land

MDPI

Article

Environmental and Social Benefits of Extensive Green Roofs Applied on Bus Shelters in Edinburgh

Zuzana Koscikova [1,2,*] and Vladimir Krivtsov [3,4]

[1] School of GeoSciences, University of Edinburgh, Alexander Crum Brown Road, Edinburgh EH9 3FF, UK
[2] School of Architecture and the Built Environment, KTH Royal Institute of Technology, 100 44 Stockholm, Sweden
[3] School of Biological Sciences, University of Edinburgh, 1.03H Rutherford Building, The King's Buildings, 190 Mayfield Road, Edinburgh EH9 3BF, UK; vkrivtso@exseed.ed.ac.uk
[4] Royal Botanic Garden Edinburgh, Arboretum Pl, Edinburgh EH3 5NZ, UK
* Correspondence: zuzkakoscikova@gmail.com

Abstract: The presence of green roofs in urban areas provides various ecosystem services that help mitigate climate change. They play an essential role in sustainable drainage systems, contribute to air quality and carbon sequestration, mitigate urban heat island, support biodiversity, and create green spaces supporting public well-being. Bus stops provide good opportunities for installing green roofs. Various cities worldwide have started installing green roofs on bus shelters, but often without thoroughly comparing expenses and the resulting benefits. This study quantifies the social and environmental benefits of installing green roofs on bus shelters in the City of Edinburgh. An assessment of the benefits and their monetary values was conducted using the B£ST analysis tool combined with manual calculations, which is easily transferable to other cities worldwide. It was compared to the current situation with no green roofs installed at bus stops. Installation of green roofs on all bus shelters in the City of Edinburgh may result in £12.9 million–£87.2 million in total benefit present value. The total cost was projected to be £15,994,000. By green roof installation, the City of Edinburgh can be closer to being carbon-neutral by 2030, a sustainable city as part of the City Plan 2030 and City Vision 2050.

Keywords: blue-green cities; ecosystem services; green infrastructure; cost benefit analysis; climatic mitigation; *Sedum*

check for updates

Citation: Koscikova, Z.; Krivtsov, V. Environmental and Social Benefits of Extensive Green Roofs Applied on Bus Shelters in Edinburgh. *Land* **2023**, *12*, 1831. https://doi.org/10.3390/land12101831

Academic Editor: Zhonghua Gou

Received: 9 August 2023
Revised: 13 September 2023
Accepted: 16 September 2023
Published: 25 September 2023

1. Introduction

The installation of green roofs (GRs) in cities contributes to the development of a healthy blue-green infrastructure network [1], which is indispensable for sustainable urban development [2,3]. GRs are partially or fully vegetated roofs that extend the conventional roof by a waterproof membrane (with the possible addition of a root barrier), a drainage layer, a filter layer, a lightweight substrate, and vegetation (Figure 1) [4].

The fundamental division of GRs according to substrate depth and plant species recognises extensive (EGRs) and intensive green roofs (IGRs). EGRs are specified by shallow mineral-based substrate supporting low plants such as *Sedum* spp., moss, wildflowers, or grass, which make them well-suited for bus shelter applications. Bus shelters provide unused roof spaces that can be transformed into additional green urban infrastructure. This paper gives a brief overview of the benefits provided by EGRs. It presents a case study comparing the benefits and costs of their installation on bus shelters in Edinburgh.

1.1. Benefits of Green Roofs in the Urban Context

GRs provide a number of environmental and social benefits. Substrate and vegetation are the essential and the most understood structural layers of GRs regarding the benefit provided.

Substrate captures rainwater, reduces the runoff volume, and delays its peak. Warmer and wetter weather with increased heat islands and frequent heavy rainfalls is predicted for the east of Scotland. Between 1981–2010, the frequency of heavy rainfalls increased by 5% compared to the years 1961–1990 [5]. GRs applied on roofs in urban areas have an essential role in Sustainable Drainage Systems (SuDS), being one of the leading stormwater management solutions [1,4,6,7]. GRs in urban settings can simultaneously achieve three main aims of SuDS—reduce the quantity of runoff and delay its peak, improve runoff quality, and provide good amenity values [6,8–11].

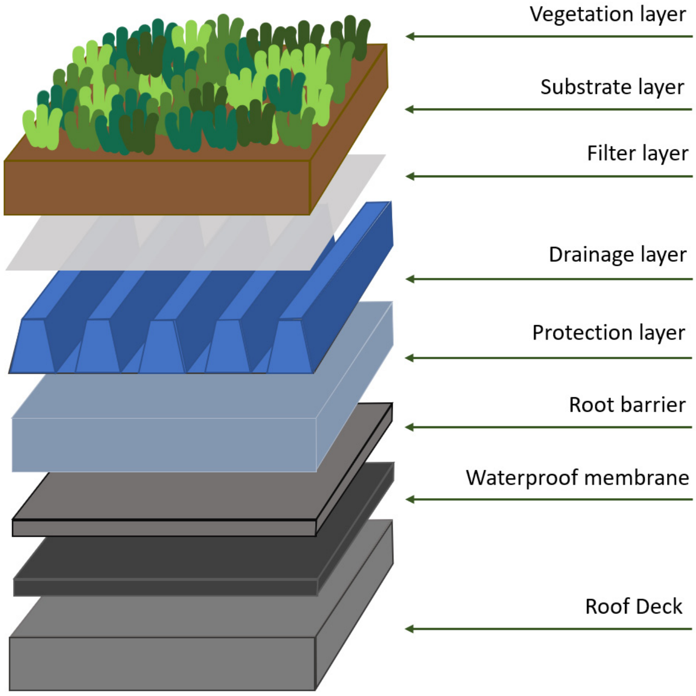

Figure 1. Structure of a typical green roof.

Vegetation is also essential in erosion prevention and evapotranspiration, providing a greater surface and influencing initial substrate moisture [12–14]. The vegetation layer mitigates urban heat island (UHI) through increased evapotranspiration, increased albedo, and reduced direct sensible heat emissions [15,16]. Roads are among the hottest areas in cities, due to their low albedo [17–19]. It has been concluded that GRs might be more efficient when their height is lower than 10 m [20], making city bus stops an ideal location.

The green roof hydrological cycle is prosperous for both stormwater management and evapotranspiration's cooling effects [21]. According to various authors, the water content in soil is the strongest factor for evapotranspiration [22–26]. Feng et al. [27] found that increased water content in the substrate from 30% to 60% reduced heat stored in GR by 24%. This agreed with studies by Coutts et al. [28] and Wong et al. [20], showing limited evapotranspiration rates and cooling effects of GRs after a dry period. Water content in leaves may also cause higher reflectance [29].

In addition, the vegetation layer improves air quality by direct pollutants sequestration and lowering air temperature, which results in a reduction in air pollution creation, thus preventing ozone formation [4]. Plants provide a surface area for the wet and dry deposition of pollutants [30,31]. Particles that are not captured by leaves can be absorbed by cuticle digestion, stomata penetration, or deposited in soil and absorbed by roots [32–34]. Gaseous pollutants are sequestered by vegetation through their stomata [34]. The roof type and planted vegetation also control the sequestration of CO_2 [35]. Generally, GRs can reduce CO_2 through direct sequestration or indirect shading effect and evapotranspiration, lowering ambient air temperature and electricity demand [36].

