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Prediction of residential water-saving potential based on the implementation of water efficiency standards and labeling scheme

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ABSTRACT

With the acceleration of industrialization and urbanization, China's domestic water consumption has increased year by year. To improve the efficiency of household water use, China has issued mandatory national standards for Minimum Allowable Values of Water Efficiency and Water Efficiency Grades for Water Closets (GB 25502-2017) and Minimum Acceptable Values and Grades of the Energy Efficiency and Water Efficiency for Smart Water Closets (GB 38448-2019) and implemented a water efficiency labeling scheme. Based on scenario analysis, this paper designs a BAU scenario without implementing water efficiency standards and labeling scheme, a Standard Scenario where only water efficiency standards are implemented, and a Standard + Labeling Scenario where water efficiency labeling is carried out based on implementing water efficiency standards. By analyzing the market share and water efficiency distribution of ordinary and smart toilets in 2021–2025, the water consumption of toilet flushing and bidet functions in the three scenarios above were calculated. Compared with the BAU scenario, it is estimated that under the Standard Scenario, the annual water savings is 1.39~3.35 × 10^8 m^3, and the cumulative water saving is about 10.75 × 10^8 m^3 in five years; Under the Standard + Labeling Scenario, the annual water saving is 1.39~5.45 × 10^8 m^3, and the cumulative water saving is about 17.39 × 10^8 m^3 in five years.

Keywords: Water efficiency standards; Water efficiency labeling; Residential water use; Water saving potential; Scenario analysis

1. Background

Water shortage has become the bottleneck factor restricting economic and social development. With the acceleration of urbanization and industrialization, the domestic water consumption of residents is increasing day by day [1]. According to the China Water Resources Bulletin, China's domestic water consumption has continued to increase from 76.48 billion cubic meters in 2010 to 87.17 billion cubic meters in 2019, and the proportion of domestic water consumption in total water rose from 12.7% to 14.5% (Fig. 1). Thus, improving domestic water use efficiency and reducing domestic water consumption can help alleviate the situation of water shortage [2].

There are many factors affecting domestic water use. A study on the integrated urban metabolism analysis tool (IUMAT) shows that the household size, efficiency of appliances and participation in water conservation programs are the most decisive indicators of indoor water consumption [3]. Other researches based on Chinese household shows family income, frequency of bathing and cooking, female proportion, education, ages, number of family members, climate and water price [4–7].

Research on water distributing characteristics shows that the urban domestic water generally obeys the distribution of Burr, and there exists basic water consumption which is closely related to the family size [8]. Larger household size is related to lower per capita domestic water consumption

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because several types of water use, such as gardening and cooking, tend to grow less than household size [9]. The composition of the family population also deeply affects domestic water use. Specifically, the families with adults, adolescents and children performance with more showering time [10]. A residential water demand case study based on GIS in Australia suggests that household size; members at the age over 65 and income have strong positive relationships with the water demand, whereas age between 18 and 64 and age below 18 show a weak positive and even negative relationship with water demand [11]. Another research concludes similarly that households with children under 12 years of age consume significantly less water than those households with no children [12]. According to the end-use water analysis, the water consumption of a household is the sum of the water consumption of each terminal, and the water consumption of each terminal is affected by factors such as appliances, frequency of use, and water use efficiency [13]. A study shows that the enhanced efficiency of toilets and clothes washers contribute to a 22% decrease in per household daily water use and a 15% reduction per capita from 1999 to 2016 [14]. Demand-side management programs, including replacement of residential water appliances and devices, can be expected to reduce water consumption by 10% to 20% over 10–20 y, suggesting that it is very necessary to introduce water efficiency rating schemes in the water appliances [15,16].

The Water Efficiency Labeling and Standards (WELS) scheme in Australia is mandatory applied since 2007 to showers, taps, toilets, urinals, flow controllers, dishwashers and washing machines, which must be tested and labeled in accordance with related standards [17]. The water savings attributable to WELS is calculated to be 185 GL/y in 2026 and increased to 231 GL/y in 2036 [18]. In the USA, the Environmental Protection Agency sponsored the water sense label for water-efficient products, since 2006, the water sense labeled products have saved 5.3 trillion gallons of water [19]. Since 2011, multiple mandatory national standards of China about water efficiency have been developed regarding domestic water appliances, which are related to electric washing machine, faucet, water closet, squatting pan, the flush valve of the water closet, urinal stall, shower set and RO water filter, etc. The water efficiency labeling scheme was officially implemented in China in 2018, with water closets as the first batch of implementation products, and smart water closets and dishwashers replenished into the list in 2020. As toilets are important water terminals in the water supply chain [20], it is of great significance for evaluating the benefits from the implementation of the standards and labeling scheme for ordinary water closets and smart water closets to analyze the water-saving potential from 2021 to 2025 after the performance.

