Report

Smoke Control Area Impact Study 2024

Final Report

For Cambridge City Council

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1 Executive Summary

Burning of solid fuels for heating in homes and commercial buildings is an important source of air pollution, which when exposed to, carries significant detrimental impacts for human and environmental health. In the UK, $PM_{2.5}$ emissions decreased by 72% between 1990 and 2022[1]. The major drivers for this were the reduction in the burning of coal for power generation, and improved emission standards for transport and industrial processes. In recent years, the rate of reduction in annual emissions of PM has slowed, with decreases in emissions from certain sectors being offset by increases in emissions from wood burning in domestic settings and from solid fuel burning by industry[3]. Hence, burning of solid fuels in homes and businesses is becoming an increasingly important source as emissions reduce from other sources. In the Cambridge City Council area, domestic solid fuel burning is estimated to account for 40% of total $PM_{2.5}$ emissions, with wood burning making up the majority of the domestic total.

One of the key policy mechanisms to tackle pollution from burning of solid fuels for heat has been Smoke Control Areas (SCA), which restrict the type of fuels that can be burned and the type of appliance used. Cambridge has three existing SCAs covering the central and western areas of the city, established during the 1960s. Cambridge City Council commissioned Logika Group to undertake this study to assess the effects of amending its existing SCAs (extending or removing) in terms of changes in pollutant emissions, health and socio-economic considerations. The following scenarios were considered:

- **Baseline:** This estimated emissions in Cambridge from domestic premises and river vessels based on the current SCA boundary.
- **Scenario 1:** This looked at the changes in emissions and impacts if all moored residential boats are also included in SCA rules, with no change to the current SCA boundary for residential properties.
- **Scenario 2:** This extends the SCA boundary to become a city-wide SCA (and continues to exclude the moored residential boats).
- **Scenario 3:** This is the same as Scenario 2 (extend SCA boundary to become a city-wide) but includes moored residential boats in SCA rules.
- **Scenario 4:** This estimates what emissions in Cambridge might have been if the existing SCAs had not been declared (this is similar to, but not the same as, removal of the existing SCA).

The analysis performed uses the most up-to-date and robust data and approaches and follows relevant best-practice guidelines for the assessment of associated effects. The methodology has been developed on the basis of the expertise of the project team and has been discussed and agreed with the Council. That said, there are limitations and uncertainty in the assessment and assumptions made, in both the baseline and the scenarios. The most important uncertainty relates to the resulting behaviour change of households and moored vessels if the SCA is expanded. Hence sensitivity tests have been run around the scenarios above, looking at 25% non-compliance with the SCA, and also testing the sensitivity of some of the baseline assumptions.

Residential emissions are the largest single source of emissions of $PM_{2.5}$ in Cambridge and the majority of properties are currently outside of the SCA. Expanding the SCA city wide (Scenario 2) is estimated to have a large positive effect on emissions from solid fuel burning, resulting in a 69% reduction (18.9

[1] https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-particulate-matter-pm10-and-pm25#:~:text=Annual%20emissions%20of%20PM2.,65%20thousand%20tonnes%20in%202022.

tonnes) of $PM_{2.5}$ from domestic solid fuel burning overall. Even with 25% non-compliance assumed, there is still predicted to be a significant (61%) reduction in overall $PM_{2.5}$ emissions from solid fuel burning. Moored river vessels represent a much smaller contribution to overall emissions, and current assumptions are that most are already likely to be burning Manufactured Solid Fuel (or MSF, which is a compliant fuel under SCA rules, meaning that they would not need to change behaviour in response to an extension of the SCA to cover moored vessels). Therefore Scenario 1, which only includes moored vessels, achieves a much smaller reduction in $PM_{2.5}$ emissions of 2% (0.52 tonnes). Scenario 3, the expansion of the SCA, including moored vessels, provides the greatest benefit, but is very similar to Scenario 2 due to the small contribution that moored vessels make. Scenario 4 shows that the current SCA delivers a benefit of around a 4% reduction in $PM_{2.5}$ emissions from domestic solid fuel burning (1.1 tonnes).

These reductions in air pollutant emissions will deliver ***positive benefits for human and environmental health***, with the size of effects moving in line with the size of the emission reductions – hence Scenarios 2 and 3 will deliver a significantly greater benefit than Scenario 1. A wide (and increasing) range of health conditions are linked to air pollution exposure, and reducing emissions will reduce the risk of lung cancer, stroke, ischemic heart disease, asthma, respiratory hospital admissions and deaths attributable to air pollution. These benefits can be expressed in monetary terms using 'damage costs', which capture associated changes in health care costs, 'productivity' benefits and the value people place on their own good health. When valued in this way, Scenarios 2 and 3 deliver a societal benefit valued at £1.6m each year, in comparison to £44,000 per year for Scenario 1. By comparison, analysis of Scenario 4 suggest that the existing SCA delivers a societal benefit of around £93,000 per year for Cambridge residents (i.e. a benefit that could be lost should the SCA be removed).

These monetised health impacts have been combined into a wider assessment of the ***socioeconomic effects*** of adjusting the SCA. Where possible, the impacts of the Scenarios have been quantified and captured in a cost-benefit analysis comparing the benefits of the scenarios against the costs. The costs to home and vessel owners of switching fuel or upgrading stoves, and to the Council with implementation and enforcement are greatest under Scenarios 2 and 3: Scenario 3 is estimated to carry a cost of £250,000 per annum relative to Scenario 1 which would cost around £15,000 per year. Overall, all scenarios to extend the SCA are estimated to deliver a 'net benefit to society' – in other words, the health improvements from reduced air pollution and benefit of greenhouse gas emission reductions outweigh the combined costs to the Council and owners of homes and moored vessels. The size of the net benefit delivered rises in line with the size of air quality benefits, hence Scenarios 2 and 3 deliver the largest net benefit in the order of £2.8m per year, with a ratio of benefits-to-costs or 12-to-1. Scenario 4, the existing SCA, was not subject to quantitative analysis given uncertainty around what would happen should an SCA be removed, however expert judgement suggests it is likely that the costs of removing the SCA in terms of the air pollutant benefits lost (i.e. increased emissions) and higher GHG emissions would outweigh any benefits in terms of fuel cost savings, hence delivering an overall disbenefit for society.

While increasing the coverage of the SCA results in a net benefit to society, it is important to consider ***additional impacts and risks that have not been quantified and captured in the cost-benefit analysis***. For households, there may be some practical implications of switching, such as search costs of finding new fuel sources, the need to allow access to the home to upgrade stoves, and installation risks – however there is no evidence to suggest these risks are significant overall. This is particularly the case as based on census data, there are no (or very few) households using wood or other solid fuel as their only source of heating, and those who do use solid fuels are typically not in the more deprived deciles of the Index of Multiple Deprivation (IMD). That said, the implications for moored vessel owners appear more consequential, in particular as 85% (~60 boats) use solid fuel as their primary heating source. As a group, evidence suggests moored vessel owners may have relatively lower incomes (A Canal and River Trust survey found that 27% of boaters declared an income under £20,000/year, and 43% under £30,000/year) and hence alternative options may be less affordable for some. Furthermore, this group tend to be more vulnerable (i.e. more likely to be elderly or have a disability or long-term health conditions) and vessels tend to be less well-insulated. Hence there is a greater risk that moored vessel owners may face difficulties affording to comply with the SCA, which in turn may have a detrimental impact on living standards amongst a more at-risk group.

Overall, the assessment presents either Scenario 2 or 3 as the preferred option. Analysis shows that benefits of expanding the SCA outweigh the costs, and there is predicted to be a net benefit to society of extending the SCA to the whole of Cambridge, driven by improvements to health. These findings are however dependant on behaviour change driven by the SCA which is uncertain and unlikely to be the full extent modelled, albeit costs and benefits will scale in line with the response and a net positive impact is likely even where response is lower than modelled here. As such, awareness-raising information campaigns and/or enforcement will be important to ensure the SCA succeeds in achieving behaviour change. Further work such as a city-wide survey may be helpful for better understanding burning behaviour and potential behaviour change related to extension of the SCA. Inclusion of river vessels in the SCA would deliver an additional net benefit and could achieve a significant impact on emissions from a more visible source (although the additional benefit as a whole is relatively small). There are however some additional risks and concerns for this small group of affected citizens, including higher economic vulnerability and risks from changes in living conditions. The data relating to proportions of river vessels burning wood and coal products, and the appliances which are being used is also more uncertain than for residential properties. Therefore, where Scenario 3 is pursued, additional engagement with moored vessel owners is recommended to further explore solid fuel burning activity within this group, as well as the potential impacts and risks to this group, and complementary measures should be considered where potential issues are identified to mitigate risks for vulnerable boat owners where possible.

2 Introduction

2.1 Context

Burning of solid fuels for space and water heating in homes and commercial buildings is a source of air pollution. Emissions from solid fuel burning contribute to elevated concentrations of Particulate Matter (PM) in the atmosphere. PM, both in the form of PM_{10} and $PM_{2.5}$[2], has many different sources, both natural and anthropogenic. These can be grouped into primary sources, where the particles are emitted directly into the atmosphere, or secondary sources, where the particles are formed from precursor gases through chemical reactions in the atmosphere. Sources of primary anthropogenic emissions include road and non-road vehicles, industrial activities, power stations, domestic heating, and shipping. Natural sources of particles include sea salt. The formation of secondary particles happens over hours to days, thus secondary PM is found downwind (sometimes tens or hundreds of kilometres) of the sources of emission. Reducing exposure to PM is particularly challenging, given the variety of sources, and contributions from secondary components.

In the UK, $PM_{2.5}$ emissions decreased by 72% between 1990 and 2022[3]. The major drivers for this long-term decrease were the reduction in the burning of coal for power generation, and improved emission standards for transport and industrial processes. However, in recent years the rate of reduction in annual emissions of PM has slowed, as shown in Figure 2-1. Considerable decreases in emissions from certain sectors have been largely offset by increases in emissions from wood burning in domestic settings and from solid fuel burning by industry[3]. Hence, burning of solid fuels in homes and businesses is becoming an increasingly important source as emissions reduce from other sources.

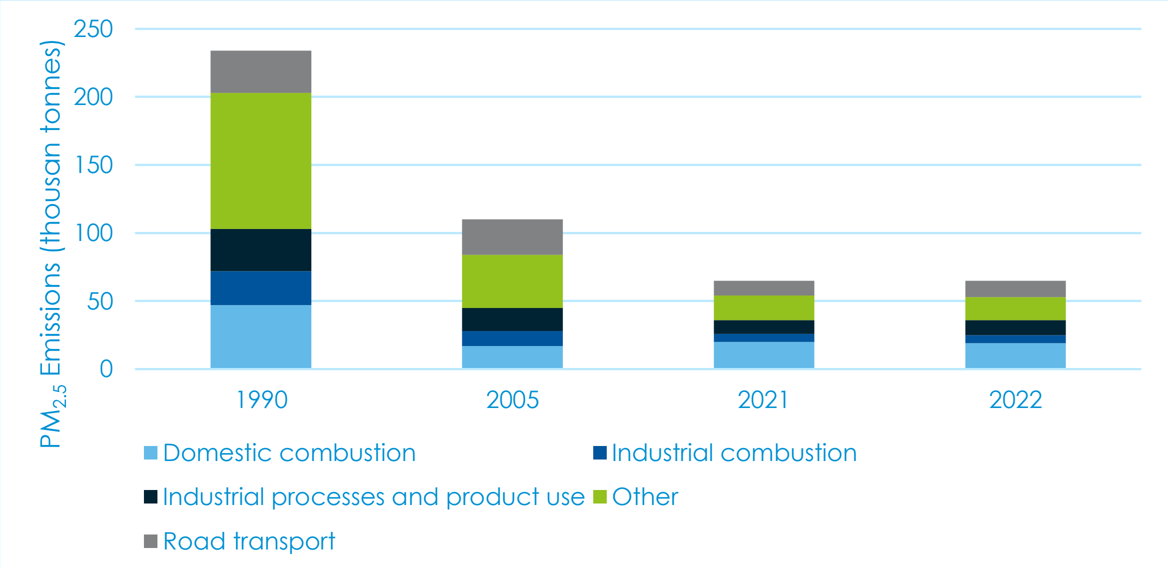

Figure 2-1 UK annual emissions of $PM_{2.5}$ by major emission source (1990, 2005, 2021, 2022)[3]

[2] PM_{10}, or course particles, are particles that are less than 10 microns (µm) in diameter. $PM_{2.5}$, or fine particles, are particles that are less than 2.5 µm in diameter and hence are a subset of PM_{10}

[3] https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-particulate-matter-pm10-and-pm25#:~:text=Annual%20emissions%20of%20PM2.,65%20thousand%20tonnes%20in%202022.

Concentrations of $PM_{2.5}$ tend to be greatest in urban environments in the southern and eastern areas of the UK due to a variety of factors, including higher population density, weather conditions and greater exposure to pollution sources from mainland Europe.

In the Cambridge City Council area, it is estimated that total primary $PM_{2.5}$ emissions from all sectors is 87 tonnes per annum[4]. The 2021 National Atmospheric Emissions Inventory (NAEI)[5] breaks this down into 11 categories, as shown in Figure 2-2 (note: the figure splits out category '02 non-industrial combustion plants into its separate components 'Domestic Solid Fuel Burning' and 'Other non-industrial combustion' form to highlight emissions from domestic solid fuel burning.

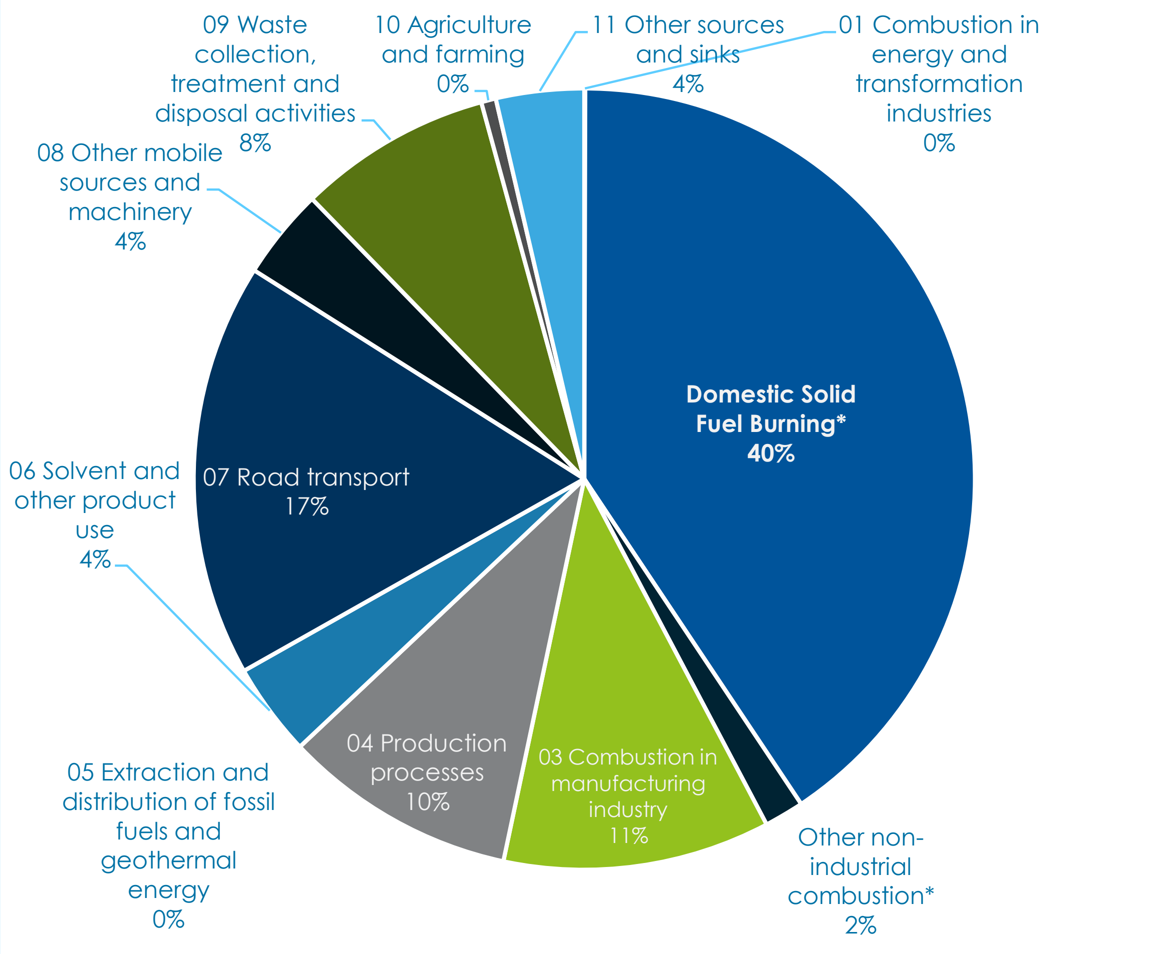

Figure 2-2 NAEI (2021) $PM_{2.5}$ sector emissions for Cambridge City Council area. *Note: 'Domestic Solid Fuel Burning' and 'Other non-industrial combustion' form category '02 non-industrial combustion plants' in the NAEI – they have been separated here to highlight emissions from domestic solid fuel burning.