One of the main reasons for GR installation in urban areas is the creation of new habitats and biodiversity support. With the spread of GRs in the 20th century, more profound research focused on their design, rainwater retention, and insulation benefits. However, there is still a lack of studies targeting GRs' importance in biodiversity, habitat support, and the long-term monitoring of fauna and flora behaviour and establishment [37,38]. Together with the substrate layer, the vegetation layer creates new habitats for lost urban biodiversity and supports pollinators [1], which are threatened by the expansion of urban conglomerates [7]. Furthermore, it can ease the movement of wildlife and deliver measurable biodiversity net gain (BNG) [39]. This is especially vital in the context of new policies requiring 10% of BNG in any new urban planning project in the UK [40].

In addition to all of the environmental benefits GRs deliver, improving previously unused roofs makes people happy and more inclined to care about nature [41]. GRs have an important role in adding aesthetics to highly built-up areas and increasing the value of surrounding properties by 9% [42]. Furthermore, therapeutic benefits were measured from flower terpenes, colours, and sound variations that GRs provide [39,43]. One of the main barriers to implementing GRs is the lack of public knowledge [44]. However, when implemented, GRs in urban areas might be a great opportunity to raise awareness of their benefits and encourage further implementation [45].

1.2. Scope for the Case Study

Different cities have adopted the law of implementing at least partially vegetated roofs on new buildings [46]. Utrecht was the first city to implement green bus shelters, installing 316 of them. Different cities in the Netherlands (Haarlem, Gouda, Apeldoorn, Woerden, Wageningen), Leipzig in Germany, and Helsingborg and Malmö in Sweden are following this trend. In the UK, Leicester has installed 30 GRs on bus shelters; Milton Keynes, Manchester, Newcastle, Cardiff, Oxford, and Brighton have installed GRs on some of the bus shelters as well (Figure 2) [47]. The majority of these projects are funded by grants and funds with no additional costs to the city councils [48].

Figure 2. Green bus stops across cities: (**a**) Utrecht [49], (**b**) Leicester [48], (**c**) Manchester [50], (**d**) Milton Keynes (Ch. Bridgman, personal communication, 21 January 2022).

Despite the global expansion of GRs integration into urban architecture, there is a lack of studies based on solid scientific analysis of the costs and benefits involved [1], which was identified as the main knowledge gap. This paper's objective is to provide a comparison of the costs and benefits of EGRs application in the City of Edinburgh with suggestions for its green future as part of the City Plan 2030. This will help the city transition to net-zero carbon emissions by 2030 and contribute to the creation of thriving green spaces as part of Edinburgh's 2050 city vision [51]. Moreover, it will benefit initiatives such as Cleaner Air for Scotland—The Road to a Healthier Future [52] and bring opportunities for increasing BNG in new and existing infrastructure.

This study uses the Benefits Estimation Tool (B£ST) to quantify and monetise the benefits of EGRs application on bus shelters in Edinburgh. The scenario with EGRs applied on all the bus shelters in the city is compared to the baseline scenario representing the current situation (no EGRs installed on bus shelters). The study aims to quantify the social and environmental benefits of installing green roofs on bus shelters. Quantification of environmental benefits such as sequestration of air pollutants, CO_2 reduction, retained rainfall, mitigated UHI, and biodiversity support will be addressed. Monetary values will be assigned to all ecosystem services provided by GRs, including social services such as health, education, and amenity. Two hypotheses will be tested: (1) the application of GRs will provide the city with multiple quantifiable benefits such as improved air quality, decreased stormwater runoff, decreased temperature of UHI, provision of new habitats supporting biodiversity, and improved general appearance of the area; (2) the number of benefits provided through ecosystem services by GRs will offset the costs associated with the roof's installation and maintenance.

2. Methods

A combination of a literature review and the Benefit Estimation Tool B£ST [53] was used to evaluate the benefits of green infrastructure in the City of Edinburgh. This section describes the case study site, gives a brief overview of the B£ST tool and its methodology, and describes the quantification and monetisation of benefits. Input data and calculations, including assumptions justification for each calculated benefit in alphabetical order, are also provided. Specific values and the confidence score included in the B£ST analysis can be found under each benefit's heading.

2.1. Study Site: Edinburgh

Edinburgh is located in the central east Scotland. Its area represents 264 km^2, with 527,620 residents and a population density of 2003 per km^2 [54]. Edinburgh public transport is provided by the Lothian Buses company, operating 70 services in Edinburgh and the surrounding areas of Midlothian, with the major shareholder being The City of Edinburgh Council [55]. The Council has approximately 2238 modular bus stops, of which 1454 are sheltered (Figure 3). Standard shelters have polycarbonate glazing with an area of approximately 4 m^2. A Foster design of shelters (opaque roof, widely used in the UK designed by Norman Foster) is provided by the JCDecaux company. It has an area of approximately 6 m^2 and uses fibreglass as a glazing material with a cost of £8000/unit (A. Renwick, personal communication, 19 April 2022). Edinburgh has identified six Air Quality Management Areas (AQMA). These areas, including the city centre and main routes to the centre, are characterised by city canyons and high vehicle traffic, with a high proportion of bus shelters. Pollution management programmes, including Cleaner Air for Scotland—The Road to a Healthier Future [52], only focus on the source of pollution instead of addressing already produced air pollution as well [56]. While many cities have mandated the incorporation of green infrastructure on all new buildings, Edinburgh has not yet introduced such a mandate. Currently, 83 GRs have been recorded in the City of Edinburgh, primarily located in the city centre, covering 22.4% of the rooftop area, of which 53 are EGRs [1]. However, there are no EGRs installed on bus shelters yet. EGRs in Edinburgh could help with increased heavy rain periods and related runoff (The Edinburgh Partnership, 2012), provide green spaces, and support biodiversity threatened by urban infrastructure development. They can contribute to thermal regulation, and may be one of the solutions to mitigate already-produced air pollution [39].

Figure 3. Current bus stops across the City of Edinburgh (September 2023).

2.2. Best Tool

This study was conducted using B£ST version 5_1_1 v0C, July 2019, with the manual release version 4.01a, 2019 (Appendix A). B£ST is published by CIRIA, with the default values based on UK standards. It consists of three parts: (1) W047a B£ST—spreadsheet-based benefits estimation tool; (2) W047b B£ST—complex guidance including background to the tool, instructions on completing the assessment, and data input suggestions; and (3) W047c B£ST—a comparison tool when comparing more than one scenario. B£ST is used to evaluate and monetise the long-term benefits of blue-green infrastructure (BGI) and compare various scenarios [57].

The methodology of the B£ST tool is primarily based on the study by Ashley et al. [58] and on stakeholders' engagement supporting the likeliness of the benefits to have the greatest significance [59]. The monetary valuation of benefits is based on market and non-market evidence. The complete list of resources used as evidence for B£ST establishment can be found in the Values Library included in the tool or the B£ST evidence review summary [60].

