Water Treatment for Decarbonisation

Mitigating Limescale's Environmental Impact

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HYDROTEC

Executive Summary

Limescale formation within domestic hot water systems and other water-connected equipment is a well-known issue that significantly reduces energy efficiency. While many water heater manufacturers and plant operators regularly clean and service equipment to remove limescale deposits and maintain the longevity of the plant, this approach does not address the reduction in energy efficiency that occurs between maintenance intervals. The most effective strategy to ensure consistent, efficient operation is to prevent limescale deposition in the first place.

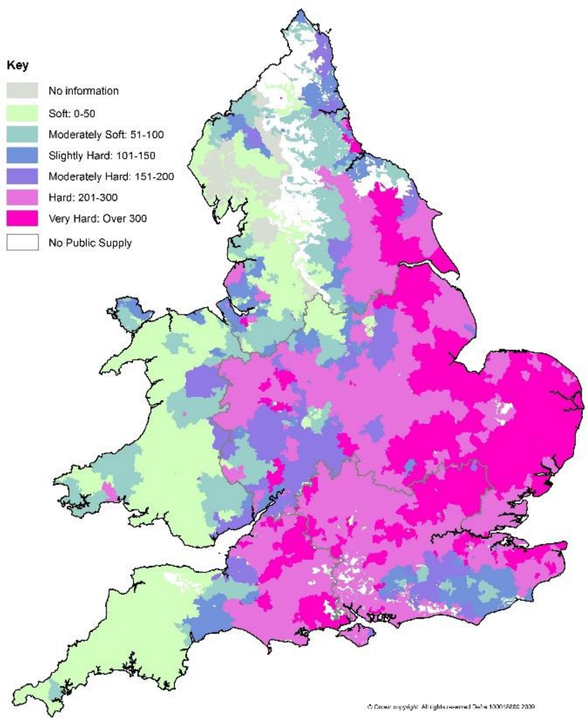
This study highlights the importance of limescale prevention in reducing carbon emissions. By implementing preventative measures, significant carbon savings can be achieved, ensuring more efficient energy use in water heating systems.

This paper explores the environmental consequences of limescale-induced inefficiencies, focusing on the resultant carbon emissions. The study demonstrates that just 5mm of limescale buildup can reduce energy efficiency by 50% and lead to a 26% increase in carbon emissions over a five-year period. This can translate into hundreds of tonnes of avoidable and preventable carbon emissions.

By implementing limescale prevention and control technologies, stakeholders can significantly reduce these emissions. Even after accounting for the carbon footprint associated with installing and operating these technologies, there is still a substantial net reduction in carbon emissions. Moreover, these technologies not only prevent further limescale buildup but can also help in removing existing deposits, restoring energy efficiencies closer to the baseline.

Given that over 70% of properties in the UK are supplied with hard water, which exacerbates limescale formation, this issue is particularly relevant.

The paper underscores the importance of proactive measures in maintaining energy efficiency and reducing operational carbon emissions in the built environment. With energy use in buildings contributing up to 28% of global emissions, and water heating accounting for a significant portion of this, effective limescale management presents an important opportunity for reducing the environmental impact of energy use in buildings.



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Introduction

Energy use in buildings is a major contributor of global carbon emissions, with water heating accounting for up to 12.5% of total energy use in the domestic sector and 6.5% in the commercial sector. Limescale formation is a common issue in water-connected equipment, particularly within domestic hot water systems, and it exacerbates this energy consumption by reducing the efficiency of heat transfer surfaces.

While many water heater manufacturers and plant operators perform routine maintenance to remove limescale and extend equipment life, not all do, and energy losses between maintenance intervals persist. Despite recognition of the detrimental effects of limescale on equipment operability, the associated environmental impact — particularly in terms of increased carbon emissions due to reduced efficiency — has not been thoroughly quantified.

This white paper addresses this gap by assessing the carbon emissions caused by energy inefficiencies from limescale buildup. Using quantitative data, it demonstrates the substantial environmental benefits of implementing limescale prevention and control technologies. These technologies not only reduce operational carbon emissions but also help restore energy efficiency in systems already affected by limescale.

In a world focused on mitigating climate change, effective management of limescale offers a practical and impactful means of reducing carbon emissions associated with building energy use.

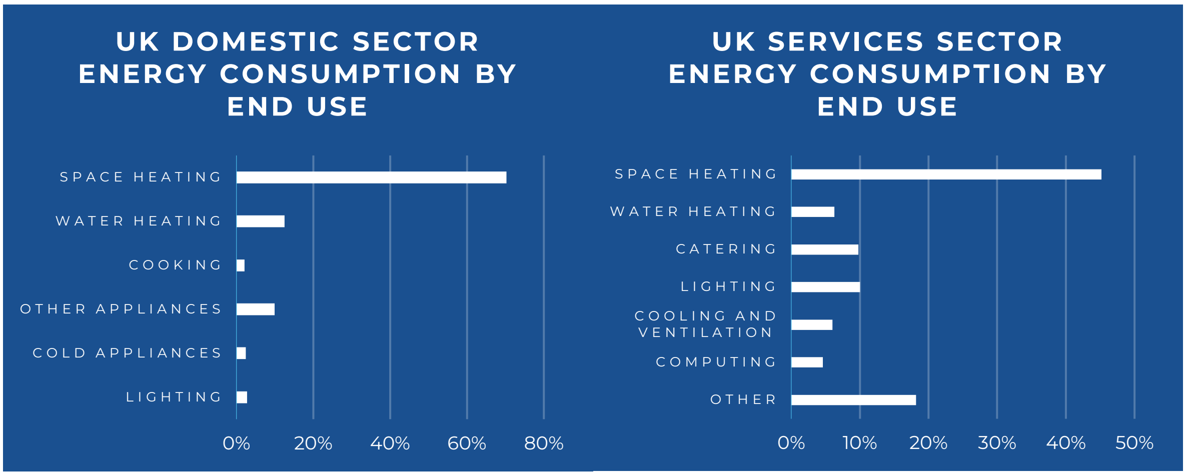


Table 1: UK Domestic Sector and Services sector energy consumption by end use, 2016 – total 1730 PJ (Source: BEIS, 2021c)

Methodology

In this section, we outline the approach used to calculate the increase in carbon emissions due to limescale buildup and the effectiveness of prevention technologies. The analysis compares gas and electric water heaters, with efficiency reductions attributed to limescale accumulation modelled over a five-year period.

We will calculate the annual incremental increase in carbon emissions for both water heater types, with efficiency decreasing each year based on the thickness of limescale formation on the heat transfer surfaces. Starting with a baseline efficiency of 100%, we will apply reductions year by year according to the limescale thickness. The increased energy demand due to reduced efficiency will then be converted to the corresponding carbon emissions for each energy source. The results will be presented as a five-year operational carbon emissions profile.

Currently, no comprehensive public datasets directly link energy efficiency to limescale thickness. While several reputable sources have published summaries of their internal findings, full datasets remain unavailable. However, publicly available information includes the following:

- British Water reported that just 1.6mm of limescale could reduce efficiency by 12%, and 3mm could further reduce efficiency by 25%.
- Portsmouth University found that 5mm of limescale more than doubled the time required to heat the same amount of water, implying a 50% reduction in energy efficiency.
- Advantica's study found that 9 grams of limescale reduced gas boiler efficiency by 17%.
- A Carbon Trust report noted that a 1mm layer of limescale could cause a 7% increase in energy consumption.
- ASHRAE's study found that 1.5mm of limescale reduced the efficiency of a heat exchanger by 11% on average.

The available data is presented as follows:

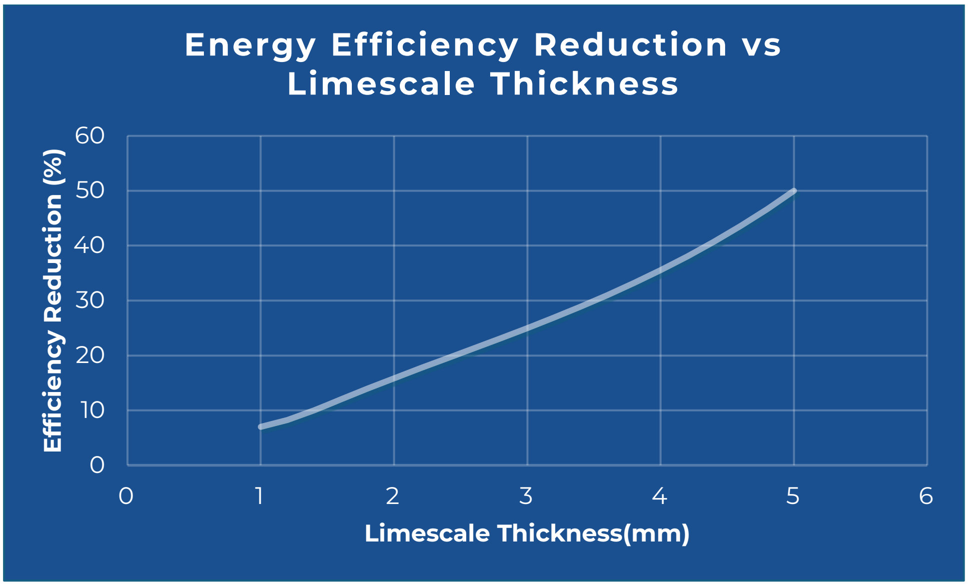
Thickness (mm)	**Reduction In Efficiency (%)**
1	7(1)
1.5	11(2)
1.6	12(3)
3	25(3)
5	50(4)

1) As per Carbon Trust
2) As per ASHRAE Study
3) As per British Water
4) As per Portsmouth University, based on increase of heating time based on scale thickness

Using the short-form data available we can calculate the approximate missing efficiency values at various thicknesses of lime scale.

Thickness (mm)	Efficiency Reduction (%)
1	**7**
1.2	8.25
1.4	10.02
1.5	**11**
1.6	**12**
1.8	13.95
2	15.84
2.2	17.68
2.4	19.5
2.6	21.31
2.8	23.14
3	**25**
3.2	26.92
3.4	28.91
3.6	31
3.8	33.21
4	35.55
4.2	38.05
4.4	40.72
4.6	43.59
4.8	46.68
5	**50**

These values were obtained by fitting a cubic spline to the known data points. This interpolation method smoothly estimates the efficiency values for the missing thicknesses. The newly prepared data set produces the following graph:



To validate our data, and due to the lack of comprehensive public datasets, we reviewed and compared it with other publicly available graphical representations showing the relationship between limescale thickness and energy efficiency reduction. Our results are consistent with other data, demonstrating a clear linear relationship between limescale thickness and energy efficiency reduction.

