Water and Electricity Consumption and Carbon Footprint of Washing Machines

Potrošnja vode, električne energije i ugljenični otisak veš mašina

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Abstract - Considering the relatively high share of households in global final energy and water consumption, washing machines are home appliances with a significant potential for electricity and water saving. The potential depends on the energy rating of a washing machine and the consumption habits of consumers in a household. Therefore, a survey was conducted to determine the laundry habits of domestic consumers and the characteristics of their washing machines. Considering collected information, the annual consumption of water and electrical energy and carbon footprint caused by the use of washing machines can be estimated and compared with the rest of the world. It was concluded that laundry washing causes around 10% and 4% of total water and energy consumption in the Republic of Serbia, respectively, with a carbon footprint of 423.33 $ktCO_2$.

Index Terms – Carbon footprint, Consumer habits, Energy efficiency, Saving potential, Sustainability, Washing machines

Rezime – Relativno visok udeo domaćinstava u globalnoj finalnoj potrošnji energije i vode, ukazuje na potencijal veš mašina sa aspekta uštede električne energije i vode. Pomenuti potencijal zavisi od karakteristika veš mašina, kao i od potrošačkih navika korisnika. Shodno tome, anketa je sprovedena sa ciljem da se utvrde potrošačke navike korisnika u Republici Srbiji kao i karakteristike njihovih veš mašina. Nakon prikupljanja potrebnih podataka procenjena je godišnja potrošnja vode, električne energije i odgovarajući karbonski otisak. Dobijeni rezultati su upoređeni sa referentnim uzorcima. Zaključeno je da veš mašine u Republici Srbiji učestvuju u okvirno 10% i 4% ukupne potrošnje vode i električne energije, respektivno, sa ugljeničnim otiskom od 423.33 $ktCO_2$.

Ključne reči – karbonski otisak, potrošačke navike, energetska efikasnost, potencijal uštede, održivost, veš mašine

I INTRODUCTION

Climate changes, air pollution, human health, environmental pollution, available drinking water, and available energy are currently some of the biggest problems the world is facing caused by improper human behaviour towards energy and natural resources [1]. The mentioned problems can be partly solved with adequate energy and water management in households. According to Eurostat, households shared 27% of final energy consumption in the European Union in 2020 [2]. According to the Statistical Office of the Republic of Serbia [3], the average household consumed around 5,050 kWh of electricity in 2020, while the average household in Europe consumed around 15,119 kWh [4]. Energy and water consumption in households mostly depend on the consumption habits of members. Taking that into account, it can be assumed that households carry a huge potential for energy and water savings. As claimed by Wood & Newborough [5] there are three general routes for reducing energy consumption and CO_2 emissions in the residential sector:

1. Replace the existing housing stock with low-energy buildings designed primarily to minimize heating and cooling loads;
2. Develop, and achieve widespread replication for, low-energy domestic equipment (e.g. appliances, lighting, and IT);
3. Promote and achieve „energy-conscious" behaviour among the users.

Out of these three proposed routes, the second and third could offer significant changes with less economic effort than the first one, especially in countries with a lower level of development. This study will focus, on one specific home appliance – washing machines, characterized by its significant electricity and water consumption. Götz and Tholen [6] stated that washing laundry is one of the most widespread housework tasks worldwide, with around 840 million domestic washing machines consuming more than 92 TWh of electricity and 19 billion m^3 of water, and emitting more than 62 $MtCO_2$.