Domestic solid fuel burning is the largest single source of $PM_{2.5}$ emissions in the Cambridge City Council area, contributing 35 tonnes in 2021, (40%) of total $PM_{2.5}$ emissions. Of which, the largest contributing source is from burning wood (76%), compared to relatively small contributions from solid smokeless fuels (SSF), as shown in Figure 2-3. Domestic wood burning hence represents a large proportion of primary emissions of $PM_{2.5}$, and hence one which should be addressed.

[4] Summed across 63 1km by 1km grid squares with data from the 2021 National Atmospheric Emissions Inventory
[5] Available via interactive map: https://naei.beis.gov.uk/emissionsapp/

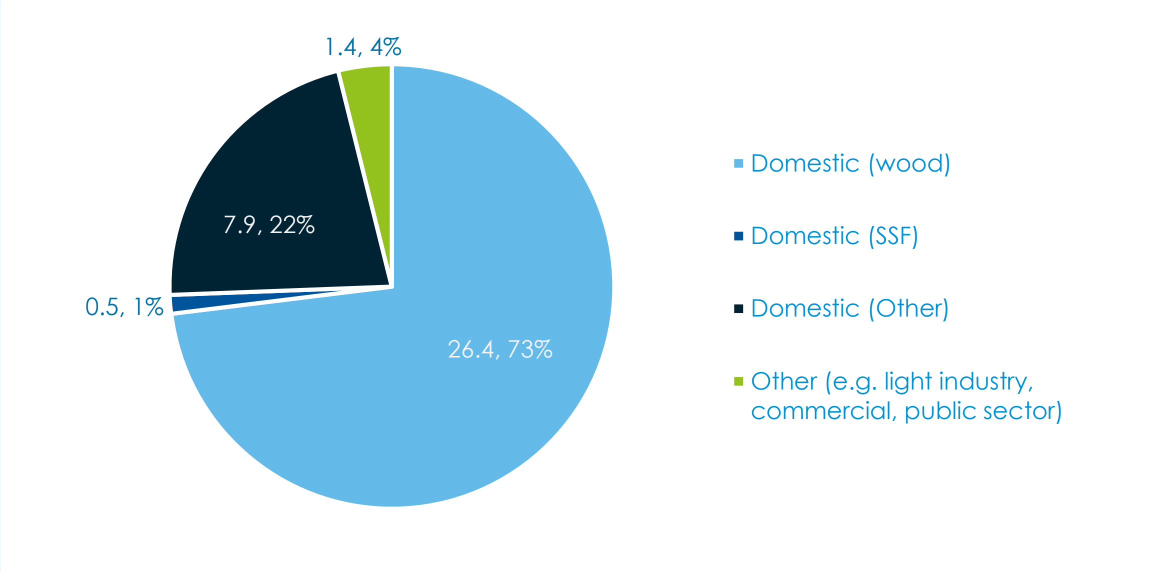

Figure 2-3 $PM_{2.5}$ emissions from '02 Non-industrial combustion plants' by fuel source (tonnes, per cent)[4]

One of the key policy mechanisms to tackle pollution from burning of solid fuels for heating purposes are Smoke Control Areas (SCAs). A SCA requires that households and businesses within the area use either an approved appliance (boiler, stove, etc) or an approved solid fuel (e.g. certain types of Manufactured solid fuels (MSFs) or anthracite) – fuels not approved (e.g. wood) can only (legally) be used in an approved appliance. SCAs are mandated through the Clean Air Act (originally 1956, most recently 1993, and as amended by the Environment Act 2021), and are declared through an order made by the Local Authority (s18, CAA 1993). They can be applied to all or a defined part of the Local Authority's area and the order may vary how the provisions of the Act are applied, e.g. through the specification of building classes or appliance which can be included. One of the changes introduced through the Environment Act 2021 is the potential to include residential, moored river vessels within SCAs.

Cambridge has three existing SCAs covering central and western areas of the city which were established during the 1960s. A map of the current areas can be found on the Cambridge City Council website[6], although very limited information is available regarding the rationale underpinning their original design and declaration. There were a handful of exemptions in one of the original orders (dated 6th November 1961) for fireplaces in buildings owned by the University; these have been confirmed as either replaced by modern heating systems or used infrequently for celebratory events.

2.2 Study aim and scope

Cambridge City Council commissioned Logika Group to undertake this study to explore changes to its existing SCA regime, in order to potentially reduce the air quality (and health) impacts of solid fuel burning across the city. This study has quantified the effects of different options which consider amending the SCA in Cambridge to encompass the whole of the Local Authority Area, and to incorporate moored boats within the designation. The effects on emissions, health and socio-economic considerations are set out in the following sections.

[6] https://www.cambridge.gov.uk/media/3454/smoke-control-area-map.pdf

The approach taken follows the following steps:

- Question 1: Establish the number of households and moored residential vessels burning solid fuels and an emissions baseline;
- Question 2: Calculation of air quality impacts of policy scenarios;
- Question 3: Health impact assessment of air quality impacts; and
- Question 4: Socio-economic assessment of policy scenarios.

Air pollution can be quantified in terms of the emissions (the amount of pollutants released into the atmosphere from a source, usually defined in terms of tonnes) or concentrations (the amount of a pollutant in a given volume of air at a given location) of pollutants. This report focusses on emissions. Emissions are related to concentrations, but not in a linear way, due to the effects of meteorology and atmospheric chemistry. Typically, converting emissions to concentrations is achieved by running atmospheric models. However, such modelling and estimates of population exposure add a further level of uncertainty into the study outcomes and were not in the scope of this study. Nonetheless, whilst health impact evidence and approaches associate exposure to air pollutant concentrations with adverse health outcomes, well-established methodologies have been produced to allow policy evaluation based on emissions only[7]. This study draws on these approaches to produce robust and comparable outputs for the different scenarios.

This study has focused on quantifying the impacts of changes in solid fuel burning on $PM_{2.5}$ and has not modelled the impacts on other pollutants (e.g. Nitrogen Oxides NOx). This approach was deemed appropriate because the underlying evidence base linking air pollutant exposure to health effects attributes the most significant effects to changes in $PM_{2.5}$ relative to other pollutants. Hence, only quantifying the impacts associated with $PM_{2.5}$ will still capture the vast proportion of the effects of the change in air pollution. Should other pollutants also have been included, this would not substantially increase the overall benefits assessed and hence is unlikely to have an impact on the overall results of the study.

The following sections of the report are structured as below:

- **Section 2** sets out the study approach including modelling methodology.
- **Section 3** presents the results of the air quality assessment.
- **Section 4** presents the results of the Health Impact Assessment.
- **Section 5** presents the results of the socio-economic assessment including overall costs and benefits of policy scenarios.
- **Section 6** presents a summary and conclusions.

[7] https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance

3 Approach

3.1 Policy Scenarios Assessed

The policy scenarios assessed are presented below:

- **Baseline:** Current SCA coverage, no moored vessels
- **Scenario 1:** Current SCA coverage, with moored vessels
- **Scenario 2:** City-wide SCA, without moored vessels
- **Scenario 3:** City-wide SCA, with moored vessels
- **Scenario 4:** This estimates what emissions in Cambridge might have been if the existing SCAs had not been declared (this is similar to, but not the same as, removal of the existing SCA).

3.2 Baseline emissions calculations

3.2.1 Domestic

Quantifying emissions associated with solid fuel burning in domestic and commercial premises has several challenges:

- Types of appliance used to burn solid fuel vary enormously (from open fires to sophisticated pellet-fed wood boilers), with widely varying emissions profiles;
- Activity data is incomplete, with limited information on quantities of fuel used, and in the case of wood, fuel condition (e.g. moisture content);
- Domestic heating appliances do not require any form of registration, and so the number of appliances is uncertain; and
- Emissions factors also have uncertainty associated with them and are updated on a regular basis, for example through the NAEI.

Two approaches were explored to overcome these challenges – a top-down approach based on NAEI emissions, and a bottom-up approach based on other sources of information (e.g., surveys). The two approaches were compared and a decision taken on which approach to use for the assessment of the policy scenarios.

Top-down

Gridded emissions from different source categories are contained in the NAEI[8]. The NAEI contains estimates of emissions to air of a variety of pollutants, split by sources and geographical area. This includes estimates of emissions from solid fuel burning on a 1km by 1km grid, disaggregated by fuel type, as presented in Figure 2-3. The gridded data for Cambridge have been used to estimate the difference in emissions per household between residents currently inside and outside the SCAs.

[8] https://naei.beis.gov.uk/

Bottom-up

Data on domestic solid fuel burning behaviours has been derived largely from the Burning in UK Homes and Gardens Survey[9], undertaken by Kantar on behalf of Defra, in 2018 and 2019 (hereafter referred to as the Kantar Survey). This survey provides data regarding the prevalence of solid fuel burning for the 'East of England' specifically, split for *some (but not all)* categories (e.g. split by appliance type is not available at regional level), split between urban and rural areas, and split between activity within SCAs and outside SCAs (both of the latter two splits are at England level). There are also some data on appliance type, such as the split between open fire or closed appliance, with additional information on broad categories of installation date for closed appliances.

OS AddressBase[10] data has been used to estimate the numbers of properties within and outside of the existing and expanded SCA boundaries.

Calculations were undertaken for emissions from properties within the SCAs and outside of the SCAs (further detail on the specific data and assumptions used are outlined in Section 3.2.5). The calculations utilised the number of properties within and outside of the SCAs, multiplied by the proportions of properties burning wood or coal-like products, multiplied by a typical quantity of solid fuel burned per year. Adjustments were made to convert house coal to manufactured solid fuel (MSF, also known as smokeless coal) based on energy outputs of the different fuels. The total numbers of properties burning solid fuels were then split by appliance type (for wood and coal-like products), and emission factors applied for each appliance and fuel type.

NAEI emission factors were used for combustion (wood and coal-like products) in open fires and for three types of closed stoves. Further detail on stove types is included in Section 3.2.5. It should be noted that for $PM_{2.5}$ the NAEI currently uses the same emission factors for wood on any given appliance regardless of the moisture content, which is thought to lead to significant variation in the quantity of $PM_{2.5}$ emitted. However, as a SCA does not stipulate a requirement for moisture content of wood, this will not affect the emissions changes calculated between policy scenarios. Note that other sources of emission factors are available, such as the EMEP Guidebook published by the European Environment Agency[11]. However, it was concluded that, while the EMEP Guidebook offers a more extensive range of emission factors for small scale and domestic combustion, the resolution of the input data meant that there was little to be gained from this. In addition, using the NAEI emission factors makes the emission estimates produced more comparable to other UK-based results (including the NAEI itself).

3.2.2 Commercial

The restrictions under SCAs also apply to commercial properties and there is therefore the potential for emissions reductions from businesses in sectors such as hospitality (in particular hotels, pubs, and restaurants), which may burn solid fuel. Commercial properties have not been included in the calculations for a number of reasons as follows:

- Using data available in the NAEI on a 1km by 1km basis, the commercial emissions make a small contribution (2%) to the current total emissions outside of the SCAs in Cambridge;
- Due to the relatively few commercial establishments compared to residential properties, the reduction from these sources is likely to be small (and certainly within the uncertainties of other assumptions);

[9] https://uk-air.defra.gov.uk/library/reports?report_id=1014
[10] https://www.ordnancesurvey.co.uk/products/addressbase
[11] https://www.eea.europa.eu//publications/emep-eea-guidebook-2023

- There is no basis for estimating what the reductions may be, in contrast with domestic properties where data from the Kantar survey can be used to demonstrate domestic solid fuel burning practices inside and outside SCAs; and
- On a per-grid-cell basis, the emissions in the NAEI for commercial solid fuel burning are higher within the current SCAs than outside. Therefore, where we apply our approach of adjusting emissions outside SCAs based on what is currently observed inside SCAs, this would result in calculating an increase in emissions if the SCA is extended, which is the opposite of what should happen in practice.

Omitting commercial emissions from the calculations could marginally underestimate the benefits in policy Scenarios 2 and 3. This should be taken in context of some of the other assumptions which may overestimate the benefits, which are discussed later in the report, and in some cases tested through sensitivity tests.

3.2.3 Moored River Vessels

Assessing emissions from solid fuel burning from moored river vessels is highly uncertain; heating appliances are often non-standard and it can be difficult to establish patterns of use. Broadly, the number of moorings in Cambridge was multiplied by the proportion of vessels assumed to be burning solid fuels, followed by assumptions on proportions of vessels burning different types of fuel (MSF and wood). These figures were then multiplied by an assumption of quantity of MSF or wood burnt per year per boat, assuming conventional or high efficiency stoves, using boat-specific emissions factors for these stove types.

In 2017, the Canal and Rivers Trust commissioned a study to establish emission factors for UK river and canal traffic. Emission factors were developed for solid fuel heating appliances used on vessels (as well as for the engines which are not relevant for this project). We have used these emission factors, which are specific to river vessels and therefore differ from the emission factors used from the NAEI for residential properties, for our present analysis. These have been combined with assumptions outlined in Section 3.2.5 relating to activity to produce emissions estimates for moored vessels from solid fuel burning for heating purposes only.

Data for solid fuel burning activity (e.g. quantity of fuel used) on moored vessels is scarce. In some cases assumptions have been derived from the Canal and River Trust Boater Census Survey 2022[12]. In other cases, where no data exist, online blogs[13] have been used (for example to estimate the average amount of MSF used per year to heat a boat). These are assumptions which could be refined further through discussion with the boating community in Cambridge.

3.2.4 Behavioural response and scenario tests

There are a number of potential behavioural responses to the designation of a SCA. If the household or boat owner is burning MSF, this is still allowable within any appliance, and hence behaviour is unlikely to change. If burning wood, if the household or boat owner has a stove which is Defra exempt, then again, no behaviour change would be required. If the household or boat owner is burning wood on an appliance which is not Defra exempt, but can burn multiple fuel types, the response could be to change from burning wood to burning MSF without an upgrade of appliance. Further response could entail an upgrade of stove to continue to burn wood, or stopping burning altogether.

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[12] https://canalrivertrust.org.uk/boating/boating-news-and-views/boating-news/boater-census-survey-2022

[13] For example https://www.canalworld.net/forums/index.php?/topic/55406-how-much-coal/ and https://www.canalworld.net/forums/index.php?/topic/113482-narrowboat-heating-whats-best/

There are several key challenges for the scenario testing:

- Households have limited awareness of SCAs and often limited knowledge on precisely what fuels they are burning, what appliance they are using, and whether they comply or not with a SCA[14];
- It is unclear as to how people would respond to an expanded SCA, and how fuel burning habits would change;
- Breaches of SCAs are difficult to enforce, requiring evidence that emitted smoke is due to non-exempt fuels being used on non-approved appliances; and
- Estimating behaviour change for moored vessels comes with its own sets of uncertainties, as very little data exist around types of stoves on boats, specific emissions factors for boats, and what fuel is being burnt.
- Hence, defining what the behavioural response of households and moored vessels would be to the different SCA policy options is highly uncertain, as is defining the level of enforcement required to elicit a given response. To facilitate the analysis, we have made a number of assumptions based on existing evidence, expert judgement of the project team, and discussions with Cambridge City Council. These assumptions are summarised below.

