

Article

Introducing a Calculator for the Environmental and Financial Potential of Drain Water Heat Recovery in Commercial Kitchens

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Abstract: Food service providers like restaurants, cafes, or canteens are of economic importance worldwide, but also contribute to environmental impacts through water and energy consumption. Drain water heat recovery from commercial kitchens, using a heat exchanger, has shown large potential to decarbonise hot water use across food services, but is rarely deployed. This work translates previous findings on the technical feasibility and heat recovery potential for commercial kitchens into a publicly available calculator. It facilitates decision-making towards recovery and reuse of the freely available heat in kitchen drains by estimating both financial costs and payback time, as well as environmental burdens associated with the installation and environmental savings from avoided energy consumption. Environmental burdens and savings include, but are not limited to, carbon emissions. Further, the tool highlights key aspects of the technical implementation to understand installation requirements. The tool is freely available and could contribute to the uptake of heat recovery in the food service sector, ideally in conjunction with policy support through financial incentives or subsidies.

Keywords: carbon footprint; catering; climate change mitigation; cooking; energy efficiency; greenhouse gas emissions; hospitality; life cycle assessment; meal preparation; wastewater reuse



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1. Introduction

The food service sector is an important economic part of the global tourism and hospitality industry. After transport and accommodation, tourist expenditure on food services generates the third highest revenue in tourism [1,2]. Globally, an estimated 75 billion meals are served in international tourism [3]. Additionally, food services are enjoyed by local visitors as well as at their places of work or education. They include restaurants (including those in hotels), pubs, cafes, catering services, canteens (e.g., in schools, businesses, or hospitals), and quick services (e.g., takeaways, fast food) [4]. In the US, food services are the largest private-sector employer, and 42% of the food expenditure in 2008 by US consumers was in food service establishments [5,6]. In 2019, consumers in the Republic of Ireland spent approximately 1300 Euro per person on food and non-alcoholic drinks consumed outside their home [7,8]. These statements relate to pre-pandemic times, but it can be expected that the tourism and food service sector will continue its pre-pandemic growth, once recovered [9,10].

1.1. Water, Energy, and Greenhouse Gas Emissions in Food Services

The hospitality and food service sectors not only contribute to economic revenue but are also major consumers of water and energy. In the United Kingdom (UK), for instance, approximately 143 M m³ of water was used in hospitality and food services in 2010 to

prepare 8.2 billion meals, which compares to 190 M m³ in the same year in the total food and drink manufacturing subsectors [4].

Energy consumption for the preparation of meals in food services in the UK stands at 36 TWh of primary energy per year, equalling 46% of primary energy consumption in hospitality and 10% of the primary energy of the whole service sector, i.e., more primary energy is used in food services than for domestic cooking, with 24 TWh [11]. Pubs and restaurants alone are estimated to have an energy consumption of approximately 7.5 TWh [12]. In Austria, 450 million meals were consumed by foreign and domestic tourists in 2017 and energy consumption ranges between 5–10 kWh/meal, resulting in 2.3–4.4 TWh for all tourist meals [10].

Energy consumption in food services is associated with considerable amounts of greenhouse gas (GHG) emissions. In 2017, energy consumption in UK food services was met 70% by fossil fuels, 21% by electricity, and just 9% by bio- and waste energy [11]. In light of the urgency to reduce global carbon emissions and mitigate climate change, the UK hospitality association has signed an agreement, the “Courtauld Commitment”, targeting a 50% reduction of GHG emissions between 2015 and 2030 [13,14].

