets is expected in the future. In this study, we first proposed a model of electric bidet use on the basis of the results of a questionnaire survey. In Japan, the frequency of electric bidet use is considered to be the same as that of toilet use, and this model is used by the Ministry of Economy, Trade and Industry (METI) in its official evaluation of equipment performance. However, in this survey, we found that 30–40% of respondents did not use electric bidets, even though they have become commonplace in Japan. The reason for this was a vague sense of anxiety about sanitation. Based on the results of the survey, the model for electric bidet use was set to once a day for men for flushing following defecation and once a day for women for either flushing following defecation or bidet flushing. This is considerably less frequent than the conventional Japanese electric bidet use model for women, which models for one flush following defecation and three flushes following urination. Japan's Energy Conservation Law requires improved energy efficiency in 32 items of equipment, of which the electric bidet is one. Because of this regulation, the electricity consumption of electric bidets has decreased by one fourth in the past 10 years. When a new model representing actual usage was applied, the environmental impact of the electric bidets currently sold was shown to be minimal.

Keywords: municipal water infrastructure; electric bidet; water use model; CO_2 emission; environmental impact

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1. Introduction

For the design of urban water infrastructure, or for the assessment of its environmental impact, a model of users' water consumption when using water-related equipment is needed to calculate water demand. The technological development of water-related equipment has led to continuous progress in water saving. We have previously calculated the CO_2 impact of urban water infrastructure [1]. Furthermore, by assessing the impact of water saving on the CO_2 impact, we have shown that water saving contributes to the low-carbonization of cities [1–4]. CO_2 emissions from water and sewage operations account for 1% of all emissions in Japan and will continue to be emitted every year [5]. Therefore, when considering the design of future urban water infrastructure, consideration of CO_2 emission reduction is essential.

To confront the intensifying climate change seen in recent years, global warming countermeasures have become an urgent priority around the world, including Japan. The Paris Agreement was ratified in a cooperative effort to promote measures to combat

global warming, and each country has set its own goals and is working toward those goals. To achieve its international pledge to reduce greenhouse gas emissions by 46% by FY2030 compared with FY2013, the Japanese government has formulated a global warming countermeasure plan that breaks down the target values for each sector and specifically promotes and manages the plan. In the revised plan released in July 2021, the targets were increased from those in the original plan, as shown in Table 1, in an effort to further accelerate global warming countermeasures. More emissions reductions are required, especially in the public and residential sectors [6]. The revised targets suggest that Japan will increasingly be required to save energy in homes, offices, water infrastructure, and other public services, and to increase the amount of renewable energy sources to achieve net zero energy.

Table 1. Sectoral reduction targets in Japan's Global Warming Prevention Plan (compared with 2013 levels) [5].

Sectors	FY2016 Plan	FY 2021 Revision
Industrial sector (factories, etc.)	7%	37%
Transportation sector (automobiles etc.)	28%	38%
Public sector (Infrastructure etc.)	40%	50%
Residential sectors	39%	66%

With regard to energy saving in buildings such as homes and offices, the Top Runner Program of the Energy Conservation Law aims to encourage companies that supply equipment used in such buildings to develop energy-saving products. The equipment selected for the Top Runner Program covers 32 items that have a large impact on CO_2 emissions in Japan because of their large energy consumption and high diffusion rate [7]. The electric bidet is one of these.

Additionally, to promote the reduction of CO_2 emissions, the government is promoting a system to manage not only CO_2 emissions derived from primary and secondary energy consumption at factories and business sites but also supply chain emissions from the use of equipment manufactured and sold by such companies [8]. In consideration of these trends, it will become increasingly important to quantitatively calculate the CO_2 emissions of various equipment and facilities used in buildings. Therefore, it is essential to construct a use model for the equipment.

In this situation, water use models for water-related housing equipment and CO_2 emission factors of water have been developed and registered as officially approved CO_2 emission calculation criteria named J-credits [9]. However, although the domestic diffusion rate of electric bidets is over 80% [10], this usage model has unclear validity of the evidence. This model was based on the assumption that the frequency of electric bidet use is the same as that of toilet use, without surveying the actual use [7].

In this study, we investigated the actual use of electric bidets through a questionnaire survey, modeled this, estimated their CO_2 emissions, and compared them with the values already calculated in the Top Runner Program.

In Japan, electric bidets have become widespread, but their use has begun to increase not only in Asian countries such as Vietnam and China, but also in the United States and the European Union [11–14]. The widespread use of electric bidets will lead to increases in both water and electricity consumption. The evaluation of the impact of the electric bidet in this study will be helpful in determining whether they will have a negative impact on the trend of CO_2 emission reduction in cities in regions in which they are becoming widespread.