According to Pakula and Stamminger [7] the electricity and water consumption for laundry washing in private households is determined by the technology of the washing machines, the number of washes, the chosen washing temperature, and the load size. Analysing the electrical energy consumption of washing machines Milani et al. [8] showed a positive correlation between the energy consumption of washing machines and the year of purchase. This correlation can be explained by considering that technology improves over the years increasing efficiency and reducing energy consumption per cycle. Monitoring the washing machines market in Europe, Mischel et al. [9] demonstrated that washing machines made after 2010 use significantly less energy, for example, washing machines made in 2009 averagely used around 226 kWh per year, while washing machines made in 2014

averagely used around 185 kWh per year. Fatih & Orphan [10] analysed home appliances' load profiles and power consumption. They concluded that most of the energy consumed by the washing machine is used for water heating. For example, for the cotton and synthetics washing program at 40°C at full load, 90.3% of the power consumption was caused by the water heater. As stated by GINETEX (the International Association for Textile Care Labelling) [11], the proper use of the washing machine implies:

- Washing at a lower temperature which still ensures a satisfactory result;
- Reducing the washing temperature from 40 to 30°C may reduce approximately 30% of the consumed energy;
- Always use the entire load capacity of the washing machine in use (a half-loaded machine will consume 50 to 70% more energy per kg of textiles);
- A quick wash cycle may serve another 20% of the energy consumption;
- The use of washing temperatures higher than 40°C may help to remove difficult stains but lead to significantly higher energy consumption (60°C + 50%, 90°C more than double the energy used).

To summarize the overview, a variety of factors (primarily, age and consumer habits) influence the electricity and water consumption of washing machines. The goal of this work is to determine the laundry habits of domestic consumers in the Republic of Serbia and the characteristics of their washing machines, and then considering the collected information to estimate the consumption of water and electrical energy and carbon footprint caused by the use of washing machines.

II SURVEY ON WASHING MACHINES

The internet survey was conducted using Google Forms [12] platform, with the goal of collecting information about washing machine characteristics and laundry washing habits of the citizens in the Republic of Serbia. The survey was shared using social networks and popular messaging platforms. The number of collected samples is 306, with slightly more female respondents (61.44%). The age distribution of the respondents is shown in table 1.

Table 1. The age distribution of the respondents

Age	0 – 18	19 – 29	30 – 44	45 – 59	60 – 79
Share	3.26%	41.83%	35.29%	16.67%	2.61%

Question 1: Which company made your washing machine? (Figure 1)?

The results of the survey show that washing machines produced by 3 companies („Gorenje" (33.99%), „Beko" (18.82%), and „Candy" (9.57%)) have a share of more than 60% of the market. The average capacity of used washing machines is 7 kg.
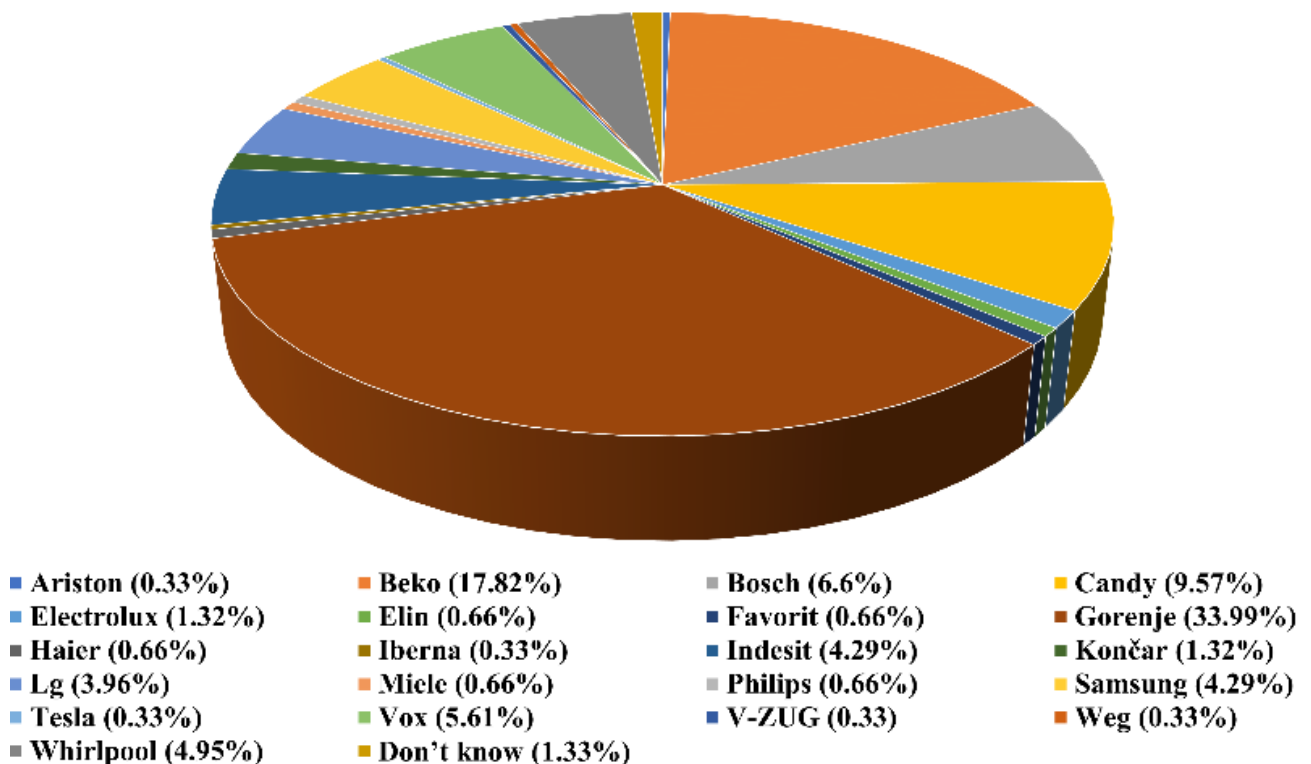