1.2. Heat Recovery for GHG Mitigation

Due to the use of hot water, e.g., for dishwashing and boiling food, wastewater from commercial kitchens constitutes a considerable source of heat, which is available independently of the season or weather as can be the case with renewable energy such as wind or solar energy. Drain water heat recovery therefore offers the opportunity to decarbonise thermal energy consumption in food services. This work is based on previous research from [15,16] on the drain water heat recovery potential and its technical, environmental, and financial aspects in the widely unexplored field of commercial kitchens. A study by [15] found that approximately 1.4 TWh of heat could be recovered every year in the UK food service sector, 90% of which could be achieved in a financially feasible way. In a case study restaurant, recovered heat from drain water was estimated to be capable of replacing 30% of the thermal energy needed for water heating [16]. GHG emissions of approximately 490 kt CO₂ eq. could potentially be avoided if appliances for direct heat recovery from drain water were installed in the over 250,000 commercial food outlets in the UK [16]. This would equal 52 kt CO₂ eq. in Ireland’s 27,000 outlets [7]. Further environmental benefits beyond climate change mitigation were found to apply for drain water heat recovery from kitchens, such as the reduction of eutrophication, acidification, human and eco-toxicity, or resource depletion, even under consideration of the life cycle environmental impacts of the required heat recovery equipment. Environmental savings could be shown for the avoidance of both fossil fuels, such as natural gas, and renewable energy, such as geothermal or solar energy (Supplementary Materials S1). Despite promising energy and emission savings, decentralised drain water heat recovery is rarely applied to commercial kitchens outside of case study restaurants and thus represents a novel field of application.

Instead, research and application of decentralised drain water heat recovery has to date mostly focused on shower drains. Energy savings from shower drain heat recovery for hot water heating have been reported in the range of 4–15% annually in a high-rise residential building in Hong Kong [17] and an estimated 9–27% depending on the size of the heat exchanger and water use pattern, amongst others [18]. McNabola and Shields estimated the national savings potential for shower drain water heat recovery for Ireland with 808 GWh of energy or 400 kt CO₂ eq. of emissions per year, using a horizontally installed heat exchanger [19]. The quantity of energy recovered and hence, financial and environmental viability, depends on the design and orientation (vertical or horizontal) of the heat exchanger, and increases with the volume of wastewater and its temperature flowing through the heat exchanger [20–23]. Intensive use of a heat exchanger is therefore preferable and some studies have been conducted on drain water heat recovery in hospitals, hotels, or sport facilities [21–24]. In the UK, the average domestic daily water consumption

is about 350 L/day [25], while commercial kitchens reach an average daily water flow of up to 12,500 L/day [15], presenting a benefit of kitchen drain water heat recovery.

As a lack of awareness of the possibility of drain water heat recovery from commercial kitchens and its potential environmental and financial gains exists amongst food outlets, there is a need for a tool to support the uptake of heat recovery in this novel and promising area of application.

1.3. Facilitating the Implementation of Heat Recovery in Food Businesses

This work translates the findings from studies by Spriet et al. [15] and Schestak et al. [16] (see Section 2) into a freely available decision-support tool for commercial kitchens in order to facilitate the implementation of drain water heat recovery as a measure to reduce climate change and other environmental impacts from food services. The tool intends to help overcome barriers which have been identified for the uptake of efficiency measures in the food service industry. Becken and Dolinica [26] conducted a survey amongst over 600 small and medium-sized (SME) accommodation and food service businesses in the US and Europe. They found the most important barriers to be costs or administrative hurdles, followed by the difficulty of choosing the right measure. On the other hand, cost savings and financial or fiscal incentives as well as environmental protection were said to be the top motivators. Strategies suggested to foster the implementation of efficiency measures were grants and subsidies, but also consultancy, the demonstration of new technologies, and support through reporting and self-learning tools. We pick up on these findings by providing an easy-to-use tool which informs about (a) the technology of drain water heat recovery, including the required equipment and implementation conditions; (b) the kitchen-specific/user-specific potential financial costs and savings; and (c) the individual potential for environmental benefits, including but not limited to, carbon emission savings. The latter, apart from addressing food businesses' own "green conscience", increases the attractiveness of the business given a growing consumer interest in sustainability [6]. According to the US National Restaurant Association, 60% of consumers claim to be "likely to choose a restaurant based on its environmental efforts" and 44% based on a restaurant's energy and water conservation efforts [6]. The results generated through the tool enable the users to judge if drain water heat recovery can be technically feasible, as well as financially and environmentally viable, in their own food establishment.

2. Methodology

The tool is based on the research and findings from [15,16], which estimated the heat recovery potential as well as the financial and environmental performance of kitchen drain heat recovery based on monitoring campaigns in the UK and Ireland. The following paragraphs summarise the most important background information on the development of the toolkit taken from [15,16], explaining the technical assumptions and data underlying the calculations of the toolkit, as well as exploring the user interface with data entry and generated results. For further methodological background, refer to [15,16].