2. Methodology

2.1. Proposal for a Use Model of Electric Bidet Based on a Questionnaire Survey

The summary of the survey on the use of electric bidets is shown in Table 2. The survey was conducted twice, in August and September 2017 and again in June and July

2018. (The survey form can be found in Table S1 in Supplementary Materials). The use of electric bidets is limited to defecation for men, but various uses were expected for women. Therefore, we set a large number of women as the survey targets and selected students of a women's university in Fukuoka Prefecture and their families. The survey received responses from men and women aged from their teens to their 60s. The questions in the survey were selective to make it easier to answer and asked about the use of electric bidets at home and elsewhere.

Table 2. Outline of the survey on the use of electric bidets at home and elsewhere.

Period of survey	1st time: August and September 2017 2nd time: June and July 2018
Survey target	Women's university students and their families, living in Fukuoka Prefecture Men and women aged from their teens to their 60s
Number of valid responses	296 (1st time: 170, 2nd time: 126)
Survey method	Questionnaires were distributed to the target students and collected at the university laboratory
Survey items	• Respondent's profile • Whether an electric bidet is installed in their home • Whether they use the hot-water flushing function at home, and why not if not • How they sit on the toilet seat at home • Whether they use the hot-water flushing function when outside the home, and why not if not • How they sit on the toilet seat when outside the home

The questionnaire responses were analyzed using SPSS statistics and significance tests were conducted using *t*- and Chi-square tests. The significance level for the chi-square test was set at $p < 0.05$.

Using the results of the questionnaire survey and the toilet use model adopted in the J-credit system [9], we proposed a use model for the electric bidet at home. The toilet use model is based on the frequency of each elimination act (urination and defecation) for men and women. Therefore, we proposed an electric bidet use model by assigning information on whether an electric bidet is used following each of these elimination acts, which was obtained in this study. The survey asked whether and how often the respondents used electric bidets following defecation and urination and for menstrual washing (women only). Following defecation, the electric bidet's "anal flushing" mode was used, and those who selected "urination" or "menstruation" were assumed to use the "bidet flushing" mode at the frequency stated in the survey. The frequency response of "every time" represented electric bidet use following every action (i.e., 100%), and the response of "sometimes" was assigned the average use percentage noted in respondents' descriptive responses. The frequency of bidet flushing during a woman's menstrual period was asked in the questionnaire. However, we did not ask about the length of menstrual period. A woman's menstrual period was set to be one week per month. Electric bidet was therefore assigned one fourth of the frequency of women's toilet uses as being during the menstrual period.

2.2. Environmental Impact Calculation

Using the electric bidet use model based on the results of the questionnaire survey and the performance data of the equipment identified in the Top Runner Program [7], we calculated electric bidets' water and electricity consumptions and CO_2 emissions from water and electricity consumption. In addition, because the operating performance of the electric bidet has been greatly improved in accordance with the regulations of the Top Runner Program of the Energy Conservation Law, we also compared the environmental

impact of the latest model with that of the 2008 model, when electric bidets were becoming widely used. The calculation formula is shown in Equations (1)–(3).

$$V_w = n \times q \times t_o \quad (1)$$

$$Et = (w^s{}_{sb} \times t^s{}_{sb}) + (w^s{}_o \times t_0) \times n + (w^w{}_b \times t^w{}_b) + (w^w{}_o \times t_0) \times n \quad (2)$$

$$CO_2 = ef_w \times V_w + ef_e \times E_t \quad (3)$$

The calculation is also in accordance with the method used in the Top Runner Program. Water consumption (V_w) is expressed as the product of the frequency of use of the electric bidet (n), the flushing flow rate (q), and the operation time (t_o). Power consumption (E_t) is the sum of power consumption from heating the toilet seat and heating the flushing water, and power consumption during standby time for each was added to the calculation [7]. In the equation, (w) represents the voltage of the equipment, (t) represents the operating time, (s) in superscript represents the toilet seat, (w) represents the washing water, (sb) in subscript represents the standby time, and (o) represents the operating time. CO_2 emissions (CO_2) are the sum of emissions from water consumption and emissions from electricity consumption, and the emission factors for each are ef_w and ef_e, respectively.

3. Results and Discussion

3.1. Modeling of Electric Bidet Use Based on Questionnaire Survey

3.1.1. Respondent Attributes

Because the gender, age, and number of household members of the respondents were similar in the first and second surveys, the two surveys were compiled and analyzed together. Respondents' attributes are shown in Figure 1. In the survey design, the target respondents were women's university students and their families, which resulted in a small number of respondents in their 30s. However, we were able to obtain 296 valid responses, with a male: female ratio of 26:74, with both men and women ranging in age from their teens to their 60s. As mentioned earlier, this survey has a large number of female subjects, and the following analysis was conducted by defining 10s and 20s as the young female population, and 40s and 50s as the middle-class female population. The ratio of the young generation to Japan's female population is about 18%, and the ratio of the middle-class generation is about 27% [15]. Together, the respondents to this survey represent 45% of the entire generation of Japanese women.