- Ariston (0.33%)
- Beko (17.82%)
- Bosch (6.6%)
- Candy (9.57%)
- Electrolux (1.32%)
- Elin (0.66%)
- Favorit (0.66%)
- Gorenje (33.99%)
- Haier (0.66%)
- Iberna (0.33%)
- Indesit (4.29%)
- Končar (1.32%)
- Lg (3.96%)
- Miele (0.66%)
- Philips (0.66%)
- Samsung (4.29%)
- Tesla (0.33%)
- Vox (5.61%)
- V-ZUG (0.33)
- Weg (0.33%)
- Whirlpool (4.95%)
- Don't know (1.33%)

Figure 1. Manufacturers of the washing machines

Question 2: How old is your washing machine (Table 2)?

Table 2. Age of the washing machines

Answer	Share
0 – 2 years	25.49%
3 – 5 years	32.03%
6 – 8 years	14.38%
9 – 10 years	4.58%
10+ years	17.65%
Don't know	5.87%

Answers indicate that most of the washing machines are between 3 and 5 years old (32.03%). Approximately, every fourth washing machine was bought in the last two years, while every sixth machine is older than 10 years. According to the survey, the average age of washing machines is around 7 years, which corresponds to the average age in German households [7].

Question 3: How many times a week do you wash your clothes at 30^oC and 40^oC (Table 3)?

Table 3. Number of washes per week at 30^oC and 40^oC

Answer	Share
0	4.58%
1 - 2	42.48%
3 - 4	30.07%
5	11.76%
5+	11.11%

It is noticeable that most people wash at 30^oC and 40^oC between 1 and 4 times a week (72.55%). According to the results of the survey average number of washes at 30^oC and 40^oC is 3 times a week.

Question 4: How many times a week do you wash your clothes at 60^oC (Table 4)?

Table 4. Number of washes per week at 60^oC

Answer	Share
0	18.95%
1 - 2	57.19%
3 - 4	15.36%
5	4.9%
5+	3.6%

Similarly to 30^oC and 40^oC, most people wash their laundry 1 to 4 times a week at 60^oC (72.55%). The average number of washes

at 60^oC is around 1.8 times a week.

Question 5: How many times a week do you wash your clothes at 90^oC (Table 5)?

