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Electric Kettles: An Assessment of Energy-Saving Potentials for Policy Making in the European Union

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Abstract: Electric kettles are found in almost every household in the European Union. Within the preparatory study to establish the Ecodesign Working Plan 2015–2017, the electricity consumption of this product group in Europe was estimated at 20 to 33 TWh in 2012, with an energy-saving potential of more than 20%. This led to an Ecodesign preparatory study on kettles in 2020 to analyse the potential role of environmental policy-making for electric kettles in Europe in more detail. Based on elements from this study, this paper reviews worldwide policies covering this product group, methods to assess its energy efficiency and analyses of the potential of technical improvements to enhance energy efficiency. A method is suggested for measuring the power of kettles, and corresponding power-temperature measurements of selected kettles are presented. Overall, the findings indicate that technical optimization alone has a limited potential to improve the energy efficiency of kettles and to highlight the absence of a standard for measuring the energy consumption of electric kettles. However, user-related aspects of operating kettles offer a substantial saving potential. Heating too much water or at higher than required temperatures increase the energy consumption and related energy costs of private households. This could provide leverage for policy makers to improve the market and to reduce the environmental impact of this product group beyond mere technical optimization of energy efficiency, including aspects related to circular economy and energy sufficiency.

Keywords: electric kettles; Ecodesign; energy efficiency; life cycle costs; minimum energy performance standard

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1. Introduction

Electric kettles for boiling water are present in almost every household in the European Union (EU). Compared to other alternatives for boiling water, they are rather effective household appliances in terms of the time taken to boil water and their energy consumption [1]. Due to their high power rating and daily utilisation, however, they can contribute a substantial share of overall household electricity consumption. Within the Preparatory Study to establish the Ecodesign Working Plan 2015–2017 implementing Directive 2009/125/EC [2], the energy-saving potential of several energy-related products has been shortly assessed. It came out, that 20% of energy savings would be possible for kettles, this raised the interest of policy makers in the EU regarding the elaboration of a possible product regulation, e.g., minimum energy performance standard (MEPS) or energy label. To support the policy making process, a detailed analysis of kettles is required [3]. However, there are very few papers or studies of this specific product group. Ref. [4] investigated kettle usage patterns in 14 households over 2 years. Other studies focus on life cycle assessments of kettles [5,6]. Their results show that electricity consumption during the use phase is predominant in terms of environmental impact and indicate potential savings but do not address market considerations or the potential of single measures. This paper aims to contribute to closing this gap by reviewing the technical, behavioural and economic factors of electric kettles that need consideration when designing policy measures to reduce their energy consumption. It is based on the results of the recent Ecodesign Preparatory Study on Kettles [7] elaborated along the Methodology for the Ecodesign of Energy-related Products (MEErP) [3].

In this paper, representative kettles—so-called base cases—for the EU market are defined first, based on EU-27 market data, and information on the usage and typical technologies (Figure 1). Second, the three identified base cases are characterized, in particular, with regard to their energy consumptions and required test procedure. Third, improvement potentials in terms of energy consumption are analysed. For this, measures are identified, and their impacts on the energy consumption and the life cycle cost of the products are analysed. The results are then discussed, also including broader considerations for policy measures, before the conclusions.

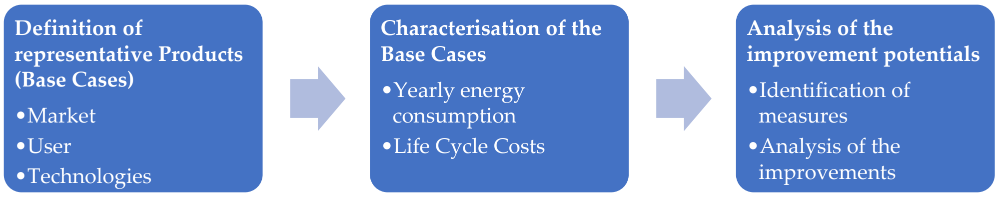


Figure 1. Methodology used for the paper.

2. Definition of Representative Kettles for the EU-27 Market

2.1. Common Kettle Technologies

The kettles covered by this paper are defined as stand-alone, unpressurised, electrically powered kitchen appliances primarily intended for boiling a batch of up to 10 l of drinking water. They may also be used to heat water to user-defined target temperatures below boiling point and/or to ensure water is kept warm after heating. Despite their differences, electric water kettles are, generally speaking, simple products with a limited number of components comprising the following:

- A container filled with water where the actual heating and boiling takes place. It is usually equipped with a handle and a lid and offers additional room for sensors and the control system. The container can differ in construction design (single-wall, double-wall, insulated, and vacuum), material (plastic, steel, and glass), capacity, and included features (e.g., water-level indicator, filters, etc.);
- Cordless models are portable as they feature a base that is connected to the mains;
- A power cord with a plug;
- A heating element. This can be an immersed element in direct contact with the water or an underfloor element concealed in the bottom of the container. The types of elements are as follows:
    a. Common tubular heating element: This consists of a heating wire (as the original resistance heating element), often comprising a nickel-based, nichrome heating element (NiCr), magnesium oxide powder, and an outer casing;
    b. A thick film heating element, which generally consists of a metal core. The core is coated with a glass-ceramic lining, which ensures electrical insulation and carries conductive, screen-printed heater tracks. These elements can transfer a higher amount of energy/heat per surface. Additionally, such elements offer a lower thermal mass; therefore, heat losses to the surrounding material are lower. Currently, thick film heating elements are more expensive than conventional, tubular ones. Kettles with thick film heating element are very rare on the EU market.
- Sensors, control units, and mechanical or electrical switches that ensure the proper function of the kettle with features such as auto-switch-off, temperature selection, keep-warm, and boil-dry protection (i.e., precaution against empty operation). Temperature control is based on the following main technologies:

- Bi-metal switches: Steam from the boiling water is conducted to a mechanical bi-metallic disk in the base, handle, or lid. When the steam reaches a defined temperature, the bi-metallic disk snaps its position and cuts off the power. Bi-metal switches have tolerances of +/− 5 to 7 K.
    a. Thermistors: Electric elements that change their electrical resistance in response to a change in temperature. Kettles use Positive Temperature Coefficient (PTC) models typically chosen for several pre-set temperatures (step-approach) or Negative Temperature Coefficient (NTC) models with step or stepless temperature setting.
    b. Both NTCs and PTCs can provide features such as auto-switch-off, boil-dry (PTC), temperature selection, and keep-warm and are more accurate than bi-metal switches.

2.2. Overview of the Market in the EU-27

Based on market information from GfK [8] (Figure 2), estimated sales of electric kettles in the EU-27 (i.e., without the UK) were around 16.3 million units/year in 2018. The market data for 2018 indicate that kettles with a rated volume between 1.6 and 1.8 l have the largest market share (56%). Plastic was the most common container material with a 47% market share, although this trend is decreasing. At present, metal has a similar market share (44%), and glass represents 9% of the market with steady growth since 2013. The power range of 2200–2400 W is the most popular with a 44% share of the market. Two thirds of the kettles have "windows" as a water level indicator. Among electric kettles, 16% have immersed heating elements, and only a minor share features advanced properties such as temperature selection or a keep-warm function (both 6%).