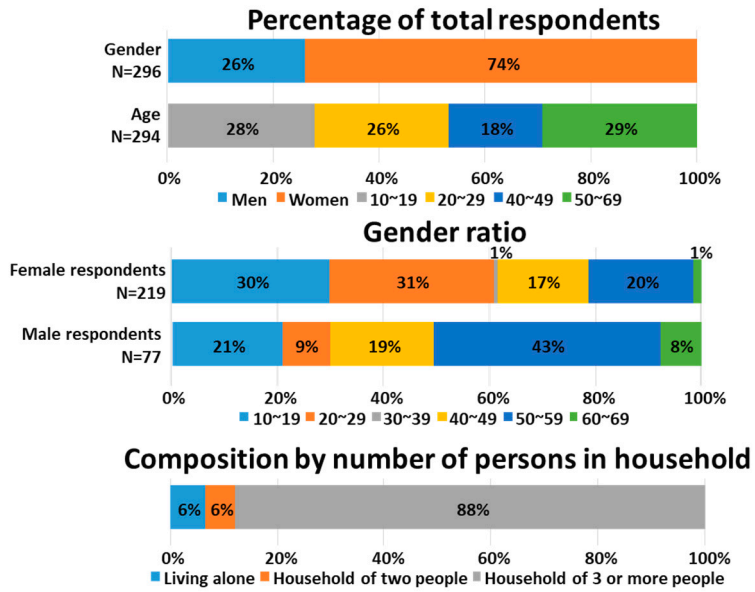

Figure 1. Respondents' attributes.

The household size distribution is also shown in Figure 1. Because 94% of the respondents lived with their families, the average number of persons per household was 2.81, which was slightly higher than the national average of 2.33 persons per household [14]. Because this survey was conducted in a rural city, the number of household members was slightly higher than the Japanese average, but the data still enable us to understand the average electric bidet use in Japanese homes.

3.1.2. Use of Electric Bidets at Home

In this survey, 89% of homes had electric bidets installed, which is close to the 80.4% (as of 2019) stated in the Cabinet Office's consumption trend survey [10]. Therefore, the results of this survey provide an accurate insight into the average usage of electric bidets in homes.

Respondents who had electric bidets installed in their homes were asked whether they used them. The results are shown in Figure 2. Overall, 72% of men and 60% of women answered that they used an electric bidet at home. Men tended to be more likely to use an electric bidet at home. With regard to age, 48% of the respondents in their teens, 52% of those in their 20s, 70% of those in their 40s, and about 81% of those in their 50s and 60s answered that they used an electric bidet. The older the respondent, the higher the likelihood that they would use an electric bidet; a chi-square significance test showed a significant difference by age ($p < 0.001$). The intergenerational comparison of women was more pronounced, with 72% of the female respondents in their 40s and 50s using electric bidets, compared with 52% of those in their teens and 20s. This difference was also significant ($p = 0.009$). These trends are in good agreement with the survey information disclosed on the web [16,17], and were judged to be valid survey results.

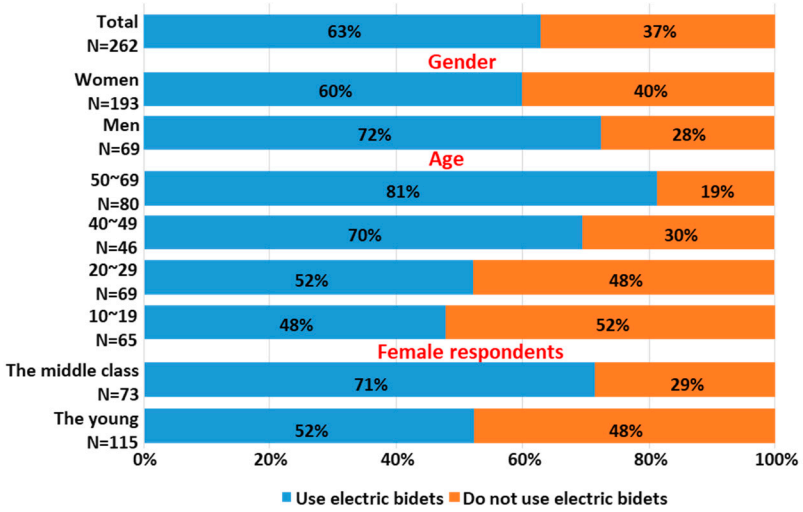

Figure 2. Use of electric bidets at home.