2. Methodology

This paper is written to analyze the water-saving potential of the use of water closets, and smart water closets in 2021–2025 after the Minimum Allowable Values of Water Efficiency and Water Efficiency Grades for Water Closets (GB 25502-2017) and Minimum Allowable Values and Grades of the Energy Efficiency and Water Efficiency for Smart Water Closets (GB 38448-2019) as well as the water efficiency labeling scheme were implemented. Combined with the domestic sales and distribution of water efficiency grades before the issue of the water efficiency standards and based on the forecast results of domestic sales of water closets in 2021–2025, this research designs three scenarios of different policy strengths, namely BAU (business as usual) scenario without implementation of water efficiency standards and labeling scheme, the Standard Scenario with only reasonable water efficiency standards and Standard + Labeling Scenario where both the water efficiency standards and labeling scheme reach the desired effect. By calculating the water consumption of toilet flushing and bidet functions in the above three scenarios, this research analyses the water-saving potential of the standards and labeling scheme.

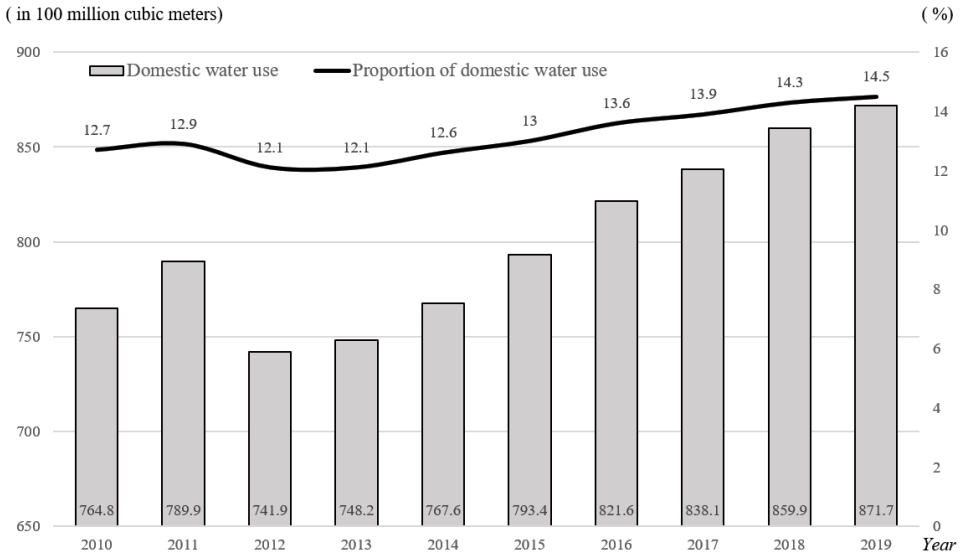


Fig. 1. Domestic water use and its proportion in total water use over recent years.

2.1. Domestic sales of water appliances

In recent years, the domestic market demands for water closets were stable, and the domestic sales of 42~47 million units per year were maintained, among which dual-flush toilets account for about 80%, and single-flush ones account for about 20%. Combined with the domestic sales of the smart water closets in 2015–2020, a linear regression equation of domestic sales of the smart water closets is generated as shown in Eq. (1). The results show that the correlation coefficient between variables is 0.9731, suggesting the suitability of the equation. The domestic sales show an increasing trend. The smart all-in-one toilets and the smart toilet seats account for 50%, respectively in the early stage, while the former's market share has increased rapidly, and the proportion of the smart all-in-one toilets is expected to reach 65% in 5 y.

$$y = 81.286x + 136.33 \quad (1)$$

According to the industrial inference results and Eq. (1), after implementing the standards and labeling scheme, the sales of single-flush and double-flush toilets and smart toilets in 2021–2025 are shown in Fig. 2. From the perspective of water functions, the sales of water closets with single-flush, double-flush and bidet functions (Fig. 3).