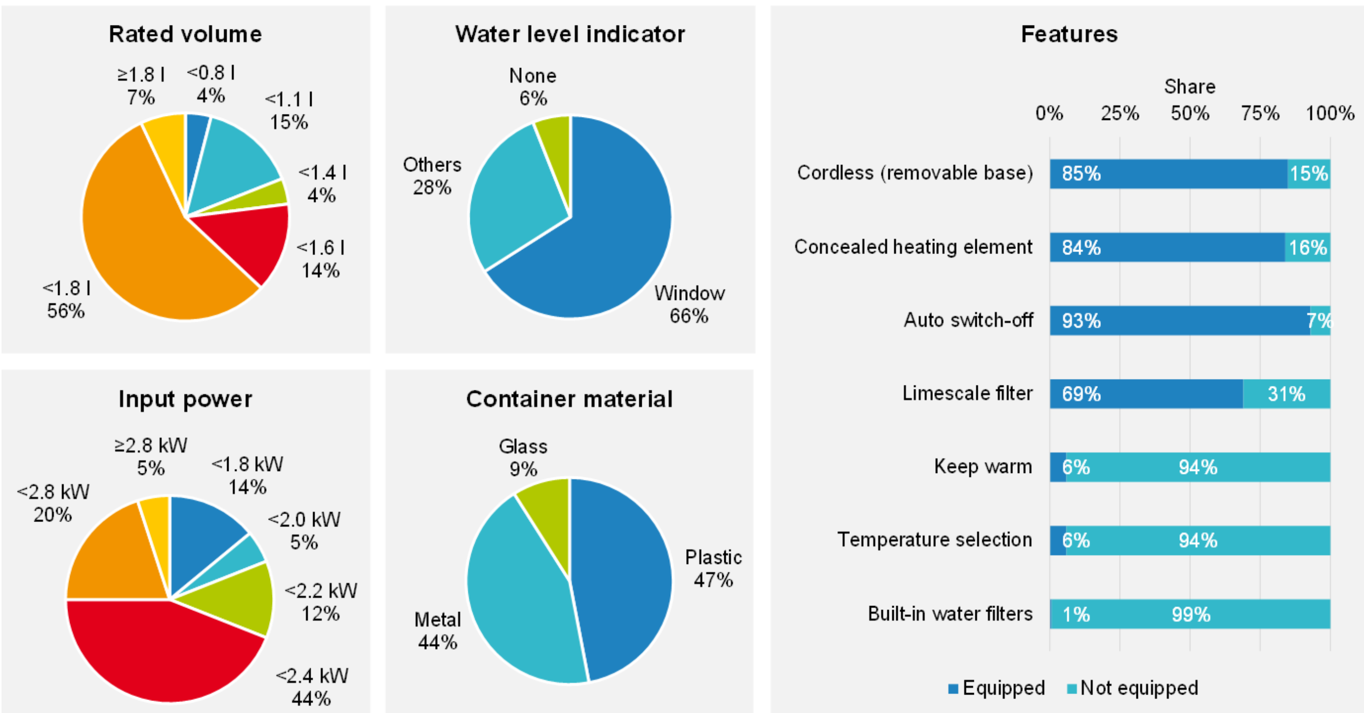


Figure 2. EU market shares according to electric kettle characteristics in 2018, adapted from [7] based on [8].

The EU-27 kettle market is largely saturated. In 2030, 17.8 million units/year are expected to be sold. This translates into a stock increase from 93.7 million units in 2018 to 103.9 million units in 2030.

2.3. Utilisation of Kettles

How electric kettles are used is highly relevant for the energy consumed. Important factors that can be influenced by users include the amount of water to be boiled, kettle lifetime, and—in more advanced kettles—temperature level and the keep-warm function.

When considering the energy-saving potential, it is useful to distinguish between the gross and net volume of boiled water. The former indicates the amount of water boiled in a kettle and the latter indicates the amount of water actually required by the user. The difference, also called "overboiling", is the amount of unused heated water that cools down again and/or is discarded. Despite limited data, this phenomenon seems to play an important role in practical kettle usage. A representative survey (Figure 3) for the UK [9] indicates that nearly two-thirds (65%) of the participants at least occasionally boil too much water in a kettle.

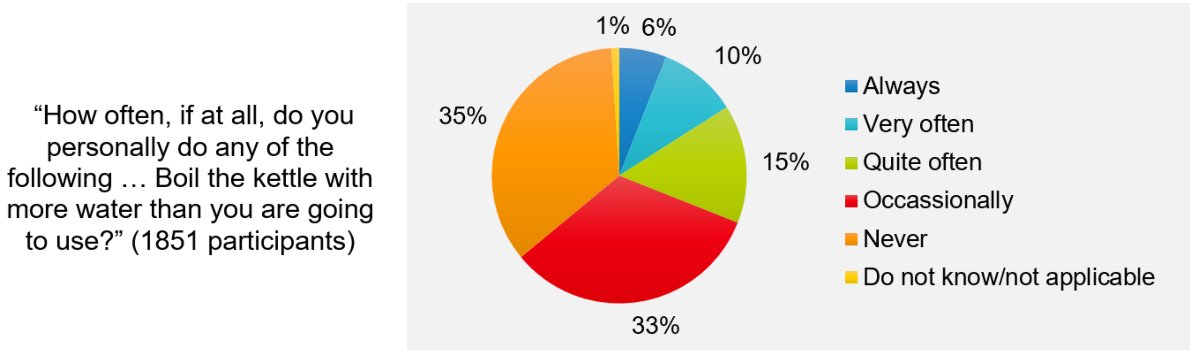


Figure 3. Survey results concerning overboiling, based on data from [9].