Due to data availability from the monitoring campaigns, the toolkit has been developed to represent commercial kitchens in Ireland and the UK, using country-specific background data on costs and environmental impacts. However, the toolkit can be adapted to other countries worldwide.

2.1. Drain Water Heat Recovery Technology

The heat recovery system considered here uses a tube-in-tube heat exchanger and hence represents a kind of direct and passive heat recovery without the need for a heat pump. This and similar kinds of heat exchangers are typically used for shower water heat recovery, for which they have been studied and installed in domestic and commercial settings across the UK and Europe [20,21,27–30]. In 2020, the installation of a heat recovery system was completed at a case study restaurant at the Penrhyn Castle tourist attraction in Wales, UK, initiated and overseen by the authors as part of the Dŵr Uisce

INTERREG project, and was proven to be effective at recovering heat from kitchen drain water [15,16,31,32].

The heat exchanger is made from copper in the form of a double walled pipe. The inner pipe leads the warm kitchen drain water, while the outer pipe leads the incoming cold water which is pre-warmed in the heat exchanger and then enters the boiler or other conventional water heating system (Figure 1). For this calculator, the heat exchanger is assumed to replace a part of the kitchen drain of approximately 2 m in height; however, shorter heat exchangers are available on the market as well. In order to reach its maximum heat exchange effectiveness of about 60%, it needs to be installed vertically [33]. With currently available designs, vertical heat exchangers have been proven to reach higher heat exchange effectiveness and are less prone to blockage than horizontal ones, which is important for the use with kitchen wastewater carrying higher organic contaminations than shower wastewater [19,30]. In order to connect the heat exchanger to the cold-water supply and boiler, fittings, and further pipework are required, the length of which depends on site-specific conditions, and which are assumed to be insulated.

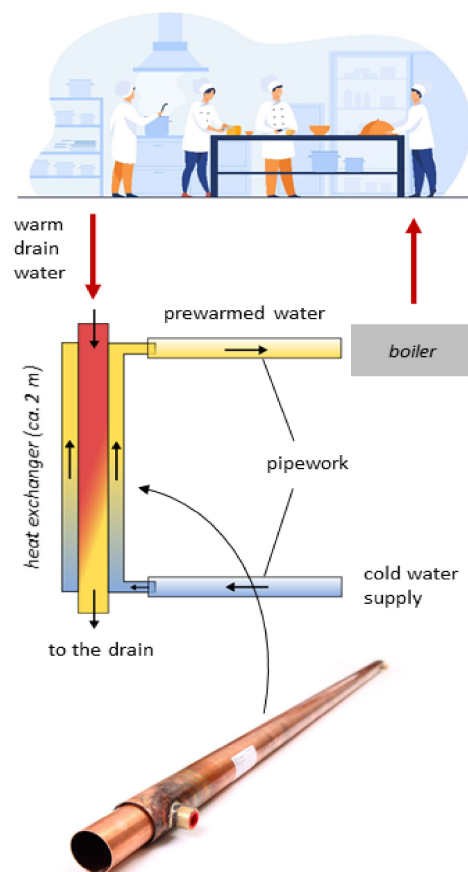


Figure 1. Overview of heat recovery from kitchen drain water with a pipe-in-pipe heat exchanger. With graphical elements modified from [27,34].

Although previous studies revealed that financial and environmental savings are likely for the large majority of commercial kitchens in the UK—90% when considering an average kitchen in regard to the heating energy sources used [15,16]—the suitability of a kitchen for drain water heat recovery ultimately depends on three main factors. These are (1) the amount of recoverable heat, depending on the water consumption or kitchen size; (2) the type of energy source replaced through heat recovery; and (3) the equipment needed and its material (e.g., copper, steel, or polyethylene pipework), which differs from kitchen to kitchen. For pipework, the user of the toolkit can therefore choose between three materials: copper, steel, and polyethylene (PE).