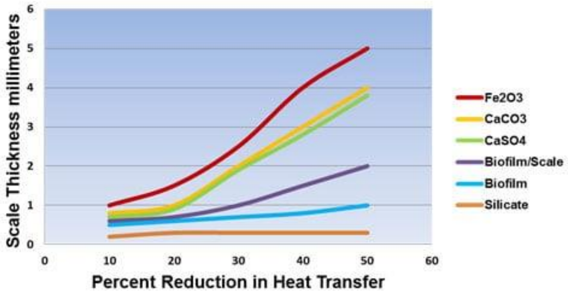


Figure 1: Source: Boullosa-Falces, D., Sanz, D. S., Garcia, S., Trueba-Castañeda, L., & Trueba, A. (2022). Predicting tubular heat exchanger efficiency reduction caused by marine biofilm adhesion using CFD simulations. Biofouling, 38(7), 663–673

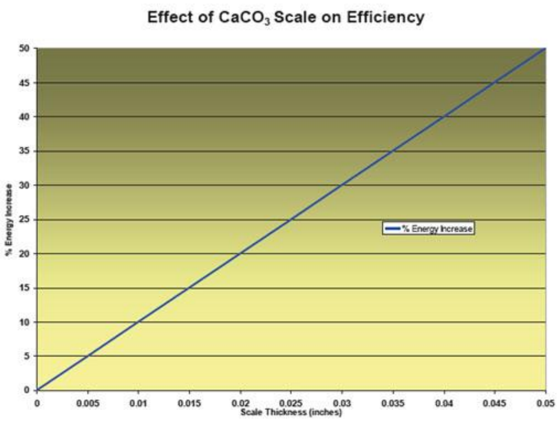


Figure 2: Source: Association of Water Technologies https://www.awt.org/resources/seed-program/water-careers/science-of-scaling/

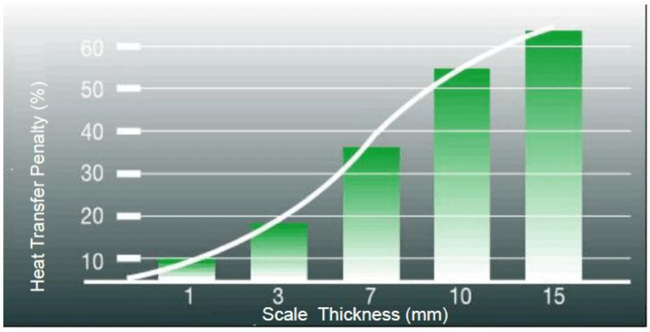


Figure 3 Source: Caleffi S.P.A

Another unreported parameter is the volume of limescale that can be deposited over time. Previous research indicates a linear relationship between water hardness, temperature, and usage in determining the amount of limescale that can form.

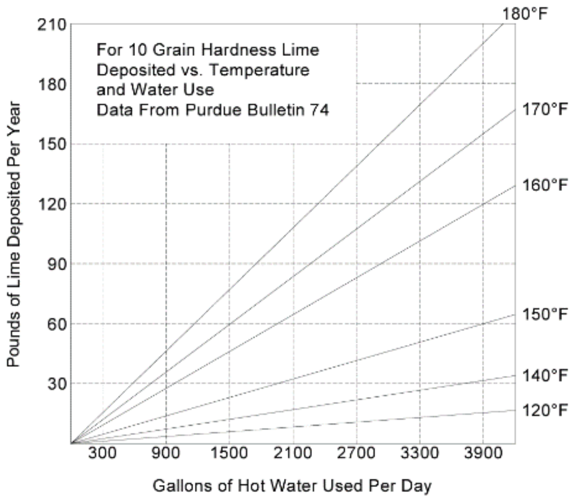


Figure 4: Source: Krappe, Justus Maximilian, Engineering experiment station. Gas engineering bulletin; no. 6; Research series; no. 74; On cover: Engineering bulletin, Purdue university. Vol. xxiv, no. 3a. June, 1940

However, this approach does not account for the fact that limescale typically does not deposit uniformly on heat transfer surfaces, nor does it indicate the rate at which limescale forms in terms of thickness. This variability is likely due to numerous factors, including water residence time, additional water chemistry parameters beyond pH, total and calcium hardness, conductivity, the primary energy source, the heat exchanger type, and the incoming and target water temperatures.

Understanding these variables is critical for accurately assessing the long-term environmental impact of limescale accumulation in domestic hot water systems. A commonly cited estimation for limescale accumulation is 1.2mm per year, though this figure is frequently used as a general reference without attribution to specific studies. For the purposes of this methodology, we will assume a maximum limescale accumulation rate of 1mm per annum.

Additionally, we must calculate the energy required to heat any given volume of water from one temperature to another. The formula used for this calculation is:

$$Q=mc(T_1-T_2)$$

Where:

- **Q:** Amount of heat required to reach the target temperature (kJ)
- **m**: Mass, equivalent to the volume of water (kg)
- **c**: Specific heat capacity of water, 4.184 J/gK, meaning it requires 4.184 J to heat one gram of water by one degree Celsius or Kelvin
- **(T1 - T2):** The temperature difference between the target temperature (T1) and the initial temperature (T2) in Celsius or Kelvin

The calculated energy (kWh) is then converted into associated carbon emissions using the relevant conversion factors. The operational carbon was calculated by applying the derived kWh values to the Department for Energy Security and Net Zero Greenhouse Gas Reporting 2023 conversion factors. Carbon emissions for electricity were calculated by summing the emissions associated with both transmission and distribution, as well as electricity generation. For natural gas, the carbon emissions were based on the combustion of natural gas per kWh.

Green House Gas Conversion Factors	
Gas	
Natural gas emissions factor for 2023 (kg CO_2e per kWh)	**0.184319**
Electricity	
Combined generation, transmission, and distribution emissions factor for grid electricity (kg CO_2e per kWh)	**0.224990**

Table 2:Source UK Government GHG Conversion Factors for Company Reporting 2023 Version 1.1

In addition to assessing the increase in carbon emissions caused by reduced heat exchanger efficiency due to varying levels of limescale formation, we will also evaluate two commonly used limescale prevention technologies: water conditioning and water softening. More importantly, we will assess whether the net carbon savings from maintaining efficiency are sustained after factoring in the embodied carbon of the products themselves, alongside their operational carbon related to energy use, consumables, and wastewater production.

For comparison purposes, we will use a HY-MAG water conditioner and an appropriately sized HydroION water softener, both manufactured and supplied by Hydrotec UK Ltd.

The embodied carbon of these products was calculated in accordance with EN 15804+A2:2019 and ISO 14025 standards, with the data independently verified by EPD HUB. No inclusions were made for the embodied carbon of the domestic hot water generation plant or the carbon related to maintaining optimal efficiency through preventative maintenance.

Operational carbon for both products was calculated based on their energy consumption in watts, as measured by the manufacturer, which was then converted to kWh. This value was further converted to kg CO2e using the Department for Energy Security and Net Zero Greenhouse Gas Reporting 2023 conversion factors.

Power consumption for the devices used in the modelling was measured with a calibrated Chauvin Arnoux 6165 Appliance Multitester, based on a power supply of 230V at 50Hz. The results are presented in the following table.

	Unit Embodied Carbon kg CO2e	Max. Power Consumption (W) Base Controller	kWh/year (base controller)	kg CO2e per annum
HY-MAG DN25	55.14	31.00	271.56	61.10
HY-MAG DN50	166.43	56.00	490.56	110.37
HY-MAG DN100	564.79	259.00	2268.84	510.47
HydroION VAS25CS1B	289.49	5.50	48.18	10.84
HydroION VAS125CS1.5	1171.19	5.50	48.18	10.84
HydroION VAS375CS1B	3259.41	5.50	48.18	10.84

Table 3: Source: Verified EPD https://manage.epdhub.com/

At the time of writing, there is no publicly available data regarding the embodied carbon of tablet salt used in water softeners. Since salt is a critical component in the operation of a softener, it is essential that its embodied carbon be accounted for.

To estimate the embodied carbon of tablet salt, we considered several factors involved in its lifecycle, including production, processing, packaging, and transportation. The factors considered were:

- **Mining or Extraction:** Salt is extracted from underground deposits or through seawater evaporation.
- **Processing:** Refining and compressing the salt into tablet form.
- **Packaging:** The materials and energy used in packaging the salt tablets.
- **Transportation**: The energy and emissions associated with transporting the salt from the production facility to the point of sale or use.

Mining/extraction: Life cycle assessment (LCA) studies indicate that CO2e emissions can range from 0.1 to 0.3 kg CO2e per kg of raw material, depending on the extraction method and energy sources used. (*Source: Ecoinvent Database)*

Processing: Processing emissions, primarily from energy consumption during refining and manufacturing, typically range from 0.1 to 0.2 kg CO2e per kg of processed material (*Source: DEFRA Emission Factors, Ecoinvent Database*).

Packaging: Packaging emissions vary depending on the material used. Plastic packaging is estimated to contribute approximately 0.05 to 0.1 kg CO2e per kg of product (*Source: DEFRA Emission Factors*).

Transportation: Emissions from transportation depend on distance and transport mode. For moderate distances, emissions are estimated between 0.02 and 0.05 kg CO2e per kg of product (*Source: DEFRA Emission Factors, Ecoinvent Database*).

Based on these estimates, the approximate emissions for each stage are:

- Mining/Extraction: 0.2 kg CO2e per kg of salt
- Processing: 0.1 kg CO2e per kg of salt
- Packaging: 0.05 kg CO2e per kg of salt
- Transportation: 0.03 kg CO2e per kg of salt

Total CO2e = 0.2 kg CO2e + 0.1 kg CO2e + 0.05 kg CO2e + 0.03 kg CO2e = 0.38 kg CO2e per kg of tablet salt

Thus, the approximate embodied carbon of tablet salt used in water softeners is around 0.38 kg CO2e per kg of salt.

The carbon emissions associated with wastewater production during the softener's regeneration phase were calculated by multiplying the declared wastewater volume (in litres per regeneration) by the wastewater treatment emissions factor from the Department for Energy Security and Net Zero Greenhouse Gas Reporting 2023 conversion factors.

Activity	Type	Unit	kg CO_2e
Water treatment	Water treatment	cubic metres	0.201
		million litres	201.3

Table 4: Source UK Government GHG Conversion Factors for Company Reporting 2023 Version 1.1

To apply these results in real-world scenarios, we considered three different water use patterns:

Scenario 1:

- **Supermarket**: 2,000 litres of hot water per day, generated via a heat exchanger using gas or electricity.

  Limescale Prevention Technology:
  1. Water softener with a capacity of 4,000 litres between regenerations (regenerates every two days).
  2. Electromagnetic physical water conditioner, sized based on a peak flow rate of 0.55 l/s (assumed for one-hour peak recovery of total daily water use).