There are no official statistics concerning the demand for hot water, but various assumptions, estimates, and extrapolations do exist, mainly taken from grey literature. Estimations of the annual amount of boiled water per kettle from eleven (#1 to #11) different sources are shown in Figure 4 and briefly described in the following. Analyses from the UK Market Transformation Programme (#1) according to [2] assume a gross value of 1542 l per year and household. This value is adopted by [5] (#2) as a functional unit for gross boiled water demand. Other information [2] refers to the results from the UK Energy Saving Trust (#3), which determined an average annual electricity consumption of electric kettles of 167 kWh/year based on measurements in 412 households. This corresponds to a very similar value of 1392 l (gross) per unit and year when assuming an average consumption of 0.12 kWh/l and one kettle per household. A third reference (#4) given in [2] reports on a study of 250 households in the UK and cites 168 kWh/year per kettle. Applying the previous assumption about average consumption (0.12 kWh/l), this yields 1400 l (gross) per year. While these publications refer to the situation in the UK, others address different markets. A study on the environmental labelling of kettles [10] (#5) assumed an average demand of 3 l of boiled water per two-person household, which corresponds to 1095 l per year (if one kettle is used in the household), and which is described as a conservative estimate. Ref. [2] (#6) also indicates a net consumption of 1000 l for boiling water, of which 650 l is used for hot drinks and 350 l for cooking but does not provide information whether only electric kettles cover this demand. In another study [11] (#7) on electric and stovetop kettles, a functional unit is used to boil 0.5 l water 3 times a day each weekday, i.e., a gross value of 548 l per year. A study from Sweden [12] (#8) aimed to illustrate the energy demand of two fully filled vessels per day with 1 and 1.7 l, respectively. Again assuming 0.12 kWh/l, this translates into a gross value of 717 l and 1167 l per year, respectively. In a screening life cycle assessment [6] (#9), a kettle in Poland is assumed to be used three times a day to boil 1 l of water, resulting in 1095 l (gross) per year. Another estimated value is mentioned in a test of electric kettles in the German magazine "test" [1] (#10), which applied a proxy value of 2.5 l per day (913 l per year for one kettle) to illustrate the energy demand and costs of various types of water heating options. In the method used by Topten [13] (#11), the overall demand of an electric kettle is determined based on the assumption of boiling 1 l per day, resulting in an annual gross consumption of 365 l. In sum, there are no harmonised statistics available but relatively similar assumptions. It can be observed that the first four publications referring to the UK seem to indicate higher values than indications and assumptions for other parts of Europe. The simple average for the remaining regions is about 800 l (gross volume) per year—this corresponds roughly to using a 1.7 l kettle twice per day filled to 2/3 of its capacity. This value is used for further calculations in this paper.

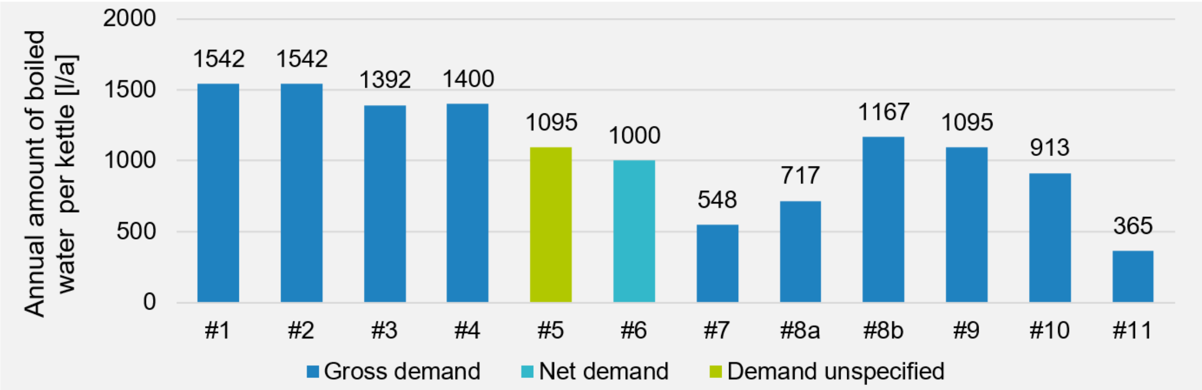


Figure 4. Estimates of annual boiled water using kettles, based on data based from [7].

Advanced kettle models allow for a flexible choice of target temperature. Setting temperatures below boiling has a direct impact on energy demand. However, these models currently have a limited market share, which might explain why there is very little empirical information on the use of such lower temperatures. One assumption for a study on the environmental performance of kettles [5] uses a distribution of 73% of consumption at 100 °C, 22% at 90 °C and 5% at 80 °C. Given the absence of further empirical evidence, the assumption for the reference situation is based on this distribution for the analysis of energy efficiency measures.

The keep-warm function offered by some kettles is another user-related aspect with a significant impact on energy demand. This allows the user to select a mode of operation that keeps the water at a specified temperature after regular heating stops, i.e., the kettle will then automatically reheat the water when it drops below a specified temperature. Again, there is a lack of empirical information about the use of this function. For a limited sample of kettles, the upper duration of the keep-warm function is between 15 and 40 min [12].

When discussing energy efficiency measures, kettle lifetime is another important factor that co-determines their economic performance. According to the investigation by [2], higher quality kettles are designed to last for up to 20,000 uses, which is said to correspond to 7 years of operation in the case of 8 uses per day. While lower priced models were attributed a lifetime of 3 years, an average of 5 years was assumed in the cited study. Further evidence on kettle lifetime is available from a consumer survey in the Netherlands, which found a median lifetime of 7.0 years for kettles in the year 2000 and 6.4 years for kettles in the year 2005 [14]. A survey for the German Environment Agency [15] points in a similar direction, but its results also show considerable heterogeneity in kettle lifetimes; the average replacement cycle was determined to be 5.7 years with a standard deviation of 4.2 years. To conclude, based on the mentioned data, assuming an average lifetime of 6 years seems to be an adequate proxy for real-life usage of electric kettles.

2.4. Definition of Representative Kettles

Based on data from the European market, three representative base cases (BC) were defined (see Table 1). A detailed overview of the characteristics and energy performance of the base cases is presented in Section 3.4. The three models cover a range of kettles and include a small simple model with 1 l capacity and an immersed heating element, a larger 1.7 l model with a concealed heating element as a popular and typical market average, and a third premium model with similar features to the second, but additional functions.

Table 1. Overview of the three base cases, source [7].

General	Description	Unit	BC 1	BC 2	BC 3
			Simple	Typical	Premium
Description	Concealed heating element		No	Yes	Yes
	Cordless		No	Yes	Yes
	Container material		Plastic	Plastic	Plastic
	Container capacity	[l]	1.0	1.7	1.7
	Real input power	[W]	1000	2200	2200
	Temperature selection		No	No	Yes
	Keep-warm		No	No	Yes
Technical data	Lifetime	[a]	6	6	6
	Water boiled	[l/a]	800	800	800
	Standby power	[W]	-	-	0.250
	Maximum volume (V_{max})	[l]	1.0	1.7	1.7
	Minimum volume (V_{min})	[l]	0.50	0.50	0.50
Price	End-user price	[Euro]	16	26	62
Sales	Market share in 2020	%	15%	79%	6%

3. Characterisation of the Base Cases

3.1. Existing Test Standards and Energy Efficiency Metrics

A review of EU documents on kettle performance indicates that most national regulations predominantly cover safety aspects. No stringent requirements regarding energy efficiency could be found, except for stand-by requirements. So far, except EN 50564:2011 Electrical and electronic household and office equipment—Measurement of low power consumption [16], which also applies to kettles, no IEC or EN standard or national standard/regulation in any EU Member State deals with the energy consumption or the energy efficiency of electric kettles. Only the standard IEC 60530:1975 Methods for measuring the performance of electric kettles and jugs for household and similar use [17] specifically deals with the performance of kettles but only in terms of the time to boil water, nothing on energy efficiency.