2.2. Heat Recovery Potential

The calculation of the heat recovery potential is based on data from a monitoring campaign at several kitchens in the UK and Ireland, during which drain water temperatures were measured, amongst other parameters [15]. Spriet and McNabola [15] determined the average heat recovery potential of a commercial kitchen taking into account varying drain water flows over the time of day during kitchen operation, the temporal mismatch between drain water flow and hot water consumption, a retention time of water through kitchen appliances of no longer than 1 h, a 90% return rate of the consumed water into the drain, and the use of several heat exchangers in parallel for high flow rates. The remaining 10% of the water consumption was considered to leave the kitchen via different means such as evaporation or incorporation into food. Here, we convert the information on the amount of heat recovered, expressed as kWh/L of water consumed at a specific water flow rate (derived from [15], Table 1), into the amount of heat recovered based on user data entry (see Section 3.1). The amount of recovered heat equals the amount of energy saved which would otherwise have been provided through the conventional water heating energy source of the respective kitchen. For further methodological details about the calculation of the heat recovery potential, refer to [15].

Table 1. Background data on (A) flow-specific heat recovery potential and (B) water consumption per meal.

(A) Flow, Heat Recovery, and Number of Heat Exchanger Pipes Derived from [15,16]		
Flow (L/h)	Heat Recovery (kWh/L)	# Of Heat Exchanger Pipes
45	0.0083	1
69	0.0083	1
75	0.0083	1
94	0.0083	1
120	0.0083	1
185	0.0083	1
200	0.0083	1
250	0.0082	1
390	0.0078	1
601	0.0081	2
650	0.0080	2
750	0.0078	2
813	0.0077	2
1156	0.0078	3
1250	0.0077	3
1563	0.0078	4
(B) Water Consumption from [4]		
(L/meal)	Type of Food Outlet	
12	Quick service category: pub, fast food, cafe, takeaway, mobile catering	
18.5	Canteen category: staff catering, schools, universities	
20	Hotel category: restaurant in a hotel	
25	Restaurant category: restaurant with table service, food services in hospitals and care/nursing homes	

As the heat recovery potential considers an average water consumption and wastewater generation in a kitchen, the toolkit only provides an estimate of the heat recovery potential of a kitchen. This, however, has the advantage of not requiring data on water use through different appliances or at a specific time of the day and hence simplifies the use of the toolkit (see Section 3.1).

2.3. Financial Assessment

Financial cost-effectiveness is considered a key driver for the uptake of kitchen drain heat recovery. The calculator considers both operational financial savings through avoided energy use, and the investment costs (capital costs) for the heat exchanger, pipework,

fittings, and insulation. Purchase costs are taken from manufacturers or suppliers of the respective parts in Ireland and the UK. A heat exchanger such as the one suggested by the toolkit costs around £500, or €600 [15]. Savings depend on the heat recovery potential and the energy price of the conventional heating source provided by the user. Labour costs have not been included in the financial assessment due to high variability: they depend not only on specific hourly rates charged by the installing company, but also on site-specific conditions, such as distance and obstacles between the drainpipe and boiler. Nevertheless, the total operational savings for a chosen service life provide the user with a financial frame for labour costs while ensuring payback.

2.4. Environmental Assessment

Similar to the financial assessment, the environmental assessment considers operational environmental savings, such as GHG savings, but also environmental burdens connected to the equipment. Burdens related to the environmental footprint from the life cycle (manufacture, use, end of life) of the heat recovery system, including all parts (heat exchanger, pipework, insulation, fittings), have been determined via a complete cradle-to-grave life cycle assessment (LCA) [16] (Supplementary Materials S2). Environmental burdens across seven impact categories have been shown to derive mainly from the manufacture of the copper heat exchanger, linked to emissions from mining and energy use during processing of the material, such as forming and finishing [16]. The environmental impacts considered in the toolkit are climate change (GHG emissions), acidification, freshwater eutrophication, freshwater ecotoxicity, and resource depletion (of mineral, fossil, and renewable resources), as recommended by the International Reference Life Cycle Data System (ILCD) handbook [35].

The environmental profile greatly depends on the amount and material of the pipework used, which can exceed burdens from the heat exchanger, especially when copper or steel is used. Further, environmental savings are influenced by the amount and the type of water heating energy source replaced through heat recovery. The user can choose between the following energy sources: natural gas, grid electricity, green electricity, light fuel oil, geothermal energy, solar thermal energy, and wood chips, modelled as in [16]. Grid electricity is modelled as the marginal grid electricity from a natural gas power plant, while green electricity represents the current mix of renewable energies in the UK [36].