2.2. Scenario design

The BAU scenario (Scenario 0) assumes the proportion distribution of toilets' water efficiency remains at the level before the release of Minimum Allowable Values of Water Efficiency and Water Efficiency Grades for Water Closets (GB 25502-2017) and Minimum Allowable Values and Grades of the Energy Efficiency and Water Efficiency for Smart Water Closets (GB 38448-2019), it is a benchmark for water-saving potential analysis. Taking the only implementation of mandatory water efficiency standards as the Standard Scenario (scenario 1), where the products that do not meet the criteria in this scenario are eliminated, and the market share for water-saving products (products with water efficiency Grades 1 or 2) is gradually improved. In the Standard + Labeling Scenario (scenario 2), not only the

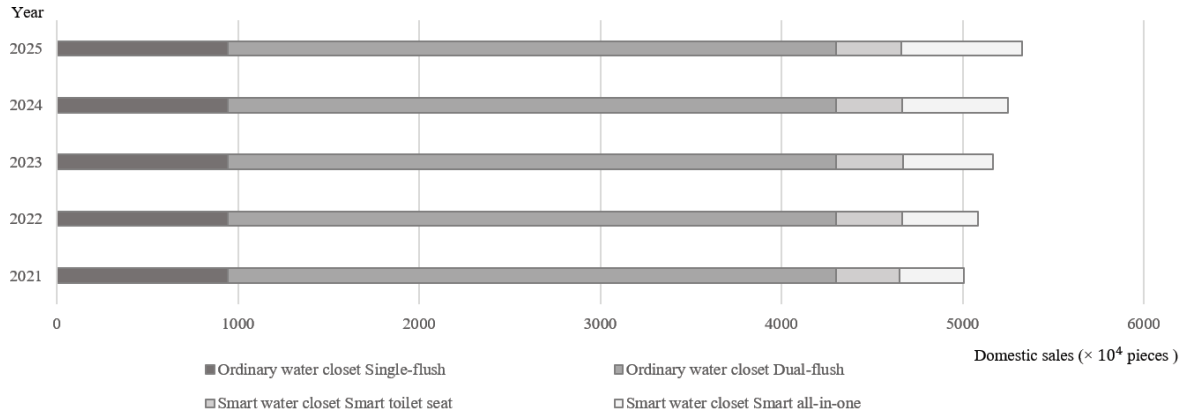


Fig. 2. Anticipated domestic sales of single-flush and dual-flush ordinary water closets, smart all-in-one water closets and smart toilet seats (in 10,000 pieces).

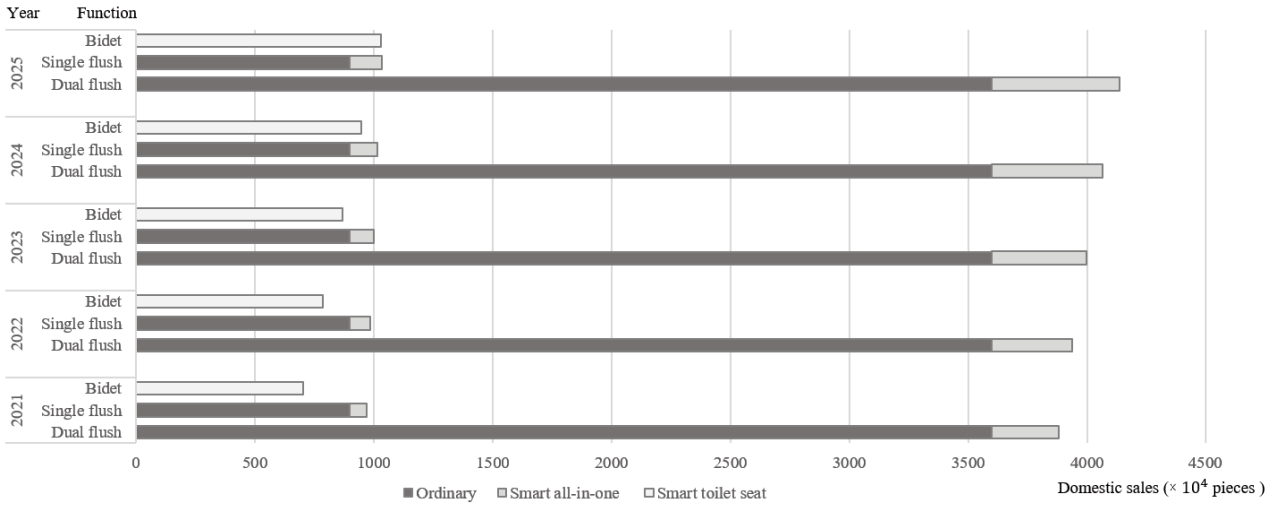


Fig. 3. Anticipated domestic sales for water closets assorted with different functions.