<u>Scenario 2:</u>

- **Office block:** 10,000 litres of hot water per day, generated via a heat exchanger using gas or electricity.

  Limescale Prevention Technology:

  1. Water softener with a capacity of 20,000 litres between regenerations (regenerates every two days).
  2. Electromagnetic physical water conditioner, sized based on a peak flow rate of 2.7 l/s (assumed for one-hour peak recovery of total daily water use).

<u>Scenario 3:</u>

- **Hotel:** 25,000 litres of hot water per day, generated via a heat exchanger using gas or electricity.

  Limescale Prevention Technology:

  1. Water softener with a capacity of 50,000 litres between regenerations (regenerates every two days).
  2. Electromagnetic physical water conditioner sized based on a peak flow rate of 6.9 l/s (assumed for one-hour peak recovery of total daily water use).

For each scenario, we will assess the operational and embodied carbon associated with the respective water treatment systems.

Results

Scenario 1

As outlined in the method, we modelled the energy use for two domestic hot water generation strategies for the same scenario: a supermarket using 2,000 litres of hot water per day with a temperature increase (ΔT) of 45°C. The difference between the two models is the energy source: one used gas and the other electricity.

<u>Gas as the Energy Source</u>

The baseline energy required to heat 2,000 litres of water from 15°C to 60°C using a gas-fired water heater, assuming 100% efficiency, is 104.65 kWh/day. Applying the greenhouse gas conversion factor for gas, this equates to 6,987 kg CO2e per annum. Over a six-year period with effective limescale mitigation, the cumulative carbon emissions would be 41,924 kg CO2e.

	kWh/Day	Cumulative kg CO2e
Year 1	104.65	6987.42
Year 2	104.65	13974.85
Year 3	104.65	20962.27
Year 4	104.65	27949.69
Year 5	104.65	34937.11
Year 6	104.65	41924.54

Table 5: 5 year baseline cumulative kg CO2e with gas as energy source

Without preventative measures, the energy efficiency would decrease linearly each year with 1mm of limescale deposition, as shown in the method's graph. At the end of the six-year period, the cumulative carbon emissions would be 56,936.36 kg CO2e.

	mm of limescale	Loss in efficiency	kWh/Day	kg CO2e per annum	kg CO2e cumulative
Year 1	0	0.00%	104.65	6987.42	6987.42
Year 2	1	7.00%	112.53	7513.36	14500.78
Year 3	2	15.84%	124.35	8302.55	22803.33
Year 4	3	25.00%	139.53	9316.56	32119.89
Year 5	4	35.55%	162.37	10841.62	42961.51
Year 6	5	50.00%	209.30	13974.85	56936.36

Table 6: 5 year untreated energy use & and cumulative kg CO2e with gas as energy source

By failing to prevent limescale deposition on heat transfer surfaces, there is a risk of producing an additional 15,011 kg CO2e, equivalent to 15 tonnes of avoidable carbon emissions.

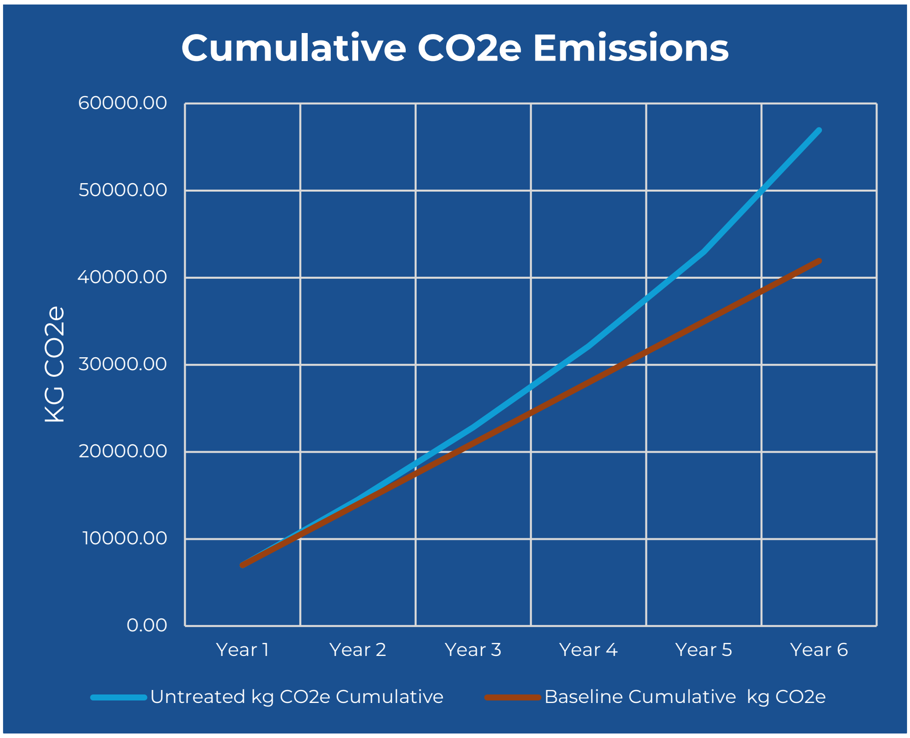


Figure 5: Comparison of untreated and baseline cumulative kg CO2e with gas as energy source

Electricity as the Energy Source

The baseline energy required for an electrically powered water heater to heat 2,000 litres of water from 15°C to 60°C, assuming 100% efficiency, is 104.65 kWh/day. Using the greenhouse gas conversion factor for electricity, this equates to 8,593.9 kg CO2e per annum. With effective limescale mitigation, the cumulative carbon emissions over six years would be 51,564 kg CO2e.

	kWh/Day	Cumulative kg CO2e per annum
Year 1	104.65	8594.00
Year 2	104.65	17188.00
Year 3	104.65	25782.00
Year 4	104.65	34376.00
Year 5	104.65	42970.00
Year 6	104.65	51564.00

Table 7: 5 year baseline cumulative kg CO2e with electricity as energy source

Without preventative measures, the energy efficiency would decrease linearly with 1mm of limescale accumulation each year, as detailed in the method's graph. After six years of scale buildup, the cumulative carbon emissions would rise to 70,027.39 kg CO2e.

	mm of limescale	Loss in efficiency	kWh/Day	kg CO2e per annum	kg CO2e cumulative
Year 1	0	0.00%	104.65	8594.00	8594.00
Year 2	1	7.00%	112.53	9240.86	17834.86
Year 3	2	15.84%	124.35	10211.50	28046.36
Year 4	3	25.00%	139.53	11458.67	39505.03
Year 5	4	35.55%	162.37	13334.37	52839.39
Year 6	5	50.00%	209.3	17188.00	70027.39

Table 8: 5 year untreated energy use & and cumulative kg CO2e with electricity as energy source

Failing to prevent limescale formation could result in an additional 18,463.39 kg CO2e—over 18 tonnes of avoidable carbon emissions. This additional carbon can be effectively mitigated using widely available water treatment systems.

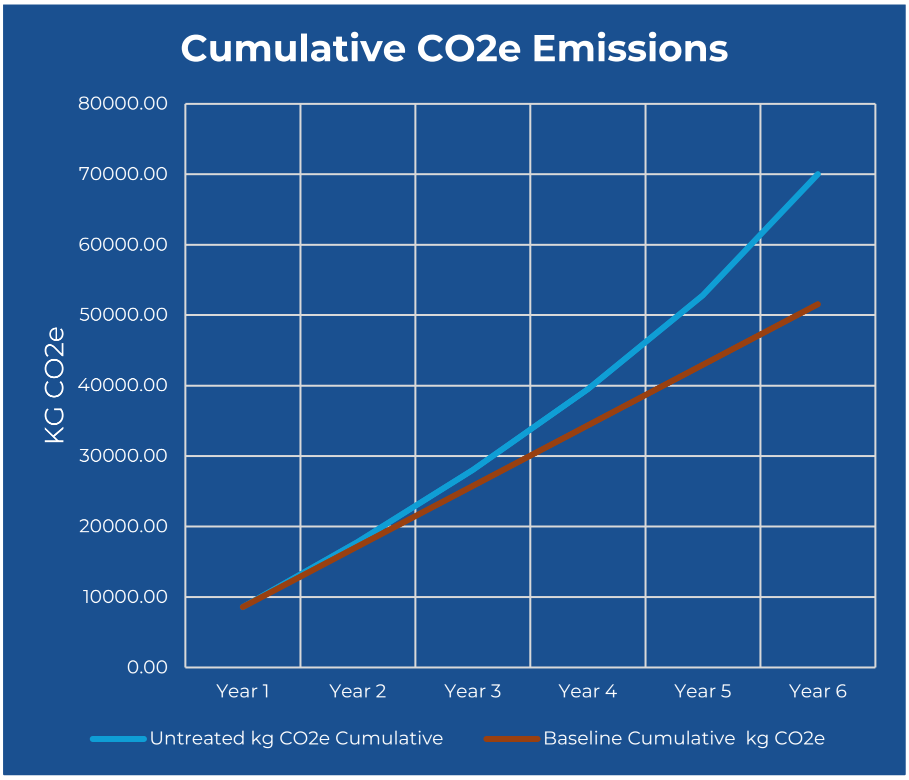


Figure 6: Comparison of untreated and baseline cumulative kg CO2e with electricity as energy source

Both ion exchange water softening systems and physical water conditioning devices have proven highly effective in preventing and controlling limescale formation in domestic hot water generation systems. However, each technology has its own embodied and operational carbon values, which must be considered when using them as carbon emission mitigation tools. If the carbon emissions from their use exceed the emissions mitigated by preventing limescale deposition, they could create a carbon-positive scenario, undermining their effectiveness as mitigation tools.

For example, a properly sized water softener capable of treating 2,000 litres per day and regenerating every two days has an embodied carbon value of 289.48 kg CO2e, with an operational carbon value of 156 kg CO2e per year, accounting for energy use, salt consumption, and wastewater production.

An appropriately sized water conditioner, capable of conditioning a flow rate of 0.55 l/s—sufficient to meet the daily demand in a one-hour period—has an embodied carbon value of 55.14 kg CO2e. Its operational carbon is 61.1 kg CO2e per year, based solely on energy use.