3. User Interface

The calculator is based on MS Excel to offer accessibility to a wide range of users in line with similar energy efficiency and carbon emission calculators [37,38], and has been developed to be used by those without a sciences or technical background. Functionality and user-friendliness have been validated with kitchen managers, and the calculator was adapted upon feedback provided during a public webinar where the calculator was presented. The tool is divided into three main sections: (1) an introduction which describes the purpose of the tool, intended users, considered technology, technical requirements, and expected outcomes in layperson language; (2) data entry; and (3) individual results and conclusions.

3.1. Data Entry

The calculator requires the user to enter the following data:

- **Water consumption:** This can be entered as yearly water consumption in cubic metres or, alternatively—depending on the data availability of the user—as the number of meals served per year and specification of the type of food outlet. To facilitate data entry, sample values are provided. If served meals are used, yearly water consumption is derived from benchmark values for water consumption per meal for specific food outlet types from [4] (Table 1). This is available for restaurants with table service, hospital and nursing home kitchens, hotel restaurants, canteens for staff catering,

schools, or universities, and quick service restaurants which include pubs, fast food, cafes, takeaways, and mobile catering.

- Opening times: This information is required to determine the hourly water flow rate which links to the heat recovery potential.
- Currently used energy source for hot water: This determines the environmental savings through avoided energy consumption.
- Country: Either UK or Ireland in the current version of the calculator, to derive country-specific installation costs.
- Energy price for water heating per kWh: To determine financial operational savings.
- Approximate distance between the kitchen drainpipe and boiler: This information serves to determine the amount of pipework required for the installation.

The calculator assumes a service life of 10 years and polyethylene pipework as default values; however, the user can change these values to understand how they affect the results. As no long-term study has been performed using the proposed heat recovery system with kitchen drain water, the calculator assumes a conservative maximum service life of 20 years compared to a service life of up to 50 years with shower water [21].

3.2. Results

The following results are generated by the tool:

- Heat recovery potential: The calculator provides the amount of heat which can potentially be recovered per year, and during the whole service life, expressed in kWh (Figure 2).
- Financial assessment: The financial results include the operational savings per year and over the service life, total investment costs (capital costs), and simple payback time in years (Figure 3).
- Environmental assessment: This section is divided into savings and impacts related to carbon emissions and other environmental categories. The carbon section contains—equivalent to the financial results—operational carbon savings per year and per service life, carbon costs (footprint), and carbon payback time (Figure 4). The carbon savings are also translated into the amount of vehicle kilometres saved, considering the emissions of an average gasoline car in Europe [39], for context.
- Further to carbon savings, the results for four other environmental impact categories are shown. In a compromise between comprehensiveness and consideration of a user without an environmental sciences background, the following four categories have been chosen for display: acidification of soils and water bodies, freshwater eutrophication, freshwater ecotoxicity, and resource depletion (mineral, fossil, and renewable resources) (Figure 5).
- Conclusion: A conclusion field contains a summary of the overall results, concluding if heat recovery could be applied in a financially and environmentally viable way, based on the user-specific data entry.

Results are displayed in parallel for (a) baseline and (b) custom assumptions regarding the material of the pipework and the service lifetime. This enables the direct comparison of results and the evaluation of individual choices which is relevant to understand the higher environmental burden and financial costs of copper and steel compared to polyethylene. Figures 2–5 exemplify the results for a kitchen with a water consumption of 2000 m³/year, which can be considered a medium-sized kitchen compared to average rates of different food outlet categories in the UK, which range from 360 to 12,500 L/day or 130 to 4600 m³/year [15]. The results in the example show that, when the recovered heat replaces natural gas at a rate of 3.1 Eurocent/kWh [40], and 10 m of pipework (polyethylene) is needed in addition to the heat exchanger, the capital costs would be paid back within just over 4 years. The carbon footprint would be offset in under one month. In case of a heat recovery system with steel pipework (example for customised data entry), environmental payback times would range from under one month (carbon footprint) to over

three years (resource depletion), i.e., the heat recovery system in the example would offer environmental viability, as environmental burdens are paid back within its service life.