Domestic properties: all properties moving into the SCA will have the same assumptions as those made for properties currently within the SCA. In other words, the proportions of households burning wood or coal-like products, the split of appliance types, and compliance with the regulations will change such that they are the same as for properties already within the existing SCAs.

Moored vessels: half of those burning wood on a non-compliant stove will transition to burning MSF, and half will upgrade their appliance.

Given the uncertainty, these assumptions are also subject to sensitivity analysis to test whether the results of the analysis and conclusions drawn would change under different assumptions.

In comparison to the baseline (i.e. current SCA coverage, no moored vessels) changes in $PM_{2.5}$ emissions have been calculated for the following scenarios:

- Scenario 1: Current SCA coverage with moored vessels
- Scenario 2: City-wide SCA without moored vessels – incorporating Sensitivity Test with 25% non-compliance
- Scenario 3: City-wide SCA with moored vessels – incorporating Sensitivity Test with 25% non-compliance
- Scenario 4: This estimates what emissions in Cambridge might have been if the existing SCAs had not been declared (this is similar to, but not the same as, removal of the existing SCA).Sensitivity test on the assumption of stove types in homes in Cambridge.

3.2.5 Assumptions and key data points used in the estimation of numbers burning solid fuels and emissions

Assumptions and key data points used to estimate the number of households and moored vessels burning solid fuels, their behavioural response under the scenarios, and resulting emissions changes are outlined in the tables below. All assumptions used have been discussed and agreed with

[14] This is based on responses to the survey being run to update the Kantar survey, but has not been published at the time of writing.

Cambridge City Council. It is recognised that these assumptions could be updated once the survey of solid fuel use being undertaken by IPSOS[15] on behalf of Defra is published, or by using more local information should this become available in the future (for example any future surveys on solid fuel use across the residential or boating sectors).

Table 3-1: Assumptions in the bottom-up approach: Domestic Properties

Description	Value	Unit	Rationale
$PM_{2.5}$ emission factors from the latest NAEI (2021) – no separation between wood moisture content (i.e. dry / seasoned / wet)	Several (8 different emission factors; wood and MSF across 4 appliance types)	kt/TJ	This is the latest that is available from the NAEI. The SCA regulations do not differentiate between burning dry/seasoned/wet wood. Updates to the next NAEI are anticipated to have different emission factors for wood condition.
Number of households inside / outside current SCAs from OS AddressBase	3,832 inside / 63,053 outside current SCAs within CCC boundary	Number of Households	Selected all address points that were classed as 'residential' to be comparable to the Kantar data (i.e., including flats etc. as the Kantar data provides a % of all households that are burning)
Proportions of households burning wood inside / outside SCA	3.1% inside SCAs / 5.5% outside current SCAs	% of households	Inside SCA metric taken from 'SCA' figures from Kantar data. Outside SCA taken from 'average urban' figures from Kantar data (as 'outside SCA' also includes rural)
Proportions of households burning coal-like products inside / outside SCA	1.4% inside SCAs / 2.3% outside current SCAs	% of households	As per row above
Amount of wood burnt per burning household	1.06	Tonne /household	Calculated from Kantar data (East of England)
Amount of coal-like products burnt per burning household	1.75	Tonne /household	Same as row above, but Kantar data provides coal products consumption including house coal (approx. 9%). Applying same method as above would work out at 1.53 tonnes per household. However, as house coal is now unavailable for domestic use due to the ban on sales under the Domestic Solid Fuel Regulations, we have converted this 9% of house coal to MSF based on energy in the fuel (require more MSF to have the same heat output as house coal)
Household compliance with	Inside SCA: 0% wood on an open	Appliance % split	Simplified approach based on installation dates. 'Basic' stoves

[15] A new survey (led by IPSOS and supported by AQC) has been commissioned by Defra to update the Kantar study and includes a specific hospitality sector survey. The results are not yet publicly available.

Description	Value	Unit	Rationale
current SCA regulations (i.e., full compliance means no burning of wood on an open fire or non-compliant stove within SCA)	fire, 100% on stoves. Of stoves: 0% on basic, 27% on upgraded, 73% on EcoDesign. Outside SCA: 24% wood on open fires, 76% on stoves. Of stoves, 18% on basic, 18% on upgraded, 64% on EcoDesign.		assumed to be installed pre-2000, 'Upgraded' installed 2000-2009 and EcoDesign assumed to be installed post 2009. Kantar data only has information on installation dates, not on exempt versus non-exempt stoves. Potentially underestimates current emissions and potentially overestimate emissions reductions. This is explored further in a sensitivity test.
Burning of coal-like products (MSF) by appliance	No difference in profile inside/outside SCAs. 36% on an open fire, 64% on stoves. Of stoves, same as wood outside SCA distribution (18%, 18%, 64%)	Appliance % split	The fuel itself is classed as 'smokeless' and is exempt from SCA regulations – it does not matter what appliance is used.
Determining usage on compliant / non-compliant stoves. NAEI classifications of stoves (for emission factors): 'Basic', 'Upgraded' and 'EcoDesign'.	'Basic' assumed not exempt appliance; 'Upgraded' assumed exempt; 'EcoDesign' assumed exempt.	Appliance % split	Simplified approach based on installation dates. A sensitivity test on the baseline has been included which assumes that 25% of post 2000 installations are non-exempt appliances and 30% of pre 2000 appliances (or 'unsure') are exempt.

Table 3-2: Assumptions in the bottom-up approach: Boats

Description	Value	Unit	Rationale
Number of moorings	70	Number of boats	There are currently 70 moorings available in Cambridge and there is a waiting list for spaces, therefore assumed full capacity.
Proportion of boats with solid fuel burning stoves	85%	%	Canal and River Trust Survey of Boating Community suggests 66% of boats nationally burning solid fuel. Increased this value to 85% as there are no electric hook ups in Cambridge.
Proportion of boats burning MSF/ wood	75% MSF, 25% wood	% Split	Based on boating blogs, professional judgement, discussion with Cambridge City Council
MSF consumed per boat per annum	1,500	kg/boat	Based on 2x25 kg bags of MSF per week in winter and additional burning in summer (at a much

Description	Value	Unit	Rationale
			lower rate) – based on boating blogs/ discussions
Wood consumed per boat per annum	3,167	kg/boat	Based on same energy output required by MSF, converted to wood
Split between conventional stoves and high efficiency stoves (Defra exempt)	100% conventional stoves	% split	Based on professional judgement – very little incentive until now for boating community to install high efficiency stoves
Compliance of stoves on boats (to reflect categories which we have emission factors for)	Conventional Stove = not exempt High Efficiency Stove = Exempt	% Split	There are only 2 types of stoves that we have emission factors for, so seems logical to apply the exempt / non-exempt split amongst these.
Boating emission factors based on report for Canal and River Trust	MSF (1.6), wood on a conventional stove (14.1), wood on a high efficiency stove (5.4)	g $PM_{2.5}$ / kg fuel	Only boating specific figures for emissions we are aware of: split between 'conventional' stoves and 'high efficiency' stoves

3.3 Health Impact Assessment

There is substantial evidence linking air pollutant exposure to a range of negative human health outcomes, including different respiratory and cardiovascular illnesses, and an increased mortality risk.

The health impacts have been monetised using Defra's air pollutant damage costs[16]. These are summary estimates which aggregate key impacts associated with air pollution, expressed per tonne of emission. For the analysis, the '$PM_{2.5}$ domestic' damage cost is selected . This is also applied to emissions from moored vessels, given no specific damage cost is available for inland waterway emissions, but these are assumed to have similar proximity to population given the location of emissions.

We have quantified the impacts of changes in $PM_{2.5}$ emissions from the scenarios described above - the health impact assessment has focused on $PM_{2.5}$ as this is the fraction of particulate matter for which Defra's air pollutant damage costs are defined. However, the damage costs combine the health impacts of changes in both $PM_{2.5}$ and PM_{10} as the impacts of both are combined in the $PM_{2.5}$ damage cost, so the impacts of both will also be captured in this analysis.

In applying the Defra damage costs, this also implicitly carries through the underlying assumptions made in the construction of the damage costs. Importantly, this includes the relationship between the emission of the air pollutant and resulting concentration. In other words, the health impact analysis implicitly assumes that exposure to pollution from domestic burning in Cambridge is the same as exposure to the average unit of $PM_{2.5}$ emitted from domestic burning anywhere in the UK. It is not possible to test the robustness of this assumption without detailed concentration modelling specifically for Cambridge, which was not in the scope of this study – however, applying the damage costs in this way follows Defra's best-practice appraisal guidance for assessments of this size and sensitivity to the damage costs is tested as part of our sensitivity analysis.

[16] https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance

The health impacts captured by the damage costs can be split out by applying the underlying approaches, data, and methods used to derive the damage costs. Hence, the assessment of individual health impacts is fully consistent with Defra's damage costs and underpinning the Committee on the Medical Effects of Air Pollution (COMEAP) guidance, and hence follows UK best practice appraisal guidance.

The quantified outputs present changes in life-years lost, deaths, respiratory hospital admissions, and incidence of ischemic heart disease, stroke, lung cancer and asthma in children. The assessment captures the relative impact of the scenarios and the health burden of baseline emissions. The table below summarises the key inputs to the calculations captured in the analysis.

Table 3-3: Health impact pathways captured, and key input assumptions (all associated with exposure to $PM_{2.5}$)

Impact pathway	Output metric	Concentration response function (change per 10 μgm^{-3})*	Baseline health outcome (all ages, cases per 100,000)	Monetary valuation of health endpoint (£ per output metric, 2022 prices)
Mortality (associated with chronic exposure)	Life years lost (LYL) / deaths	8% (RR)	858	£50,600 per LYL
Respiratory hospital admissions	# Admissions	0.96% (RR)	1,995	£9,800
Ischemic heart disease (IHD)	# New cases (incidence)	7% (RR)	171	£72,000 per Quality adjusted life year (QALY), applied to discounted QALY over duration of the disease
Stroke	# New cases (incidence)	11% (RR)	133	
Lung cancer	# New cases (incidence)	9% (RR)	78	
Asthma in children	# New cases (incidence)	1.48 (OR)	461	

Notes: *RR = relative risk, where concentration response functions (CRFs) are presented as a percentage change per 10 μgm^{-3} change in $PM_{2.5}$; OR = odds ratio, where CRFs are presented as the change in odds ratio per 10 μgm^{-3} change in $PM_{2.5}$.

3.4 Socio-Economic Assessment

3.4.1 Quantitative assessment

In response to the SCA, those burning non-compliant solid fuels (i.e., wood) on a non-compliant appliance can either: upgrade to an exempt appliance, switch to a compliant fuel, or stop burning. Each carries with it a different set of impacts and consequences for the household or vessel owner.

Fuel and utility cost changes: Those who change fuel or stop burning face several effects: a fuel cost saving of the fuel no longer burnt, a fuel cost increase of any new fuel burnt, and a change in 'utility' (either the difference between burning the new relative to existing fuel, or the lost utility from no longer burning the existing fuel). Utility refers to the intangible, non-monetary benefit that people derive from burning fuel. This captures the pleasure or ambience effect of burning, and also includes any heat and warmth benefit delivered by the solid fuel (where this is not replaced by other heating options).

The emissions modelling has captured the change in fuel consumption of wood (not compliant in SCAs) and MSF (compliant in SCAs) across the different policy scenarios assessed. This shows that the overall consumption of both wood and MSF reduces in response to Scenarios 2 and 3. Hence for MSF, the increase in consumption from fuel switching is outweighed by the reduction from those who stop burning all together. Even though MSF is a compliant fuel and there is no legal requirement to stop burning, the modelling approach results in a reduction in fuel consumption due to the different behavioural profile inside relative to outside an SCA, as outlined in Table 3-1.

By assuming the solid fuel burning behavioural profile that currently exists within the SCAs is applied to residential properties outside the SCAs, the air quality assessment effectively presents a combined response of those who switch fuel and those who stop burning. One limitation therefore for the subsequent economic modelling of fuel cost and utility effects is it is not possible to separate the change in fuel consumption between those who switch fuel and those who stop burning.

A second limitation in assessing these effects is it is not possible to estimate the total utility effect of burning solid fuels that may be lost. In theory, the utility benefit must be at least as great as the fuel cost (otherwise people would not burn solid fuels in the first place). However, no data or methods exist to suggest how much greater the utility benefit is, over and above the fuel costs. In the absence of a better methodology, for those that stop burning, we assume the utility benefit is equal to the fuel cost savings – as such the net impact is zero for those that stop burning. Overall, this understates the costs of stopping burning.

In summary:

- We do not know what proportion of households switch fuel or stop burning;
- For those that switch, we can cost the difference in fuel costs associated with the switch – this implies an increase in costs as MSF is generally more expensive that wood (also accounting for the higher energy density of MSF relative to wood); and
- For those that stop burning, we cannot capture the utility lost, and can only assume this is at least as great as the fuel costs. These impacts offset, leaving no net impact to stop burning. This understates the costs.

For each policy scenario, we combine the two approaches above for those households that stop burning and those that switch fuel in a way that demonstrates the most 'conservative' (i.e. highest) cost. We do so by assuming: (a) 100% of the reduction in wood consumption is switched to MSF – in which case we capture the maximum net cost of fuel switching; (b) the remaining fuel consumption change is those who stop burning – this carries a net neutral cost (noting this does not capture the utility effect). In practice, not all those burning wood will switch to MSF, as such this will overstate the net cost of fuel switching. However, we cannot capture the utility effect of those who stop burning, and the quantitative analysis will understate this impact. By adopting these assumptions, we present the most conservative quantitative estimate of costs for comparison to the benefits.

For those that switch fuel, the changes in fuel use of the different policy scenarios as calculated under the emissions assessment are combined with fuel prices sourced from the Nottingham Energy Partnership[17]. The fuel prices used are shown in the table below. Prices were sense checked against fuel prices used in a recent Impact Assessments by the Scottish Government (presented as the price sensitivity below)[18].

[17] Energy Cost Comparison — Nottingham Energy Partnership (nottenergy.com)
[18] 3. Business and Regulatory Impact Assessment - Impacts of the sale of house coal and the most polluting manufactured solid fuels: report - gov.scot (www.gov.scot)

Table 3-4 Fuel price data

Fuel	Price (£/tonne)	Price Sensitivity (£/tonne)
Wood (kiln dried logs)	365	389
MSF	667	406

Investment costs: Those that upgrade to a compliant stove face a one-off cost associated with this upgrade (see point below on 'investment costs') but are assumed not to change fuel consumption and hence face no associated ongoing costs. Investment costs for the installation of new Defra-exempt stoves driven by policy scenarios were calculated by combining the number of new stoves purchased (as calculated under the emissions modelling) with an average cost of an EcoDesign stove including installation costs, sourced from a targeted review of literature and online sources[19,20,21,22,23]. An average cost for an EcoDesign stove (the only type of stove that is legally possible to purchase and are also exempt in SCAs) and installation was determined to be £1,500. It is assumed that those choosing to purchase a new stove already have a flue and so there are no additional costs associated with flue installation. Investment costs were annualised with an assumed stove life of 10 years and discount rate of 3.5%[24], for comparison with the single year of emissions impacts assessed.

No data was found regarding the costs of EcoDesign stoves for boats. Hence the analysis assumes the same upgrade costs for boats as for houses.

The analysis assumes that non-compliant stoves are upgraded with new compliant stoves, however in practice other options may be available. This includes potential retrofit options, which may be considerably cheaper than the cost of a new stove. It was decided to not include these costs due to uncertainty around the proportion of stoves which could technically be retrofitted and the likelihood of retrofits being the chosen behavioural response. As such, investment costs may be slightly overstated if there is uptake of retrofits rather than new EcoDesign stove purchases.