water efficiency standards and implemented, but also the labeling scheme is launched, and the products that do not meet the standards are eliminated in this scenario, and the market share of water-saving products will increase significantly, speeding up the standard revision process. See Table 1 for the scenario settings and their meanings.

As a survey on water efficiency of the water closets before implementation of the standards shows, the water closets of water efficiency for flushing Grades 1–3 separately account for 8%, 25% and 52%, those of water efficiency did not meet Grade 3 account for about 15%; the smart water closets of water efficiency for bidet Grades 1–3 separately account for 6%, 44% and 31%, those of water efficiency did not meet Grade 3 account for 19%.

According to the above industrial conditions, under the BAU scenario (Fig. 4), the water efficiency of the water closet and smart water closet will remain the unreleased level in 2021–2025: The water closets with different water efficiency for flushing account for 8% of Grade 1, 25% of Grade 2, 52% of Grade 3 and 15% under the threshold, respectively, and the smart water closets with water efficiency Grades 1–3 for bidet and substandard ones account for 6%, 44%, 31% and 19% (Fig. 4). In the Standard Scenario (Fig. 5), the substandard products were retired, and the water efficiency of the toilets were gradually improved. From 2021, the water closets with the Grade for flushing 1, 2 and 3 are raised from 20%, 40% and 40% to 60%, 30% and 10%, and the smart water closets meet Grades 1–3 as bidet are raised from 30%, 45% and 10% to 50%, 40% and 10%. Under the Standard + Labeling Scenario (Fig. 6), the substandard products were eliminated, and the toilet water efficiency is greatly increased and promoting the standards to update, it is anticipated that the proportions of the water closets in levels of the 2022 upgraded water efficiency Grades 1–3 will reach 60%, 30% and 10% for flushing and 50%, 40% and 10% for bidet function.

3. Water-saving potential analysis

According to the forecast results of sales in 2.1 and combined with the proportion distributions of the water efficiency as analyzed in 2.2, the water use and water savings are calculated in 2021–2025 under the BAU, Standard and Standard + Labeling Scenarios, respectively. In the

Table 1
Scenario design for water-saving potential analysis

Scenario	Implication
Scenario 0: BAU scenario	Neither water efficiency standards nor labeling scheme is implemented, and this will be taken as a benchmark for comparison with other scenarios. The products with different water efficiency remain the market share as before, including the outdated capacity under the water efficiency limit values (Fig. 4).
Scenario 1: Standard Scenario	Implementing the mandatory water efficiency standards. Products under the limit values are eliminated, and the market share of water-saving products will gradually increase in 2021–2025 (Fig. 5).
Scenario 2: Standard + Labeling Scenario	On the basis of the water efficiency standards, the labeling scheme is implemented. Products under the threshold are retired, and in 2021–2025 the market share of water-saving products will increase rapidly, and the water efficiency standards will be revised during this period (Fig. 6).

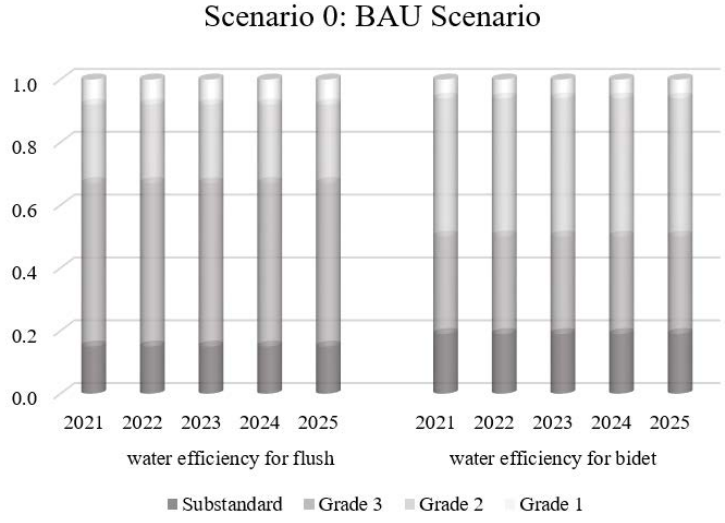


Fig. 4. Distribution of water efficiency of flushing and bidet functions in the BAU scenario in 2021–2025.