Table 5. Number of washes per week at 90^oC

Answer	Share
0	19.93%
1 - 2	63.4%
3 - 4	11.44%
5	2.94%
5+	2.29%

According to answers, a high share of respondents does not use the 90^oC regime, but among the people using it, the most of them wash 1 to 4 times a week (74.84%). The average number of washes at 90^oC is 1.5 times a week.

Question 6: How many times a month do you wash your white laundry at partial load (Table 6)?

Table 6. Number of monthly washes at partial load (white laundry)

Answer	Share
0	27.12%
1 - 2	28.1%
3 - 5	23.53%
6 - 10	14.38%
10+	5.56%

There is a high share of people with responsible consuming habits washing white laundry at partial loads at most 2 times a month (55.22%). Due to the bad consuming habits of the rest of the respondents, the average number of washes at partial load for white laundry is 4 times a month.

Question 7: How many times a month do you wash your colourful laundry at partial load (Table 7)?

Table 7. Number of monthly washes at partial load (colourful laundry)

Answer	Share
0	22.22%
1 - 2	15.69%
3 - 5	26.14%
6 - 10	19.93%
10+	14.7%

In the case of colourful laundry, people pay less attention due to lower washing temperatures. More than a third of respondents (37.91%) showed responsible consuming habits by washing colourful laundry at partial load at most 2 times a month. The average number of washes of colourful laundry at partial load is 5.5 times a month.

Considering the results of the survey, the following can be stated:
- The average capacity of the washing machines is 7 kg;
- The average age of the washing machines is 7 years;
- Average number of washes on 30°C and 40°C, 60°C, and 90°C is 3, 1.8, 1.5 times a week, respectively;
- Around a quarter of respondents showed responsible consuming habits, avoiding more than 2 washes a month at a partial load;
- Average number of washes for white and colourful laundry at partial load is 4 and 5.5 times a month respectively.

III ESTIMATING THE ENERGY AND WATER CONSUMPTION

The annual energy and water consumption for laundry washing for the Republic of Serbia estimation framework is shown in Figure 2.
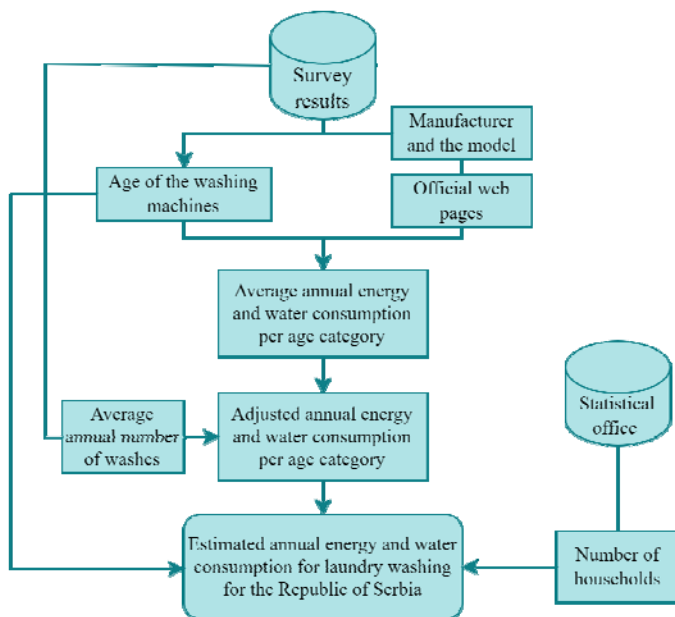

Figure 2. The framework of the estimation methodology

Three sources of data were used for estimating. The majority of data is obtained from the survey (the age distribution of washing machines, the manufacturer and model, and the number of washes), the number of households owning a washing machine was estimated using data from the Statistical Office of the Republic of Serbia [3], while consumption characteristics of the washing machines are collected using The Internet. The first step is the calculation of the average annual water and energy consumption per age category using the annual water and energy consumption based on standard 220 washing cycles given by the