Next, the 98 respondents who answered that they do not use electric bidets were asked why not. Figure 3 shows the results. Of these respondents, 70% did not feel the need to use an electric bidet and 20% were concerned about hygiene. The tendency of not feeling the need was seen more in respondents in their teens and 20s. These trends are also in good agreement with the results of the questionnaire survey disclosed on the web [16,17].

There are many reports investigating the health hazards of electric bidets. According to these reports, no microbial contamination of the flushing water was found, and hygiene concerns have been shown to be unfounded [18]. However, because this information is not widely recognized, it is presumed that vague hygienic concerns may have discouraged some users from using electric bidets.

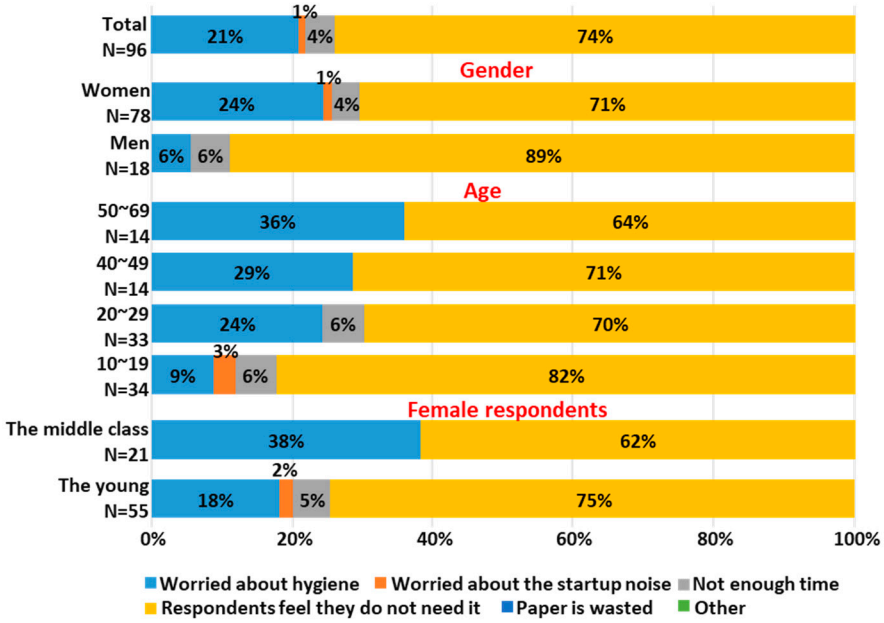

Figure 3. Reasons for not using electric bidets at home.

Next, to construct a model of electric bidet use, we asked about the relationship between the act of elimination in the toilet and the use of an electric bidet by presenting various patterns. Men's electric bidet use was assumed to occur only immediately following a defecation. Therefore, this survey was limited to women. The results are shown in Table 3.

Table 3. Relationship between women's use of an electric bidet and the act of elimination at home and the average frequency of using an electric bidet.

Bidet Use Type	Response Rate	Frequency of Use Per Day Set for Each Bidet Use Type		Frequency of Anal Flushing	Frequency of Bidet Flushing
		Anal Flushing	Bidet Flushing		
Use following every defecation and urination	7%	1	4	0.07	0.28
Use following every defecation, urination and during menstruation	3%	1	4	0.03	0.11
Use following every defecation only	34%	1	0	0.34	0.00
Use following every defecation and during menstruation	11%	1	$4 \times (1/4)$	0.11	0.11
Use following every defecation and sometimes during menstruation	7%	1	$4 \times (1/4) \times 0.5$	0.07	0.04
Use following some defecations	13%	0.44	0	0.06	0.00
Use sometimes during defecation and every time of menstruation	4%	0.62	$4 \times 1 \times (1/4)$	0.03	0.04
Use sometimes during defecation and menstruation	6%	0.33	$4 \times (1/4) \times 0.37$	0.02	0.02
Use every time of menstruation	6%	0	$4 \times (1/4)$	0.00	0.06
Use sometimes during menstruation	8%	0	$4 \times (1/4) \times 0.41$	0.00	0.03
	100%			**0.73**	**0.69**

Toilet use model: J-credit methodology (one defecation plus four urinations per person per·day). Electric bidet use following defecation was assigned to anal flushing and following urination to bidet flushing. The menstrual period was set at 1 week/4 weeks.

Other models of home toilet use and electric bidet use were adopted into the Energy Conservation Law Top Runner Program. In the Top Runner Program, toilet use was set at once per day for defecation for men and once per day for defecation plus three times per day for urination for women. Based on a model of the frequency of toilet use at home,

the use of electric bidet is set at one anal flush per person per day for men and one anal flush plus three bidet flushes per person per day for women. A recent field survey [1,19,20] showed that a model that includes one additional urination, that is one defecation plus four urinations per day, is closer to the actual situation for both men and women. This model is referred to as the "new model" and has been adopted by the J-credit system as the methodology for calculating CO_2 emissions from water consumption of water-saving toilets. The J-credit system is a carbon trading system promoted by the Ministry of Economy, Trade and Industry (METI) as one measure to promote a low-carbon society. However, the J-credit system does not set a model for the use of electric bidets.