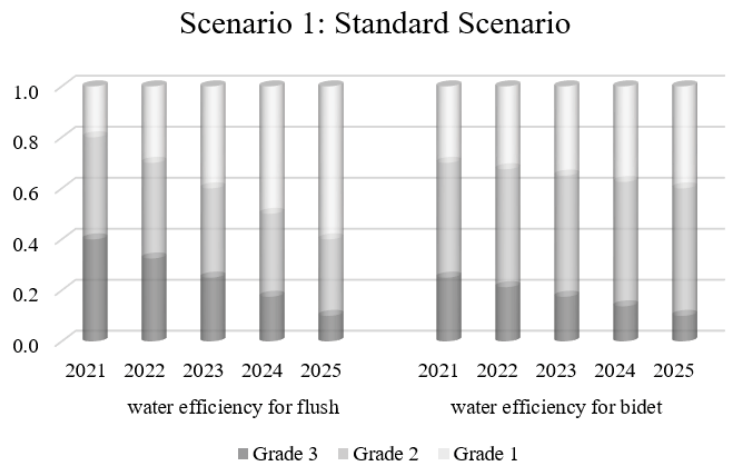


Fig. 5. Distribution of water efficiency of flushing and bidet functions in the Standard Scenario in 2021–2025.

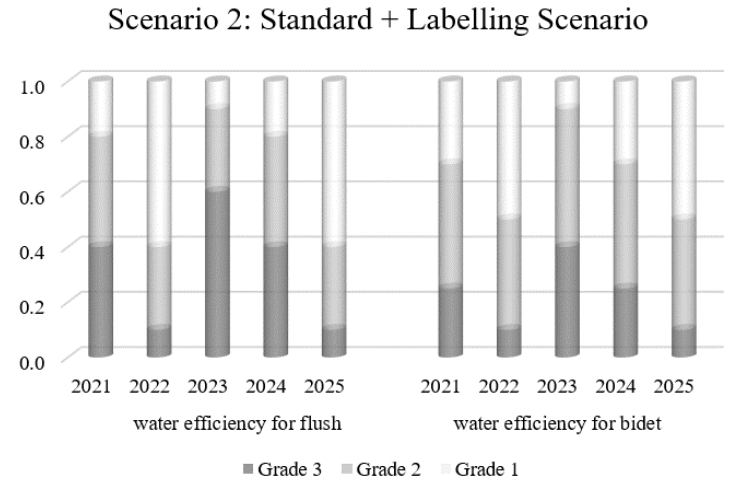


Fig. 6. Distribution of water efficiency of flushing and bidet functions in the Standard + Labelling Scenario in 2021–2025.

Standard + Labeling Scenario, due to the highly improved water efficiency for toilets, the water efficiency standards are supposed to be revised in 2022. See Table 2 for the current and proposed revised indicators of water efficiency standards for water closets and smart water closets. The application frequency of toilets is set at 10 times a day and therefore 3,650 times a year.

3.1. Water consumption forecast under the BAU scenario

Under the BAU scenario, the water efficiency distribution of the water closets and smart water closets remains the same in 2021–2025 as that before the water efficiency standards were issued. The water closets with different water efficiency for flushing account for 8% of Grade 1, 25% of Grade 2, 52% of Grade 3 and 15% under the threshold, respectively, and the smart water closets with water efficiency Grades 1–3 for bidet and substandard ones account for 6%, 44%, 31% and 19%.