Outside the EU, only a handful of countries have implemented energy efficiency regulations for electric kettles. However, most of these regulations are voluntary energy labelling schemes (see Table 2). It can be noted that most of the tests and regulations focus on boiling water and are based on the specific energy consumption needed to heat 1 l of water, and that the definition of "boiling water" is not harmonised. Energy efficiency is only considered in a few cases (in the Chinese and Thai standards and by specific manufacturers) and refers to the ratio between the measured energy and the theoretical energy to heat water. Finally, the "Topten approach" is the only one to take the "keep-warm performance" into account.

Table 2. Overview of the measurement methods and energy efficiency metrics related to electric kettles, source [7].

Name/Reference	Description	Country	Volume [l]	Start–End Water Temperature [°C]	Energy Efficiency Metric	Detail
IEC 60530:1975 [17]	Test standard		1	15–95	None (focus on boiling time)	
Blue Angel/RAL-UZ 133 [18]	Eco label (voluntary endorsement label)	Germany	1	20–100 (switch off)	Specific energy consumption [kWh/l] $W_{20} = W_M \times 80/T_M$	W_M: power consumption until automatic switch-off of the kettle Temperature difference compared to the boiling temperature of 100 °C
Topten [13]	Voluntary endorsement label (private initiative)	Switzerland	1	15–100 (switch off)	Yearly energy consumption [kWh/a] $E_{kettle} = E_{boil} + E_{keepwarm} + E_{stand\text{-}by}$	$E_{boil} = 365 \times E_{consumption}$ to heat 1 l if T-setting feature is available: −10% $E_{keep\ warm} = P_{keep\ warm} \times 0.5 \times$ (max time keep-warm) $\times$ 365 ll if no measurement possible: 15 W × 1 h × 365 $E_{stand\text{-}by}$: $P_{stand\text{-}by} \times 8760$ h
Eco-Label Standard (EL408:2013) [19]	Voluntary endorsement label	South Korea	1	15–99	Specific energy consumption [kWh/l]	
GB/T 22089-2008 [20]	Voluntary standard	China	Rated volume	20 *–80	$\eta = C \times M \times (80 - T_1)/E \times 100\%$	T_1: start temperature
Greenmark N126 [21]	Voluntary endorsement label	Taiwan	1	15–99	Specific energy consumption [kWh/l]	
Energy Efficiency Label [22]	Voluntary comparative label	Thailand		30–90	$\eta = \rho \times (90 - 30)/(0.24\ P \times t) \times 100$	
ISIRI 7875 [23]	MEPS and Energy Label	Iran	1	20–90	Specific energy consumption [kWh/l]	
Manufacturer (confidential)	Test method applied by a manufacturer			20–98	Efficiency: η = Q/Energy Consumption	With: Q = (98 − 20) × 4186 × Volume

* Not explicitly specified but the thermal efficiency test requires us to “make the initial water temperature as consistent with the ambient temperature as possible” ambient temperature is 20 +/− 5 °C.

3.2. Measurement Method

Due to the lack of harmonised test standards to assess the energy consumption and the energy efficiency of kettles, figures are hardly comparable, unless documented in detailed test protocols (e.g., initial water temperature, volume of water, and final water temperature). To increase transparency and harmonise measurements, a test procedure was suggested (for details, see Annex C of Task 7 of Preparatory Study for Kettles implementing the Ecodesign Working Plan 2016–2019 [7]) based on elements from IEC 60530:1975. According to this test procedure, 1 l of cold water (15 °C) is heated and the electricity consumption and time are measured until the water is heated to at least 80 °C or until the kettle switches off automatically. Ambient temperature and preconditioned appliance were at a temperature of 20 +/− 3 °C. The procedure also foresees additional measurements at the minimum water capacity of the kettle expressed in volume (V_{min}) and at the rated water capacity of the kettle (V_{rated}).

When applicable, the following tests were also carried out:

- For kettles with pre-set temperature: energy consumption and time measurement for heating until shut-off at a pre-set temperature of 70 °C (or the nearest pre-set temperature above 70 °C) at minimum water capacity;
- For kettles with keep-warm feature: average input power, average water temperature, and maximum keep-warm time measurement for the keep-warm function at the

maximum keep-warm temperature, and maximum time setting at a rated water capacity. In addition: temperature drop during a cool-down phase of 30 min after boiling at rated water capacity.

Stand-by and off-mode tests have to be measured according to a harmonised standard [16].

Based on this, a set of nine measurements have been suggested (Table 3) for the test procedure. A durability test is also included, which is based on GB/T 22089-2008 as applied in China [21].

Table 3. Overview of the test conditions according to the suggested test procedure, source [7].

Test	Type of Test	Quantity of Water	Measurement	Measured or Calculated Parameters
1	Heating 80 K	Rated water capacity	Until shut-off (at least +80 K)	$E_{95°C,Vrated}$, $t_{95°C,Vrated}$, EEI
2	Heating 80 K	Minimum water capacity	Until shut-off (at least +80 K)	$E_{95°C,Vmin}$, $t_{95°C,Vmin}$
3	Heating 80 K	1 l *	Until shut-off (at least +80 K)	$E_{95°C,1}$, $t_{95°C,1}$
4	Heating	Rated water capacity	Until shut-off, when 70 °C pre-set temperature (or the nearest pre-set temperature above 70 °C) is selected	$E_{70°C,Vrated}$, $t_{70°C,Vrated}$
5	Heating	Minimum water capacity	Until shut-off, when 70 °C pre-set temperature (or the nearest pre-set temperature above 70 °C) is selected	$E_{70°C,Vmin}$, $t_{70°C,Vmin}$
6	Keep-warm	Rated water capacity	Max keep-warm temperature selected Longest possible keep-warm time	t_{kwmax}, T_{kw}, $P_{kw,Vrated}$, $P_{kw,Vrated}$
7	Cool down	Rated water capacity		T_{drop}
8	Standby	0 l	According to current harmonised standard	$P_{standby}$
9	Durability	1 l (or V_{rated} if V_{rated} > 1 l)	Until shut-off (at least +80 K)	N_{cyc}

* applicable if V_{rated} > 1 l.

3.3. Measurement Results

3.3.1. Specific Consumption for Heating

The specific energy consumption (Wh/l) decreases with an increasing volume of water to be heated. This was observed when analysing measurements carried out by Fraunhofer ISI (three kettles) and by the Swedish Energy Agency (eight kettles). In these, each kettle was filled to the minimum and maximum level of water, and the water was heated until shut-off (see Figure 5).