The Values Library suggests low and high values for all the benefits, background studies, related years, guidance on use, double-counting caution, and additional context. All the future benefits are discounted to ensure consistency. This puts higher importance on the benefits occurring now, which significantly lowers the value of benefits occurring in the future. The standard discount rate of 3.5% is used. The tool considers uncertainties in assessment and, therefore, allows users to apply confidence scores (25%, 50%, 75%, 100%) based on how confident they feel about the benefits realisation [61]. Confidence scores account for quantified performance data and monetising the outcomes. The optimised bias is very minimised in the tool by the suggested values, which, on the other hand, may result in underrated net present values [57].

The B£ST tool requires the input of site-specific information to obtain an output. The results help to understand the benefits and costs of the planned investment and aid decision-making. B£ST divides benefits into four categories: regulating, supporting, cultural, and provisioning (Table 1), from which seven individual benefits were chosen for the study (air quality, biodiversity and ecology, carbon sequestration, flooding, amenity, education, health). The benefit of UHI was manually calculated and was not included in the B£ST due to the lack of B£ST's values and options. The decision on benefits chosen was based on the initial screening questions provided in the spreadsheet within the B£ST tool (W047a). The complex guidance [59] with the suggested values was followed in this study.

2.3. Input Data and Calculations

The baseline scenario representing the current situation (no EGRs installed on bus shelters) was compared to the installation of EGRs on 1454 bus shelters with 6 m^2. It was assumed that the life expectancy of GRs is 40 years [62]. As a result of the current bus shelter structure, the retrofitting option was unavailable (A. Renwick, personal communication, 19 April 2022), and therefore, the construction of new bus shelters capable of supporting the green roof and their installation was needed and was estimated at £11,000/unit. The cost was adapted from the cost of a green bus shelter by the Clear Channel company (£9237), excluding construction and maintenance costs, and the cost of their standard bus stop design (£7662) (D. Zhao, personal communication, 26 April 2022). This was compared to the standard Foster design bus stop provided by JCDecaux in Edinburgh (£8000). Yearly maintenance costs and labour were assumed to be included in the estimation based on personal communication with a Senior Transport Team Leader in Edinburgh, A. Renwick (A. Renwick, personal communication, 19 April 2022). The maintenance of extensive green roofs included annual fertilisation, plant management consisting of the removal and replacement of dead plants or undesirable species, and general maintenance such as deep cleaning of the roof parts [39].

Table 1. Benefits and their categorisation in the B£ST tool.

Category	Benefits
Regulating	Air quality *, building temperature, carbon reduction, and sequestration *, flooding *, water quality, water quantity
Supporting	Biodiversity and ecology *
Cultural	Amenity *, crime, education *, flooding *, health *, noise, recreation, traffic calming, water quality
Provisioning	Asset performance, crime, economic growth, enabling development, tourism, water quantity

* chosen benefits for this study.

CBA was carried out using B£ST to analyse potential benefit values versus costs related to the construction and maintenance of GRs. It was assessed for 40 years (i.e., the expected life span of GRs). A 3.5% discount rate was used until the year 2048, then 3.0% until 2062, with the modification for air pollution being 1.5% and 1.29%, respectively, in line with the HM Treasury's Green Book guidance [59,63].

2.3.1. Air Quality

Removal levels of SO_2, NO_2, PM_{10}, and O_3 were calculated for an area of EGRs. B£ST's default values of removal levels based on the studies by Yang et al. [56] and Currie and Bass [33] were used (Table 2). The pollutant removal monetary value was not available for O_3 and, therefore, was excluded from the benefit value estimation. The conversion of PM_{10} and $PM_{2.5}$ was carried out by a conversion factor of 0.644 [64]. Higher quantity confidence values were assigned to pollutants that reached higher levels in Edinburgh (NO_2, PM_{10}). Monetary values were set to 100% as they were based on real market data [59].

2.3.2. Biodiversity and Ecology

Improved grassland was chosen from the available options assuming the closest match to the green roof nature. A high confidence score regarding quantity was assigned (100%) as there is currently no green infrastructure on the bus shelters. Moreover, 75% of the confidence score was assigned to monetary value, as suggested in the guidance (Table 3) [59].

Table 2. Air quality values used in the B£ST tool.

Section AQ2 Used *						
					Confidence Score	
	Green Roof Extensive (ha)	Duration	Pollutant	Vegetation Pollutant Removal Levels (Tonnes/Year/ha) /Default Values/	Quantity for All Pollution Removal Values	Valuation for All Monetary Values (£)
Baseline option	-	-	-	-	-	-
Proposed option	0.8724	2022–2062	SO_2	0.0198	50%	100%
			NO_2	0.0233	75%	100%
			O_3	0.0450	50%	100%
			PM_{10}	0.0065	75%	100%

* section dedicated to using default values.

Table 3. Biodiversity and Ecology values used in the B£ST tool.

Section BE2 Used *: Changes to Biodiversity and Ecology Land Use (Only One Type)					
				Confidence Score	
	State of Existing Area of Intervention (ha)	Type of Area of Intervention Selection	Duration	Quantity	Valuation (£)
Baseline option	0	-	-	-	-
Proposed option	0.8724	Improved grassland	2022–2062	100%	75%

* section dedicated to using default values.

2.3.3. Carbon Sequestration

As the calculation options by B£ST were only provided for deciduous and coniferous trees, a manual calculation was conducted, and the present value was inserted into the analytical tool (Table 4). A study from Berlin (Germany) was used for a reference due to the most similar climate conditions and green roof properties (9-cm substrate depth; non-irrigated; *Sedum floriferum*, *S. album*, and *Allium schoenoprasum*) [65]. Their 100% vegetation coverage scenario's result (212.5 g C/m^2 yearly) was used as the same was assumed for this study. Their result was scaled up to Edinburgh's bus shelter area.

Table 4. Carbon sequestration values used in the B£ST tool.

Section CS1 Used *				
			Confidence Score	
	Present Value of the Benefit (£)	Duration	Quantity	Valuation (£)
Baseline option	-	-	-	-
Proposed option	2192	2022–2062	75%	100%

* section dedicated to values from the user's independent assessment.

Monetary value was calculated based on the current price for traded carbon [66]. The discount rate of 3.5% for 40 years was applied in Microsoft Excel (Version 2308) using the XNPV function. The value was then used in the B£ST analysis as a benefit's present value.

The confidence score regarding monetary valuation was set to 100% as the values were assigned based on the current trade carbon price. Considering vegetation mortality, the quantity confidence score was lowered to 75% [59].