Softener carbon emissions (kg CO2e)		Conditioner carbon emissions (kg CO2e)		Comments
Year 1	446.34	Year 1	116.23	Includes embodied + operational CO2e
Year 2	156.86	Year 2	61.10	operational CO2e only
Year 3	156.86	Year 3	61.10	operational CO2e only
Year 4	156.86	Year 4	61.10	operational CO2e only
Year 5	156.86	Year 5	61.10	operational CO2e only
Year 6	156.86	Year 6	61.10	operational CO2e only
Total	**1230.64**	**Total**	**421.73**	

Table 9: Carbon emissions associated to each scale control method

Gas as the Energy Source and Using Limescale Prevention

The total carbon emissions associated with operating a water softener to maintain the efficiency of water heating equipment amount to 1,230 kg CO2e. Subtracting this from the six-year total for untreated systems results in a mitigation of 13,871 kg CO2e. The inclusion of a water softener adds 2.85% to the water heater's baseline carbon emissions, demonstrating that a very small carbon cost can prevent a significant quantity of emissions.

The total carbon emissions associated with operating a water conditioner to maintain the efficiency of water heating equipment amount to 421 kg CO2e, resulting in a mitigation of 14,590 kg CO2e. The inclusion of a water conditioner adds just 1% to the water heater's baseline carbon emissions, showing that a minimal carbon cost can prevent substantial carbon emissions.

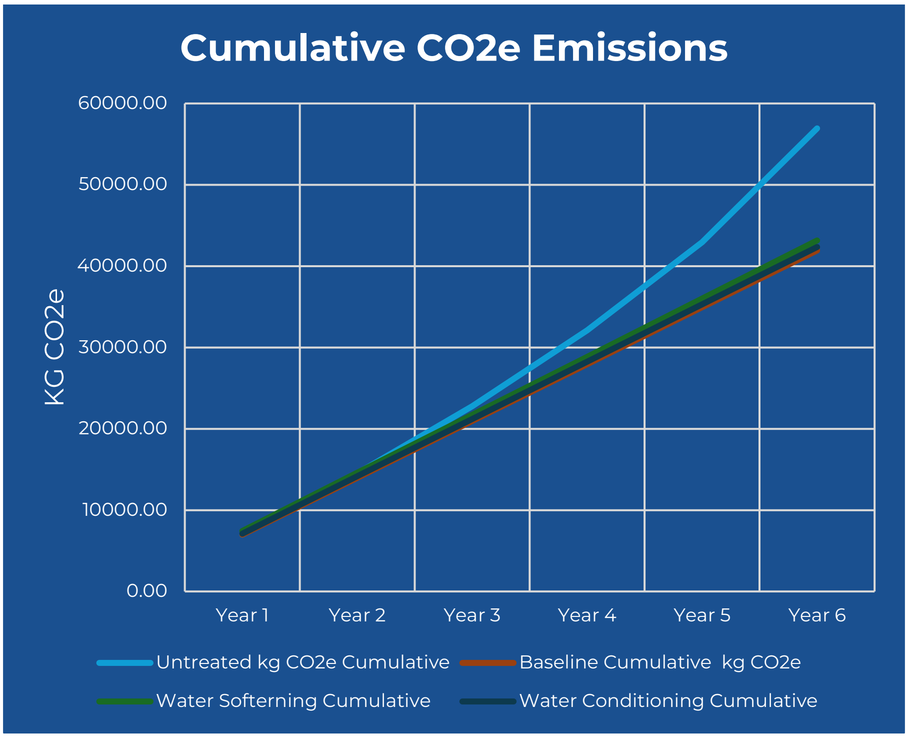


Figure 7: Comparison of cumulative kg CO2e between baseline, untreated, softened and conditioned with gas as energy source

<u>Electricity as the Energy Source and using Limescale Prevention</u>

The total carbon emissions associated with operating a water softener to maintain the efficiency of water heating equipment are 1,230 kg CO2e, leading to a total mitigation of 17,232.76 kg CO2e. The inclusion of a water softener adds only 2.33% to the water heater's baseline carbon emissions, demonstrating that a very small carbon cost can prevent a substantial quantity of carbon emissions.

The total carbon emissions associated with operating a water conditioner are 421 kg CO2e, resulting in a total mitigation of 18,041.67 kg CO2e. The inclusion of a water conditioner adds just 0.81% to the water heater's baseline carbon emissions, showing that for an insignificant carbon cost, a large amount of carbon can be prevented.

In both cases, the use of a scale prevention and control technology ensures a significant net reduction in the forecasted six-year cumulative carbon emissions associated with operating a domestic hot water generation system without preventative measures.

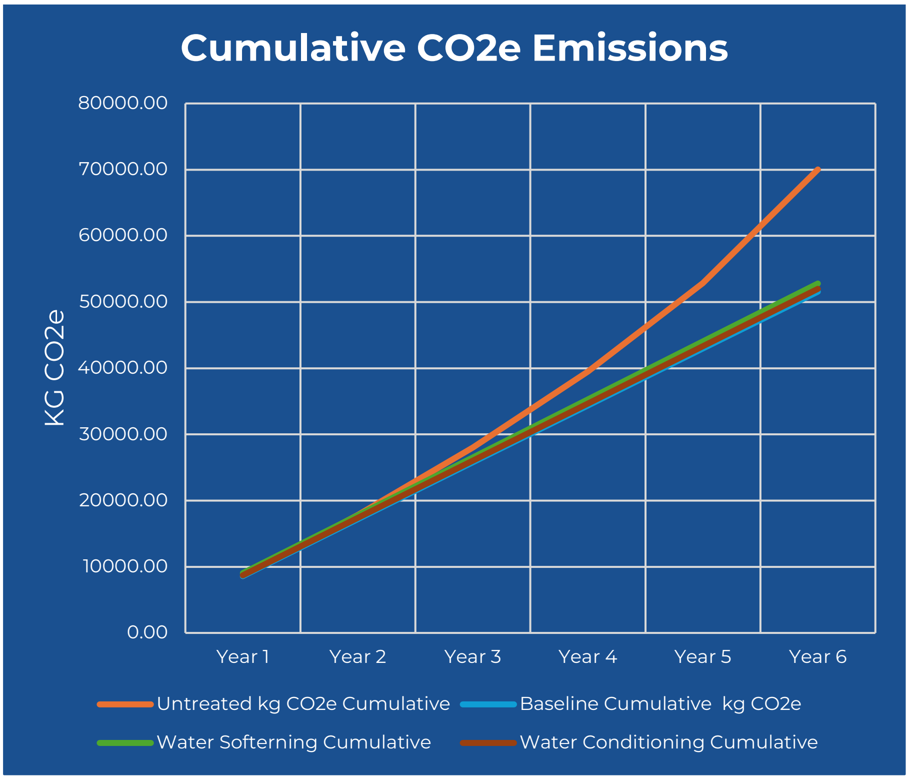


Figure 8: Comparison of cumulative kg CO2e between baseline, untreated, softened and conditioned with electricity as energy source

Summary

In both cases, the use of scale prevention and control technologies ensures a substantial net reduction in the forecasted six-year cumulative carbon emissions associated with operating a domestic hot water generation system without preventative measures in place.

Scenario 2

As detailed in the method, we modelled the energy use for two domestic hot water generation strategies for the same application: a commercial office space using 10,000 litres of hot water per day with a temperature increase (ΔT) of 45°C. The difference between the two models lies in the energy source: one uses gas and the other electricity.

<u>Gas as the Energy Source</u>

The baseline energy required for a gas-fired water heater to increase the temperature of 10,000 litres of water from 15°C to 60°C is 523.25 kWh/day, assuming 100% efficiency. Using the greenhouse gas conversion factor for gas, this equates to 34,937 kg CO2e per annum. Over six years with effective limescale prevention, the cumulative carbon emissions would be 209,622 kg CO2e.

	kWh/Day	Cumulative kg CO2e
Year 1	523.25	34937.11
Year 2	523.25	69874.23
Year 3	523.25	104811.34
Year 4	523.25	139748.46
Year 5	523.25	174685.57
Year 6	523.25	209622.69

Table 10: 5-year baseline cumulative kg CO2e with gas as energy source

Without preventative measures, energy efficiency decreases linearly with each 1mm of limescale deposition, as shown in the method's graph. After six years of limescale accumulation, the cumulative carbon emissions would rise to 284,681.77 kg CO2e.

	mm of limescale	Loss in efficiency	kWh/Day	kg CO2e per annum	kg CO2e cumulative
Year 1	0	0.00%	523.25	34937.11	34937.11
Year 2	1	7.00%	562.63	37566.79	72503.90
Year 3	2	15.84%	621.73	41512.73	114016.64
Year 4	3	25.00%	697.67	46582.82	160599.46
Year 5	4	35.55%	811.87	54208.09	214807.55
Year 6	5	50.00%	1046.50	69874.23	284681.78

Table 11: 5 year untreated energy use & and cumulative kg CO2e with gas as energy source

By not preventing limescale deposition on heat transfer surfaces, there is a risk of producing an additional 75,059 kg CO2e—equivalent to 75 tonnes of avoidable carbon emissions.

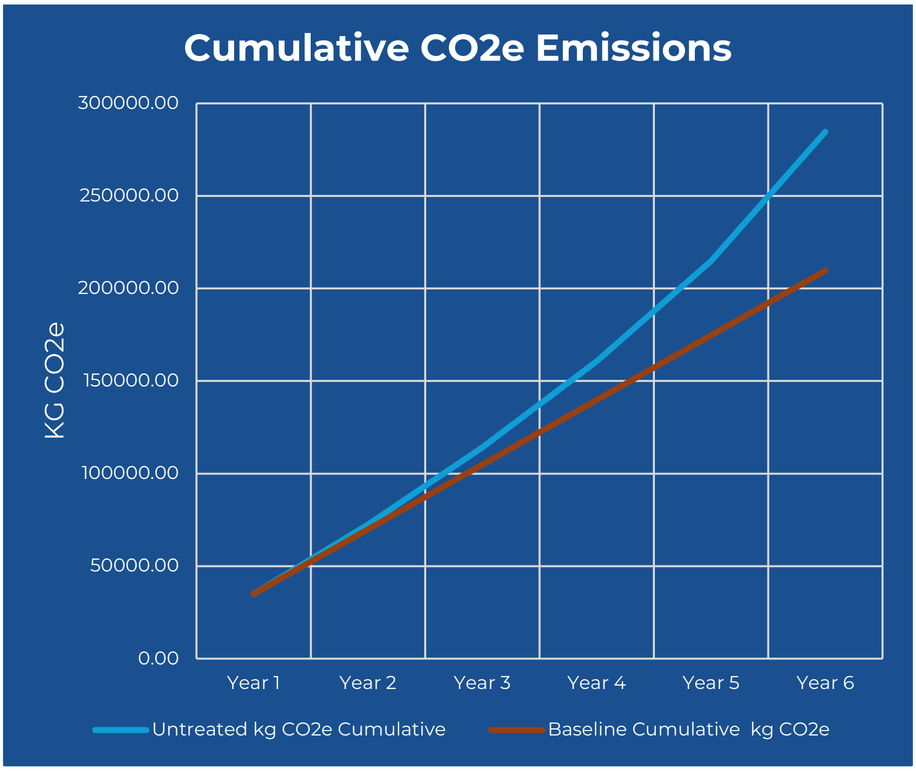


Figure 9: Comparison of untreated and baseline cumulative kg CO2e with gas as energy source