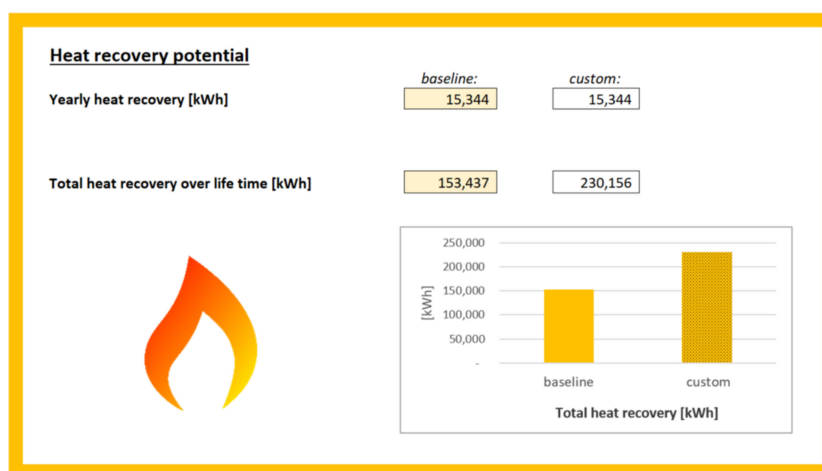


Figure 2. Example for results of the heat recovery potential from the toolkit. Assumptions: water consumption of 2000 m³/year and a service life of 10 years (baseline) and 15 years (custom).

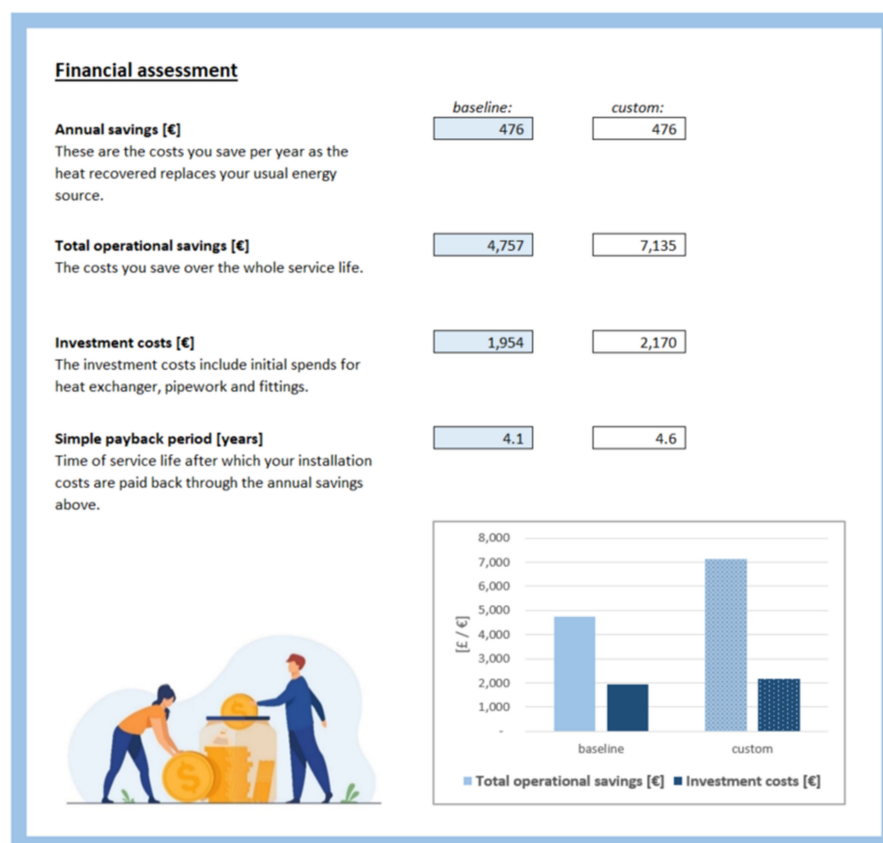


Figure 3. Example for results of the financial assessment of the heat recovery toolkit. Assumptions: water consumption of 2000 m³/year; natural gas as heating fuel at a rate of 3.1 Eurocent/kWh [40]; country: Ireland; distance between kitchen drain and boiler of 10 m. Baseline: 10-year service life and pipework from polyethylene. Custom: 15-year service life and pipework from steel. With graphical element modified from [41].