2.3.4. Flooding (Rainwater Runoff)

Rainwater runoff reduction (classified as 'flooding' in the B£ST tool) benefit valuation was manually calculated. Rainwater retention of GRs was assumed to be 55% based on the studies from the UK with >80% vegetation coverage, *Sedum* species, or a mixture of *Sedum* species, moss, and herb species [11,39,67]. Equation (1a) was used to calculate rainwater retention per year in Edinburgh.

$$\begin{gathered}\text{retained rainwater/year} = \text{annual average rainfall in Edinburgh} \times \text{bus shelter area} \times \text{retention} \\ \text{retained rainwater/year } (\text{m}^3/\text{year}) = 727.7\ (\text{m}^3/\text{m}^2) \times 8724\ (\text{m}^2) \times 0.55\end{gathered} \tag{1a}$$

The annual damage cost from flooding in Edinburgh was used as a baseline benefit's present value [68]. The cost divided by the impermeable area of the city [69], followed by scaling up to the area of bus shelters, resulted in the avoided cost per year. The retention percentage was considered as well (Equation (1b)).

$$\begin{gathered}\text{avoided cost/year} = \text{annual damage cost/impermeable city area} \times \text{bus shelter area} \times \text{retention} \\ \text{avoided cost per year } (\pounds/\text{year}) = \pounds 8{,}500{,}000/175\ (\text{km}^2) \times 0.008724\ (\text{km}^2) \times 0.55\end{gathered} \tag{1b}$$

The benefit's present value was calculated through the discount rate of 3.5% for 40 years. The difference from the baseline scenario was used as present value damage in the B£ST analysis. The confidence score for monetary values was set high (100%) as they are based on the local data set for the annual damage cost. The confidence score regarding the quantitative estimate was set to 75%, assuming the accuracy of the manual calculation (Table 5) [59].

Table 5. Flooding values used in the B£ST tool.

Section F1 *				
			Confidence Score	
	Present Value Damage before Confidence Applied (£)	**Duration**	**Quantity**	**Valuation (£)**
Baseline option	8,500,000	-	75%	100%
Proposed option	8,494,942	2022–2062	75%	100%

* section dedicated to values from the user's independent assessment.

2.3.5. Urban Heat Island

The evaluation of UHI benefit through B£ST was unavailable due to the projection of GRs on bus stops instead of buildings. Surface area temperature was manually calculated through the specific heat coefficient (Table 6). The specific heat value for shelter material [70] and soil [71] was used. Individual values of specific heat were multiplied by the average highest city temperature [72] to find the energy (J) needed to heat the material to the required temperature (Equation (2a,b)).

Table 6. Specific heat values of shelter materials.

Specific Heat Values	
Fibreglass	700 J/kg C
Dry Soil	800 J/kg C
Wet Soil	1480 J/kg C
Medium Soil	1140 J/kg C

The same amount of energy was then projected onto both soil and conventional shelter material to find the difference in the temperature reached. The difference between temperatures represents how much hotter/cooler the surfaces would be with the same amount of energy received (Equation (2c,d)).

Due to the inability to calculate the air temperature via B£ST or manually, it was adapted from Berardi [73] and estimated to be reduced by 0.2 °C at the pedestrian level. In Berardi's study, the substrate depth was 15 cm, and EnviroMet analysis was used for the 24-h simulation.

$$\begin{gathered}\text{Energy required to heat a kg of fiberglass to } 19.5\ ^\circ\text{C} = \text{specific heat coefficient for fiberglass} \times 19.5\ ^\circ\text{C} \\ 13{,}650 \text{ J/kg} = 700 \text{ J/kg C} \times 19.5\ ^\circ\text{C}\end{gathered} \tag{2a}$$

$$\begin{gathered}\text{Energy required to heat a kg of medium soil to } 19.5\ ^\circ\text{C} = \text{specific heat coefficient for medium soil} \times 19.5\ ^\circ\text{C} \\ 22{,}230 \text{ J/kg} = 1140 \text{ J/kg C} \times 19.5\ ^\circ\text{C}\end{gathered} \tag{2b}$$

$$\begin{gathered}\text{temperature to which fiberglass will be heated at the time when medium soil will be heated to } 19.5\ ^\circ\text{C} = \\ \text{energy required to heat a kg of medium soil to } 19.5\ ^\circ\text{C/specific heat coefficient for fiberglass} \\ 31.7\ ^\circ\text{C} = 22{,}230 \text{ J/kg/700 J/kg}\end{gathered} \tag{2c}$$

$$\begin{gathered}\text{Temperature difference with the same amount of energy received} = \\ \text{energy required to heat a kg of medium soil to } 19.5\ ^\circ\text{C/specific heat coefficient for fiberglass} \\ \text{Temperature difference with the same amount of energy received } (^\circ\text{C}) = 31.7 - 19.5\ ^\circ\text{C}\end{gathered} \tag{2d}$$

2.3.6. Amenity

The baseline scenario was calculated based on the percentage of Scots living within 5 min access to green space [74]. The same percentage was assumed for Edinburgh residents. For the proposed option, residents living within a 100-m radius of the bus stop were added to the baseline scenario. It was calculated by Equation (3). Confidence scores relating to quantitative estimates and monetary values were set low due to the software settings considering small trees (Table 7).

$$\begin{gathered}\text{People living within a 100-m radius from bus stops} = \text{area of a circle (r = 100 m)} \times \text{number of bus shelters} \times \text{population density} \\ \text{No. of people living within a 100-m radius from bus stop} = 0.0314\ (\text{km}^2) \times 1454\ (\text{bus shelters}) \times 2003\ (\text{residents/km}^2)\end{gathered} \tag{3}$$

Table 7. Amenity values used in the B£ST tool.

Section AM2 Used *: Street Improvements through Greening					
				Confidence Score	
	Estimated No. of Residents Living in Green Streets	Monetary Value Selection (£/Year/Resident)	Duration	Quantity	Valuation (£)
Baseline option	232,152	Low (21.97)	-	50%	25%
Proposed option	322,287	Low (21.97)	2022–2062	50%	25%

* section dedicated to using default values.

2.3.7. Education

It was assumed that GRs installed on the bus shelters would have an educational effect on all people using bus stops. The percentage of people using bus stops [75] was considered a proposed scenario for the B£ST's required estimation of the number of students visiting the site annually. The percentage of non-sheltered bus stops was excluded from the calculation (Equation (4)). Based on the B£ST guidance suggestion, confidence scores were set low due to the scarcity of evidence [59] (Table 8).

$$\begin{gathered}\text{No. of people visiting sheltered bus stops} = \text{no. of people using buses at least once per month} \times \%\text{ of sheltered bus stops} \\ \text{No. of people visiting sheltered bus stops} = 205{,}771\ (\text{people}) \times 0.64\%\end{gathered} \tag{4}$$

Table 8. Education values used in the B£ST tool.

Section Edu2 * Used					
				Confidence Score	
	Estimated No. of Students Visiting per Year	Monetary Value Selection (£/Student/Trip)	Duration	Quantity	Valuation (£)
Baseline option	0	Low (16.93)	-	-	25%
Proposed option	131,693	Low (16.93)	2022–2062	25%	50%

* section dedicated to using default values.