manufacturers of the washing machines. The total annual water and energy consumption for laundry washing can be estimated by taking into account the number of households in the Republic of Serbia that own a washing machine, the percentage share of every washing machine age category, and the average annual water and energy consumption per age category. The calculated average annual energy consumption is based on standard 220 washing cycles, but considering the survey results, the average number of washes in the Republic of Serbia is around 6 times a week, which is 312 cycles yearly. This number of annual washing cycles is very high, considering the fact that an average household in the region of Germany, Austria, and Switzerland uses around 211 wash cycles per year for a four-person household [13]. Figure 3 shows the number of annual wash cycles per household worldwide.
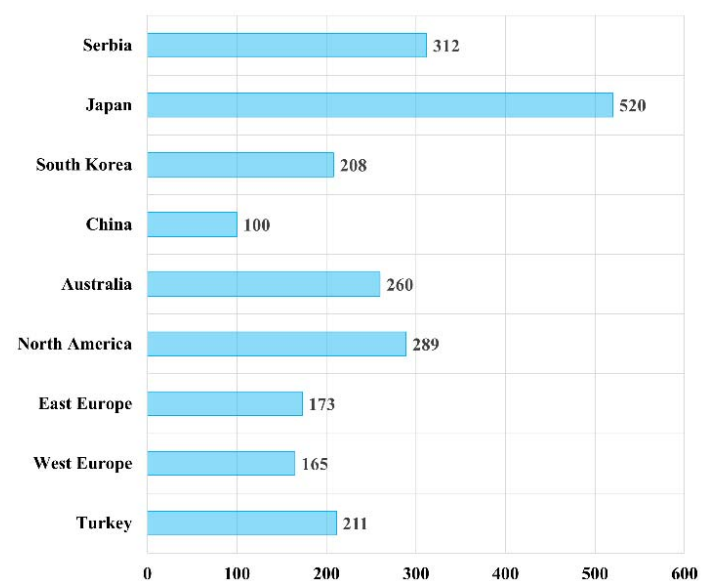

Figure 3. The number of annual wash cycles per household worldwide [7]

Table 8 shows the average annual energy and water consumption per age category (based on standard 220 washing cycles [14]).

Table 8. Average annual energy and water consumption per age category

Age category	Average annual energy consumption [kWh]	Average annual water consumption [l]
0 – 2 years	136	9,806
3 – 5 years	153	9,568
6 – 8 years	172	10,017
9 – 10 years	218	11,012
10+ years	240	11,828

Table 9 shows the adjusted average annual energy and water consumption per age category for the Republic of Serbia (based on 312 washing cycles).

Table 9. Adjusted average annual energy and water consumption per age category

Age category	Adjusted average annual energy consumption [kWh]	Adjusted average annual water consumption [l]
0 – 2 years	193	13,907
3 – 5 years	217	13,569
6 – 8 years	244	14,206
9 – 10 years	309	15,617
10+ years	340	16,775

According to the results of the 2022 Census of Population, Households, and Dwelling done by the Statistical Office of the Republic of Serbia [3], the total number of enumerated households is around 2,520,854. In the Republic of Serbia, 95.8% of households own a washing machine [3], which is around 2,414,978 households. Considering the analysed sample, the number of households using each age category of washing machines can be determined, as well as the total energy and water consumption by age category (Table 10).

Table 10. The number of households and total energy consumption per washing machine age category

Age category	Number of households	Total energy consumption [MWh]	Total water consumption [m³]
0 – 2 years	615,578	118,806.53	8,560,841.75
3 – 5 years	773,517	167,853.29	10,495,858.3
6 – 8 years	347,274	847,34.82	4,933,372.12
9 – 10 years	110,606	341,77.25	1,727,333.78
10+ years	426,244	144,922.83	7,150,236.68
Total		**550,494.72**	**32,867,642.65**

Results in table 10 show that in the Republic of Serbia, the citizens annually use around 550.49 GWh of electricity and around 32.867 Mm³ of water for laundry washing, which is around 227.95 kWh of electricity and 13.6 m³ of water per household.