<u>Electricity as the Energy Source</u>

The baseline energy use for an electrically powered water heater required to raise the temperature of 10,000 litres of water from 15°C to 60°C is 523.25 kWh/day, assuming 100% efficiency. Using the greenhouse gas conversion factor for electricity, this equates to 34,937 kg CO2e per annum. With effective limescale mitigation, the cumulative carbon emissions over six years would be 209,622 kg CO2e.

	kWh/Day	Cumulative kg CO2e per annum
Year 1	523.25	42970.00
Year 2	523.25	85939.99
Year 3	523.25	128909.99
Year 4	523.25	171879.99
Year 5	523.25	214849.98
Year 6	523.25	257819.98

Table 12: 5 year baseline cumulative kg CO2e with electricity as energy source

For each subsequent year of operation, energy efficiency decreases linearly by 1% for each 1mm of limescale deposition, as detailed in the method. Failure to prevent limescale buildup on heat transfer surfaces could result in the production of an additional 92,316.97 kg CO2e, equivalent to over 90 tonnes of avoidable carbon emissions.

	mm of limescale	Loss in efficiency	kWh/Day	kg CO2e per annum	kg CO2e cumulative
Year 1	0	0.00%	523.25	42970.00	42970.00
Year 2	1	7.00%	562.634	46204.30	89174.29
Year 3	2	15.84%	621.732	51057.51	140231.80
Year 4	3	25.00%	697.667	57293.33	197525.13
Year 5	4	35.55%	811.87	66671.83	264196.96
Year 6	5	50.00%	1046.5	85939.99	350136.95

Table 13: 5 year untreated energy use & and cumulative kg CO2e with electricity as energy source

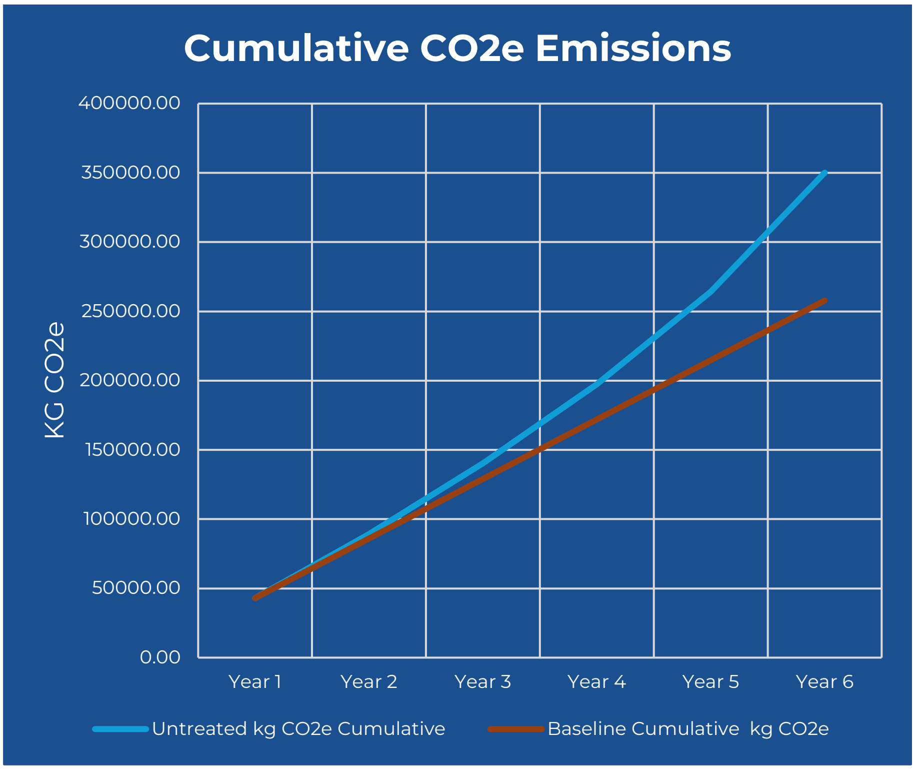


Figure 10: Comparison of untreated and baseline cumulative kg CO2e with electricity as energy source

Using widely available water treatment systems, this additional carbon can be easily mitigated. Both ion exchange water softening systems and physical water conditioning devices have proven highly effective in real-world applications for preventing and controlling limescale formation in domestic hot water generation equipment.

However, each technology comes with its own embodied and operational carbon values, which must be factored in when using them as carbon mitigation tools. If the carbon emissions associated with their use exceed the emissions, they prevent by reducing limescale, a carbon-positive scenario could occur, making them ineffective as mitigation solutions.

An appropriately sized water softener capable of treating 10,000 litres per day and regenerating every two days has an embodied carbon value of 1,171.19 kg CO2e and an operational carbon value of 153.7 kg CO2e per year, considering energy use, salt consumption, and wastewater production.

An appropriately sized water conditioner, capable of conditioning a flow rate of 2.7 l/s to meet the daily demand in a one-hour period, has an embodied carbon value of 166.43 kg CO2e and an operational carbon value of 110.37 kg CO2e per year, based on energy use.

Softener Carbon Emissions (kg CO2e)		Conditioner Carbon Emissions (kg CO2e)		Comments
Year 1	1324.90	Year 1	276.80	Includes embodied + operational CO2e
Year 2	153.70	Year 2	110.37	operational CO2e only
Year 3	153.70	Year 3	110.37	operational CO2e only
Year 4	153.70	Year 4	110.37	operational CO2e only
Year 5	153.70	Year 5	110.37	operational CO2e only
Year 6	153.70	Year 6	110.37	operational CO2e only
Total	2093.41	Total	828.66	

Table 14: Carbon emissions associated to each scale control method

<u>Gas as the Energy Source and Using Limescale Prevention</u>

The total carbon emissions associated with the operation of a water softener, aimed at maintaining the efficiency of water heating equipment, is 2,093.41 kg CO2e. Deducting this from the difference between the baseline and the six-year total for untreated systems results in a total mitigation of 72,965.68 kg CO2e. The inclusion of a softener adds just 0.99% to the water heater's baseline carbon emissions, demonstrating that a very small carbon cost can prevent a substantial amount of carbon emissions.

The total carbon emissions associated with the operation of a water conditioner is 828.66 kg CO2e. Deducting this from the difference between the baseline and the six-year total for untreated systems results in a total mitigation of 74,230.43 kg CO2e. The inclusion of a water conditioner adds only 0.39% to the water heater's baseline carbon emissions, showing that a very small carbon cost can prevent significant quantities of carbon emissions.

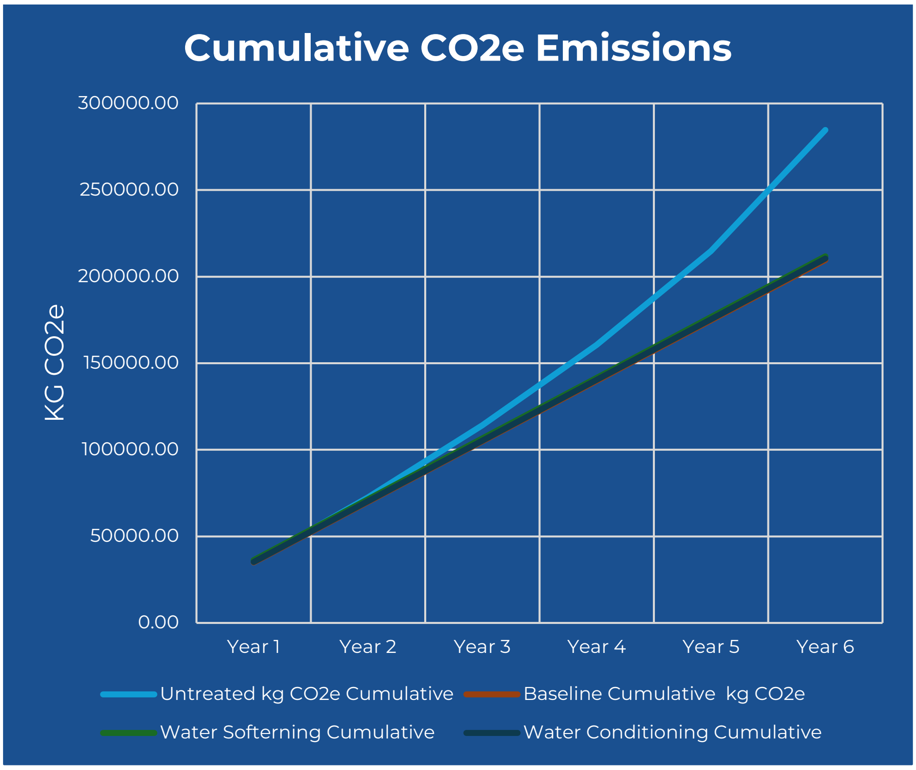


Figure 11: Comparison of cumulative kg CO2e between baseline, untreated, softened and conditioned with gas as energy source

<u>Electricity as the Energy Source and Using Limescale Prevention</u>

The total carbon emissions associated with the operation of a water softener, aimed at maintaining the efficiency of water heating equipment, is 2,093.41 kg CO2e. Deducting this from the difference between the baseline and the six-year total for untreated systems results in a total mitigation of 90,223.57 kg CO2e. The inclusion of a water softener adds just 0.81% to the water heater's baseline carbon emissions, demonstrating that a very small carbon cost can prevent significant quantities of carbon emissions.

The total carbon emissions associated with the operation of a water conditioner is 828.66 kg CO2e. Deducting this from the difference between the baseline and the six-year total for untreated systems results in a total mitigation of 91,488.32 kg CO2e. The inclusion of a water conditioner adds only 0.32% to the water heater's baseline carbon emissions, showing that for a statistically insignificant carbon cost, substantial carbon emissions can be prevented.

In both cases, the use of scale prevention and control technology ensures a significant net reduction in the forecasted six-year cumulative carbon emissions associated with operating a domestic hot water generation system without preventative measures.