2.3.8. Health

The same assumption regarding the estimated number of visits per year was made here as in amenity benefit. A high confidence score (75%) was assigned to both quantitative estimates and monetary values based on the accurate assumption of the number of people associated with the green roofs on bus shelters and on the scheme context matching our study [59] (Table 9).

Table 9. Health values used in the B£ST tool.

Section H2b Used *: Physical Activity Avoided Costs					
				Confidence Score	
	Estimated No. of Visits by Adults to Green Space per Year	Monetary Value Selection (£)	Duration	Quantity	Valuation (£)
Baseline option	232,152	Average (2.55)	-	75%	75%
Proposed option	322,287	Average (2.55)	2022–2062	75%	75%

* section dedicated to using default values.

3. Results

3.1. Social Benefits

Social (identified as 'cultural' in B£ST) ecosystem services of GRs include amenity, education, and health benefits. It was estimated that 232,152 residents of Edinburgh live within 5 min from access to green spaces, which were used as a base for amenity and health benefits. The density of 2003 people/km^2 was multiplied by 45 km^2, representing the 100-m radius of all sheltered bus stops. An additional 90,135 residents benefiting from the GRs on bus stops (including amenity and health benefits) were added to the baseline scenario, resulting in 322,287 residents. Social benefits showed significantly higher benefit value than environmental benefits.

3.2. Environmental Benefits

B£ST distinguishes regulating (air quality, carbon sequestration, stormwater runoff, and urban heat island) and supporting (biodiversity) benefits, which this study classifies together as environmental benefits. Total annual pollution removal (SO_2, O_3, NO_2, and PM_{10}) was estimated at 0.0825 t for the proposed scenario. Table 10 shows removal estimates, monetary values, and present values (PVs) before and after confidence for each calculated pollutant; 8724 m^2 of GRs installed on bus shelters would sequester 1.8 t of carbon and retain 3491.65 m^3 of rainwater per year. The yearly runoff would be 2856.8 m^3. £0.048 was the yearly damage cost for 1 m^2 of the impermeable area in Edinburgh. Assuming a 55% retention capacity, the installation of GRs in this area avoids a cost of £5058 per year.

Table 10. Removal values, monetary values, and present values before and after confidence score applied for each of the pollutants when GRs are installed on all Edinburgh's bus shelters.

Pollutant	Annual Pollutant Removal Estimates (t)	Annual Pollutant Removal Benefit (£) *	Present Value before Confidence Applied (£)	Present Value after Confidence Applied (£)
SO_2	0.0173	29	851	425
NO_2	0.0203	218	6384	4788
O_3	0.0392	-	-	-
PM10	0.0057	398	11,641	8731
TOTAL	*0.0825*	-	*18,876*	*13,944*

* Calculated as annual removal estimation × removal monetary value.

The benefit of UHI is not included in the B£ST analysis. The surface temperature of the conventional fibreglass roof would be 12.2 °C higher when heated by the same amount of energy as medium-wet soil. Fibreglass would reach 31.7 °C, receiving 22,230 J energy, while medium wet soil would only reach 19.5 °C (Edinburgh's highest average temperature) [72] with the same energy received. The difference between ambient air temperature at a pedestrian level near a green bus stop and a conventional bus stop may be 0.2 °C, according to studies and a consideration of the relatively small area of one bus stop. The supporting benefit of biodiversity scored the lowest present value of all calculated benefits.

3.3. Present Values and Cost-Benefit Analysis

PVs of benefits are higher before confidence is applied compared to values after confidence scores. Education has the highest PV. Each of the benefit's PVs before and after applying the confidence score is shown in Table 11.

Table 11. Present values of each benefit before and after the confidence score was applied.

Benefit Category	Present Value before Confidence Applied (£)	Present Value after Confidence Applied (£)
Air quality	18,876	13,944
Amenity	38,888,652	4,861,082
Biodiversity and ecology	648	486
Carbon reduction and sequestration	2192	1644
Education	43,787,559	5,473,445
Flooding	5058	3794
Health	4,508,776	2,536,186

A significant difference between the PV before and after the confidence score was applied is mainly shown in cultural benefits (Figure 4) due to the higher quantity and monetary value uncertainty. Cultural benefits had the highest PV. Air quality had the highest PV from regulating and supporting ecosystem services, followed by a decreased risk of flooding. Biodiversity resulted in the lowest PV. However, UHI benefit reduction was not included in the B£ST analysis.

A summary of total benefits and costs is presented in Table 12. The proposed scenario resulted in a positive net present value (NPV) if confidence scores were not applied. When confidence scores were considered, costs exceeded benefits by £3.1 million. The benefit-cost ratio was significantly lower after confidence scores were applied. Similarly, NPV was the highest before the confidence score was applied. The benefit distribution score indicates the flexibility of the scenario's performance on a range of A–E, where A is the most flexible [59]. After applying the confidence score, the proposed scenario attained C, representing flexibility to some extent.

Table 12. Summary of total benefits and costs, net present value, benefit-cost ratio, and benefit distribution score are presented.

Present Value Assessment Stage	Total PV Benefits (£)	Total PV Costs (£)	Net Present Value (£)	Benefit-Cost Ratio	Benefit Distribution Score
Present Value before confidence applied	87,211,761	15,994,000	71,217,761	5.5	D
Present Value after confidence applied	12,890,581	15,994,000	−3,103,419	0.8	C