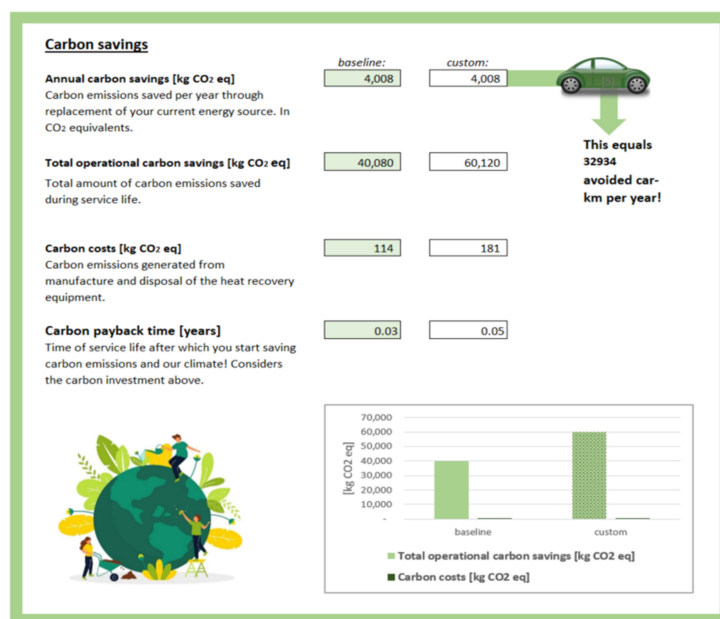


Figure 4. Example for results on carbon costs (footprint) and savings from the heat recovery toolkit. Assumptions: see Figure 3. With graphical element modified from [42].

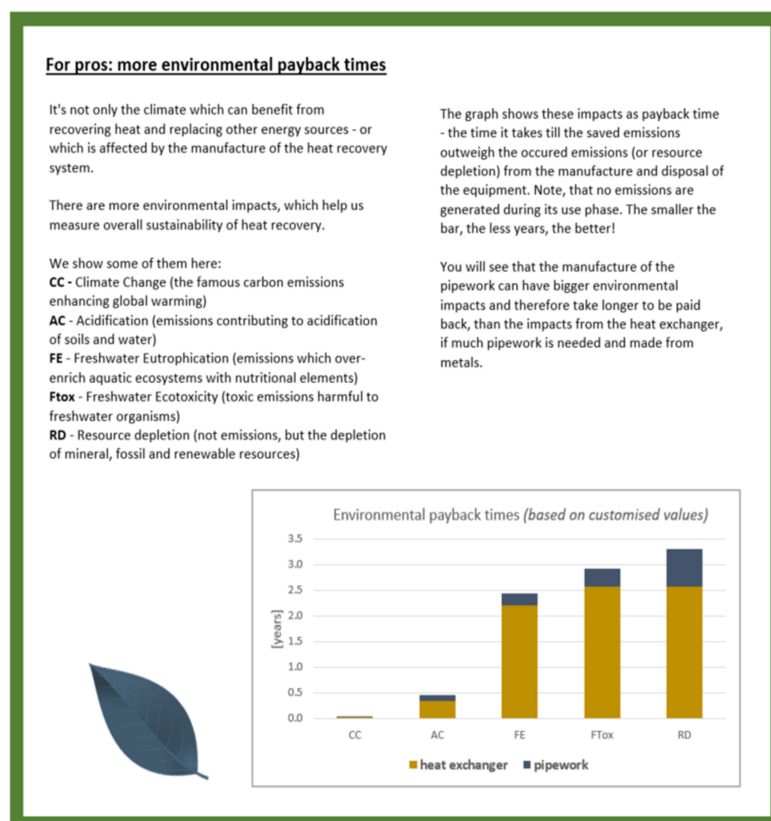


Figure 5. Example for results for payback time (in years) for carbon emissions and other environmental impacts of the heat recovery system, with a water consumption of 2000 m³/year, natural gas as replaced heating fuel, and 10 m pipework from steel. With graphical element modified from [43].