Information on the rate and frequency of electric bidet use was correlated with data on each elimination activity in the new model of home toilet use used in the J-credit system and the average frequency of electric bidet use was calculated. Of 50 male respondents who used an electric bidet at home, 48 indicated the frequency with which they used it. Of these 48, 44 answered that they used the electric bidet every time they defecated. Therefore, we assumed that those who used an electric bidet would flush their anus following every defecation and set the rate at one flush per person per day.

We assumed that women use bidets in various situations such as following defecation and urination and during menstrual washing. Therefore, we asked the frequency of flushing assuming set rates of each activity. The results are shown in Table 3. We assumed that the electric bidet is used each time a woman defecates and urinates. However, in reality, women who are in the habit of using electric bidets mainly use them for defecation and less for urination and menstrual bidet flushing. This was presumably because of concerns about the hygiene of the flushing water, as mentioned above, which made women hesitant to use bidet flushing. Therefore, we set the average use of electric bidet among women with the habit of using electric bidets at 0.7 anal flushes plus 0.7 bidet flushes per person per day.

It has been assumed that the electric bidet is used by all people every time they use the toilet. However, this study revealed that 30%–40% of both men and women do not use electric bidets. Considering this non-use rate, we consider the average frequency of use of the electric bidet at home set in my model to be accurate.

3.1.3. Use of Electric Bidets Outside the Home

The use of an electric bidet outside the home was also investigated in the same way. Figure 4 shows whether respondents use electric bidets and Figure 5 shows their reasons for not doing so. The non-use rate increased from 37% at home to 71% outside, and 69% of respondents who used it at home did not do so when they were outside. This tendency was more pronounced among women and younger respondents. The number of respondents who cited "hygiene concerns" as a reason for not using bidets jumped from 20 out of 96 when using them at home to 84 out of 210 when using them outside the home. Toilets in places outside the home are used by an unspecified number of people. Therefore, it was inferred that respondents were hesitant to use electric bidets because of growing concerns about hygiene.

The largest number of respondents used electric bidets outside of the home only for defecation, the same as at home. The next most frequent answer was "every time when defecating and menstruating", with fewer people using it when urinating. Electric bidet use outside the home was lower than at home, but the situations of use were not much different from those at home, shown in Table 3.

The tendency to be hesitant to use electric bidets because of hygiene concerns was also reflected in the survey results on how respondents sit on toilet seats outside the home. In toilets at home, 80%–90% of both men and women sat directly on the toilet seat. However, in toilets outside the home, as shown in Figure 6, direct seating was less common and people took hygiene measures such as placing toilet paper on the toilet seat or wiping the seat with a sanitizing sheet.

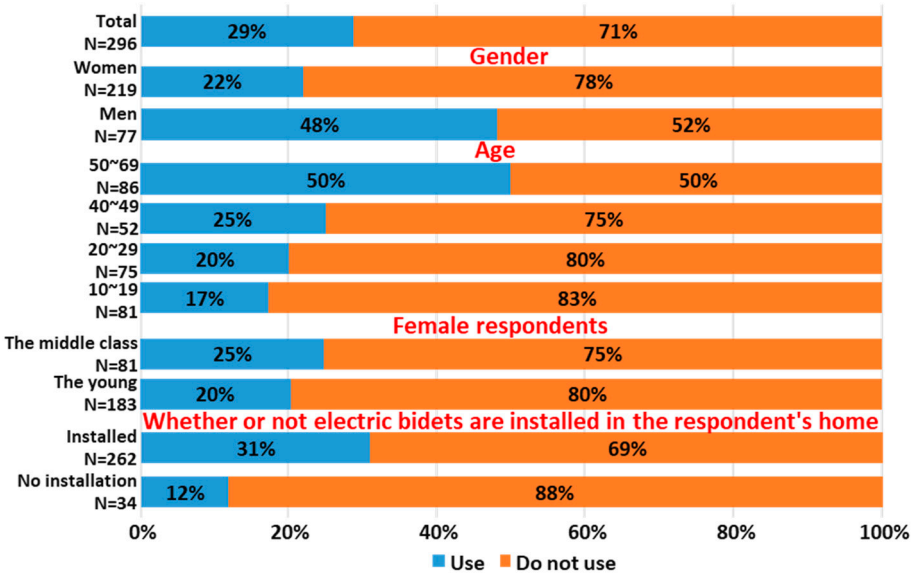

Figure 4. Use of electric bidets while away from home.