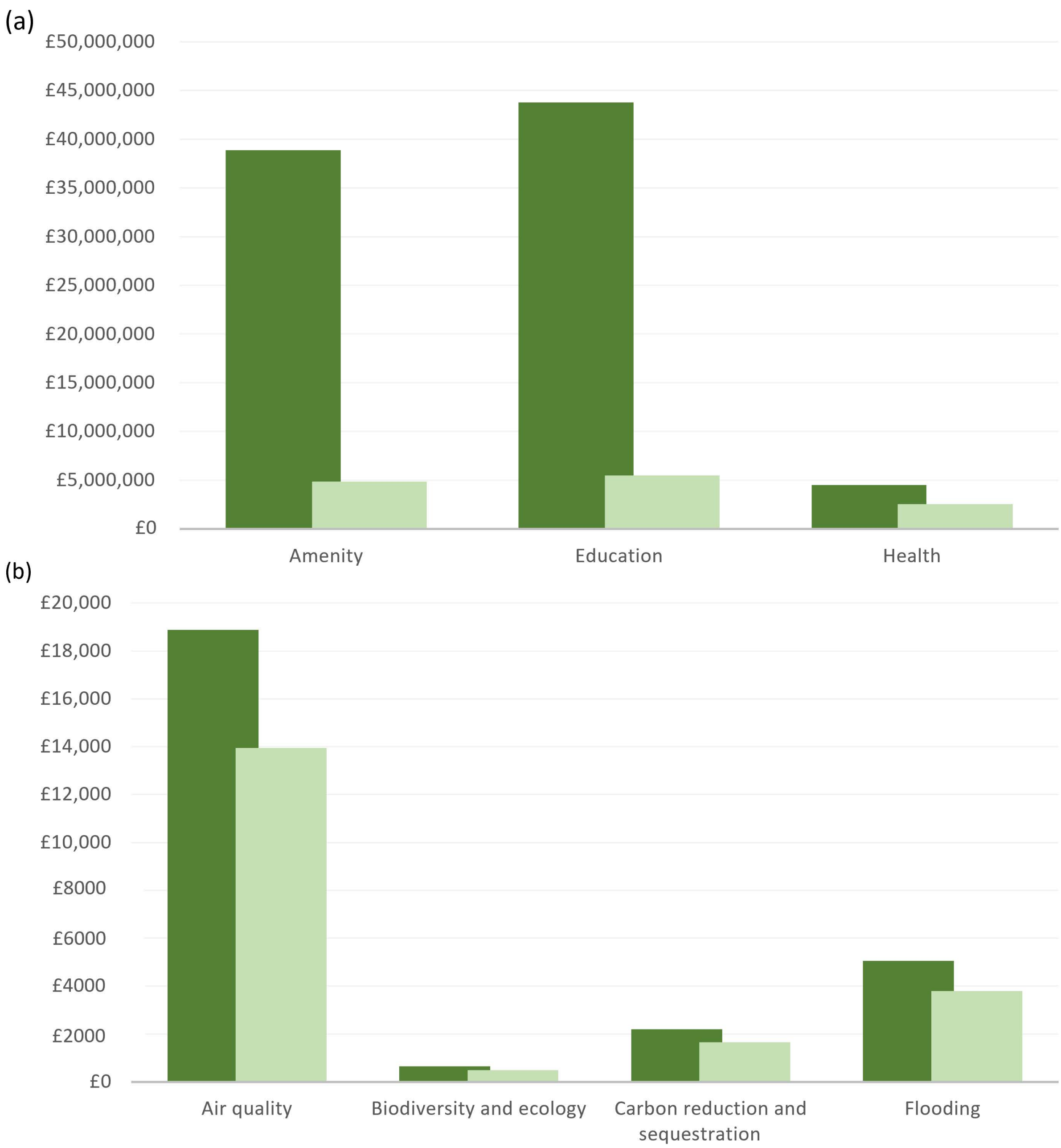

Figure 4. Cultural benefit present value comparison (**a**) and regulating and supporting benefit present value comparison (**b**) for the proposed scenario.

4. Discussion

The quantification of benefits of GRs application on Edinburgh bus shelters showed great opportunities to enhance the mitigation of urban climatic problems, thus supporting the first hypothesis assuming that the application of EGRs will provide the city with multiple quantifiable benefits. In contrast, the second hypothesis did not appear to hold, acknowledged by higher associated costs than benefits value.

Despite analysis resulting in negative NPV, it also showed a range of benefits. It should be noted that the valuation was inclined toward the worst-case scenario due to the assumption-based analysis and B£ST confidence score system, allowing a maximum of 100% (resulting in the same PV as before confidence) or lower (resulting in lower PV) values. However, the breakeven point might have been reached by finding a different design for the GR or provider that would reduce initial costs or by enhancing the GR benefits, which would support the second hypothesis. The benefit distribution score also showed medium flexibility. This was caused by high differences between benefit categories (cultural, regulating, supporting) but minor differences in benefits within each category.

The discussion below addresses the results associated with the specific benefit categories, their limitations due to the scope of analysis and the methodology used, recommendations for Edinburgh, implications for other cities, and suggestions for further work.

4.1. Benefits of Green Roofs

This study was solely based on previous literature, with no in situ experiment carried out using the estimation tool B£ST. B£ST analysis provides many functions. However, its results might be biased due to the limited options, specifically for GRs projects. Most entered values, including confidence scores, were based on assumptions and estimation, which may over- or underestimate the results. A combination of the carbon sequestration and flood risk NPV calculated via the Excel XNPV function and the rest of the benefits NPV calculated through B£ST may show different results. It should be noted that the Excel XNPV function considers a stable discount rate throughout all 40 years. In reality, however, the discount rate is likely to be variable. The whole area of the bus shelters was assumed to be covered by plants, and no margins were considered, which may result in overestimation. The main limitations include a lack of research in the study area addressing GRs benefits, especially when installed elsewhere than on buildings and an assumption-based approach.

4.1.1. Social Benefits (Cultural)

Amenity and Health

In total, 322,287 residents would have benefited from the GRs on bus stops. The majority of bus stops in the City of Edinburgh are in highly populated areas. Compared to typical buildings, their relatively short height results in better visibility of GRs installed on their shelters at the pedestrian level. The prevalence of double-decker buses also increases their visibility from their upper deck. It was assumed that all people living close by (presuming they are passing by) would be positively affected by the greening of bus stops regarding amenity and health benefits. It is expected that people who live near the bus stops will also use public transport. Therefore, regular public transport users were not added to the number of residents living near the bus stops to avoid double-counting. However, there is a possibility of an overestimation of results due to the double-counting when considering the same people do benefit from amenity and health benefits from the green bus shelters.

It should also be noted that while some people can find the *Sedum* green roof attractive, for some others, it may inspire a boring or messy feeling [76]. Similarly, it may not provide the same aesthetic benefit throughout all seasons [77]. These findings support the evidence that GRs can serve residents with psychological benefits, although we need to consider differences in human perceptions. Therefore, the assumptions and confidence score regarding the amenity and health may be over- or underrated, resulting in biased benefits PV.

Education

The highest PV (before and after the confidence score) is for education benefit. The similarity between amenity and health benefit outcomes may have caused double counting with the result of overrated benefits PV. It was assumed that all regular public transport users would benefit from the educational aspect of GRs. This is due to the possible infographic displayed inside the bus stop in addition to installing the green roof explaining the different GR benefits and raising general environmental awareness with possible solutions. The combination of double-decker buses, the street area, and the height of the bus shelters make them the best locality option for the GR installation for educational purposes. They can serve as live educational material accessible to a large number of people. Based on the location of bus stops, different audiences can be targeted. In addition to residents of the City of Edinburgh, the GR installation would educate international students and tourists.

Similar projects in New York, Boston, and Leicester support our results. In New York, a GR was installed on the 'BioBus' as an addition to the educational posters inside the bus resulting in an easy introduction to the GR topic [44]. It resulted in positive feedback, raised awareness of environmental issues such as stormwater management or UHI and green infrastructure solutions, and encouraged the environmentally conscious behaviour of residents. Wildflower green bus stops installed in Leicester received positive feedback from residents but also received international attention (D. Zhao, personal communication, 26 April 2022). In Boston, the 'Science to Go' project was created to raise public awareness of climate change via QR codes placed throughout the city with a link to the website with more information.

The main limitations regarding social benefits are assumptions about how many people would be (positively) affected by installing GRs. These assumptions, however, may not reflect the reality due to:

- Only permanent residents were considered, but Edinburgh has many temporary residents and tourists who might be positively affected as well;
- Only regular public transport users were considered, although pedestrians can benefit as well;
- Only people living within a 100-m radius were added to the baseline scenario based on Scotland's percentage instead of Edinburgh's.