From 2021 to 2025, the flushing water consumption of the dual-flush toilets (including ordinary and intelligent all-in-one) will be 10.50×10^8 m^3, 10.65×10^8 m^3, 10.82×10^8 m^3, 11.00×10^8 m^3 and 11.19×10^8 m^3, the flushing water consumption of the single-flush toilets (including ordinary and intelligent all-in-one) will be 2.11×10^8 m^3, 2.14×10^8 m^3, 2.17×10^8 m^3, 2.21×10^8 m^3 and 2.25×10^8 m^3, and the water consumption for bidet will be 0.16×10^8 m^3, 0.18×10^8 m^3, 0.20×10^8 m^3, 0.22×10^8 m^3 and 0.24×10^8 m^3. Hence, the water consumption of newly sold toilets in 2021–2025 is 12.77×10^8 m^3, 12.97×10^8 m^3, 13.19×10^8 m^3, 13.42×10^8 m^3 and 13.67×10^8 m^3, respectively.

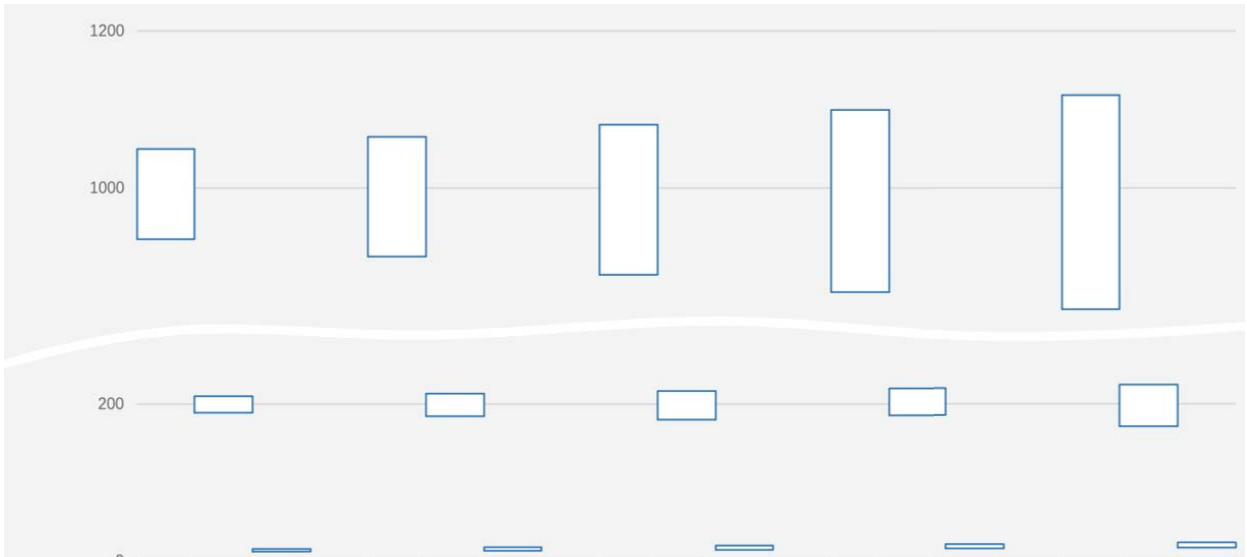
3.2. Water-saving potential analysis under the Standard Scenario

Under the Standard Scenario, the substandard products were retired, and the water efficiency of the toilets were gradually improved. From 2021, the water closets with the Grade for flushing 1, 2 and 3 are raised from 20%, 40% and 40% to 60%, 30% and 10%, and the smart water closets meet Grades 1–3 as bidet are raised from 30%, 45% and 10% to 50%, 40% and 10%.

From 2021 to 2025, the flushing water consumption of the dual-flush toilets will be 9.35×10^8 m^3, 9.13×10^8 m^3, 8.90×10^8 m^3, 8.68×10^8 m^3 and 8.45×10^8 m^3, the flushing

Table 2
Current and proposed revision water efficiency indicators for ordinary and smart water closets

Water appliance	Categories	Current indicators (L)			Proposed indicators (L)		
		Grade 1	Grade 2	Grade 3	Grade 1	Grade 2	Grade 3
Ordinary water closet (GB 25502-2017)	Average water use of water closet	≤4.0	≤5.0	≤6.4	≤3.0	≤4.0	≤5.0
	Full flush water use of dual-flush water closet	≤5.0	≤6.0	≤8.0	≤4.0	≤5.0	≤6.0
Smart water closet (GB 38448-2019)	Average water use for cleaning	≤0.3	≤0.5	≤0.7	≤3.0	≤4.0	≤5.0