There will be **implementation costs** for the Council associated with enforcement (i.e. in terms of additional enforcement officer time) and information campaigns. It is not known precisely what the implementation costs will be. Through discussion with the Council, an assumed cost of £50,000 was included as an illustrative estimate of overall implementation costs.

Greenhouse gas (GHG) impacts driven by the change in quantities of fuels burned were calculated using GHG emissions factors from the European Monitoring and Evaluation Programme (EMEP) guidebook and NAEI, applied to the fuel consumption changes calculated under the emissions modelling. These were then monetised using carbon prices from the Department for Energy Security and Net Zero's (DESNZ) guidance[25]. Note, the analysis of GHG emissions effects only captures changes in Scope 1 emissions (i.e. those associated directly with the burning of the fuel). It does not

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[19] https://www.yorkshirestoves.co.uk/wood-burning-stove-installation/#:~:text=Whether%20you're%20looking%20to,installation%20from%20just%20%C2%A31769
[20] https://www.checkatrade.com/blog/cost-guides/log-burner-install-cost/
[21] https://www.directstoves.com/our-blog/the-ultimate-guide-to-wood-burning-stove-installation-costs-in-2023/
[22] https://www.minster-stoves.co.uk/wood-burning-stove-installation-cost-estimator/
[23] https://www.thecosystovecompany.co.uk/how-much-does-it-cost-to-install-a-wood-burning-stove/
[24] In line with the discount rate for social cost-benefit analysis recommended by the HM Treasury Green Book: https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent/the-green-book-2020
[25] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

capture possible Scope 3 (or 'lifecycle') effects of the fuel, which would also capture emissions associated with sourcing, transportation and other aspects of the fuel. Scope 3 emissions were not in the scope of the analysis and are challenging to estimate, in particular given uncertainty around the source of the wood burnt. Lifecycle emissions can vary widely depending on source, for example between wood foraged locally and wood pellets imported to the UK.

The outputs of the quantitative cost analysis and monetised greenhouse gas emissions impacts were combined with the monetised benefits of the air quality impacts calculated in the health impact assessment to calculate an overall **net present value** (NPV) and **benefit:cost ratio** (BCR) of the different policy scenarios. These summary metrics present the overall balance of benefits and costs of a scenario, relative to the baseline – i.e. where the NPV is positive or the benefit:cost ratio greater than one, the benefits of the scenario outweigh the costs and would indicate an overall positive change for society.

3.4.2 Qualitative assessment

A range of important effects could not be captured quantitatively in the analysis, either due to a lack of data on the effects of the SCA, or a lack of methodologies and approaches to quantify the effects.

Burning solid fuels can have a significant impact on ***indoor air quality***, with an additional detrimental impact on health that is not captured by the assessment of changes in ambient air quality, as presented above and captured using the damage costs. Although there is growing awareness of this risk, the evidence base is more nascent and approaches to quantify effects (in particular that reliably identify additional impacts over ambient exposure) are not well established. These effects were considered further through targeted literature review to elaborate the nature and potential size of effects.

Compliance with the SCA will have varying impacts on the household or vessel owner depending on their specific circumstances. More specifically, where those affected can afford to switch to an alternative means of heating (e.g. through fuel switch or upgrading stoves), this is unlikely to have an impact on the living conditions of the dwelling. However, where households or vessel owners cannot afford to switch to a viable alternative, this may impact on living conditions, with consequent impacts for health. The assessment has considered in further detail ***where the compliance costs could fall*** between different types of households, by reviewing different data sources which provide insight into the demographic profile of solid fuel users. Robustly quantifying impacts associated with ***changes in living conditions*** (e.g. reduced temperature, increased levels of damp,) was not possible as data is limited on current conditions and changes in heating patterns in response are uncertain. Furthermore, there is no established approach to quantifying impacts. That said, the consequences of such changes have been elaborated through targeted literature review.

Finally, the ***practical implications of changing heating practices*** were explored through a targeted literature review to identify potential effects and challenges for domestic users, and moored vessels that are not captured in the quantitative analysis, e.g. the learning required for new heating systems, and availability of different fuels.

4 Air Quality Assessment

4.1 Baseline

Table 4-1 presents baseline $PM_{2.5}$ emissions (representing current emissions, i.e. without any further intervention) from solid fuel burning in residential properties and moored river vessels in Cambridge. This presents the results from the top-down and bottom-up approaches.

The bottom-up estimate for residential emissions could be assumed representative of the current year, although it is recognised that the Kantar survey used to quantify the baseline represents conditions in 2018, and wood burning stove use has been increasing[26] in recent years. It should also be noted that emissions factors, on which these estimates are based, are reviewed and refined at regular intervals. Those used in the calculations below are based on the current NAEI (2021) for residential properties, and for moored vessels from a boating-specific report published in 2017.

The top-down approach utilised the 2021 NAEI and represents the sum of 1km by 1 km grid squares across Cambridge that were designated as largely inside or outside the current SCAs. As uniform grid squares do not perfectly align with the extent of the current SCAs, there is likely to be some error associated with this approach.

Table 4-1 compares the top-down and bottom-up approaches. Table 4-1 shows that the majority of emissions from solid fuel burning in Cambridge are from residential properties outside of the current SCAs. Emissions from moored vessels and residential properties inside the SCAs make up a relatively small proportion of total emissions. There is good agreement with the two methods, and we have therefore used the bottom-up approach for subsequent analysis given this: (a) can be amended more easily in the future as the assumptions are potentially refined, and (b) can be used as the basis of a more robust economic assessment.

Table 4-1: Baseline $PM_{2.5}$ Solid Fuel Burning Emissions in Cambridge (all figures tonnes per annum)

Emissions Source	Baseline $PM_{2.5}$ Emissions (tonnes pa) using bottom-up approach	Baseline $PM_{2.5}$ Emissions (tonnes pa) using top-down approach (NAEI)
Residential – Inside SCA	0.50	0.61
Residential – Outside SCA	26.22	27.34
Moored vessels (stationary, for heating purposes only)	0.77	n/a
Total	27.48	27.95

Table 4-2 details the assumed baseline data on number of households and moored vessels using specific solid fuels and appliances, inside and outside the current SCAs.

[26] For example: https://www.bbc.co.uk/news/uk-england-bristol-63241940

Table 4-2: Baseline parameters

Parameter	Inside SCA	Outside SCA
Number of Properties	3,832	63,053
Number of Properties Burning Wood	119	3,485
Number of Properties Burning Coal-like Products	55	1,474
Number of Properties Using Open Fire (Wood)	0	821
Number of Properties Using Open Fire (Coal-like Products)	20	529
Number of Properties Using Basic Stove (Wood)	0	480
Number of Properties Using Basic Stove (Coal-like Products)	6	170
Number of Properties Using Upgraded Stove (Wood)	32	480
Number of Properties Using Upgraded Stove (Coal-like Products)	6	170
Number of Properties Using EcoDesign Stove (Wood)	87	1703
Number of Properties Using EcoDesign Stove (Coal-like Products)	22	604
Number of Moored Vessels[27]	-	70
Number of Moored Vessels Burning Wood	-	15
Number of Moored Vessels Burning Coal-like Products	-	45

4.2 Scenario Tests

4.2.1 Scenario 1: Current SCA Coverage with Moored Vessels

The modelled change in Scenario 1 is that the SCA regulations are extended to moored vessels, in addition to the current SCAs for residential properties. The behavioural change assumptions for this scenario are that: of the 25%[28] of boats which are assumed to burn wood, half change to burning MSF and half upgrade their stove to an exempt appliance (the baseline assumes that all boats do

[27] Assumed all using standard appliances, all closed stoves (only emission factors available specific to boats for conventional and high-efficiency stoves)

[28] Note that 75% of boats which use solid fuel are assumed to be already burning MSF (which they can legally carry on doing).

not have an exempt appliance). Table 4-3 shows that of the moored vessel emissions there is a reduction of 67% relative to the baseline. However, overall, this scenario reduces $PM_{2.5}$ emissions from solid fuel burning in Cambridge by only 2%. In summary, there is a relatively large impact of the SCA regulations on emissions from moored vessels relative to existing emissions from moored vessels, but as this is a small proportion of total emissions, there is only a small impact relative to the total baseline emissions.

Table 4-3: Emissions Reductions under Scenario 1

Emissions Source	Baseline $PM_{2.5}$ Emissions (tonnes pa)	Scenario 1 $PM_{2.5}$ Emissions (tonnes pa)	Scenario Impact (tonnes pa) (% relative to baseline)
Residential (total)	26.71	26.71	±0 (0%)
Moored vessels (stationary, for heating purposes only)	0.77	0.25	-0.52 (-67%)
Total	27.48	26.96	-0.52 (-2%)

4.2.2 Scenario 2: City Wide SCA without Moored Vessels

This scenario only influences emissions from residential properties, while the emissions from moored vessels remains as in the baseline. This scenario assumes that the 63,053 properties currently outside of the SCAs are now covered by a city-wide SCA. The behavioural assumptions, such as numbers of households burning and appliance types used, that were assumed for households under the existing SCA are applied to households newly captured in the extended area. See Table 3-2 for assumptions in full, but there is a reduction in the proportion of properties burning solid fuel (including wood), there is no burning wood on open fires, and it is assumed that all stoves used are exempt (i.e. non-compliant stoves are upgraded). Table 4-4 shows that of the residential emissions (which make up a large proportion of overall emissions), there is a reduction of 71%. Overall, this scenario reduces $PM_{2.5}$ emissions from solid fuel burning in Cambridge by 69%.

Table 4-4: Emissions Reductions under Scenario 2

Emissions Source	Baseline $PM_{2.5}$ Emissions (tonnes pa)	Scenario 2 $PM_{2.5}$ Emissions (tonnes pa)	Scenario Impact (tonnes pa) (% relative to baseline)
Residential (total)	26.71	7.85	-18.86 (-71%)
Moored vessels (stationary, for heating purposes only)	0.77	0.77	±0 (0%)
Total	27.48	8.62	-18.86 (-69%)

4.2.3 Scenario 2a: Sensitivity Test Assuming 25% non-compliance

Scenario 2a provides a sensitivity test assuming 25% non-compliance across the properties which are currently outside of the SCAs if a city-wide SCA was established (i.e., 25% will continue to burn wood on open fires and 25% will not upgrade non-compliant stoves). Table 4-5 shows that instead of a 71% reduction in residential emissions as shown in Scenario 2, a 62% reduction in residential emissions is observed (and a 61% reduction in overall solid fuel burning emissions).

Table 4-5: Emissions Reductions under Scenario 2a

Emissions Source	Baseline $PM_{2.5}$ Emissions (tonnes pa)	Scenario 2a $PM_{2.5}$ Emissions (tonnes pa)	Scenario Impact (tonnes pa) (% relative to baseline)
Residential (total)	26.71	10.02	-16.69 (-62%)
Moored vessels (stationary, for heating purposes only)	0.77	0.77	±0 (0%)
Total	27.48	10.79	-16.69 (-61%)

4.2.4 Scenario 3: City Wide SCA with Moored Vessels

Scenario 3 combines Scenarios 1 and 2 by applying the assumptions for increasing coverage of the SCA to include both city-wide residential properties and moored vessels across the Cambridge area. This therefore combines the emissions reductions in both Scenarios 1 and 2. The result is an overall 71% reduction in $PM_{2.5}$ emissions from solid fuel burning, as shown in Table 4-6.

Table 4-6: Emissions Reductions under Scenario 3

Emissions Source	Baseline $PM_{2.5}$ Emissions (tonnes pa)	Scenario 3 $PM_{2.5}$ Emissions (tonnes pa)	Scenario Impact (tonnes pa) (% relative to baseline)
Residential (total)	26.71	7.85	-18.86 (-71%)
Moored vessels (stationary, for heating purposes only)	0.77	0.25	-0.52 (-67%)
Total	27.48	8.10	-19.38 (-71%)

4.2.5 Scenario 3a: Sensitivity Test Assuming 25% non-compliance

Scenario 3a provides a sensitivity test assuming 25% non-compliance across the properties which will be covered by the expanded SCA (as per Scenario 2a), as well as an assumed 25% non-compliance amongst moored vessels (i.e. of the boat owners remaining burning wood, half upgrade their stove and half do not). Scenario 3a (Table 4-7) shows that instead of a 71% reduction in total emissions as shown in Scenario 3, an overall 62% reduction in total emissions is observed, which is still a substantial reduction.

Table 4-7: Emissions Reductions under Scenario 3a

Emissions Source	Baseline $PM_{2.5}$ Emissions (tonnes pa)	Scenario 3a $PM_{2.5}$ Emissions (tonnes pa)	Scenario Impact (tonnes pa) (% relative to baseline)
Residential (total)	26.71	10.02	-16.69 (-62%)
Moored vessels (stationary, for heating purposes only)	0.77	0.35	-0.42 (-54%)
Total	27.48	10.38	-17.11 (-62%)

4.2.6 Scenario 4: No SCA

This scenario assumes that the residential properties which are currently in the SCA are no longer subjected to the requirements of a SCA. As such, this applies the behavioural assumptions made for households currently outside of the SCA to all properties in Cambridge (i.e. including those within the existing SCA). In practice, this is not a realistic assumption as residents would be very unlikely to downgrade stoves (i.e. remove a compliant EcoDesign stove and install a non-compliant basic stove), but is estimated to provide an indication of the current effect of the SCA on $PM_{2.5}$ emissions. Table 4-8 shows that if the current SCA was revoked there would be a 4% increase in $PM_{2.5}$ emissions from solid fuel burning. This increase is all from residential properties, as moored vessels are currently outside of the SCAs no change is assumed for these solid fuel users.

Table 4-8: Emissions Reductions under Scenario 4

Emissions Source	Baseline $PM_{2.5}$ Emissions (tonnes pa)	Scenario 4 $PM_{2.5}$ Emissions (tonnes pa)	Scenario Impact (tonnes pa) (% relative to baseline)
Residential (total)	26.71	27.81	+1.10 (+4%)
Moored vessels (stationary, for heating purposes only)	0.77	0.77	±0 (0%)
Total	27.48	28.58	+1.10 (4%)

4.3 Other Sensitivity Tests

4.3.1 Stove Exemptions

One of the assumptions around which there is greatest uncertainty is the proportion of different stove types used within households and moored vessels in Cambridge. There is no available information that we are aware of, either nationally or locally, on the proportion of stoves currently in use which are classed as Defra exempt. Hence, assumptions about upgrades of stoves when residents move into the SCA is also highly uncertain. The key data sources that do exist include:

- The Kantar survey, which has information (nationally) on the date at which stoves have been installed (split into pre-2000, 2000-2009 and post 2009); and
- The NAEI emissions factors for stoves, which are based on the following categories of closed stove: 'Basic', 'Upgraded' and 'EcoDesign'.

For the baseline we have assumed that pre-2000 installations are 'Basic', those installed between 2000-2009 are 'Upgraded', and Post 2009 installations are 'EcoDesign'. In addition, 'Basic' are assumed to be not exempt appliances, while 'Upgraded' and 'EcoDesign' are assumed to be Defra exempt (i.e. those households with the latter 2 categories of stove would not need to upgrade stoves to be compliant with a SCA).

There are a number of issues with these assumptions, not least that there have been Defra exempt appliances since the Clean Air Act came into force in 1956, and therefore the date of installation is not necessarily a good indicator of a compliant stove or not. However, in terms of emissions, installation date is likely to be a better indicator (i.e. stoves are getting progressively cleaner) and if residents moving into an SCA upgrade their stove, it is likely that they can now only buy an EcoDesign stove[29]. Hence from the perspective of calculating emissions, these assumptions seem reasonable. Because of these uncertainties, this sensitivity test is based on the assumption that 25% of post 2000 installations are not exempt appliances, and 30% of pre 2000 appliances (or classed as 'unsure' in the Kantar Survey) are exempt appliances. Table 4-9 shows that with these altered assumptions, there would be a 16% increase in $PM_{2.5}$ emissions from residential wood burning in the baseline, or a 15% increase when compared to the overall baseline of solid fuel burning emissions in Cambridge. This sensitivity on the baseline emissions/stoves means that, if this were to be the case, there would be more opportunity for emissions savings from upgrading of non-compliant stoves in the policy scenarios.