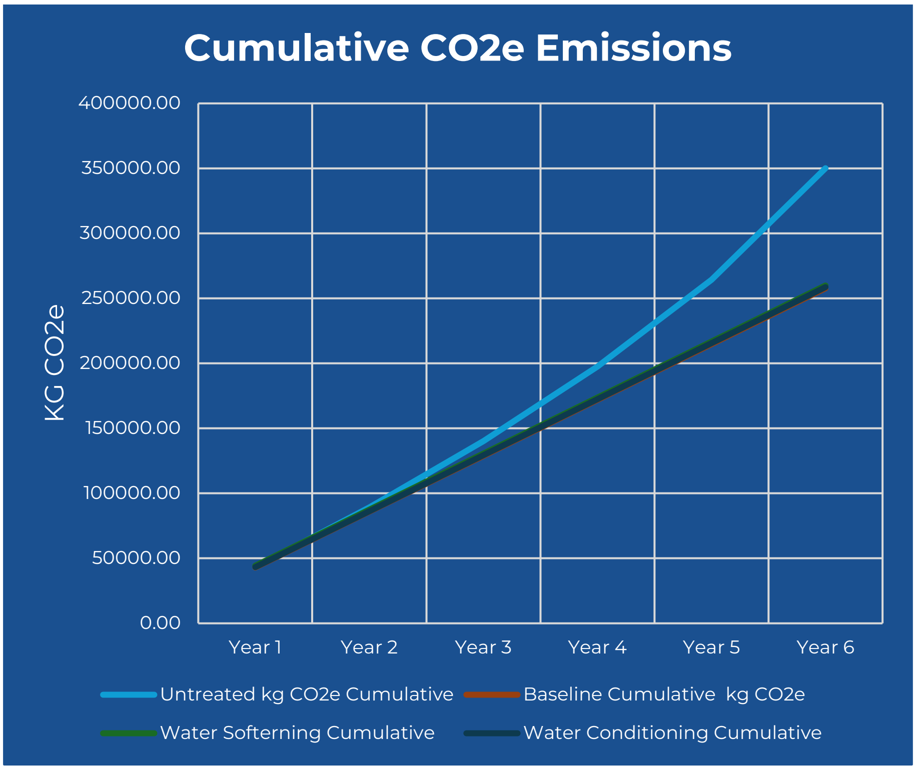


Figure 12: Comparison of cumulative kg CO2e between baseline, untreated, softened and conditioned with electricity as energy source

<u>Summary</u>

In both cases, the use of scale prevention and control technology ensures a significant net reduction in the forecasted six-year cumulative carbon emissions associated with operating a domestic hot water generation system without preventative measures.

Scenario 3

As detailed in the method, we modelled the energy use for two domestic hot water generation strategies for the same application: a high-specification hotel using 25,000 litres of hot water per day, with a temperature rise (ΔT) of 45°C. The difference between the models is the energy source: one uses gas, the other electricity.

Gas as the Energy Source

The baseline energy use of a gas-fired water heater required to increase the temperature of 25,000 litres of water from 15°C to 60°C is 1,308.125 kWh/day, assuming 100% efficiency. Using the greenhouse gas conversion factor for gas, this equates to 87,342.79 kg CO2e per annum. If this baseline is maintained through effective limescale mitigation measures, the cumulative carbon emissions over six years would be 524,056.72 kg CO2e.

	kWh/Day	Cumulative kg CO2e
Year 1	1308.13	87342.79
Year 2	1308.13	174685.57
Year 3	1308.13	262028.36
Year 4	1308.13	349371.15
Year 5	1308.13	436713.93
Year 6	1308.13	524056.72

Table 15: 5-year baseline cumulative kg CO2e with gas as energy source

Without preventative measures, the energy efficiency decreases linearly each year for every 1mm of limescale deposition, as detailed in the method. After six years of limescale accumulation, the cumulative carbon emissions would rise to 711,704.44 kg CO2e.

	mm of limescale	Loss in efficiency	kWh/Day	kg CO2e per annum	kg CO2e cumulative
Year 1	0	0.00%	1308.13	87342.79	87342.79
Year 2	1	7.00%	1406.59	93916.98	181259.76
Year 3	2	15.84%	1554.33	103781.83	285041.59
Year 4	3	25.00%	1744.17	116457.05	401498.64
Year 5	4	35.55%	2029.67	135520.23	537018.87
Year 6	5	50.00%	2616.25	174685.57	711704.44

Table 16: 5-year untreated energy use & and cumulative kg CO2e with gas as energy source

Failing to prevent limescale formation on heat transfer surfaces results in the production of an additional 187,647.72 kg CO2e, equivalent to nearly 190 tonnes of totally avoidable carbon emissions.

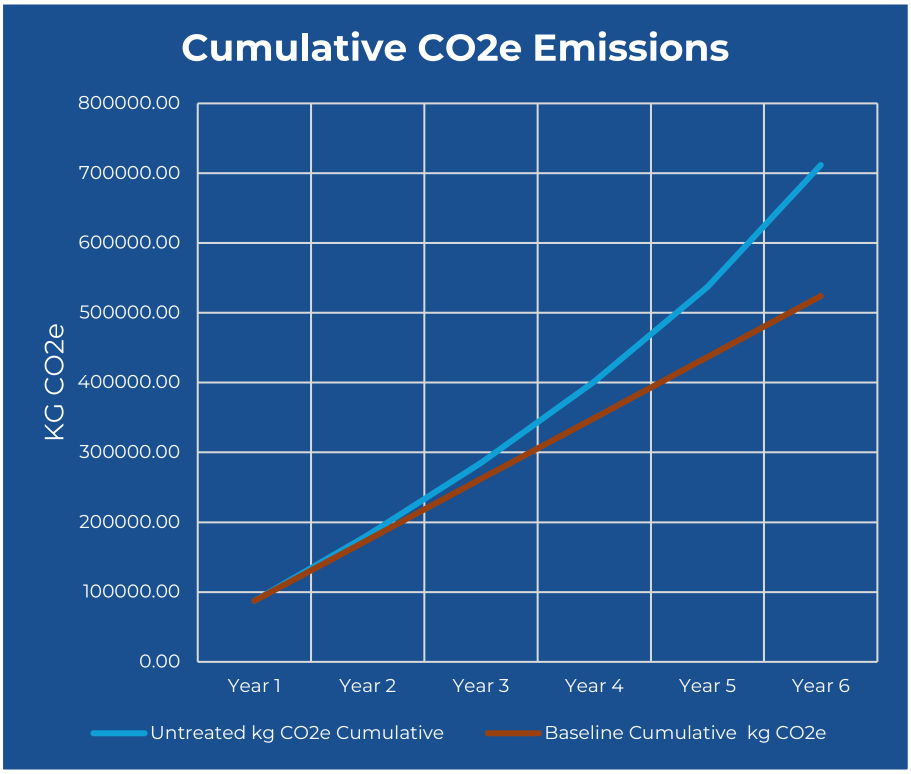


Figure 13: Comparison of untreated and baseline cumulative kg CO2e with gas as energy source

<u>Electricity as the Energy Source</u>

The baseline energy use of an electrically powered water heater required to increase the temperature of 25,000 litres of water from 15°C to 60°C is 1,308.125 kWh/day, assuming 100% efficiency. Using the greenhouse gas conversion factor for electricity, this equates to 107,424.99 kg CO2e per annum. If this baseline is maintained through effective limescale mitigation measures, the six-year cumulative carbon emissions would be 644,549.95 kg CO2e.

	kWh/Day	Cumulative kg CO2e per annum
Year 1	1308.125	107424.99
Year 2	1308.125	214849.98
Year 3	1308.125	322274.97
Year 4	1308.125	429699.96
Year 5	1308.125	537124.95
Year 6	1308.125	644549.95

Table 17: 5-year baseline cumulative kg CO2e with electricity as energy source

For each subsequent year of operation, energy efficiency decreases linearly for every 1mm of limescale deposited, as detailed in the method. Failing to prevent limescale buildup on heat transfer surfaces could result in the production of an additional 230,792.44 kg CO2e, equivalent to over 230 tonnes of avoidable and preventable carbon emissions.

	mm of Limescale	Loss in Efficiency	kWh/Day	kg CO2e per Annum	kg CO2e Cumulative
Year 1	0	0.00%	1308.13	107424.99	107424.99
Year 2	1	7.00%	1406.59	115510.74	222935.73
Year 3	2	15.84%	1554.33	127643.76	350579.50
Year 4	3	25.00%	1744.17	143233.32	493812.82
Year 5	4	35.55%	2029.67	166679.58	660492.40
Year 6	5	50.00%	2616.25	214849.98	875342.38

Table 18: 5-year untreated energy use & and cumulative kg CO2e with electricity as energy source

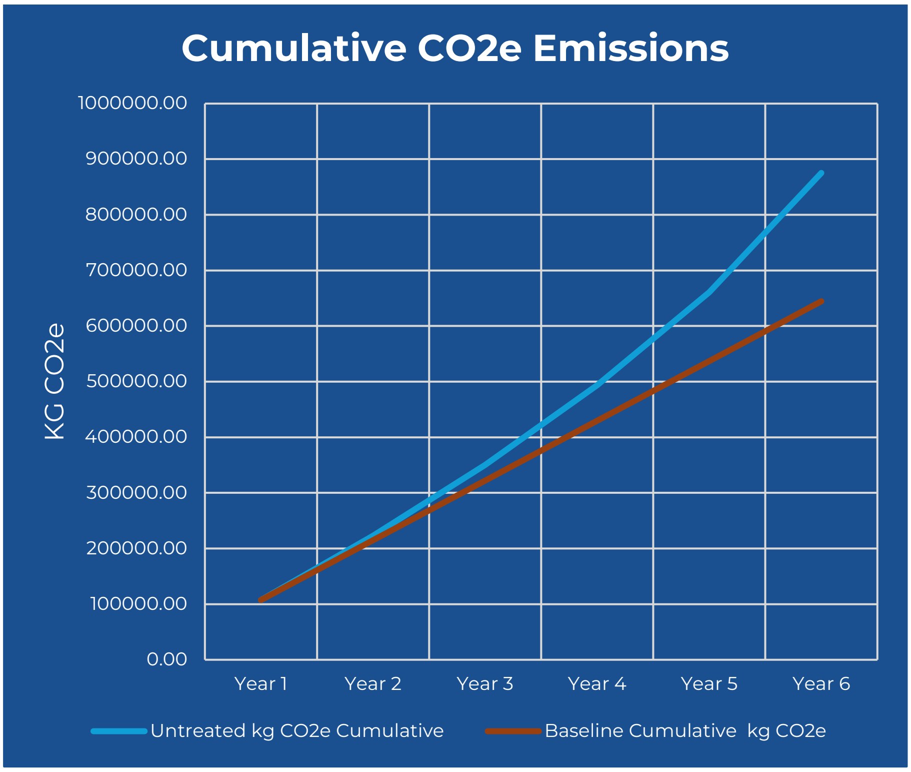


Figure 14: Comparison of untreated and baseline cumulative kg CO2e with electricity as energy source

Using widely available water treatment systems, this additional carbon can be easily mitigated. Both ion exchange water softening systems and physical water conditioning devices have demonstrated high efficacy in real-world installations at preventing and controlling limescale formation in domestic hot water generation equipment.