Similarly, the relationship between the number of bus stops and the people affected was considered to be linear. However, it is very likely that even a few installed GRs would have high benefit value. It is, therefore, likely that our results underestimate the benefit value achievable by the proposed scenario.

4.1.2. Environmental Benefits

Air Pollution

Total annual air pollution sequestration by 8724 m^2 of EGRs was estimated at 0.0825 t. However, the O_3 sequestration value was not included due to the lack of data in the B£ST analysis. In previous studies, a green roof with short grass sequestered 4.3 g/m^2 of O_3, which constituted the highest portion (52%) of all sequestered pollutants (O_3, NO_2, PM_{10}, SO_2) [56]. In Toronto, O_3 sequestration posed 41.7% of the total pollutant sequestration [33]. O_3 currently represents 0.0559 mg/m^3 pollution in Edinburgh (from 28 March 2022) and exceeded the objective value in 2018 [78]. Without including it in the analysis, the benefits may be considerably underestimated.

The performance of GR and the pollution level are highly dependent on many factors. These include climate, seasonality, vegetation types and biodiversity, aerosol chemistry, leaf morphology, canopy structure, or distance from the road [79–81], which need to be considered in further studies. For example, air pollution in urban areas of the Northern Hemisphere is more likely to form in winter due to increased heating, related emissions, and atmospheric inversions. Furthermore, increased leaf density, reflectance, evapotranspiration rate, and cooling effect can change GR performance on PM sequestration [82]. These factors are locally dependent and have not been explicitly calculated for Edinburgh, which might bias the results.

In general, there is a lack of studies focusing on air pollution sequestration by GRs compared to research on trees or parks. Therefore, it is challenging to make a viable comparison. Only a few studies are repeatedly cited throughout the available literature, and those are Pugh et al. [83], Currie and Bass [33], and Yang et al. [56]. However, these heavily rely on modelling and deposition velocities estimation, all based on values not determined for GRs [80,84]. Additionally, the pollution saturation point of GRs is unknown due to the lack of research. Thus, we cannot be sure how long pollution can be sequestered or when the harvest is needed for sequestration ability restoration [84]. All these issues should be addressed by future research.

CO_2 Sequestration

A total of 1.8 t of carbon yearly would be sequestered with installed EGRs, comparable with the study by Getter et al. [62], which would result in 1.6 t of carbon per year if applied to Edinburgh bus shelters. Similar to air pollution, the carbon sequestration saturation point is unknown, and therefore, the result may be over-rated during later years. However, the construction of GRs and related carbon emissions need to be considered. GR providers already offer carbon-negative GR designs, such as Bridgman&Bridgman; installing green bus shelters in Milton Keynes saves 440 kg of CO_2 per bus shelter [85].

Various factors affect the carbon sequestration performance of GR, including their age and design, fertiliser application, species selection, or substrate depth. With increased substrate depth, higher biodiversity with various primary production and biomass is supported, thus, higher below- and aboveground carbon may be stored. It should be noted, however, that EGRs support plant species which are characterised by repeating short life cycles, after which microorganisms decompose plants and carbon is released back into the atmosphere by respiration processes. To conclude, EGRs are not the most efficient carbon sink and should not be presented as the main solution to direct carbon sequestration [62].

Rainwater Runoff

Our results show that almost 3.5 thousand m^3 of rainwater could be retained, avoiding a damage cost of £5058 every year by installing GRs onto Edinburgh bus shelters if the retention capacity is 55%. Various studies agree that the retention of the EGRs is between 40–80% [9,10,23,86–89].

However, the intensity and depth of rainfall are also important factors in retention capacity [10,67,90–92]. Retention on a single-event basis may vary from 0% during heavy rainfall events to 100% during small rainfall events [9,67]. Nawaz et al. [11] found a variation in retention from 29.3% to 99.3% based on the rain event duration and depth, with 5.1 mm over 11.8 h and 2.04 mm over 6.77 h, respectively. This relationship was also proven by Simmons et al. [90], who found that rain events smaller than 10 mm were entirely retained.

The effective water capture performance of EGRs also depends on the substrate layer and plant evapotranspiration. A meta-analysis of 18 German studies [87] together with other studies [9,13,93–95] found that annual rainfall runoff has a strong positive relationship with substrate depth and its water holding capacity (WHC). All of these issues should be addressed by further research, which would help to decrease the uncertainty in the estimates obtained.

The restoration of retention capacity depends on climatic conditions, including humidity, air temperature, solar radiation, or wind speed [89,96], and varies seasonally or daily. A higher retention rate is expected in the summer due to the higher evapotranspiration rate [87,96,97]. This, however, may not be an important factor for the UK. UK temperate maritime climate causes a lower evapotranspiration rate throughout the year and a non-significant antecedent dry water period (ADWP) [11,67,98,99]. WHC may reach its saturation point much quicker due to the prior substrate moisture [14]. Nawaz et al. [11]

and Stovin et al. [67] found better GR retention performance in summer due to the lower rain depth and a much shorter duration of rain events rather than higher solar radiation recorded. In addition, the slope of the GR may influence single rain event runoff but has no significant relationship with runoff in long-term storm event modelling [86].

Quantifying retention capacity and runoff by GRs is a very complex topic, with myriad factors influencing it [11,87]. However, based on the demonstrated studies, GRs have a strong role in stormwater runoff management [67], as shown in our results. It should also be noted that the alleviation of runoff may result in a decrease in water quality downstream—another issue that should be investigated by further research [100].

Runoff Water Quality

Runoff water quality is important for the health and functioning of downstream ecosystems [101–104], but has not been explicitly accounted for in our calculations. When air pollutants such as NOx or PM are deposited on impervious surfaces, they are taken up by rainwater runoff ending in surface water, underground water and water bodies [105]. The toxicity of pollutants and heavy metals they contain causes severe or fatal problems to aquatic life [34,106,107]. The quality of runoff from GR is controversial, as studies report mixed results. Several studies prove that GRs filtrate pollutants from rainwater runoff by capturing them in the substrate and vegetation layers [39,91,108]. Conversely, some studies suggest that pollutants, including heavy metals, are taken up by runoff while proceeding through GR layers, where pollutants are captured by dry or wet deposition [9,109]. The appearance of heavy metals in the GR runoff may be caused by unprotected metal surfaces around the green roof, such as copper or zinc, unsuitable substrate composition being unable to capture pollutants or being the polluter itself by added fertilisers [97,107,110,111]. Therefore, official guidance and tests should be followed during the construction of GRs and should not necessarily be used as a primary tool for water quality improvement. However, it was proven that pollution would be lower from GRs compared to conventional roofs in every case [108,110], although recent work suggests that the deterioration of water quality in receiving water bodies may result from complex interactions between runoff quantity and chemistry [100]. Further studies are needed to investigate these issues.