Table 4-9: Emissions Reductions under Stove Assumption Sensitivity Scenario (Baseline)

Emissions Source	Baseline $PM_{2.5}$ Emissions (t/a)	Stove Assumption Sensitivity Scenario $PM_{2.5}$ Emissions (t/a)	Scenario Impact (t/a) (% relative to baseline)
Residential (total)	26.71	30.90	+4.19 (+16%)
Moored vessels (stationary, for heating purposes only)	0.77	0.77	±0 (0%)
Total	27.48	31.67	+4.19 (+15%)

4.4 Summary

The Air Quality Assessment has presented the likely changes in $PM_{2.5}$ emissions under four main policy scenarios, including incorporating moored river vessels into the SCA, and increasing the extent of the SCA to capture all domestic properties within the whole Cambridge area. In addition, sensitivity tests have been run looking at 25% non-compliance with the SCA and also testing the sensitivity of the assumption of stove types in the baseline. The table below presents a comparison of all the scenarios, including the impact in terms of emissions (tonnes of $PM_{2.5}$ per annum) and percentage change relative to the baseline.

[29] The EcoDesign Regulation (EU) 2015/1185 24/5/201 for solid fuel space heating appliances came into force in the UK on 1st January 2022. All stoves manufactured from that date onwards must comply with the requirements of EcoDesign.

Table 4-10: Summary of Emissions reductions from scenarios modelled

Scenario	$PM_{2.5}$ Emissions (tonnes pa)	Scenario Impact (tonnes pa) (% relative to baseline)
Baseline	27.48	NA
1. **Current SCA coverage, including moored vessels**	26.96	-0.52 (-2%)
2. City-wide SCA coverage, no moored vessels	8.62	-18.86 (-69%)
2a. As per Scenario 2 with 25% non-compliance	10.79	-16.69 (-61%)
3. City-wide SCA coverage, with moored vessels	8.10	-19.38 (-71%)
3a. As per Scenario 3 with 25% non-compliance	10.38	-17.11 (-62%)
4. No SCA	28.58	+1.10 (4%)
Stove Assumption Sensitivity	31.67	+4.19 (+15%)

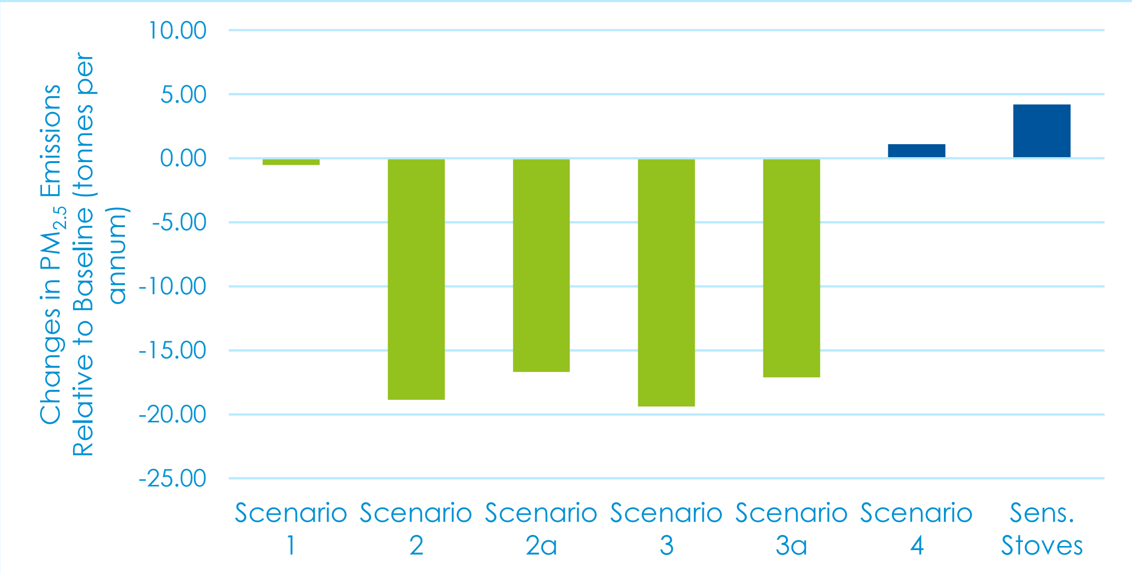

Figure 4-1 Summary of changes to $PM_{2.5}$ emissions across Cambridge in the modelled policy scenarios relative to the Baseline

The overall difference (relative to the baseline) in $PM_{2.5}$ emissions modelled using the 'bottom-up' approach across the range of policy scenarios is presented in Figure 4-1. Scenarios 1 to 3a all result in a reduction of $PM_{2.5}$ emissions. Meanwhile Scenario 4 and the sensitivity test on stove types result in an increase in $PM_{2.5}$ emissions. The largest reduction in emissions occurs in policy Scenario 3 (19.4 tonnes per annum) which simulates a city-wide extension of the SCA and inclusion of moored vessels. The sensitivity tests assuming a proportion of non-compliance with the regulations (Scenarios 2a and 3a) still result in a significant reduction in $PM_{2.5}$ emissions.

The overall change in $PM_{2.5}$ emissions under the core policy scenarios relative to total $PM_{2.5}$ emissions[30] across Cambridge is shown in Figure 4-2. The reductions in $PM_{2.5}$ emissions are significant under policy Scenarios 2 and 3; by implementing a city-wide SCA it is estimated that $PM_{2.5}$ emissions could reduce by 21.8% (Scenario 2), and by 22.4% (Scenario 3) if moored vessels are also included in the SCA. These represent substantial reductions in primary $PM_{2.5}$ emissions across the Cambridge area.

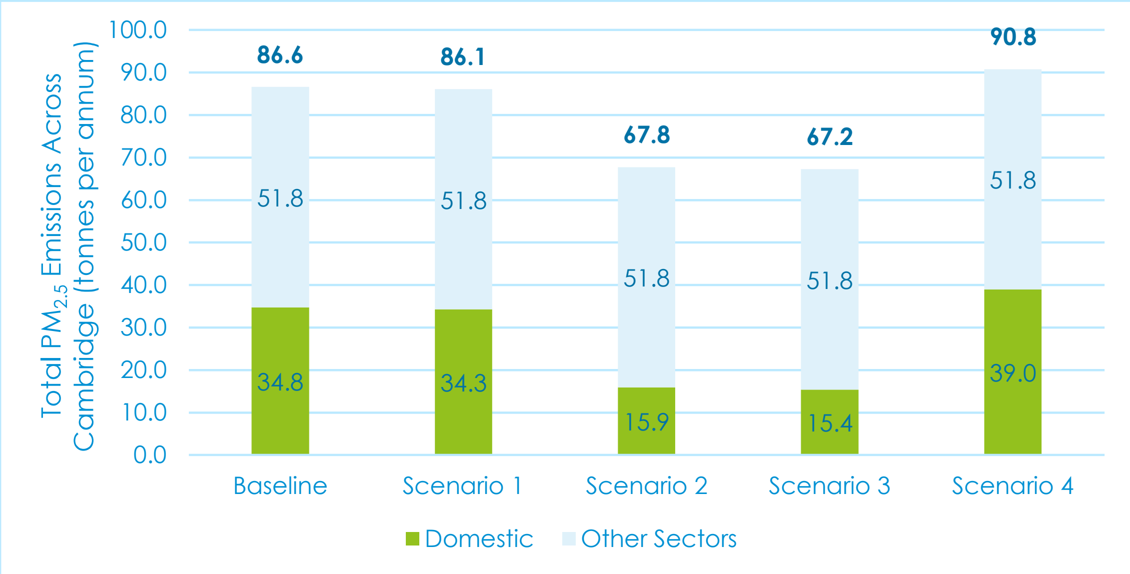

Figure 4-2 Summary of changes to $PM_{2.5}$ emissions across Cambridge in the modelled policy scenarios relative to total $PM_{2.5}$ emissions

Residential emissions represent a large proportion of overall emissions from solid fuel burning (in comparison to commercial premises and moored vessels) and the majority of properties are currently outside of the existing SCAs in Cambridge. Hence, expanding the SCA to incorporate all properties in the Cambridge City area (as under Scenario 2 and Scenario 3) is estimated to have a large effect on emissions from solid fuel burning. The reduction in emissions stems from the consequent assumed reduction in numbers of properties burning solid fuels, as well as a reduction in burning on open fires and stove upgrades for wood burning. The majority of baseline emissions and emissions savings are driven by wood burning (both a higher number of properties burning wood and higher emissions per kg of fuel burnt). Even with 25% non-compliance assumed (i.e., as under Scenario 2a), there is still predicted to be a significant (61% in the case of Scenario 2a) reduction in overall $PM_{2.5}$ emissions from solid fuel burning.

Moored river vessels represent a much smaller contribution to overall emissions, and current assumptions are that most are already likely to be burning MSF. Therefore, relatively few boat owners would need to change behaviour in response to an extension of the SCA to cover moored vessels. For both these reasons the impact of bringing moored boats into the SCA is therefore much less than for residential properties. However, despite this, there is potential for a proportionally large reduction in emissions emanating specifically from moored river vessels (67% in Scenario 1) if they were brought into the SCA. This is because $PM_{2.5}$ emissions from wood burning are much higher than for MSF per unit of fuel, so any reduction in wood burning will have a relatively large positive effect on emissions. In the baseline, although only 25% of solid fuel burning river vessels are assumed to be burning wood, this makes up 86% of overall moored vessel emissions.

[30] 2021 NAEI used for emissions of all sectors. Total domestic emissions as a subset of the'02 Non-industrial combustion plants' sector. Changes presented in Figure 4-2 subtracted from NAEI totals.

It is accepted that there are large uncertainties in the assumptions, in both the baseline and policy scenarios. There are particular uncertainties in relation to the behaviour change if the SCA is expanded. It is assumed that residents being captured in the newly declared SCA adopt the same behaviour as those who currently fall within the existing SCA, and that these changes occur when it is declared (i.e. reductions in proportions of properties burning, burning wood on open fires ceases, and changes to stoves where burning still occurs). However, sensitivity tests to explore a scenario of 25% non-compliance with the SCA regulations still show substantial reductions in emissions (62% for Scenario 3a relative to the baseline for properties and moored vessels), adding further evidence to the case for expanding the SCA.

Some of the uncertainties are likely to overestimate the emissions reductions (for example assuming full compliance with the SCA and that people will change behaviour as per those within the current SCA), while some assumptions are likely to underestimate the benefit (such as not including commercial emissions). However, even though some will potentially increase emissions in both the baseline and scenarios, and some will potentially decrease emissions, they will not necessarily act proportionally across the baseline and scenarios. For example, uncertainty about the assumption relating to the split between appliance types, will have different effects in the baseline, where the majority of properties are outside of the SCA, than in a scenario whereby it is assumed that all properties are compliant with the SCA (and hence have a different appliance split).

5 Health Impact Assessment

5.1 Health impacts of policy scenarios (Quantitative)

Each scenario will deliver a change in air pollutant emissions, which will have associated consequences for human and environmental health. The changes in emissions and associated impacts have been monetised using the Defra air pollutant damage costs – the results are presented in Table 5-1. All impacts are expressed as a change relative to the baseline.

Table 5-1: Damage costs of changes in air pollution (benefits associated with reductions in air pollutant emissions are expressed as positive numbers) (£000k), relative to the baseline, per annum

Scenario	1 Existing SCA, with moored vessels	2 City-wide SCA, without moored vessels	2a 25% non-compliance sensitivity test on Scenario 2	3 City-wide SCA with moored vessels	3a 25% non-compliance sensitivity test on Scenario 3	4 No SCA
Monetised damage costs (£2022 prices)	44	1,600	1,410	1,640	1,480	-93

Scenarios 1-3 each delivers a human and environmental health benefit relative to the baseline. This moves in line with the size of the emissions reductions achieved. The scenario with the most significant impact is Scenario 3, which is estimated to deliver a benefit valued at £1.64 million per annum in human and environmental health improvement.

Scenario 4, which simulates the removal of the existing SCA, demonstrates that the current SCA is providing a human and environmental health benefit with a value of approximately £93,000 per year (capturing health care cost savings, improved productivity, and the additional benefit to individuals themselves of improved health).

These monetised damage costs capture a range of different underpinning impacts on human and environmental health. The figure below presents the split of the overall monetised damage cost values by their individual impact pathway – this is presented for Scenario 3 only, but all scenarios follow the same pattern of results. By far the most important impact in the damage costs is the impact of mortality risk (comprising 57% of the overall impact valuation). This is followed by the morbidity pathways asthma (in children), stroke and ischemic heart disease. Respiratory hospital admissions show a 0% contribution – this is rounded down from a very small figure, which in turn is driven by the relatively low valuation relative to other health endpoints (i.e. one hospital admission incurs a much lower cost relative to say a case of asthma or death).

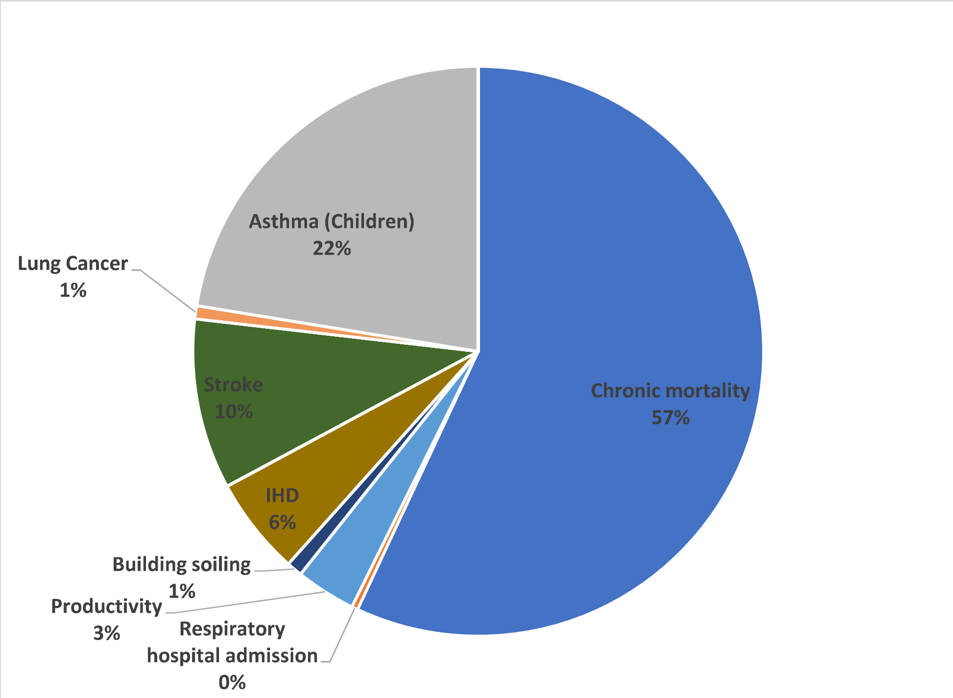

Figure 5-1: Split of monetised damage costs by impact pathway – Scenario 3

Table 5-2: Scenario health impacts (benefits associated with reductions in air pollutant emissions are expressed as negative numbers), relative to baseline

Impacts	Unit	Scenarios					
		1 Existing SCA, with moored vessels	2 City-wide SCA, without moored vessels	2a 25% non-compliance sensitivity test on Scenario 2	3 City-wide SCA with moored vessels	3a 25% non-compliance sensitivity test on Scenario 3	4 No SCA
Mortality*	Deaths	-0.05	-1.77	-1.57	-1.82	-1.61	0.10
Mortality*	LYL	-0.49	-17.96	-15.90	-18.46	-16.29	1.05
Respiratory hospital admission	HA	-0.02	-0.57	-0.50	-0.58	-0.51	0.03
IHD	#cases	-0.01	-0.35	-0.31	-0.36	-0.32	0.02
Stroke	#cases	-0.01	-0.43	-0.38	-0.44	-0.39	0.03
Lung Cancer	#cases	-0.01	-0.21	-0.18	-0.21	-0.19	0.01
Asthma (Children)	#cases	-0.02	-0.63	-0.56	-0.65	-0.57	0.04

Note: *Mortality effects are expressed using two alternative metrics – these are separate ways of expressing the same effect and are not two separate, additional impacts.