4. Expected Learnings

The toolkit delivers an estimate for the heat recovery potential of commercial kitchens, as a basis for encouraging heat recovery in appropriate contexts. It facilitates decision-making for kitchen owners interested in reducing the carbon footprint of their business

(whether in favour of or against heat recovery depending on, e.g., kitchen size and drain water flow). Following the use of the toolkit, the user will be able to answer the following questions:

- Is it technically possible to install this heat recovery system within my kitchen?
- What are the capital costs?
- Does the financial payback fit the business plan?
- Is it environmentally beneficial to recover heat? Are burdens of the system paid back within the intended service life?
- Can pipe material choice be adapted to reduce the footprint of the equipment, and reduce environmental payback time?
- Is it worth undertaking further planning into heat recovery?

5. Discussion of Heat Recovery Application in Kitchens

The achievable benefits of recovering heat from commercial kitchens regarding environmental and financial aspects have been outlined in the Introduction. Some challenges, however, need to be addressed for its application. This article focused on overcoming potential issues such as a lack of awareness by kitchen owners of the availability of heat recovery and its benefits. A lack of awareness and access to information has also been identified as an issue for the implementation of heat recovery systems for showers by domestic users [30]. From a technological perspective, the necessity to access a part of the drainpipe with an approximately 2 m vertical drop can constrain the installation of a heat exchanger, as can the existence of obstacles between the drainpipe and the boiler. The number of potentially affected kitchens is unknown. In shower heat recovery systems, this issue can be overcome by the installation of a horizontal heat exchanger [19,20,30], which could, however, lead to increased blockage when used with kitchen drain water. Heat recovery from a kitchen's grease trap could pose a more accessible heat recovery option worthwhile to study in future research. Currently, a heat recovery system for kitchen drains—mainly the connecting pipes—must be customised to fit site-specific conditions, which could increase investment costs. With a broad uptake of (kitchen) drain water heat recovery, increased installations experience, and specialisation of engineering companies into this type of heat recovery application, a decrease in these costs can be expected.

Rising energy prices such as the recently observed rise in the natural gas price in Europe [44] will further increase the financial profitability of a heat recovery installation. Nevertheless, as financial advantages play a vital role in the realisation of energy efficiency measures, public support and state aid through subsidies could further accelerate heat recovery implementation. This would be specifically beneficial for smaller food outlets where heat recovery proves to be environmentally, but not financially viable. Another policy measure could be the promotion of kitchen heat recovery through its inclusion into the reference document on best environmental management practice of the EU Eco-Management and Audit Scheme (EMAS) for the tourism sector [45,46]. The sectoral reference document for the tourism sector contains best environmental practices for restaurant and hotel kitchens and proposes measures for the reduction of water or energy consumption, for instance [45]. Heat recovery from drain water could be included as a measure for energy conservation, and the energy consumption of kitchens applying heat recovery could serve as an energy benchmark.

6. Conclusion and Outlook

A toolkit has been developed which provides technology guidance and estimates thermal energy, financial, and environmental savings potential associated with heat recovery from the drain water of commercial kitchens. It includes on the one hand environmental burdens from the life cycle of the required equipment as well as investment costs, and on the other hand operational environmental and financial savings. Based on empirically monitored data from several kitchens, the toolkit delivers a customised estimate for heat recovery potential and a first decision pro/contra installation of a heat recovery system.

The calculator is a first step towards enhancing the implementation of heat recovery in practice, which has already shown its theoretical potential for the cost-effective reduction of GHG emissions in the food service sector across the UK. The toolkit is adapted in language and content to be accessible to users lacking an engineering or environmental sciences background and requires no extensive data collection. If the toolkit generates results in favour of heat recovery, a kitchen owner is encouraged to seek professional advice for an individual assessment, which then enables detailed site-specific information to be considered. Although the toolkit cannot replace professional planning, it can raise awareness and interest by showcasing financial and environmental gains achievable from the “free heat” embedded in drain water.

Passive drain water heat recovery with a heat exchanger can be regarded as a low-cost decarbonisation measure. Nevertheless, further support of this measure in the form of subsidies could augment its uptake, especially in cases where there is a gap between a short environmental, and a long financial, payback time, or where investment costs are higher due to site-specific conditions.

The tool is available for download free of charge at the Dŵr Uisce project website: <https://www.dwr-uisce.eu/heat-recovery-tool>.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/w13243486/s1>, Figure S1: Comparison of environmental impacts from heating water through heat recovery or conventional energy sources, Figure S2: Life Cycle steps included in the environmental footprint of the heat recovery system.

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