According to the Statistical Office of the Republic of Serbia households consumed around 13,876.635 GWh of electrical energy [15] and 330 Mm³ of drinking water [16], in 2021, which means that households used around 4% of totally consumed electricity and 10% of totally consumed drinking water on laundry washing.

Analysing the electricity and water consumption for laundry washing by washing machines worldwide, Pakula and Stamminger [7] showed that energy consumption in the washing process varies worldwide. Figures 4 and 5 show the comparison of obtained results in the Republic of Serbia and worldwide. The technology of washing machines is predefining their consumption characteristics. Drum-type machines (HA) use in general less water, but more energy, while impeller-type

machines (VA) use significantly less energy because in most VA machines the washing water is not heated (typically 20°C) [17], but according to Ramasubramanian and Tiruthani [18], VA machines consume twice as much water as HA machines.
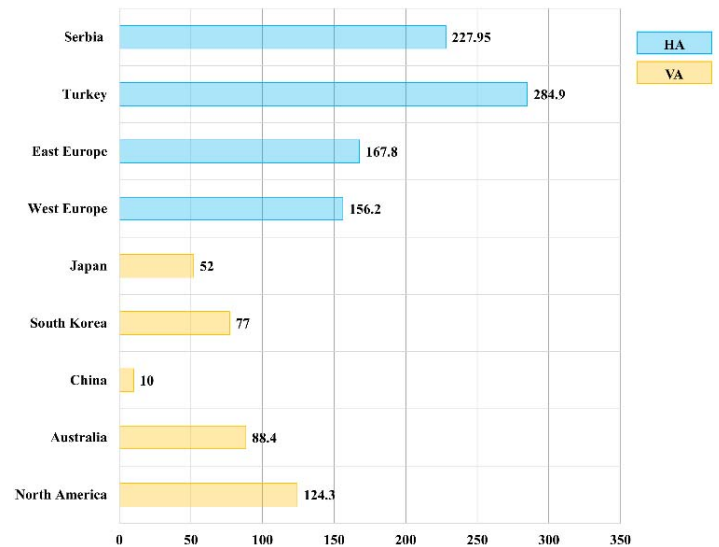
Figure 4. Comparison of annual electricity consumption for laundry washing worldwide [kWh]
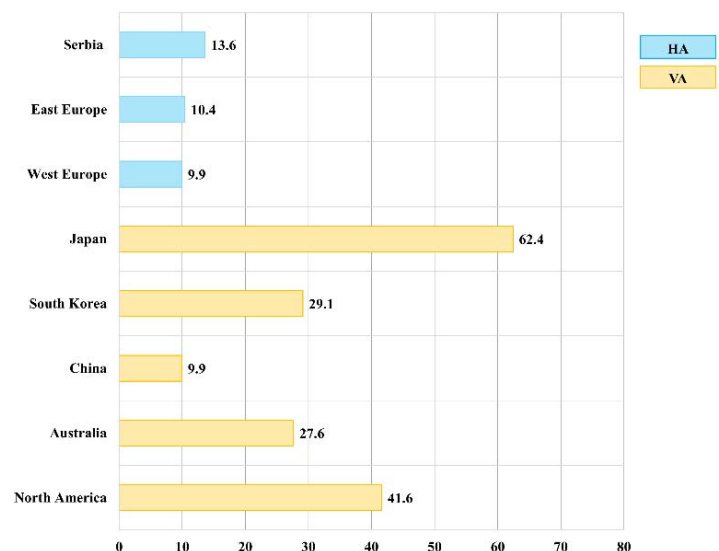
Figure 5. Comparison of annual water consumption for laundry washing worldwide [m³]

It is noticeable that the households in the Republic of Serbia consume more energy for laundry washing than Eastern and Western European households (on average 30%). Households in Turkey consume on average 284.9 kWh of electricity annually, which can be justified by the fact that Turkish households wash more than 75% of their laundry at water temperatures higher than 50°C and, out of this, 25% at more than 85°C. The fact that information on worldwide electricity use is from before 2010 makes Serbia's situation less favourable and raises the possibility

that things are worse than they appear. When it comes to water usage (Figure 5), households in the Republic of Serbia consume marginally more than the European average. Japanese households use the highest amount of water for laundry washing, but reusing warm water from the bathtub in the washing machine is usual. For example, 58% of the total water used for laundry washing in Japan in 2010 was reused bath water [19].