However, each of these technologies has its own embodied and operational carbon values that need to be considered when using them as carbon emission mitigation tools. If the carbon emissions associated with their use exceed the emissions mitigated by preventing limescale deposition, a carbon-positive scenario could result, making them ineffective as mitigation solutions.

An appropriately sized water softener capable of delivering 25,000 litres per day and regenerating every two days has an embodied carbon value of 3,259.41 kg CO2e and an operational carbon value of 1,782.09 kg CO2e per year, accounting for energy use, salt consumption, and wastewater production.

An appropriately sized water conditioner capable of conditioning a flow rate of 6.9 l/s, sufficient to meet the daily demand in a one-hour period, has an embodied carbon value of 564.79 kg CO2e and an operational carbon value of 510.47 kg CO2e per year, based on energy use.

Softener Carbon Emissions (kg CO2e)		Conditioner Carbon Emissions (kg CO2e)		Comments
Year 1	5041.50	Year 1	1075.26	Includes embodied + operational CO2e
Year 2	1782.09	Year 2	510.47	operational CO2e only
Year 3	1782.09	Year 3	510.47	operational CO2e only
Year 4	1782.09	Year 4	510.47	operational CO2e only
Year 5	1782.09	Year 5	510.47	operational CO2e only
Year 6	1782.09	Year 6	510.47	operational CO2e only
Total	13951.97	Total	3627.59	

Table 19: Carbon emissions associated to each scale control method

<u>Gas as the Energy Source and Using Limescale Prevention</u>

The total carbon emissions associated with operating a water softener to maintain the efficiency of water heating equipment is 13,951.97 kg CO2e. Deducting this from the difference between the baseline and the six-year total for untreated systems results in a total mitigation of 173,695.75 kg CO2e. The inclusion of a softener adds only 2.59% to the water heater's baseline carbon emissions, demonstrating that for a small carbon cost, significant quantities of carbon can be prevented.

The total carbon emissions associated with operating a water conditioner is 3,627.59 kg CO2e. Deducting this from the difference between the baseline and the six-year total for untreated systems results in a total mitigation of 184,020.13 kg CO2e. The inclusion of a water conditioner adds just 0.69% to the water heater's baseline carbon emissions, showing that a minimal carbon cost can prevent a significant amount of emissions.

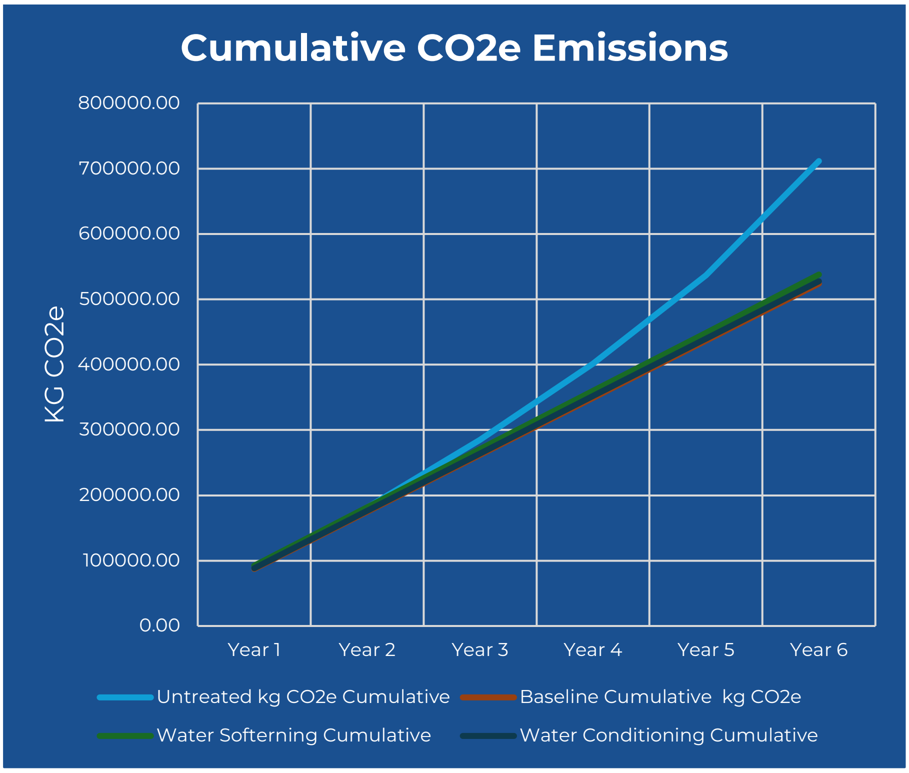


Figure 15: Comparison of cumulative kg CO2e between baseline, untreated, softened and conditioned with gas as energy source

<u>Electricity as the Energy Source and Using Limescale Prevention</u>

In the second scenario, the total carbon emissions associated with a water softener are again 13,951.97 kg CO2e, leading to a total mitigation of 216,840.47 kg CO2e. This results in an additional 2.12% carbon emissions over the baseline, highlighting the high efficiency of this method.

For the water conditioner in the second scenario, total carbon emissions are 3,627.59 kg CO2e, resulting in a mitigation of 227,164.84 kg CO2e and an additional 0.56% carbon emissions over the baseline.

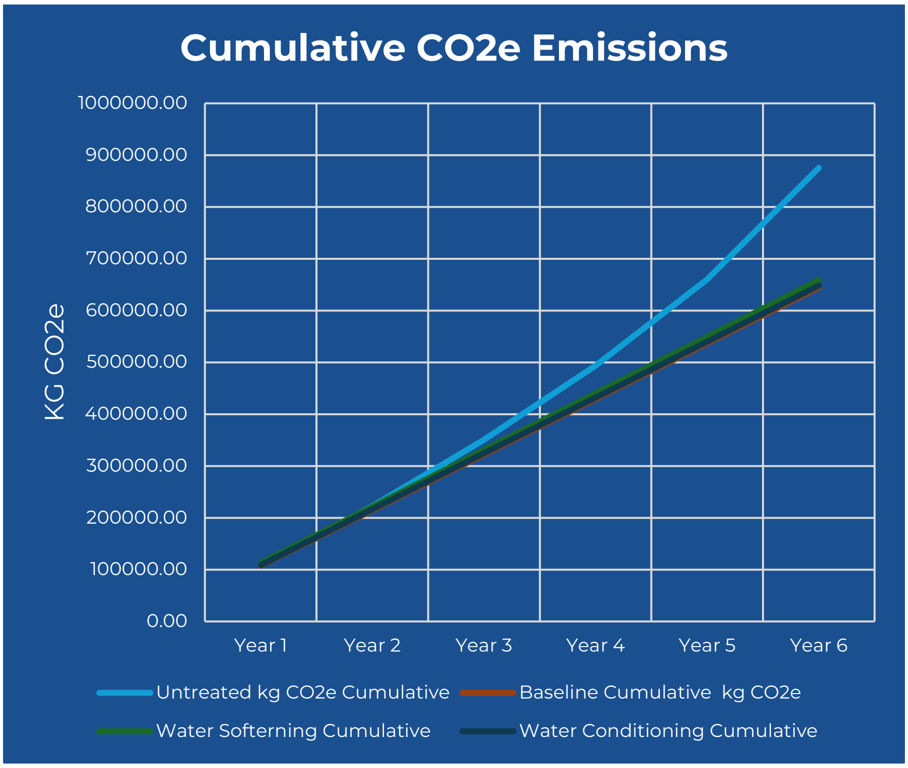


Figure 16: Comparison of cumulative kg CO2e between baseline, untreated, softened and conditioned with electricity as energy source

<u>Summary</u>

In both cases, the use of scale prevention and control technologies results in a substantial net reduction in the forecasted six-year cumulative carbon emissions associated with operating a domestic hot water generation system without preventative measures.

Conclusions

In the three scenarios detailed, regardless of the method of domestic hot water generation, using technology to prevent and control limescale formation in domestic hot water systems significantly mitigated carbon emissions.

When comparing treated versus untreated systems, the carbon mitigation achieved led to rapid carbon neutrality of the scale control technology demonstrating a swift carbon payback period.

- In the supermarket scenario, using a scale control solution could prevent the production of over 18 tonnes of carbon dioxide over a six-year period.
- In the office scenario, a scale control solution could mitigate over 90 tonnes of carbon dioxide over six years.
- In the hotel scenario, scale control could prevent the production of more than 200 tonnes of carbon dioxide over six years.

The extent of carbon emission mitigation is influenced by several factors, but for a reasonable capital and operational investment, significant carbon emissions can be avoided. In addition to emissions reduction, this also helps prevent rising energy costs due to the increased energy consumption associated with limescale buildup.

In all three scenarios the data suggests that by mitigating the increase in operational carbon associated to increase energy use due to limescale formation in the first year is greater than the operational and embodied carbon of both scale prevention and control technologies results in a carbon payback period of less than one year.

These carbon mitigation figures account for both the operational and embodied carbon associated with physical and chemical-based scale prevention and control solutions. In all cases, the carbon mitigated within the first year is equal to or greater than the operational carbon associated with running a limescale prevention regime.

As stakeholders and the building services industry move away from fossil fuel-based hot water systems as part of decarbonisation strategies, and with the increased adoption of electricity-based commercial hot water systems—considering electricity currently has a higher carbon coefficient—it becomes even more important to maintain the efficiency of these newer systems.

Furthermore, with the growing use of renewable energy sources, maintaining operational efficiency remains crucial to avoid efficiency losses and to ensure optimal carbon emission mitigation, as energy demand increases due to limescale's insulating effects in hot water generation equipment.

Limescale Prevention Impact

-18 Tonne CO2e

Equivalents:

- 35,298 Vegetarian Meals
- 684 Meat-Based Meals
- 2,903,220 Litres of Cola

Supermarket

Carbon Mitigation: Over 18 tonnes (in 5 years)

-90 Tonne CO2e

Equivalents:

- 13,500,000 Sheets of A4 Paper
- 264,690 Large Lattes
- 12,887,100 Hours of 30W LED Monitor Usage

Office Block

Carbon Mitigation: Over 90 tonnes (in 5 years)

-200 Tonne CO2e

Equivalents:

- 100 Return Flights from London to New York
- 24,000,000 Smartphone Charges
- 333,400 10-Minute Showers

Hotel

Carbon Mitigation: Over 200 tonnes (in 5 years)

Key Points

Evidence supports limescale prevention and control technologies as an effective carbon emission mitigation mechanism

Retrospective deployment may reduce carbon emissions to levels closer to the manufacturers "day-one" figures reclaiming energy efficiencies

Carbon payback and cost neutrality can be achieved swiftly

The prevention and control of limescale can maintain and even reclaim efficiencies in both open and closed water systems

Limescale prevention technologies offer a low-impact and low-cost solution to complement even the most complex decarbonisation strategies

Scale Control Solutions Overview

There are several manufacturers and suppliers of commercial devices designed to prevent and control limescale formation, which can generally be categorized into three types:

- Physical Water Conditioning: These devices apply a physical force, such as magnetism, to induce the nucleation of calcium carbonate. The resulting seed nuclei provide a preferential surface for further calcium carbonate crystal formation in areas of heat transfer, where the thermal decomposition of calcium bicarbonate to calcium carbonate is accelerated.