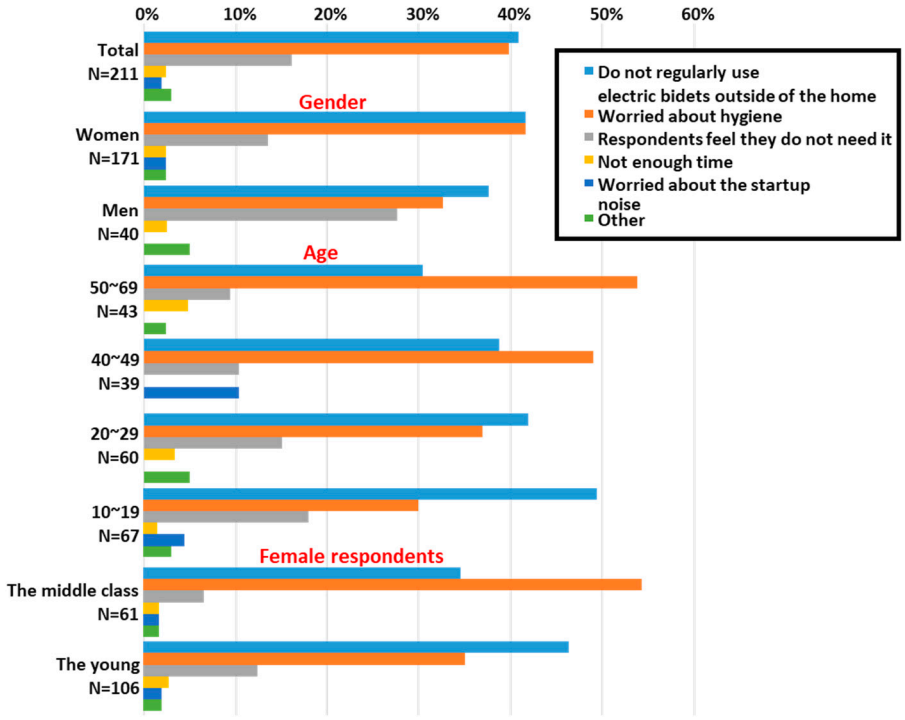

Figure 5. Reasons for not using the electric bidet when away from home.

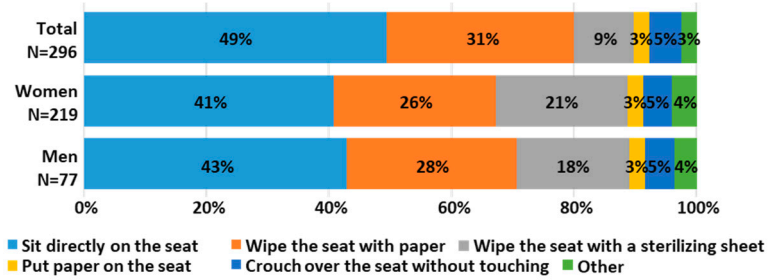

Figure 6. How respondents sit on the toilet when they go out.

These results indicate that when developing a model for electric bidet use, it is necessary to incorporate not only the frequency of toilet use but also the user's anxiety-based behavior into the evaluation.

3.1.4. Proposed Model for Electric Bidet Use at Home

We calculated the model of electric bidet use at home by multiplying the average frequency of habitual electric bidet users' bidet use described above by the electric bidet use rate. The calculation formula is shown in Equations (4) and (5).

$$\text{Men: } 1 \times 0.72 = 0.72 \text{ [times/day/person]} \quad (4)$$

$$\text{Women: } (0.73 + 0.69) \times 0.60 = 0.85 \text{ [times/day/person]} \quad (5)$$

The use of electric bidet by men is restricted to the time of defecation. The electric bidet use model for men was calculated to be 0.72 uses per day by multiplying the 72% use rate by one use per day, the average frequency of use extracted from the questionnaire survey. For women, the electric bidet use rate of 60% was multiplied by 0.73 times per day for defecation and 0.69 times per day for bidet flushing, resulting in a total of 0.85 times per day for defecation or bidet flushing.

Use models are widely used for environmental impact assessment and performance assessment of equipment. Therefore, models have previously been constructed by rounding to whole numbers to enhance their usability [7,9]. Therefore, the values in the model used for the electric bidet in this study were also rounded to the nearest integer (see Table 4).

Table 4. Models of electric bidet use at home (per person per day).