Gordic et al. [20] demonstrated that the average residual grid electricity emissions factor for the Republic of Serbia (2016 – 2020) is 0.769 $kgCO_2e/kWh$. Considering the electrical energy consumption for laundry washing, and the average residual grid electricity emissions factor, the calculated carbon footprint of domestic washing machines in the Republic of Serbia is around 423.33 $ktCO_2$. According to [21], a tree can absorb approximately around 25 kg of CO_2 per year. This means that 16,933,200 trees are needed to absorb the amount of CO_2 emitted by using washing machines in the Republic of Serbia. Considering the average tree density in the forests of Serbia (939 threes/ha [22]), that is around 180 km^2 of forests.

IV CONSUMER HABITS

Consumer habits have a huge influence on general electricity consumption in households. Using the lowest washing temperature that yields a desirable outcome and running the fully loaded machine only are the two components of proper machine usage. Table 11 (which includes the Republic of Serbia survey findings) displays the most popular washing machine technologies, load per cycle, and wash temperatures globally.

Table 11. Most frequently used washing machine technology, load per cycle, and wash temperatures per region [7]

Region/Country	Most frequently used technology	Average load per cycle [kg]	Most frequently used wash temperatures (^oC)
Republic of Serbia	Horizontal axis	5 – 6	30 and 40
West Europe	Horizontal axis	3 – 4	40
East Europe	Horizontal axis	3 – 4	40
North America	Vertical axis	3 – 4	14 – 48
Australia	Vertical axis	1.3 - 2	20 – 40
China	Vertical axis	1.3 - 2	Cold water
South Korea	Vertical axis	1.3 - 2	Cold water
Japan	Vertical axis	3	Cold water

Most Europeans, including those in the Republic of Serbia, wash their clothes between 30^oC and 40^oC. According to the survey, the average washing temperature in Serbia is 60^oC, at 80% load. Despite having the greatest number of annual cycles, Japanese households only use 50 kWh per household to wash their laundry. This fact illustrates the influence of washing temperature on the energy consumption of washing machines. Lowering the washing temperature significantly more impacts electricity consumption than increasing the machine's loading, according to [17].

The results of the survey show that citizens in Serbia wash white and colourful laundry at half load an average of 4 and 5 times a month, respectively, which is 108 washes in total yearly. Using only full load, the number of 108 half-load washes can be reduced to around 54 full-load washes, simultaneously reducing the total number of washes from 312 to 258. These changes in consumer habits can contribute to the reduction of electricity (-98 GWh) and water (-5.85 Mm^3) consumption, as well as the reduction of the carbon footprint (-75.35 $ktCO_2$).

V CONCLUSION

The overall finding is that water and electricity consumption in the Republic of Serbia is not considerably different from that of other countries that employ horizontal-axis washing machines. However, households in the Republic of Serbia wash laundry unjustifiably more frequently at higher average temperatures than in other European countries. In the Republic of Serbia, domestic laundry washing accounts for around 10% and 4% of household water and electricity usage.

In order to reduce the consumption of electricity and water for washing, specific policy measures, which promote responsible consumption habits – washing only at full load and washing at lower temperatures, are needed.

This research has two limitations. First, the approach used for collecting the answers is not suitable for the elders. According to the Statistical Office of the Republic of Serbia, around a third of the population is older than 60 years, while the share of this age group in the survey sample is around 2.6%. This finding suggests that overall water and electricity usage and carbon footprint may exceed the estimated levels. Second, indoor and machine drying of laundry were not included in the estimation of electricity use and carbon footprint, which could be a topic for further study.

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