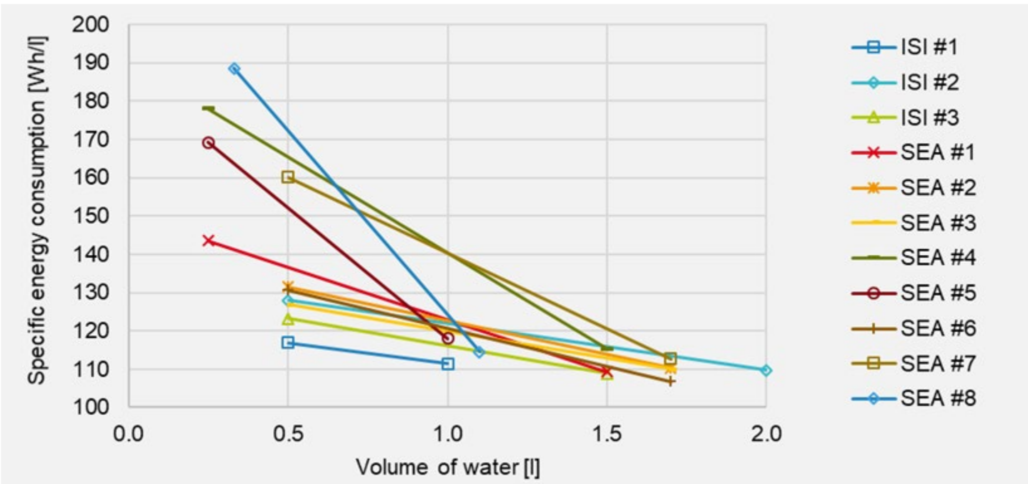


Figure 5. Specific energy consumption at maximum temperature (shut-off) according to the volume heated, based on [7].

3.3.2. Keep-Warm and Cool-Down Measurements

Figure 6 shows a typical measurement for a keep-warm test (Test 6) with a single-wall kettle. At the end of the initial heating phase, the heating element switches off and the water temperature decreases. As soon as the water temperature decreases by approximately 10 K in this case, the heating element switches on automatically until the water reaches the target temperature again. In this case, the average keep-warm power over the entire period is 114 W to keep 1 l at the maximum temperature setting.

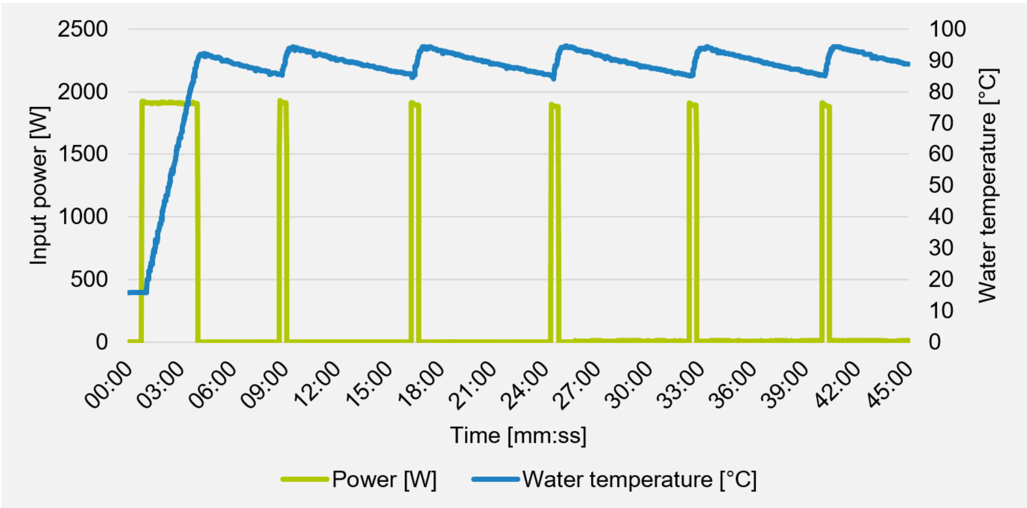
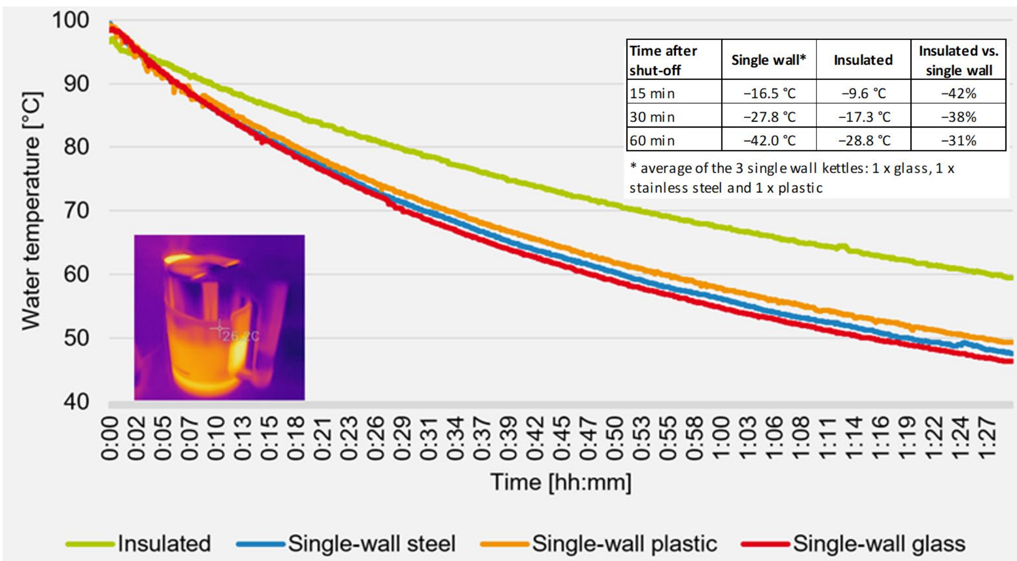


Figure 6. Example of keep-warm test, based on [7].

Cool-down measurements were carried out on a limited sample of four kettles with different types of containers (see Figure 7). The results presented in Figure 7 indicate that single-wall kettles had similar heat losses during the cool-down phase: on average, 42 °C water temperature decrease within 1 h, while the water temperature decreased by only 29 °C in a kettle with an insulated container. Furthermore, the type of container had an important impact on the average power required to keep 1 l of water warm. The results of Test 6 show that the average keep-warm power for the insulated model was roughly half that required for a single-wall kettle, which confirms a more energy-efficient performance of insulated kettles. However, further tests would be required as the sample here was very small.



Time after shut-off	Single wall*	Insulated	Insulated vs. single wall
15 min	−16.5 °C	−9.6 °C	−42%
30 min	−27.8 °C	−17.3 °C	−38%
60 min	−42.0 °C	−28.8 °C	−31%

* average of the 3 single wall kettles: 1 x glass, 1 x stainless steel and 1 x plastic

Figure 7. Cool-down measurement (Test 7) of kettles with different containers, based on [7].

3.4. Performance of the Representative Kettles

Based on the measurements, additional data and information from stakeholders including manufacturers, the performance of the representative kettles (see Table 1) was assessed (see Table 4). In terms of efficiency, the basic kettle (base case 1) performs best, as it has an immersed heating element that is in direct contact with the water to be heated, while base cases 2 and 3 have a concealed heating element. Furthermore, the keep-warm feature appears to have a considerable impact on the energy consumption of the kettle: +49% with the usage assumed here.

Table 4. Assumptions regarding the use phase of the product, source [7].