	Dual-flush	Single-flush	Bidet	Dual-flush	Single-flush	Bidet	Dual-flush	Single-flush	Bidet	Dual-flush	Single-flush	Bidet	Dual-flush	Single-flush	Bidet
	2021			2022			2023			2024			2025		
Scenario 0	1050	211	16	1065	214	18	1082	217	20	1100	221	22	1119	225	24
Scenario 1	935	190	13	913	185	14	890	181	15	868	186	16	845	171	17
Water savigns	115	21	3	152	29	4	192	36	5	232	45	6	274	54	7
Annual water savings	139			185			233			183			335		
Accumulated water savings	139			324			557			740			1075		

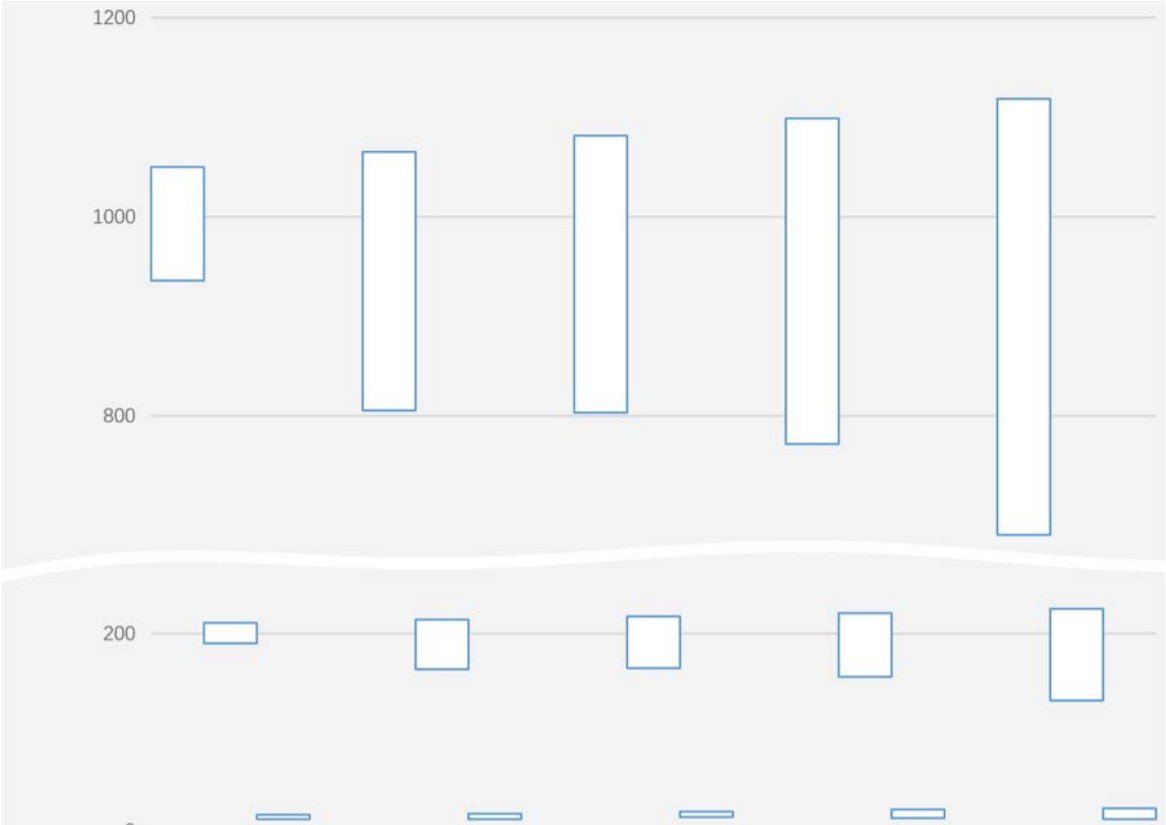
Fig. 7. Water consumption and water-saving potential under the Standard Scenario from 2021 to 2025 (in 1×10^6 m^3).

water consumption of the single-flush will be 1.90×10^8 m^3, 1.85×10^8 m^3, 1.81×10^8 m^3, 1.86×10^8 m^3 and 1.71×10^8 m^3, and the water consumption for bidet will be 0.13×10^8 m^3, 0.14×10^8 m^3, 0.15×10^8 m^3, 0.16×10^8 m^3 and 0.17×10^8 m^3. Hence, the water consumption of newly sold toilets in 2021–2025 is 11.38×10^8 m^3, 11.12×10^8 m^3, 10.86×10^8 m^3, 10.60×10^8 m^3 and 10.33×10^8 m^3, respectively. Compared with the BAU scenario, the annual water saving is 1.39~3.35 × 10^8 m^3, and the accumulated water saving is about 10.75×10^8 m^3 in five years. The toilet flushing water consumption and water-saving projections under the Standard Scenario are shown in Fig. 7.