The table above presents some of the key human health impacts which are captured by the damage costs, expressed instead in terms of health outcomes rather than monetised values as presented above. It is important to note that the damage costs do not capture all health effects that have been linked to air pollutant exposure - exposure is also associated with other human health effects which are not quantified here, including diabetes, cardiovascular hospital admissions and chronic bronchitis.

Each scenario has a range of associated effects, which again move in line with the magnitude of emissions change observed. The scenario which delivers the greatest benefit is Scenario 3, which equates to:

- 1.8 fewer deaths each year associated with air pollutant exposure, with an associated reduction in life years lost (LYL) of 18.5 – i.e. 18.5 years of life[31] are gained for each year of emissions reductions;
- Reduction in 0.6 hospital admissions per year for respiratory conditions associated with air pollution exposure – i.e. one less hospital admission every 1 year and 9 months;
- Reduction in 0.36 new cases of ischemic heart disease each year – i.e. one less new case every 2 years and 9 months;
- Reduction in 0.44 new stroke cases each year – i.e. one less stroke case every 2 years and 3 months;
- Reduction in 0.21 new lung cancer cases each year – i.e. one less new lung cancer case every 4 years and 8 months; and
- Reduction in 0.65 new asthma cases in children per year – i.e. one less new case of asthma in children every 1 and a half years.

As is common in assessments of this nature (e.g. city-level analyses considering the effects of changing policies targeting air pollution), when analysed individually the calculated health impacts appear small. It is important to note that these figures present 'statistically attributable' impacts associated with the change in air pollution, based on the methodologies drawn from the underlying epidemiological evidence base, for the purpose of policy assessment. In practice, specific health outcomes can very rarely be attributed solely to changes in air pollution – in fact changes in air pollution will benefit all citizens to some extent and will have an influence on the risk and severity of all health outcomes with which air pollution has been associated (e.g. reducing air pollution will have some impact on all cases of lung cancer, rather than simply reducing one case every 4 years or so as quantified here for Scenario 3).

5.2 Health impacts of policy scenarios (Qualitative)

5.2.1 Indoor air quality impacts

Evidence has shown that solid fuel use has a significant negative impact on indoor air quality, as demonstrated by the review of indoor air quality undertaken by the Air Quality Expert Group (AQEG)[32]. It has been linked to increased levels of a range of pollutants in the indoor environment,

[31] These years of life gained are spread across those who experience a reduction in exposure to air pollution – in this case the impacts will predominantly be gained by Cambridge residents. This figure is a representative figure of the total statistically attributable impact across affected population – in practice it is not possible to know how many people will benefit and to what extent. I.e. there could be a large benefit to a smaller population, or a smaller effect spread across a larger population.
[32] https://uk-air.defra.gov.uk/library/reports?report_id=1101

including PM, carbon monoxide, oxides of nitrogen, volatile organic compounds (VOCs), sulphur dioxide (especially in relation to coal-based fuels) and polycyclic aromatic hydrocarbons (PAHs)[33]. A paper by Chakraborty *et al.* (2020)[34] identified that significant increases in indoor air pollution are observed, even when Defra-approved stoves were used. These included an average increase of 196% in levels of $PM_{2.5}$ between times when the stoves were in use and when they were not. This increase is likely to be far higher when using an open fire, where less efficient combustion is also likely to give rise to a higher proportion of PAHs (a group of chemicals which contains many known carcinogens).

The risk of heightened levels of pollution indoor is exacerbated by the fact the UK population spends 80-90% of its time indoors[35]. A report by the WHO in 2015[36] analysed the potential health impacts of indoor air pollutants from solid fuel heating, and also demonstrated the health benefit (including lower cardiovascular and respiratory mortality) that could be obtained through upgrading appliances to more efficient versions (e.g. more modern stoves) or non-combustion heating options.

It should be noted that indoor air quality in moored vessels has also been shown to be negatively impacted by solid fuel use. This is in addition to emissions from cooking (as with fixed households) and from the diesel engine (used either in propulsion or to charge batteries)[37].

The impacts of indoor air pollution on health have not been captured in the quantitative assessment of the impacts (and benefits) of changing SCA coverage in Cambridge for three key reasons. Firstly, indoor air quality is far more variable than outdoor air quality, both over time and between locations. Activities common indoors, including cooking, using candles or incense[38,39], or even people moving about, can give rise to peaks in measured concentrations of pollutants such as $PM_{2.5}$ which would be seen as extreme in outdoor environments. Equally, a lack of such activity can see concentrations drop to very low levels, below the outdoor background level (especially if windows are closed). Added to the differences in activity in different households, this would mean any "average" concentration carries an extremely high level of uncertainty. Furthermore we do not have data on indoor concentrations of pollutants in either burning or non-burning households.

Secondly, the damage coefficients used to estimate the health impacts of air pollution on populations correlate (usually) to measured outdoor concentrations with population level health outcomes. However, these populations will spend the majority of their time indoors, and thus the coefficients include indoor exposures to a certain extent (the variability in such exposures, for the reasons set out above, are not accounted for). Thus, calculating a separate health impact for indoor exposures could represent a "double counting" of effects.

Finally, Indoor air quality has been subject to increased interest and research in recent years. However, the field is still less developed than for outdoor air pollution and while some attempts have been made to quantify its impacts on health, these are not sufficiently robust to allow inclusion here.

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[33] https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2211011000_15062022_Indoor_Air_Quality_Report_Final.pdf
[34] https://www.mdpi.com/2073-4433/11/12/1326
[35] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/831319/VO__statement_Final_12092019_CS__1_.pdf
[36] https://iris.who.int/handle/10665/153671
[37] https://www.islington.gov.uk/-/media/sharepoint-lists/public-records/environmentalprotection/information/adviceandinformation/20222023/indoor-pollution-on-canal-and-river-boats.pdf
[38] https://ineris.hal.science/ineris-01863023/document
[39] https://pubmed.ncbi.nlm.nih.gov/23288671/

5.2.2 Changes in living and working conditions

Residential

By extending the SCA to cover properties in the wider city area, it is expected that households will change their behaviour if they are currently burning wood on an open fireplace, or on a stove which is not on Defra's exemptions list. It is anticipated that the changes will largely be felt by three broad groups of households:

- those who need to burn wood as it is their only heating source;
- those who burn on occasions for the aesthetic pleasure and comfort of a solid fuel fire; or
- those who burn wood to subsidise another form of central heating[40].

To assess the proportion of households who fall into these respective groups, data from the latest (2021) Census[41] has been extracted. While there was not a direct question relating to wood burning, information on the types of central heating systems installed is available. In the Cambridge Local Authority District (LAD) **89.7%** of households heat their homes with a single-fuel central heating system that is not reliant on solid fuels (i.e., mains gas, bottled gas, electricity, oil, renewable energy, or district/communal heat networks). Meanwhile the Census data indicates that **7.8%** of households have two or more types of central heating, but **0%** of households are reliant on wood or solid fuel only for central heating.

This data therefore indicates that no (or very few) households fall into category 1 (above), i.e. using wood or another solid fuel as their only source of heating. This is encouraging; it is anticipated that no household will be without a means to heat their property if the SCA is extended. This therefore indicates that the changes in living conditions will be concentrated on those households who currently burn for pleasure and/or to subsidise another form of central heating. The likely behavioural options are therefore to a) stop burning entirely and rely on the other form of heating already available to the household, b) upgrade the appliance on which the burning is taking place or c) change from wood to a compliant solid fuel, e.g. MSF.

Based on the Census data, approximately **4,918** (7.8%) households outside the current SCA boundary could have an open fire or solid fuel burning appliance as a secondary form of heating, and therefore fall into categories 2 and 3 (above). This compares well with the modelled estimate of households currently outside the SCA using wood and coal-like products (4,959), based on the Kantar survey. Using the model estimates, this equates to 3,485 households subsiding central heating systems with wood burning, of which **821** households are likely to be using an open fire, and **480** on a stove which is not exempt. This corresponds to a total of 2.1% of households currently outside the SCA boundary.

While 2.1% of households is relatively few in the context of the whole city, this equates to 1,301 households feeling a change in their living and/or working conditions. The potential impact on households in terms of changes in living conditions is also dependent on how affordable different alternatives are, and hence importantly ties to the socio-economic situation of the household – this is explored further in Section 6.3. Another aspect of households changing burning behaviour is whether some households have a preference for a non-compliant wood stove providing heat to the property (e.g. in a primary room, with other secondary sources elsewhere) – this is explored further as part of the 'fuel and utility cost' discussion in the quantitative analysis.

[40] Note that there may be a significant overlap between groups two and three.
[41] https://www.ons.gov.uk/census/maps/choropleth/housing/type-of-central-heating-in-household/heating-type/two-or-more-types-of-central-heating-not-including-renewable-energy?lad=E07000008

Moored Vessels

A previously outlined, information on burning behaviours on river boats is relatively sparse and/or spatially aggregated compared to the data available for residential behaviours. It is currently estimated that of the 70 houseboat moorings available in Cambridge, 85% use solid fuel as their primary heating source (~60 boats), of which it is assumed 75% use MSF and 25% use wood (~15 boats). All appliances are currently assumed to not be exempt. Therefore, if moored vessels are included within the SCA, 15 moored vessels will need to change their burning behaviours. It is anticipated that half those currently using wood on a not exempt appliance would switch fuels to MSF (~7.5 boats), and half would upgrade their appliance (~7.5 boats). Compared to the number of residential households that will be required to change their behaviours (1,301), the number of houseboats impacted is relatively few. Additionally, there is no ban on burning in general so the SCA regulations should result in either a fuel switch or stove upgrade. However, if there are misinterpretations of the regulations and/or teething issues with becoming accustomed to burning differently, the effects may be felt more acutely for these Cambridge residents; houseboats are typically less well insulated than traditional brick buildings and the choice of appropriate exempt stoves may be more limited. Changes in living and working conditions are explored further in Section 6.43.

5.3 Summary

A wide (and increasing) range of health conditions are linked to air pollution exposure, and reducing emissions will reduce the risk of lung cancer, stroke, ischemic heart disease, asthma, respiratory hospital admissions and deaths attributable to air pollution. Reductions in air pollutant emissions under the scenarios will therefore deliver positive benefits for human and environmental health, with the size of effects moving in line with the size of the emission reductions – hence Scenarios 2 and 3 are estimated to deliver a significantly greater benefit than Scenario 1. These benefits can be expressed in monetary terms using ‘damage costs’, which capture associated changes in health care costs, ‘productivity’ benefits and the value people place on their own good health. When valued in this way, Scenarios 2 and 3 deliver a societal benefit valued at £1.6m each year, in comparison to £44,000 per year for Scenario 1. By comparison, analysis of Scenario 4 suggest that the existing SCA delivers a societal benefit of around £93,000 per year for Cambridge residents (i.e. a benefit that could be lost should the SCA be removed).

These quantified impacts capture the change in exposure to ambient air pollution, but they do not completely capture the additional effect of changes in exposure to indoor air pollution. Evidence has shown that solid fuel use has a significant negative impact on indoor air quality, a risk that is heightened by the fact people spend the majority of their time indoors. The impact of the SCA scenarios on indoor air pollution and health cannot be quantified as robust approaches are not available to do so. The impact of the scenarios will depend on the behavioural response of each affected household, but it reasonable to assume the scenarios will deliver some improvement for some households (i.e. where households stop burning and/or switch to a non-solid fuel heat source).

A further impact on health could come through changes in living conditions as households and vessel owners respond to the SCA. The data available suggests almost no households solely relies on solid fuel as the only source of heat - this is encouraging as it is anticipated that no household will be without a means to heat their property if the SCA is extended. Hence whether households experience a change in living conditions is likely to be closely related to whether there are affordable options available such that they can retain an adequate level of heat – this is considered in further detail in the next section. By comparison, the majority of vessels use solid fuel as a primary heating source, and boats are typically less well-insulated than brick homes – hence the potential risk is greater for boat owners but will also be tied to their socio-economic situation and how they respond to being captured in the SCA.

6 Socio-Economic Assessment

6.1 Quantitative analysis

Table 6-1 presents the results of the quantitative socio-economic analysis.

Table 6-1 Results of cost analysis (£/annum) – costs are presented as positive values

Cost impact	Scenario 1 Existing SCA, with moored vessels	Scenario 2 City-wide SCA, without moored vessels	Scenario 2a 25% non-compliance sensitivity test on Scenario 2	Scenario 3 City-wide SCA with moored vessels	Scenario 3a 25% non-compliance sensitivity test on Scenario 3
Fuel and Utility Cost	£912	£62,600	£62,600	£63,500	£63,500
Investment Costs	£1,350	£132,000	£98,800	£133,000	£99,800
Implementation costs	£12,800	£50,300	£50,300	£50,300	£50,300
TOTAL	£15,100	£245,000	£212,000	£247,000	£214,000

There is a modelled increase in combined **fuel and utility cost** associated with all scenarios. As presented in Table 6-1, the net fuel and utility cost is approximately £1,000 per annum under Scenario 1, compared to a cost of around £63,000 per annum under all other scenarios. As discussed in the methodology Section 3.4.1, we cannot split out the observed changes in fuel consumption from the emissions modelling between affected households and vessels that switch fuel and those that stop burning. As such, the estimated impacts attempt to capture several underlying impacts associated with one or both of these behavioural responses, namely: fuel cost savings (i.e. a benefit) from fuel no longer burnt, additional fuel costs from any new fuel burnt, and a loss in utility (i.e. the amenity value of burning) either associated with a fuel switch or from stopping burning altogether. As previously outlined, data does not exist to quantify the full utility loss – our approach assumes this is equal to (and hence offsets) the fuel cost saving, and hence understates the overall utility cost. To somewhat balance this underestimation, the approach therefore adopts an assumption that is likely to overstate the additional costs of fuel switch from wood to MSF, namely that all the observed reduction in wood consumption is fuel switch to MSF, maximising the net cost associated with fuel switch (in practice, not all the reduction in wood consumption will be fuel switch, and hence this cost is somewhat overestimated). It is noted that this is not a perfect approach as it is not possible to judge whether the overestimation of fuel switching costs under or over accounts for the underestimation of utility costs. That said, it is insightful to demonstrate the potential order of magnitude of effects, relative to other impacts. **Investment costs** associated with purchases of new EcoDesign stoves are estimated to be £1,350[42] on an annualised basis in Scenario 1, associated with a small number (~7.5) of boats upgrading their appliance. Costs associated with purchasing of EcoDesign stoves in houses in Scenario 2 are estimated to be £132,000 on an annualised basis. In Scenario 3, costs of upgrading stoves purchased in boats and residential properties together is estimated to be £133,000 on an annualised basis (this is the sum of Scenarios 1 and 2, but appears different due to rounding). There are uncertainties surrounding these costs, largely due to the unknown behavioural response of how many people will choose to upgrade their stove as a result of being 'moved into' a SCA. Additionally, it is unknown whether full compliance will be achieved; as explored in Scenarios 2a and 3a,

[42] This presents the cost of upgrading the 7.5 assumed non-compliant stoves in moored vessels, annualized over 10 years – this is not the total (unannualized) cost of upgrading.

investment costs are lower as a result of the 25% non-compliance as fewer people upgrade from an open fire or non-compliant stove.

Implementation costs are estimated to be the same for Scenarios 2 and 3 (and the sensitivities around these scenarios in terms of non-compliance) , with the exception of Scenario 1, where enforcement of the SCA for boats only is expected to use only a quarter of the time that would be required under a more expansive scenario. These are estimated based on costs presented by previous studies, refined through discussion with Cambridge City Council as to the likely enforcement and information campaign costs associated with implementation (see Section 3.4.1).