	Description	Unit	BC 1	BC 2	BC 3
Description	Capacity of the container [l]		1.0	1.7	1.7
	Real input power [W]		1000	2200	2200
	Temperature setting		no	no	yes
	Temperature holding		no	no	yes
Technical data Performance	Lifetime	[a]	6	6	6
	Water boiled	[l/a]	800	800	800
	Standby power	[W]	-	-	0.250
	Maximum volume (V_{max})	[l]	1.0	1.7	1.7
	Minimum volume (V_{min})	[l]	0.50	0.50	0.50
	Heat 1 l from 15 °C to 98 °C ($T_{switchoff}$)	time to heat [s]	390	189	189
		[kWh/l]	0.108	0.115	0.115
		efficiency [%]	89.0%	83.8%	83.8%
	Heat V_{max} from 15 °C to 98 °C ($T_{switchoff}$)	time to heat [s]	390	306	306
		[kWh/l]	0.108	0.110	0.110
		efficiency [%]	89.0%	87.7%	87.7%
	Heat V_{min} from 15 °C to 98 °C ($T_{switchoff}$)	time to heat [s]	213	103	103
		[kWh/l]	0.119	0.125	0.125
		efficiency [%]	81.4%	77.0%	77.0%
	Heat 1 l from 15 °C to 80 °C	time to heat [s]	n.a.	n.a.	148
		[kWh/l]	n.a.	n.a.	0.090
		efficiency [%]			83.8%
	V_{max} from 15 °C to 80 °C	time to heat [s]	n.a.	n.a.	240
		[kWh/l]	n.a.	n.a.	0.086
		efficiency [%]			87.7%
	Keep-warm: max time	[min]	n.a.	n.a.	60.0
	Keep-warm 1 l at 98 °C	[kW/l]	n.a.	n.a.	0.127
	Keep-warm 1 l at 90 °C	[kW/l]	n.a.	n.a.	0.115
	Keep warm 1 l at 80 °C	[kW/l]	n.a.	n.a.	0.099
Yearly energy consumption	Heating (assuming 1 l at T_{max} each time) – indicative	[kWh/a]	86.75	92.19	92.19
	Heating (assuming 1 l filled in and 73% at 98 °C, 22% at 90 °C, and 5% at 80 °C)	[kWh/a]	86.75	92.19	88.99
	Keep-warm (assuming 1 l at 98 °C over 60 min every day)	[kWh/a]	-	-	46.25
	Standby	[kWh/a]	-	-	2.09
	Total energy consumption [kWh]	[kWh/a]	86.75	92.19	137.33

n.a. not applicable.

4. Energy-Saving Potentials

4.1. Overview of the Measures

Based on a literature review, test reports, and exchange with several stakeholders, a set of measures is proposed to decrease the energy consumption of the three base cases:

1. Indicator: This measures aims to reduce “overboiling”, which has a significant effect on energy consumption, by directly showing the user how much water is in the kettle.

This is carried out using an enlarged water level indicator down to a low minimum volume (e.g., 0.25 l) and information on the filling level in both litres and cups.

2. Heating: In this design option, conventional heating elements (immersed or concealed) are replaced by thick film heating elements. Thick film heating elements operate with higher efficiency due to their higher energy density and lower thermal losses, which has a particularly strong effect on performance in the case of low filling levels.
3. Electronics: Measurements reveal an "overheating" of kettles, i.e., a situation where kettles exceed the boiling temperature beyond 95 °C as required by the current standard IEC 60530:1975 [17]. This measure seeks to reduce overheating by automatically shutting off the heating early by sensors and controllers with greater accuracy.
4. Insulation: To minimise energy dissipation after boiling, this measure improves kettle insulation with a double-shell container. This has special relevance for keep-warm features but also reduces heat losses in general during the cooling phase, i.e., after boiling.
5. Temperature: In some cases, e.g., preparing certain types of tea, temperatures of 95 °C or above are not required. This measure allows temperatures below 95 °C to be selected.
6. Keep-warm: Currently, this measure is intended to limit the use of the keep-warm function when this is available. Excessive re-heating of boiled water is avoided by setting a maximum duration for keep-warm to 30 min.

4.2. Data and Assumptions

Only some of these measures apply to all three kettles as indicated by an 'X' in Table 5. The changes in energy demand indicate up to what percentage the measures are expected to change the energy demand for heating water, i.e., during the boiling phase, and/or during the keep-warm phase compared to the reference, i.e., the base cases (BC). These values were compiled from available documentation, additional assumptions and following discussions with stakeholders. Table 5 also indicates the marginal increase in product price due to the measures. These values were estimated based on the available documented evidence and information from consultations with stakeholders. Notably, these prices are based on the assumption of a broad deployment of the measures, i.e., economies of scale apply. Some options, such as the water level indicator, are rather simple changes in design and expected to incur (nearly) no additional costs.

Table 5. Overview of the measures and their relevance for the base cases, source [7].

ID	Name	Details	Applies to			Changes Energy Demand During		Marginal Change in Price in Euro		
			BC 1	BC 2	BC 3	... Boiling by up to	... Keep-Warm by up to	BC 1	BC 2	BC 3
1	Indicator	Less overboiling through: Enlarged water level indicator, min volume, dual scale (in l and cup)	X	X	X	−10%	−10%	None	None	None
2	Heating	Thick film heating element	X	X	X	−8%	−8%	+3.50	+2.00	+2.00
3	Electronics	More accurate T-sensor, 95 °C target temperature	X	X	X	−5%	−5%	+4.00	+4.00	None
4	Insulation	Double-shell container	X	X	X	−1.5%	−50%	+2.00	+3.00	+3.00
5	Temperature	Allows temperatures below 95 °C to be selected		X		−3.5%	None		+2.00	
6	Keep-warm	Max 30 min			X	None	−50%			None

4.3. Analysis of Impact

Translating these measures into the impact on annual energy demand yields the results illustrated in Figure 8. The individual measures achieve approximate annual energy savings of up to 5 kWh for base case 1 (base case demand: 87 kWh), up to 9 kWh for base case 2 (base case demand: 92 kWh), and up to 24 kWh for base case 3 (base case demand: 137 kWh).

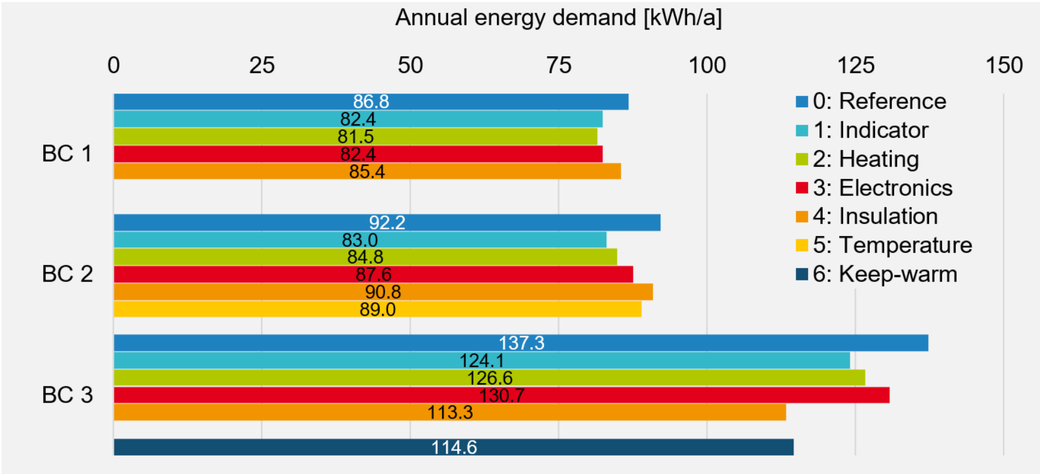


Figure 8. Annual energy demand of applying individual measures, based on data from [7].