- Chemical-Assisted Physical Water Conditioning: These devices use a chemical component to modify water quality, either inducing or inhibiting the precipitation of calcium carbonate. The most common devices utilize a sacrificial zinc anode, which releases zinc ions that delay the induction of calcium carbonate and alter the morphology of the resulting precipitates. Some advanced technologies, tested to strict German performance standards, are technically “chemical-assisted” but do not require the addition of chemicals to the water. These devices also induce calcium carbonate nucleation without altering the water’s hardness.

  Note: Neither physical nor chemical-assisted physical water conditioning softens water. These technologies do not remove the minerals responsible for water hardness, meaning the water's hardness remains unchanged before and after their application.

- Water Softening: Ion-exchange resins are used to replace magnesium and calcium ions (which contribute to hardness) with sodium ions. Fresh resin contains sodium ions at its active sites. When exposed to hard water, the resin exchanges magnesium and calcium ions for sodium ions, reducing the concentration of hardness minerals in the water. The resin is recharged by washing it with a solution containing a high concentration of sodium ions (usually dissolved common salt). This process restores the resin's capacity to continue softening water.

This document does not support the efficacy of one technology over another. We recommend stakeholders consult with reputable manufacturers to determine the most suitable technology for their specific application.

Further Considerations

When considering the use of any limescale prevention technology, we strongly recommend consulting a water treatment specialist. Numerous factors contribute to the scale-forming behaviour of water, including local water chemistry, operational temperatures, pressures, and the specific locale.

Additionally, certain aspects of a building's service design and operation can influence the rate of limescale formation. These factors may also affect the efficacy and suitability of the various scale control solutions mentioned earlier.

There is no "one size fits all" solution; the design and selection of the appropriate technology are multi-faceted and require careful consideration.

Hydrotec is a manufacturer and supplier of innovative and efficient water treatment technologies with over 30 years of experience in the EU and UK, and operations globally. We are happy to discuss your requirements regarding decarbonisation and how water treatment can complement both existing and future strategies.

Supplementary Information: Cost Implications

This document focuses on the carbon emissions related to the reduced efficiency of domestic hot water generation caused by limescale formation and its insulating properties. While reducing carbon emissions is paramount in decarbonisation strategies, cost considerations are equally important. The most attractive decarbonisation schemes are those that not only reduce emissions but also offer cost neutrality or a return on investment within a reasonable timeframe.

Using the energy consumption data calculated here, alongside OFGEM's Price Cap figures, we can estimate the annual increases in operational costs due to the additional energy required to overcome limescale formation. We have also factored in the capital expenditure of procuring a water conditioner or softener in year one, as well as operational costs such as energy use, salt consumption (for softeners), and wastewater production (for softeners), with water use data being used from Thames Water.

We note that the capital expenditure considers the list price of equipment as sold in the UK, as of September 2024. Prices may vary globally and are subject to change.

Electricity	
Per kWh	22.36p
Gas	
Per kWh	5.48p

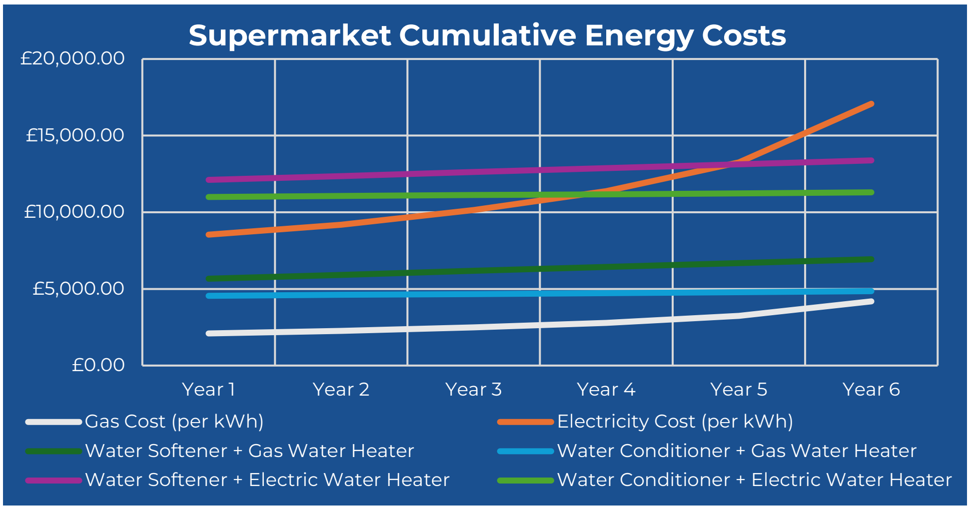
Source: https://www.ofgem.gov.uk/news/new-energy-price-cap-level-july-september-2024-starts-today

Water	
Waste Water Service per m3	98.24p

Source: Thames Water Indicative wholesale charges 2023-24 For the supply of water and wastewater services

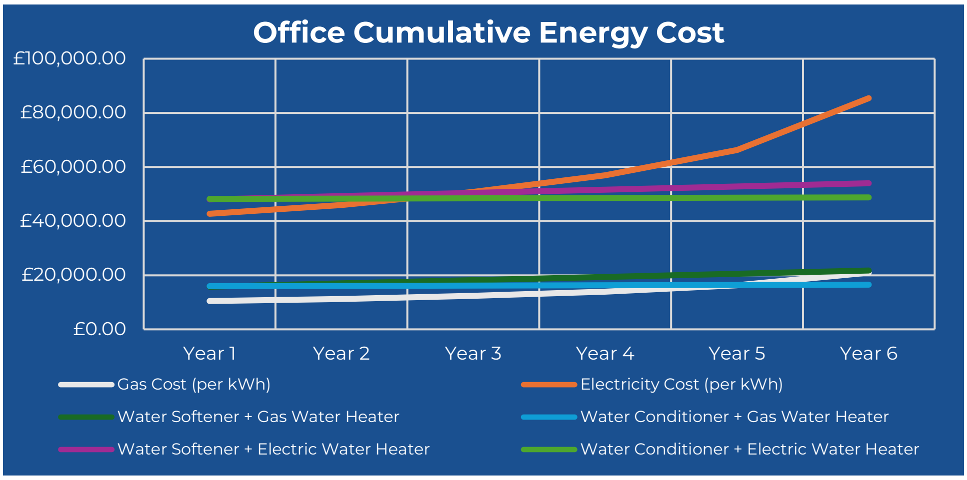
Scenario 1: Supermarket (2,000 litres of hot water/day)

In a supermarket scenario, using an unprotected domestic hot water generator results in significant energy cost increases over the life expectancy of the system. However, when a water conditioner or softener is used, these costs are mitigated. The return on investment (ROI) for the water conditioner is achieved by year three and for the water softener by year four when used with an electrically powered water heater. For gas-powered systems, ROI for the conditioner is expected by year six, and the softener achieves ROI comfortably within the building services' lifespan.



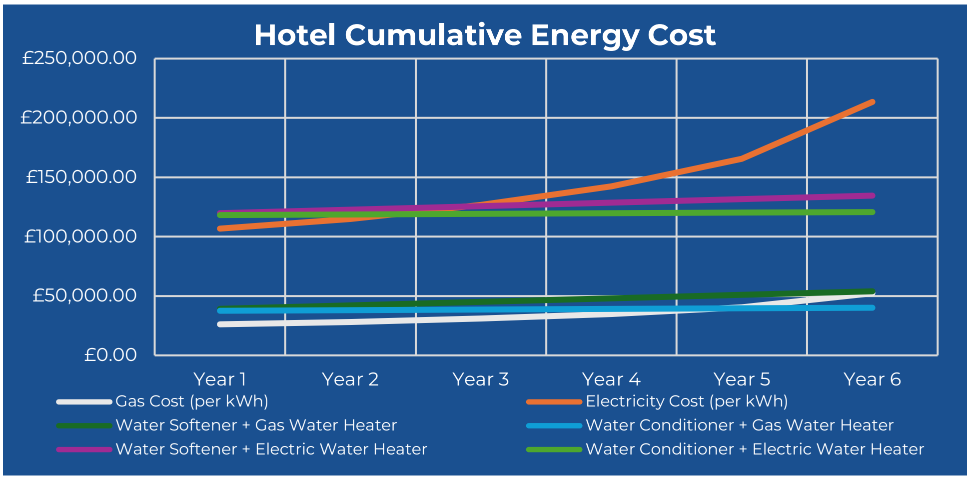
Scenario 2: Office Building (10,000 litres of hot water/day)

In an office building scenario, the mitigation of additional energy costs is substantial. For electrically powered water heaters, ROI for both the water conditioner and softener is achieved by year two. For gas-powered systems, the conditioner reaches ROI by year five, while the softener does so by year six.



Scenario 3: Hotel (25,000 litres of hot water/day)

For a hotel scenario, tens of thousands of pounds could be saved over 10 years when using a limescale prevention device with a gas-powered water heater. For electrically powered heaters, savings could exceed £100,000. ROI for water softeners and conditioners in electrically powered systems is reached by year two, while gas-powered systems see ROI by year four for the conditioner and year six for the softener.



<u>Summary</u>

The data indicates that an effectively sized and deployed limescale prevention device can prevent the generation of tonnes of additional carbon emissions while saving stakeholders significant money over the life expectancy of the building's water system. This reinforces the point that preventing limescale formation is both more energy-efficient and cost-effective than remedial solutions post-formation.

Cost Increase Mitigations

Supermarket

Depending on the method of domestic hot water generation, a supermarket could save over **£5,000** over five years by using a limescale prevention device, with return on investment being as little as **3 years.**

Office Block

Depending on the method of domestic hot water generation, a commercial office block could save over **£32,000** over five years by using a limescale prevention device, with return on investment being as little as **2 years.**

Hotel

Depending on the method of domestic hot water generation, a hotel could save over **£90,000** over five years by using a limescale prevention device, with return on investment being as little as **2 years.**