Impacts on **greenhouse gas emissions**[43] were calculated resulting from the change in quantities of wood and MSF burned. As a result of Scenario 1 extending the SCA to moored vessels only, a small increase of 2 tCO_2e is estimated (with an equivalent monetised social cost of £450 per annum). Scenario 2 results in a reduction in GHG emissions of 4,997 tCO_2e, with a monetised societal benefit with a value of £1,340,000 per annum. Scenario 3 also results in a reduction of 4,995 tCO_2e which has an associated monetary value of £1,340,000 per annum. Scenario 1 is estimated to lead to an increase in GHG emissions whereas Scenarios 2 and 3 lead to a decrease, due to the variance in energy density of wood and MSF and due to the assumed behavioural responses. Under Scenarios 2 and 3, some households 'stop burning' and overall there is an estimated reduction in burning of wood and solid fuel, delivering a GHG emission reduction. Under Scenario 1, vessels are not assumed to 'stop burning' and hence all vessels either 'switch fuels' from wood to MSF or upgrade stove (with the latter having no impact on GHG emissions as it is assumed there is no impact on fuel consumption). Whilst the tonnage reduction of wood burned outweighs the tonnage increase in MSF, the higher relative energy (and hence emissions) density of MSF relative to wood leads to a small net increase in emissions in this case. Non-compliance sensitivity analyses presented in Scenarios 2a and 3a do not impact on the estimated GHG emissions savings under Scenarios 2 and 3 respectively as it is assumed the non-compliance is amongst those that upgrade stoves only, hence no difference in the quantity of fuels burned is assumed.

The **overall impacts of policy scenarios (i.e. the Net Present Value, or NPV)** combining monetised impacts of changes in emissions, associated health benefits, and the cost analysis including impact on greenhouse gas emissions, is summarised in Table 6-2 and the figure below.

Table 6-2 Cost-benefit analysis of policy scenarios (negative values are benefits, positive values are costs, all impacts are per annum for a representative year, expressed in £2022 prices)

Impact	Scenario 1 Existing SCA, with moored vessels	Scenario 2 City-wide SCA, without moored vessels	Scenario 2a 25% non-compliance sensitivity test on Scenario 2	Scenario 3 City-wide SCA with moored vessels	Scenario 3a 25% non-compliance sensitivity test on Scenario 3
Fuel and utility Costs	£912	£62,600	£62,600	£63,500	£63,500
Investment Costs	£1,350	£132,000	£98,800	£133,000	£99,800
Air pollution impacts	-£43,900	-£1,600,000	-£1,410,000	-£1,640,000	-£1,450,000
Implementation Costs	£12,800	£50,300	£50,300	£50,300	£50,300
Greenhouse Gas Emissions	£451	-£1,340,000	-£1,340,000	-£1,340,000	-£1,340,000

[43] As presented above, the GHG emissions assessment focuses only on change in Scope 1 emissions, and does not capture the Scope 3 (lifecycle) impacts.

NPV	-£28,400	-£2,800,000	-£2,550,000	-£2,740,000	-£2,580,000
BCR	2.8	12.0	13.0	12.1	13.1

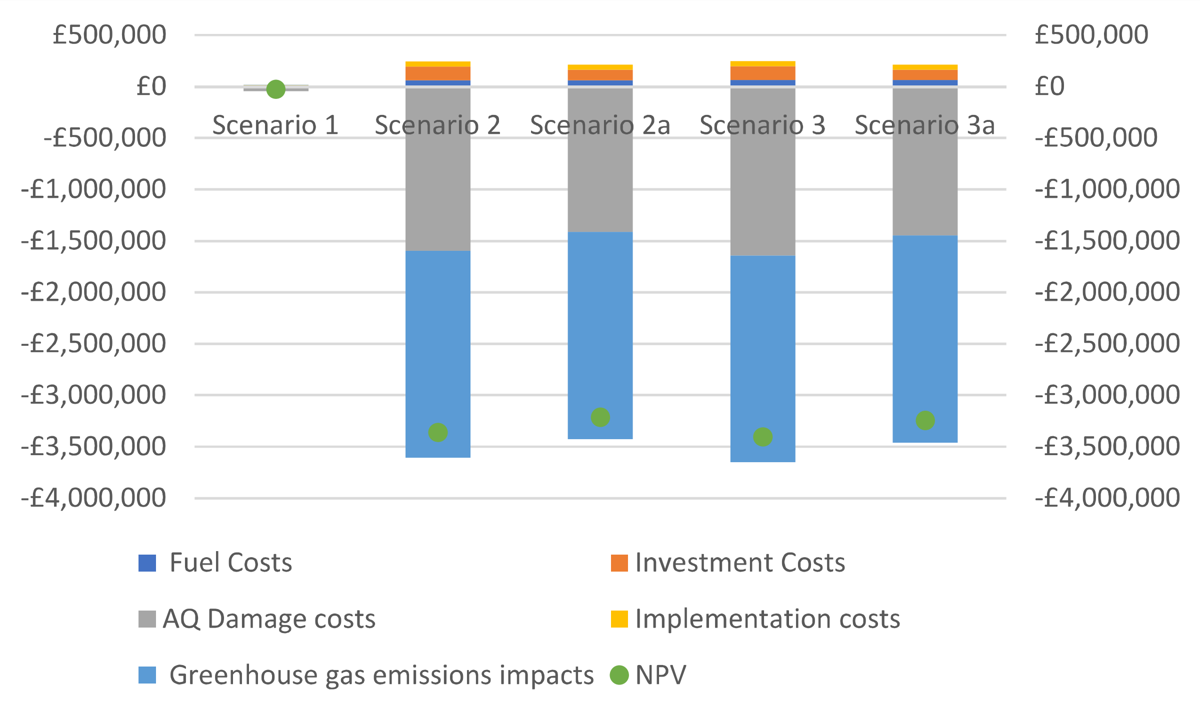

Figure 6-1: Cost-benefit analysis of policy scenarios (negative values are benefits, positive values are costs, all impacts are per annum for a representative year, expressed in £2022 prices)

Scenario 1 has the smallest magnitude of impacts, which is to be expected considering its scope is limited to only moored vessels. In this scenario, the ratio of benefits to costs (BCR) are lower (2.8) as heating systems on boats are primary heat sources and therefore all moored vessels are assumed to upgrade stove or switch fuel in response to the SCA – these behavioural responses carry a higher cost in the analysis relative to 'stop burning'. Furthermore, the assumed implementation costs are proportionally higher (noting that there is significant uncertainty around these figures which are included for illustration). Scenario 1 is also the only scenario which observes an increase in greenhouse gas emissions, as MSF has a higher greenhouse gas emission factor than wood.

Scenarios 2 and 3 (including the non-compliance sensitivities around these scenarios) have a large positive BCR and larger overall net benefits. This result is due to the value of improvements in health impacts from reduced $PM_{2.5}$ emissions and reduced greenhouse gas emissions outweighing cost increases from fuel use, investment costs and implementation costs. It is important to note (as discussed in the methodology) that there is uncertainty in the assessment, in particular around the changes in fuel costs – our adopted approach is likely to overestimate the fuel switching costs, but understate the utility lost from those who stop burning (i.e. the loss of pleasure or ambience), and it is unknown whether the former offsets the latter. That said, given the extent to which overall benefits outweigh the costs, it is deemed unlikely that the utility lost not captured would be significant enough to change the overall result of a net positive impact for society. There is only a small difference in the outcomes of Scenario 3 compared with Scenario 2 (12.1 BCR and 12.0 respectively) given the difference is driven by whether moored vessels are included in the SCA, which has a relatively limited impact (as described in Scenario 1).

The non-compliance sensitivity analyses (Scenario 2a and 3a) have a higher NPV and more positive BCR than Scenario 2 and Scenario 3, respectively. These non-compliance sensitivities assume that 25% of those burning on an open-fire or non-compliant stove choose to not upgrade their stove and not comply with the legal SCA regulations (i.e. non-compliance is focused only on those that would have upgraded stove, and does not reduce compliance amongst those that stop burning or switch fuel). This highlights that the purchasing of new stoves to replace an old non-compliant stove or an open fire is assumed in the modelling to be a relatively high-cost way of complying with the SCA, relative to stop burning or switching fuels. However, it is important to note that assumptions made to facilitate the analysis – e.g. we assume only one cost for all stove upgrades, whereas in practice there will be a multitude of choices and options for upgrade. Furthermore, where non-compliance occurs this could occur amongst those that would have upgraded stove and those that switched fuels or stopped burning. While limited, the sensitivity test does serve to show that even with a lower compliance rate, overall the SCA is still likely to deliver a net benefit for society.

6.2 Economic sensitivity analyses

There are several limitations and uncertainties around the analysis. As discussed above, a key uncertainty relates to the behavioural response of households and moored vessels who now need to comply with an expanded SCA – this is explored through Scenarios 2a and 3a. Further sensitivity analyses were conducted to explore uncertainties in the methodology applied to quantify the socio-economic impacts:

- Investment costs: a 25% higher and lower cost was assumed for installation of a new EcoDesign stove;
- Fuel prices: alternative fuel prices were used from the Scottish government impact assessment;
- Air pollutant damage costs: uncertainties exist in the damage costs related to the size of impact associated with exposure, the strength of evidence between exposure and effect and the valuation of health endpoints. High and low damage costs were taken from Defra's appraisal guidance;
- Carbon prices: a high-low bound is applied based on DESNZ's appraisal guidance.
- The results are presented in the table below, relative to the outputs of the core analysis.

As can be seen from the table above, none of the sensitivity tests change the overall result and the key conclusions drawn from the sensitivity analysis. I.e. under no sensitivity test does the net present value change from a net benefit to a net cost – in all cases all scenarios are still estimated to deliver a net overall benefit for society. Hence the results of the study are robust to these key uncertainties in the socio-economic analysis methodology.

The sensitivity test with the largest effect is the low and high range around the air pollution damage costs. Under the low damage cost, the NPV of Scenarios 2 and 3 reduces from around £2.7m net benefit per annum, to around £1.7m net benefit per annum. Hence even taking the low bound to monetise the benefit associated with changes in air pollution, the scenarios are still anticipated to deliver a net benefit overall. This result is also likely to be resilient to the uncertainty around the implicit emissions-to-concentrations relationships carried through from using national-average damage costs (i.e. by applying the Defra UK average 'domestic' damage costs, the analysis implicitly assumes that exposure to air pollution from domestic emissions in Cambridge is equivalent to exposure to an average unit of emission anywhere in the UK). Exposure to emissions from domestic sources in Cambridge would need to be significantly below the UK average to impact on the overall cost-benefit results for the scenarios.

Table 6-3: Outputs of the sensitivity analysis – shows NPV for typical year of impacts, expressed in £2022 prices

	Scenario 1 Existing SCA, with moored vessels	Scenario 2 City-wide SCA, without moored vessels	Scenario 2a 25% non-compliance sensitivity test on Scenario 2	Scenario 3 City-wide SCA with moored vessels	Scenario 3a 25% non-compliance sensitivity test on Scenario 3
Core analysis	-£28,400	-£2,700,000	-£2,550,000	-£2,740,000	-£2,580,000
Low investment cost	-£28,800	-£2,730,000	-£2,570,000	-£2,770,000	-£2,600,000
High Investment cost	-£28,100	-£2,660,000	-£2,520,000	-£2,700,000	-£2,550,000
Alternative fuel prices	-£32,700	-£2,990,000	-£2,840,000	-£3,030,000	-£2,870,000
Low damage cost	-£1,780	-£1,730,000	-£1,690,000	-£1,740,000	-£1,700,000
High damage cost	-£99,800	-£5,290,000	-£4,840,000	-£5,400,000	-£4,930,000
Low carbon price	-£28,600	-£2,020,000	-£1,870,000	-£2,060,000	-£1,900,000
High carbon price	-£28,200	-£3,370,000	-£3,210,000	-£3,410,000	-£3,250,000

6.3 Distributional analysis of costs

6.3.1 Residential

As outlined in Section 5.2.2, the 2021 Census[41] indicates that no residential dwellings in the study area rely solely on wood or another solid fuel as their primary source of central heating. Therefore, it is reasonable to assume that wood burning is supplementary, either for aesthetic purposes, or to offset the use of other heating fuels (and associated costs).

To understand who may be impacted by the SCA extension, the demographic profile of Cambridge has been investigated. In Cambridge, 7.7% of the population was classed as 'income-deprived' in 2019, placing Cambridge as the 248th most income-deprived local authority out of the 316 local authorities in England, according to the Office for National Statistics (ONS)[44]. Therefore, households in Cambridge are, on average, less deprived than those in the average local authority in England.

Going further, we have overlaid ONS census data on household heating systems with Index of Multiple Deprivation (IMD) at the Level of Lower Super Output Area (LSOA) to explore the levels of solid fuel burning in each IMD decile[45]. As explored above, very few households in the Cambridge area are reported to rely solely on wood or other solid fuels as their only heat source – for the analysis we have assessed the proportions assigned as using 'two or more types of central heating (not including renewable energy)'. The number of households in each LSOA is compared to the IMD decile rank, with 1 being the most deprived and 10 being the least deprived.

The number of households and proportion of all households in this category falling in each decile are shown in Table 6-4. From the table it appears that those using two or more types of central heating (a proportion of which includes solid fuels) appears to be concentrated amongst less deprived households: no households in the most deprived income decile use two or more types; only 5% of all

[44] https://www.ons.gov.uk/visualisations/dvc1371/#/E07000008
[45] IMD is often split into deciles, where each LSOA is assigned to one of ten deciles which nationally rank all LSOAs according to their relative level of deprivation

households using two or more types fall in the bottom two deciles; and only 15% fall in the bottom three deciles. Two caveats to this analysis are: (a) this is performed at LSOA level, and there will be variation in deprivation within an LSOA, so we cannot precisely identify the level of deprivation of each specific household using solid fuel; and (b) this analyses households using two or more types of central heating, a proportion of which will and will not use solid fuel as a source.

Table 6-4: Split of households using two or more types of central heating (not including renewable sources), in LSOAs located in the Cambridge Local Authority area, split by IMD decile

IMD decile	# of households	% of all households using two or more types of central heating (not including renewable sources)
1 (most deprived)	0	0%
2	142	5%
3	261	10%
4	124	5%
5	612	23%
6	395	15%
7	231	9%
8	345	13%
9	280	10%
10 (least deprived)	304	11%

The finding that those burning wood are likely to be less vulnerable households is somewhat corroborated by other sources. For example, the Kantar survey found that the majority of indoor burners nation-wide were relatively affluent in comparison with non-burners, however it also found that 22% of indoor burners (at national scale) found it difficult or very difficult to meet their energy costs[46]. Furthermore, a survey run by the London Wood Burning Project[47] (LWBP) suggested that households burning wood in London are more likely to be: younger (i.e. under 40), property owners, living in houses (rather than flats or other), higher earners (i.e. >£60,000) and working full-time.

The costs outlined above to upgrade appliances are therefore likely to fall largely on relatively affluent households. However, there should be attention directed to those who are using solid fuel appliances while struggling to meet their energy costs, as they are unlikely to be able to afford a new appliance and may therefore face the decision of complying with regulations, or not being able to adequately heat their homes. In Cambridge, based on the demographic profile of residents, this is likely to be less of an issue than elsewhere in England.

6.3.2 Moored Vessels

While Section 6.3.1 indicates that the demographic profile of solid fuel burners in residential properties in Cambridge is that of a relatively affluent population where solid fuel burning is not the sole source of heating, the same does not necessarily apply to the population living on river vessels at moorings

[46] https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectID=20159&FromSearch=Y&Publisher=1&SearchText=AQ1017&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

[47] The results of the survey are, as yet, unpublished. These were provided through direct communication between the study and LWBP teams.

throughout Cambridge. As outlined in a statement by the National Bargee Travellers Association[48], most boats are heated using a solid fuel stove, while some are heated using a diesel heater, and few use electricity or bottled gas for heating. This is supported by the Canal and River Trust 2022 Census[12] which identified most boaters had a solid fuel stove (66.6%) while fewer had diesel heaters (53.3%), gas boilers (17.3%), or electric heating (9.3%). Hence moored vessels are more likely to rely solely on solid fuel as their primary heat source.