A simple static life cycle costing model was used to calculate the impact of these changes in demand on the overall costs of kettles for consumers. The model adds the purchase price, the annual electricity costs (EU average household electricity price: approximately 0.21 Euro/kWh [24] multiplied by a lifetime of 6 years) and further operating costs including water, descaling and potential repairs, all which are unaffected by the measures. The results given in Figure 9 indicate that all design options are economically favourable from a life cycle perspective, i.e., the higher purchase costs due to implementing the measures are lower than the life cycle savings due to reduced electricity costs.

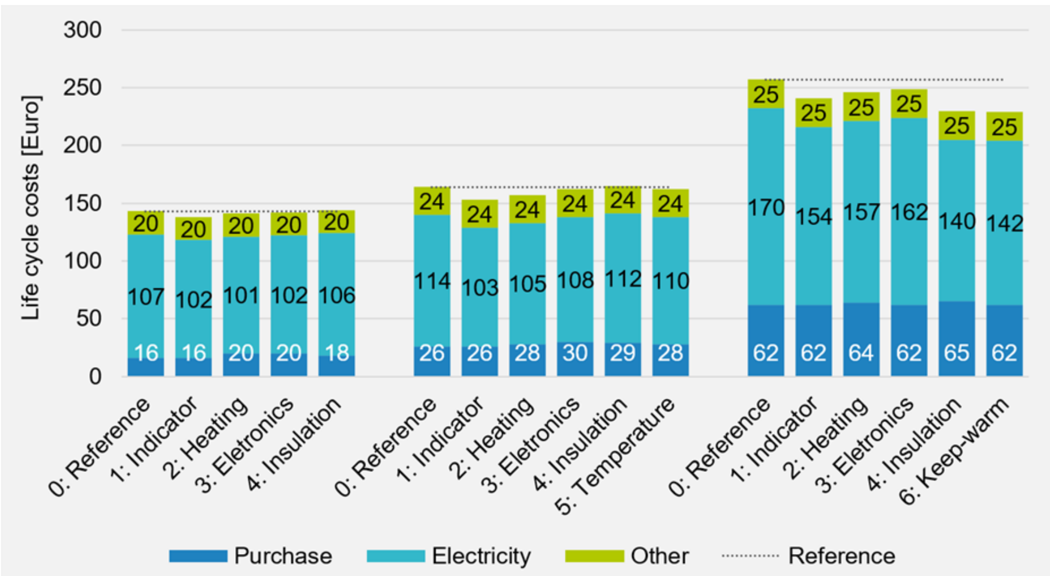


Figure 9. Life cycle costs of the measures applied individually (**left**: BC 1, **middle**: BC 2, **right**: BC 3), based on data from [7].

4.4. Analysis of Packages

Simply adding up the savings of individual measures when considering several measures simultaneously usually overestimates the achievable savings as measures usually interact. To analyse the impact of such bundles of measures, the individual measures are first sorted in descending order by their contribution to reducing the life cycle costs (LCC) compared to the base case. Then, the measures are applied successively to the reference cases in this order. Figure 10 shows the results of such an analysis with regard to LCCs and annual energy demand for the three base cases. First, it can be observed that the order of measures changes for the different base cases, i.e., the relevance of the measures varies. Second, the measures have different impacts in terms of relative savings. Third, for base cases 1 and 2, the last applied measure marginally increases the LCCs of the kettles, i.e., beyond the Least Life Cycle Costs (LLCC). Fourth, it can nevertheless be concluded that applying all the measures still reduces the LCCs compared to the base case. This means that the package of measures substantially reduces the energy consumption and consequently the environmental impact while still reducing costs for consumers.

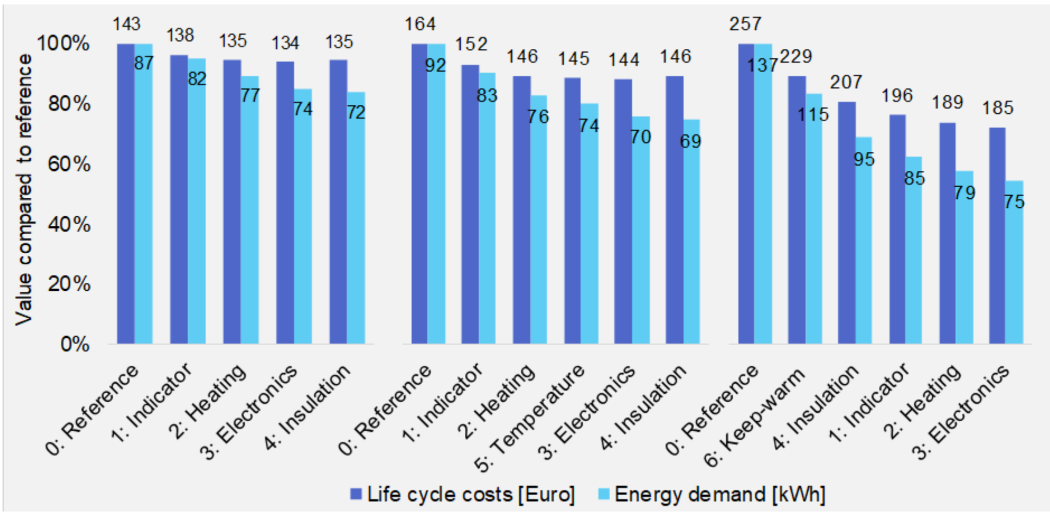


Figure 10. LCCs and annual energy demand when applying measures successively and considering their interaction (**left**: BC 1, **middle**: BC 2, **right**: BC 3), based on data from [7].

5. Discussion

Substantial improvements in terms of energy savings and LCCs can be achieved for all the identified base cases. If all new kettles on the EU market from 2023 corresponded to the LLCC level, the estimated energy consumption of the stock in the EU-27 would decrease from 9.8 TWh/year (Business as Usual: BAU) to 7.4 TWh/year (see Table 6). This means that a 24.7% reduction in energy demand would be achieved while avoiding 12.7% of the annual expenses. The LLCC level achieves energy savings that are very close to the Best Available Technology (BAT) level.

These figures suggest that setting minimum energy performance standard (MEPS) requirements for kettles at the LLCC level could be worthwhile, since this would deliver the largest cost reduction over the assumed lifetime of the product. However, it should be stressed that the LLCC level leads to higher purchase costs than the BAU configuration. Furthermore, the idea of introducing an energy label in combination with MEPS requires additional research, as the performance level difference between LLCC and BAT seems limited. Additional aspects must be addressed when considering policy measures specifically dedicated to kettles.