	Anal Flushing	**Bidet Flushing**
Men	1 time	0 time
Women	1 time	

3.2. Environmental Impact of Electric Bidet Use

3.2.1. Evaluation Using the New Model

The water and electricity consumptions of electric bidets were calculated using the evaluation model in the Top Runner Program of the Energy Conservation Law. This model assumes that the frequency of use of an electric bidet is the same as that of a toilet, and the rationale for this is unclear, as mentioned above. Before calculating the environmental impact, we investigated the differences in the results of the environmental impact assessment caused by the different models used in the assessment of electric bidets. In this evaluation, a home with an electric bidet installed was used as the evaluation unit, and annual water and electricity consumptions and CO_2 emissions from water and electricity consumptions were compared between the old and new models. In the calculation, currently available electric bidets were used for evaluation. The results are shown in Table 5. The model proposed in this study is the new model and that used in the Top Runner Program is the old one.

Table 5. Differences in the environmental impact of electric bidets depending on the model adopted.

		Old Model	**New Model**
Water consumption (L/year)		523.4	74.5
Electricity consumption (kWh/year)		56.48	47.06
CO_2 emissions (kg-CO_2/year)	Power consumption origin	25.08	20.89
	Water consumption origin	0.28	0.09
	Total amount	25.36	20.99

Calculation conditions. Evaluation unit: assumes a home with an average household size of 2.39 persons [15]. Toilet use model: defecation once per person per day plus urination four times per person per day. Flush water volume and heating: 200 mL per flush, instantaneous heating from 15 to 38 °C. CO_2 emission factor for electricity: 0.444 kg−CO_2/kWh [21]. CO_2 emission factor for water: 0.54 kg−CO_2/m^3 [22].

In this study, the new model was considered to be closer to the actual situation. The old model overestimated water consumption by 3.0 times and electricity consumption and CO_2 emissions for both by 1.2 times compared with the actual situation. The influence of the adopted model on electricity consumption was less than that on water consumption because the heating power of toilet seats accounted for a large portion of electricity consumption and was not affected by changes in the frequency of flushes.

The CO_2 emission factor for water used in the calculation is the latest value calculated by the Japan Sanitary Equipment Industry Association [22] using the calculation method proposed by the authors [1] and adopted in the J-credit methodology. This calculation shows that the Top Runner Program, which has been used for a long time, overestimates the environmental impact of electric bidets.

Next, the proposed model was used to calculate the increased environmental impact due to the installation of electric bidets. The results are shown in Table 6. In the evaluation, we compared the environmental impact between the stage at which the diffusion of electric bidets was zero and the current situation in which the diffusion has almost reached saturation at 80% of Japanese homes. The environmental impact was calculated for all homes in Japan. As shown in Table 6, the increase in water consumption was negligible and the increases in electricity consumption and CO_2 emission were low even if electric bidet use spread to the maximum possible extent. We adopted a water consumption of 0.2 $m^3/d/capita$, which is the design criterion for water infrastructure in Japan. The Japan Center for Climate Change Actions (JCCCA) has published data on CO_2 emissions. From these data, we adopted the actual figures for fiscal 2019 for emissions from electricity, gas, kerosene, light oil, garbage, and water. These actual figures correspond to emissions from homes. For electricity consumption, JCCCA data for electricity were also adopted [23]. To calculate CO_2 electric bidets' emissions from water and electricity consumption, we adopted the calculation criteria used in the Top Runner Program.

Table 6. Impact of electric bidet diffusion on water and electricity consumption and CO_2 emissions from whole homes in Japan.

	Water Consumptio nm^3/year (Millions)	**Electricity Consumption GWh/year (Thousands)**	**CO_2 Emissions t-CO_2/year (Millions)**
Electric bidet No diffusion	9035	208.9	151.37
Electric bidet Diffusion rate: 80%	9042	210.8	152.24
Increase rate	0.08%	0.94%	0.58%

Calculation conditions. Evaluation unit: assumes a home with an average household size of 2.39 persons [15]. Water consumption of homes without an electric bidet: 0.2 $m^3/d/capita$. Electricity consumption of homes without an electric bidet: 4034 kWh/year/home. Electric bidet diffusion rate: 80.4% [10].

3.2.2. Performance Evaluation

The environmental impact caused by the widespread use of electric bidets was minimal. Nevertheless, to understand why the Japanese government has strongly demanded the improvement of the performance of electric bidets under the Top Runner Program of the Energy Conservation Law, it is necessary to look at their performance evolution. In 2012, the Top Runner Program selected 32 products that were expected to be widely used and had excessive energy consumption. The Japanese government has set improvement targets for these; it has strongly urged manufacturers to improve the environmental performance of their equipment and disclosed the evaluation criteria for equipment performance and equipment performance data [7]. Electric bidets have also been subject to the Top Runner Program because they previously consumed as much as 4% of a home's total power consumption and their use was expected to spread rapidly. Therefore, the environmental impact was calculated using the new model for bidets that were initially subjected to the

Top Runner Program and the latest bidets that are currently sold. The results are shown in Table 7.