Demographic information regarding the boating population is relatively sparse, but there are some metrics which indicate the population is likely to more acutely impacted than the rest of the Cambridge population. The Canal and River Trust 2022 Census[12] found that 33.7% of boaters report that their day-to-day activities are limited because of a long-term health problem or disability, which is significantly higher than the national average (17.8%). Additionally, the majority of respondents 70.3%) declared that they receive a pension or pension credit, indicating an older population of boaters compared to the rest of Cambridge. In comparison, the 2021 Census[49] identified 11.5% of the population in Cambridge was above 65 years of age. The same Canal and River Trust census also asked boaters about the issues and challenges associated with living on a boat, of which: 21.7% responded 'employment and work', 16.5% 'accessing financial services' and 11.6% 'accessing financial help (e.g. benefits)'.

Furthermore, as part of a boat licence consultation[50], a Canal and River Trust survey identified that: 53% of boaters stated that their household income was below £40,000, 43% stated their household was income below £30,000, and just over a quarter (27%) stating their household income was below £20,000. By comparison, 34% of all UK households reported gross income below £32,000 and 15% less than £19,000 in 2020[51].

Therefore, extending the SCA to include moored vessels may have a more acute impact on boat residents than those in traditional properties in Cambridge area; they are likely to be more reliant on solid fuel burning as their primary source of heating, and they are more likely to be an older population with additional health demands. There is some evidence to suggest boat residents are also likely to be relatively lower income or suffer from additional financial challenges.

6.4 Practical implications of changing heating practices

6.4.1 Residential

The above has indicated that no (or very few) household will be left without a primary source of heating, assuming the data from the 2021 Census is correct; 0% of households in the study area reported to rely on solid fuel as their main heating source[52]. The remainder of this section therefore focusses on the implication for those households who burn solid fuels for either aesthetic reasons or to supplement their main heating source for economic reasons. For these groups, there are three main behavioural responses:

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[48] Written evidence submitted by the National Bargee Travellers Association (NBTA) (WIN0022) https://committees.parliament.uk/writtenevidence/123477/pdf/#:~:text=The%20NBTA%20estimates%20that%20there,no%20further%20breakdown%20of%20population.

[49] https://www.ons.gov.uk/visualisations/censusareachanges/E07000008/

[50] https://canalrivertrust.org.uk/refresh/media/original/48475-boat-licence-review-equality-impact-assessment.pdf

[51] See Gross banded income, UK, financial year ending 2020, here: https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/adhocs/14140bandedequivaliseddisposableincomeandnonequivalisedgrossincomeukfinancialyearending2020

[52] Noting this might be slightly above absolute zero, but rounded down in the census results.

- Change fuel, e.g. from wood to MSF;
- Change appliance, e.g. from an open fireplace or non-compliant stove to a compliant stove; and

Stop burning altogether or burn less. For example, by adjusting duration of burning events, frequency of burning events, or reduced heat output during burning events (e.g. through restricting air flow in a stove or constructing a smaller fire).

The cost implications of the first two options have been included in the cost analysis above. In practical terms, the implications of changing from wood to MSF may mean that a new fuel supplier is needed, especially if the wood used is foraged or obtained through non-market means (which would also imply a higher cost implication). This would require time and effort to find a new supplier, and potential additional travel time and distance, and challenges in transporting fuel back to the home where suppliers are located further away than existing sources. Changes in fuel storage are also likely, although MSF will occupy a smaller volume than the equivalent amount of wood for the same energy output. There is also likely to be a loss in aesthetic value which may in turn lead to a reduction in burning for those where this is a primary reason for burning.

Changing appliances will clearly have a short-term disruptive impact on those households which choose to do so, as it is likely to require physical changes within the home. Thereafter, the practical implications are minimal, assuming the installation is undertaken correctly. There is a risk that installations are undertaken incorrectly, to save costs and/or because those undertaking the work are insufficiently skilled (including DIY installations). This could lead to reduced indoor air quality, including a risk of carbon monoxide poisoning, if flue gases are allowed to escape into living rooms. There is also a risk of damage to chimneys if flue liners are incorrectly installed or if no flue liner is installed. This in turn could lead to an increased fire risk, especially if the chimney is not swept regularly (although this risk is also true for correctly installed appliances especially if they are operated incorrectly).

Stopping burning or reduced burning is likely to mean that there is increased use of other heating fuels. This is of greater significance for those households using solid fuels to supplement their main heating source (usually for economic reasons). Anecdotal evidence[53] suggests that the increase in energy prices prompted by Russia's invasion of Ukraine led to a significant increase in households using solid fuel to offset their main heating fuel (usually gas). This includes using solid fuel appliances to heat one room. However, solid fuel costs, both wood and MSF, also increased at that time, and an analysis undertaken for Global Action Plan suggests that using solid fuel heating in this way may not result in net cost savings[54]. Focussing heating on one room can also be achieved through varying thermostatic controls on central heating radiators, although this is less convenient and may not be available e.g. in private rented accommodation. It is therefore not clear whether the increase in gas (or other heating fuel) use implied by a reduction in solid fuel as a supplementary heating fuel will result in a net cost increase for households.

There may be circumstances, especially in lower income households, where the main central heating system is insufficient to heat the house, especially under extreme weather conditions, and that stopping the use of solid fuel may lead to colder homes. This in turn can lead to condensation, mould growth, and other adverse health outcomes. There are already funds available to low income households to improve insulation and improve the efficiency of heating systems, but access to these will be limited, especially in private rented accommodation. There is, therefore, a risk that extending the SCA could exacerbate fuel poverty for some households.

[53] Likely to be confirmed when the results of the recent survey on domestic burning undertaken by Ipsos for Defra are published.
[54] Relight my fire? (globalactionplan.org.uk)

Furthermore, attempts to reduce, but not cease, solid fuel use may result in the incorrect use of appliances, such as through overly restricting air flow in stoves. This could result in a more "smoky" burn, increasing both PM emissions and fouling of the chimney. If the chimney is not swept regularly, this could result in an increased fire risk and, in extreme circumstances, blockage of the flue and leakage of flue gasses (including carbon monoxide) into the living spaces.

6.4.2 Moored Vessels

The practical implications for moored vessels are slightly different, in that solid fuel is nearly always the main heating fuel. Moreover, moored vessel occupants are more likely to be lower income households and thus more vulnerable to price fluctuations in living and energy costs. Moored vessels are also typically poorly insulated, which can make them more sensitive to changes in heating system. The costs of moving from non-compliant to compliant stoves and/or from wood fuel to MSF have been included in this analysis. However, this may underestimate the costs, especially where the wood currently used is foraged or acquired through non-market means. In such cases, the need to switch to MSF may give rise to or exacerbate issues of fuel poverty. The need to use MSF rather than wood may also introduce issues of supply, with the risk of shortage of fuel during particularly cold spells.

Some moored vessel occupants may choose to opt for diesel heaters rather than either upgrading a solid fuel heater or switching fuel. We have not undertaken a cost analysis of solid fuel heating versus diesel heating, but the practical implication may mean increased noise for local residents (and other moored vessels) and an increase in diesel emissions, which have not been considered in this analysis.

6.5 Summary

The monetised health impacts have been combined into a wider assessment of the socioeconomic effects of adjusting the SCA. Where possible, the impacts of the scenarios have been quantified and captured in a cost-benefit analysis comparing the benefits of the scenarios against the costs. The costs to home and vessel owners of switching fuel or upgrading stoves, and to the Council for implementation and enforcement are greatest under Scenarios 2 and 3 (highest cost is Scenario 3 of £250,000 per annum), with Scenario 1 carrying an estimated cost of around £15,000 per year.

Overall, all scenarios to extend the SCA are estimated to deliver a 'net benefit to society' – in other words, the health improvements from reduced air pollution and benefit of greenhouse gas emission reductions outweigh the combined costs to the Council and owners of homes and moored vessels. The size of the net benefit delivered rises in line with the size of air quality benefits, hence Scenarios 2 and 3 deliver the largest net benefit in the order of £2.8m per year, with a ratio of benefits-to-costs or 12-to-1. Scenario 4 which tested the benefits of the existing SCA was not subject to complete quantitative assessment given uncertainty around what would happen should an SCA be removed. However expert judgement suggests it is likely that the costs of removing the SCA in terms of lost air pollutant benefits (i.e. emissions would increase) and higher GHG emissions would outweigh any benefits in terms of fuel cost savings, hence delivering an overall disbenefit for society should the existing SCA be removed.

While increasing the coverage of the SCA results in a net benefit to society, it is important to consider additional impacts and risks that have not been quantified and captured in the cost-benefit analysis. For households, there may be some practical implications of switching, such as search costs of finding new fuel sources, the need to allow access to the home to upgrade stoves, and installation risks – however there is no evidence to suggest these risks are significant overall. That said, the implications for moored vessel owners appear more consequential. As a group, evidence suggests moored vessel owners may have relatively lower incomes and hence alternative options may be less affordable for some. Furthermore, this group tend to be more vulnerable (i.e. more likely to be elderly or have a disability or long-term health conditions) and vessels tend to be less well-insulated. Hence there is a greater risk that moored vessel owners may face difficulties affording to comply with the SCA, which in turn may have a detrimental impact on living standards amongst a more at-risk group.

7 Summary and Conclusions

7.1 Overall assessment conclusions and recommendations

The overall conclusions of the study are summarised in Table 7-1, which presents the analysis in a multi-criteria analysis, intended to aid comparison between the scenarios and visually present the key benefits and risks of each policy option.

All scenarios result in a net benefit, with extending the SCA to the whole of Cambridge and including moored vessels in the designation providing the largest net impact (Scenario 3). This is driven by health benefits from the reduction of $PM_{2.5}$ emissions, which include a reduction of annual deaths by ~1.8 as well as improvements in other health outcomes associated with a reduction in exposure to ambient air pollution. This scenario will also deliver additional indoor air quality improvements with associated health benefits, which are not captured in the quantitative analysis due to a lack of established methodology to do so.

While all the policy scenarios result in a net benefit to society, it is important to consider additional impacts that have not been monetised. These include the distributional impacts of where changes in fuel costs and investment costs fall in society. While burning of solid fuel in domestic properties is mostly a secondary heat source used by households who are likely to be more affluent, this is not the case with moored vessels. Solid fuel is typically the primary heat source for vessels and boat residents are more likely to be lower income, be older or have a pre-existing medical condition or disability. Furthermore, vessels are likely to be less insulated and more at risk of cold, damp, and resulting mould. Therefore, Scenario 1 and (part of) Scenario 3 risks impacting on a group who may be less able to afford to respond to the SCA in a way that maintains their living conditions, and may be more susceptible to the associated health risks.

Overall, the assessment presents either Scenario 2 or 3 as the preferred option. This study has demonstrated that the monetised benefits of expanding the coverage of the SCA outweigh the costs, and there is predicted to be a net benefit to society of extending the SCA to the whole of Cambridge driven by improvements to health. These findings are, however, dependant on behaviour change in response to the SCA, which is uncertain in practice, and there is no precedence for such a change elsewhere in the UK. As such, awareness-raising information campaigns and/or enforcement will be important to ensure the SCA succeeds in achieving the potential changes in burning behaviours, and in turn, reductions in $PM_{2.5}$ emissions. Further work such as a city-wide survey may be helpful for better understanding burning behaviour and potential behaviour change related to extension of the SCA.

Inclusion of moored vessels in the SCA would deliver an additional net benefit and could achieve a significant impact on emissions from a more visible source (although the additional benefit in terms of overall emissions is relatively small). I There are however some additional risks and concerns for this small group of affected citizens, including higher economic vulnerability and risks from changes in living conditions. The data relating to proportions of river vessels burning wood and coal products, and the appliances which are being used is also more uncertain than for residential properties. Therefore. where Scenario 3 is pursued, additional engagement with moored vessel owners is recommended to further explore solid fuel burning activity within the group, as well as potential impacts and risks to this group, and complementary measures should be considered where potential issues are identified to mitigate risks for vulnerable boat owners where possible.

Table 7-1: Summary multi-criteria analysis of scenarios

Scenario	1	2	3
Emissions impacts (tonne reduction versus baseline per annum / % reduction versus baseline)	-0.52 (-2%)	-18.86 (-69%)	-19.38 (-71%)
Health impacts (£000k monetised effects / # deaths avoided per annum)	44 -0.05 deaths	1,600 -1.77 deaths	1,640 -1.82 deaths
Cost-benefit analysis	£28,000 NPV benefit Benefit Cost Ratio: 2.8	£2.7m NPV benefit Benefit Cost Ratio 12.0	2.7m NPV benefit Benefit Cost Ratio 12.1
Indoor health benefits	Potential benefits for indoor air pollution for moored vessels, although evidence on indoor pollution is less established	Potential benefits for indoor air pollution in households, although evidence on indoor pollution is less established	Potential benefits for indoor air pollution in moored vessels and households, although evidence on indoor pollution is less established
Distribution of costs	Costs fall on a small number (~15) of vessel owners and users. Boat users are more likely to be lower income	Households burning solid fuels (~3,500) do so as a secondary heating source and more likely to be affluent	Costs fall on a small number (~15) of vessel owners and users. Boat users are more likely to be lower income
Changes in living conditions	Vessels tend to be less well insulated. If alternatives are less affordable, there could be a risk for living conditions where residents stop/reduce burning, such as cold, damp and mould	Given majority of households burn for pleasure and/or are less deprived (and can likely afford replacements), risk of households living in colder, damper homes with mould are lower. Other initiatives exist to help ensure homes are adequately heated.	There is a risk that the small number of households living in moored vessels may experience a disproportionate worsening of living conditions (see Scenario 1). Risk for households is assessed to be negligible (Scenario 2)
Practical implications	Need to find alternative fuel source, which may be less convenient. Stove upgrades require access to the moored vessel.	Need to find alternative fuel source, which may be less convenient. Stove upgrades require access to the property. Small risk of incorrect installation.	Need to find alternative fuel source, which may be less convenient. Stove upgrades require access to the property or moored vessel.

Key	Large disbenefit / risk	Disbenefit / risk	Neutral	Benefit	Large benefit

7.2 Caveats and limitations of assessment

- The air quality baseline is uncertain, for reasons set out in Section 3.2, including: Types of appliance used to burn vary enormously, activity data is incomplete, domestic heating appliances do not require registration, and emissions factors have uncertainty.

- Behavioural assumptions in response the SCA are uncertain, e.g. how many people stop burning fuel, switch fuels, upgrade their stoves, or are non-compliant. In this study, responses are based on the Kantar survey and behaviour inside and outside SCAs (which also informed the NAEI), assuming that those outside the current SCA will behave like those inside an SCA once the zone is extended. This is uncertain and reality may be different. In addition, modelling undertaken for this study has assumed that behaviour change is instant with introduction of the policy, however in reality the shift may be more gradual and be helped by information campaigns.

- A single year of analysis has been conducted, presenting one year of annualised costs and air quality impacts. In reality, air quality benefits will be experienced not just in a single year but over several years, and as such air quality benefits are under-represented.

- Modelling has been done on the basis of fuels that are legally permitted to be sold (i.e. MSF). In reality, there may be a proportion of people burning house coal. In this instance, benefits of the modelled analysis are understated as there will be greater benefit from swapping to compliant fuel.

- There is uncertainty in relation to the compliance of existing stoves prior to introduction of the policy and therefore the necessity of upgrading, as well as which stoves will be purchased and their cost. Additionally, there may be the possibility of retrofitting stoves which would be cheaper and as such investment costs overstated.

- Health benefits associated with air quality improvements are estimated by utilisation of the latest damage costs. There are a wide range of detrimental health effects associated with exposure to air pollutants, of which only some are captured and quantified in the damage costs. Furthermore, only the effects associated with exposure to PM have been assessed here and not other pollutants. Both these factors will lead to an underestimation in the size of the air pollution benefits achieved. Use of the Defra damage costs also implicitly assumes the average exposure to a unit of domestic emissions in Cambridge is the same as that of the average

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