Table 6. Overview of the different scenario assumptions and impact on energy consumption by 2030, source [7].

Scenario	BC	Design Options Implemented	Annual Energy Consumption [kWh/Year]	Purchase Cost [EUR]	Annual Maintenance Cost [EUR/Year]	Energy Consumption of the EU Stock in 2030 [TWh/Year]	Expenditure for the EU Stock in 2030 [Bn. EUR/Year]
BAU	1	No	86.8	16.0	3.3	9.8	3.0
	2	No	92.2	26.0	4.0		
	3	No	137.3	62.0	4.2		
LLCC	1	1, 2, 3	73.6	23.5	3.3	7.4 (−24.7%)	2.6 (−12.7%)
	2	1, 2, 3, 5	70.0	34.0	4.0		
	3	All (1, 2, 3, 4, 6)	75.0	67.0	4.2		
BAT	1	All (1, 2, 3, 4)	72.5	25.5	3.3	7.2 (−25.8%)	2.6 (−11.8%)
	2	All (1, 2, 3, 4, 5)	68.9	37.0	4.0		
	3	All (1, 2, 3, 4, 6)	75.0	67.0	4.2		

First, a common method concerning the energy performance of electric kettles needs to be elaborated and adopted. A proposal was made in [7], but a CEN/CENELEC standard mandated by the European Commission is still required. Many existing standards focus on the energy consumption measured for boiling 1 l of water. However, such tests are not applicable to kettles with a rated capacity below 1 l. Furthermore, large kettles are designed for more than 1 l (up to 10 l), so that a standard based on 1 l does not reflect their realistic usage. Hence, it seems more reasonable to focus on the energy consumption of kettles measured at rated capacity when defining an energy efficiency metric, as is the case in China [21].

Second, some of the savings are not achieved by typical energy efficiency measures as they rather concern energy sufficiency and aim to avoid heating too much water (over-boiling) or at too high a temperature (overheating). The first issue could be addressed by providing users with more information, e.g., minimum water volume indicator, large water level indicator (with scale in s and in cups). An energy efficiency metric could help to address the second issue. This could reflect the ratio between the energy theoretically required to heat water from 15 °C by 80 K and the electricity consumed until the kettle automatically switches off. Such a metric could contribute to setting MEPS and/or defining energy classes of a label. Regarding the keep-warm function: the higher the temperature difference between the water in the kettle and the ambient temperature, the larger the heat losses through the container and the kettle lid. Consequently, keeping the warm water at the target temperature consumes more energy than re-heating it to this temperature when required. However, the keep-warm function delivers a different energy service than the boiling function and might be required by users who need a certain volume of hot water ready at any time over a limited period. Limiting the duration of the keep-warm function (e.g., to 30 min) and insulating the container of such kettles are cost-effective measures for base case 3 kettles. It should be ensured that if a policy measure addressing the keep-warm function is introduced, the consumer does not perceive the product as more energy-efficient. Otherwise, this could lead to increased sales of products with a function that the consumer does not need and to increased absolute energy consumption. In addition, information on an indicative or standardised yearly energy consumption (in kWh/a) could guide consumers to particularly efficient models. The Preparatory Study for Kettles [7] suggested a way to calculate such a metric, taking into account different use cases and features of a kettle. However, stakeholder feedback suggested that there is still a need for more extensive data on kettle usage.

Third, to reduce the environmental impact of the product, circular economy requirements could be set. In the EU context, an Ecodesign implementing measure on kettles could consider requirements such as the provision of spare parts and instructions, a durability requirement, as well as requirements regarding the material and marking of the container and the base plate to facilitate their recycling. Based on the bill-of-material of the base cases, over 90% of a kettle (in weight without packaging and documentation) consists of recyclable materials. This exceeds the requirement of the Waste Electrical and Electronic Equipment Directive [25] for this product group, and a recyclability rate requirement could be set in line with a product specific standard based on EN 45555:2019 General methods for assessing the recyclability and recoverability of energy-related products [26]. The potential for post-consumer recycled materials is limited, as the share of parts (in weight) in contact with water is high for this product group.

As a final remark concerning the results presented in this paper, it should be noted that data related to the energy efficiency of kettles and the cost-effectiveness of energy-efficiency measures for kettles are limited. This contribution adds to the existing data and indicates general trends, but further studies on the technical and economic performance of kettles based on a larger empirical basis seem advisable.

In general, these recommendations and aspects have been brought forward within the Ecodesign preparatory study [7], including detailed inputs for a possible Ecodesign legislation and a proposal for measurement methods and calculations (see Annex B "input to legislation" of [7]). However, no decision from the European Commission regarding the product group "kettles" has been officially taken yet.

6. Conclusions

Electric kettles are very popular household appliances in the EU and worldwide. However, the data and literature dedicated to this appliance are rather scarce. The aim of this paper was to review the technical, user-related, and economic factors of electric kettles that should be considered when establishing policy measures aimed at reducing their energy consumption. This paper showed a substantial cost-effective energy-saving potential in the EU-27 for kettles of up to 2.4 TWh/year (or 25%) in 2030. This absolute saving potential is lower than in the Ecodesign Working Plan study [2], as the scope is different and some assumptions (in particular concerning stock and usage) are different. Measures to achieve the potential savings include those with a direct impact on energy efficiency, such as insulation, as well as those with an indirect impact, such as those affecting user behaviour, especially with regard to overboiling and overheating. Therefore, electric kettles do seem to warrant policy action.

An ambitious product policy for kettles could include energy efficiency requirements as well as other requirements (functional and informational) in order to reduce their annual energy consumption. Establishing a common measurement method is the pre-condition for any policy action. Beyond the scope of energy efficiency and in line with the latest Circular Economy Action Plan [27], a kettle regulation could also include aspects linked to repairability, durability, and recyclability in order to reduce the product's environmental impact. The current Ecodesign framework already allows for the elaboration of comprehensive regulations for energy-related products in the EU. The EU regulatory framework is expected to be strengthened under the proposal for Ecodesign for Sustainable Products Regulation presented by the European Commission on 30 March 2022 [28]. Finally, as many other small kitchen products are similar to kettles in terms of their circular economy aspects, it might be useful to develop a common horizontal approach for this family of products. Here, the outcomes funded within the preparatory study for kettles [7] might be a good basic for further small kitchen products.

The question of regulating kettles might be raised in other parts of the world beyond the EU. This paper provides the relevant information necessary for such an assessment, but the question of a test standard remains. Any regulation would benefit from the elaboration of a test standard by IEC (TC 59). At present, in most economies, customers have no information about the energy performance of kettles, meaning that purchase decisions based on energy efficiency criteria are not possible. Information regarding the keep-warm power of kettles would be also relevant, as this feature can have a major impact on the annual energy consumption.

As the user behaviour has a key role on the energy consumption and data are scarce in that field, even in the EU, some research could be dedicated on this aspect.

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