Table 7. Electric bidet performance and performance improvements.

		2008	**2020**
Appearance			
Features	toilet seat	24-h heating	Timed heating system calibrated by learning control system
	Flushing	Heated water from hot water storage	Instant heating
Environmental performance	Amount of flushing water per time	400 mL	200 mL
	Annual electricity consumption	214.54 kWh/year/home	51.77 kWh/year/home

Calculation conditions. Evaluation unit: assumes a home with an average household size of 2.39 persons [15]. The new model was applied.

The functions of the electric bidet comprise a heated toilet seat function that warms the seat in the winter and a function that washes the buttocks with warm water. The heating function and flushing water can be turned on and off according to the season or user's wishes. On previous models, toilet seats were automatically heated for 24 h a day during the season in which they were turned on. However, recent models incorporate a learning control function that predicts the time of use on the basis of the user's measured electric bidet usage patterns and heats the seat only during those times, thus reducing the power consumption during toilet seat heating. Older models used 0.4 L of water was used per flush, so it was not possible to increase the temperature instantaneously. Therefore, later models included a tank to store the heated water in advance. Later, technology was developed to reduce the amount of water by half while maintaining high washing performance by changing the washing method from a continuous flush to an intermittent flush. By halving the amount of water discharged, it became possible to instantaneously increase the temperature at the time of water discharge. In the initial model, heat dissipation loss was caused by keeping the water continually warm. However, because instantaneous heating is now possible and the amount of water to be heated has been reduced by half, the thermal efficiency has been greatly improved. With these performance improvements, the annual power consumption has been reduced to one fourth of the original model. To calculate power consumption, we used the above-mentioned new use model and equipment data disclosed in the Top Runner Program.

In Japan, water saving is being promoted not only for electric bidets but also for toilet bowls, shower heads, and so on. Efforts are being made to promote the use of these water-saving devices not only in Japan but also in other countries. The Japanese government and industry have been actively encouraging the spread of water and energy-saving equipment overseas, viewing it as Japan's contribution to a low-carbon society [24,25]. As part of this effort, water- and energy-saving equipment has been added to the bilateral credit system [26].

Electric bidets are becoming popular in Asian countries such as China and Vietnam. This was reportedly triggered by tourists who came to Japan and experienced electric bidets and began installing them in their own homes. Furthermore, in recent years, their use

has spread to the United States and European Union [11–14]. In these regions, the latest equipment, which has improved environmental performance, is sold.

A survey on the use of electric bidets in China, where the use of electric bidets is beginning to spread, found that, as in Japan, a certain percentage of people do not use electric bidets even if they have one installed at home [27]. Therefore, the use model proposed in this study may be adaptable for use in other countries. Therefore, it is estimated that the increase in water consumption and the environmental impact of water infrastructure in other countries in which electric bidets have started to spread will be minor, just as in Japan. The widespread use of electric bidets in other countries will have little negative impact on the trend toward low carbon societies.

4. Conclusions

To counter the intensifying climate change, the reduction of CO_2 emissions has become a common global issue that needs to be addressed in all sectors. Urban water infrastructure also emits a large amount of CO_2 through energy consumption. Therefore, it is important to take measures such as improving energy efficiency in water infrastructure. A user's water use model to determine water demand is necessary for designing water infrastructure and calculating CO_2 emissions. In this study, we created a new model of electric bidet use, for which evidence had been unclear, through a questionnaire survey and proposed that men use electric bidet once per day following defecation and women use it once per day for flushing following defecation or for bidet washing. It was previously assumed that the frequency of electric bidet use was the same as the frequency of toilet use, and it was modeled that men used the electric bidet once per day following defecation, and women used the electric bidet once per day following defecation and three times per day following urination. In this study, we found that the old model overestimated the frequency of use.

Applying the electric bidet use model created in this study, the environmental impact of electric bidets was calculated to be 67% lower for water consumption and 17% lower for electricity consumption and CO_2 impact than when the old model was applied. Using the new model, the added impact of the widespread use of electric bidets on the environmental impact of all Japanese homes was calculated. The increase in water consumption was negligible and the increase in CO_2 emissions was 0.6%.

This evaluation was based on the performance of models that are currently sold and widely used in Japan. When electric bidets first became popular, their environmental impact was four times greater than the current products. This is because in Japan, electric bidets were subject to the Top Runner Program of the Energy Conservation Law and energy conservation improvements had to be continuously implemented. Currently, electric bidets are becoming popular in Asia, the United States, and the European Union. In these markets, products with improved environmental performance are already available. Therefore, the widespread use of electric bidets in these countries will have a minimal impact on the design of water infrastructure and the trend toward low carbon societies.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/w14040639/s1, Table S1: Toilet Use Survey at Home and Away from Home.

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