3.3. Water-saving potential analysis under the Standard + Labeling Scenario

Under the Standard + Labeling Scenario, the substandard products were eliminated, and the toilet water efficiency is greatly increased and promoting the standards to update, it is anticipated that the proportions of the water closets in levels of the 2022 upgraded water efficiency Grades 1–3 will reach 60%, 30% and 10% for flushing and 50%, 40% and 10% for bidet function.

From 2021 to 2025, the flushing water consumption of the dual-flush toilets will be 9.35×10^8 m^3, 8.05×10^8 m^3,



	2021			2022			2023			2024			2025		
	Dual-flush	Single-flush	Bidet	Dual-flush	Single-flush	Bidet	Dual-flush	Single-flush	Bidet	Dual-flush	Single-flush	Bidet	Dual-flush	Single-flush	Bidet
Scenario 0	1050	211	16	1065	214	18	1082	217	20	1100	221	22	1119	235	24
Scenario 2	935	190	13	805	163	12	803	164	15	772	156	14	679	132	12
Water savings	115	21	3	260	51	6	279	53	5	328	65	8	440	93	12
Annual water savings	139			317			337			401			545		
Accumulated water savings	139			456			793			1194			1739		

Fig. 8. Water consumption and water-saving potential under the Standard + Labelling Scenario from 2021 to 2025 (in 1×10^6 m^3).

8.03×10^8 m^3, 7.72×10^8 m^3 and 6.79×10^8 m^3, the flushing water consumption of the single-flush will be 1.90×10^8 m^3, 1.63×10^8 m^3, 1.64×10^8 m^3, 1.56×10^8 m^3 and 1.32×10^8 m^3, and the water consumption for bidet will be 0.13×10^8 m^3, 0.12×10^8 m^3, 0.15×10^8 m^3, 0.14×10^8 m^3 and 0.12×10^8 m^3. Hence, the water consumption of newly sold toilets in 2021–2025 is 11.38×10^8 m^3, 9.80×10^8 m^3, 9.82×10^8 m^3, 9.42×10^8 m^3 and 8.23×10^8 m^3, respectively. Compared with the BAU scenario, the annual water saving is 1.39~5.45 × 10^8 m^3, and the accumulated water saving is about 17.39×10^8 m^3 in five years. The toilet flushing water consumption and water-saving projections under the Standard + Labeling Scenario are shown in Fig. 8.

4. Conclusion

The implementation of the Minimum Allowable Values of Water Efficiency and Water Efficiency Grades for Water Closets (GB 25502–2017) and Minimum Allowable Values and Grades of the Energy Efficiency and Water Efficiency for Smart Water Closets (GB 38448–2019) as well as the incorporation of the water closet and smart water closet into the contents of water efficiency labeling scheme will enhance the water efficiency of the water closet and smart water closet. Compared with the BAU scenario where water efficiency standards and labeling scheme are not implemented, the annual water saving is about 1.39~3.35 × 10^8 m^3

in 2021–2025. The accumulated water saving is about 10.75×10^8 m^3 in five years in the Standard Scenario where water efficiency standards take a mandatory effect, but the market promotion role of labeling scheme is absent. Under the Standard + Labeling Scenario, the annual water saving is 1.39~5.45 × 10^8 m^3, and the accumulated water saving is about 17.39×10^8 m^3 from 2021 to 2025 compared with the BAU scenario. With the good effect of water efficiency improvement under the Standard + Labeling Scenario, the improvement of water efficiency of water closets and smart water closets will produce significant water-saving benefits. The research results suggest a better effect on the improvement of domestic water efficiency and water efficiency of water appliances and the complementary implementation of mandatory standards and labeling schemes. This paper does not consider the situation that new sales replace part of the market holdings, and the water-saving effect obtained tends to be conservative. When this situation is considered, product replacement will reduce the original low-efficiency toilet, resulting in greater water-saving benefits.

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