Urban Heat Island

In Edinburgh, the bus shelter surface temperatures could be reduced by 12.2 °C with GRs installed. This is comparable with the study from Toronto, where the roof surface temperature was lower by 15.8 °C and 21.7 °C with leaf area index (LAI) 1 and 2, respectively [73]. However, quantifying UHI mitigation by GRs installed elsewhere other than on the buildings is one of the biggest challenges. Most existing studies focus on GR insulation properties and indirect UHI mitigation through avoided emissions from reduced heat and cooling demand. Similarly, to calculate UHI mitigation in the B£ST analysis, only building temperature reduction was provided as an option, making it impossible to use in the study, causing underestimated results.

The highest reduction in temperature is expected in the late evening when GRs emit minimal heat compared to dark surfaces with low albedo releasing the heat during the evening and night [112]. Wong et al. [20] measured lower urban temperatures by 2–3 °C between 7 pm to 11 pm when GRs were present compared to the urban area without GRs.

The cooling effect is determined by the evapotranspiration and shadow effect of vegetation. This mainly depends on the substrate depth and its density, LAI, and local climate, specifically the humidity of the environment or wind speed and direction [24]. A lower evapotranspiration rate was found in non-vegetated GRs in Schweitzer and Erell's (2014) study, which was justified by plants' ability to provide shade, water storage, and better water control [113]. *Sedum* spp. are great adepts for EGRs, having a high shadow capacity, although they might not have the highest evapotranspiration rate [24].

A UK study found that wind, followed by cloud cover, is the strongest weather variable affecting UHI intensity [114]. Stronger wind increases the evapotranspiration rate and sensible heat flux by stimulating water vapour transfer from the soil and vegetation into the atmosphere [21,26]. It was determined that a wind speed increase from 0.1 m/s to 1 m/s can increase evapotranspiration by 10–30% [113]. These issues influence our estimates' uncertainty and should be addressed by future research.

Biodiversity

Although the biodiversity benefit resulted in the lowest PV in the B£ST analysis, GRs were analysed as an 'improved grassland', which might bias the results. Practical implementations need to be carried out in order to improve the estimates in future research. With their nature and location, the design of EGRs on bus stops could aim to imitate the conditions of the natural habitats on cliff tops and ledges, defined by drought conditions, strong winds, and shallow, low-nutrient growing medium, creating habitats for both specialists and generalists. Various substrate designs are desirable for providing different microhabitats for the range of organisms. These might combine contrasting substrate depth, moisture content, and vegetation density with a spectrum of natural elements [37].

Based on a case studies summary by Köhler and Ksiazek-Mikenas [37], besides substrate design, the variation of planted species on GRs and in the surrounding areas, as well as maintenance, are very important. Resource specialisation and structural diversity in terms of resources are essential to support different pollinators. Diversity in species also avoids full-scale mortality during unfavourable seasonal conditions when sensitive species may die. Dunnett [115] found *Sedum acre* declined after initial abundance. Kohler [116] found that only 10–15 species were consistent throughout a 20-year study of Berlin's EGRs. Nevertheless, any additional habitat in urban areas enhancing biodiversity and supporting pollinators is undoubtedly beneficial and worth implementing [37].

4.2. Benefits of Green Roofs for Edinburgh and Other Cities

According to the analysis, installing EGRs onto all sheltered bus stops in Edinburgh would result in a higher cost than benefits considering confidence scores (−£3.1 million NPV). However, as these are solely based on assumptions and B£ST guidance, the results might be inaccurate and an experimental study should be carried out to avoid uncertainties. NPV also depend on GRs' lifespan. This study was projected for 40 years, although some instances in the literature suggest up to 60 years for GR longevity [62]. The cost and longevity also depend on the City Council's contract with their bus stop provider. It is not unusual for advertising companies to operate bus stops and the rest of the city's infrastructure. Bus stops provide companies with advertisement panels from which the City Council has income. Therefore, including this value in the overall benefits may be reasonable.

Even in the worst-case scenario, with costs overcoming benefits, installing GRs on visible spaces such as bus stops can provide the city with a huge benefit. Considering education has the highest NPV, any number of GRs installed on the bus stops would raise awareness of climatic problems and the solution green infrastructure can bring to urban areas. Moreover, it might encourage more people to use public transport, thus combating personal vehicle usage. Benefit quantification in this study proved that the installation of EGRs can help the City of Edinburgh reach the goals of a net-zero carbon city by 2030, City Vision 2050, and City Plan 2030. Additionally, it can help reach 10% of biodiversity net gain in any urban planning required by the recent Environmental Act [40] and provide benefits for initiatives such as Cleaner Air for Scotland—The Road to a Healthier Future [52].

Therefore, for the City of Edinburgh, it is recommended to:

- Consider economically convenient green bus stop providers for the following contract;
- Explore available funding and partnerships;
- Start with EGRs installation across the city to increase public knowledge, support biodiversity, and benefit from all provided services;
- Include GRs projections in the next City Plan.

It should also be noted that the installation of EGRs on bus stops is spreading worldwide, mainly as additional habitats and pollinator support. The Clear Channel company aims to install 2000 green bus stops (Bee Bus Stops) mainly focused on supporting pollinators across the UK until 2030. The company maintains the project at no additional cost to the Council. An increase in green infrastructure funding availability for the councils, partnerships with businesses and charities [117], and global awareness would lead to more cities following the green bus stops trend, going beyond the original extensive green roofing idea. In Brighton, a bus stop was enriched with *Sedum* plants planted in upcycled plastic bottles found at the nearby beach. The project is funded by the Clear Channel company, and in addition to environmental benefits, it provides full-time jobs for local homeless people [118]. In Milton Keynes, the city council provided £50,000 in funding for green infrastructure. Bridgman&Bridgman, Axiom, and Green Infrastructure consultancy companies collaborated and developed carbon-neutral green bus stops with solar panels [119]. Our study provides an approach to assessing the benefits and facilitating the CBA of these installations, which should be easily transferable to other cities and applicable worldwide.

This study reduces the identified research gap related to the scientific analysis of the costs and benefits resulting from the installation of green roofs. The Edinburgh case study reveals that the application of GRs will provide the city with multiple quantifiable benefits, and the first hypothesis, therefore, appears to hold. However, due to the uncertainties and logistical limitations, it was not possible to fully prove or disprove the second hypothesis, that the number of benefits provided through ecosystem services by GRs would offset the costs associated with the roof's installation and maintenance. Nevertheless, considering the above analysis, it is likely that, with careful planning, a positive outcome may be achievable in the majority of situations. This study will, therefore, be of value for further research and practical applications related to GRs. It should also be noted that our research is relevant to such broader issues as, e.g., the emission of greenhouse gasses (GHG) [120], developing design criteria for sustainable urban parks [121], and improving the acceptance of green infrastructure by the public [122].

5. Concluding Remarks

This study provides a monetary comparison of costs and benefits involved in EGRs application in bus shelters, which may improve future city planning and make the planning process more structured. The installation of EGRs provides excellent opportunities to make the City of Edinburgh a better and greener city and spread awareness of stormwater runoff management, UHI, the loss of biodiversity, and problems with air quality. Such a large-scale installation of EGRs in the city would contribute to £12.9–87.2 thousand PV benefits. The construction cost of 1454 EGRs was projected to be almost £16 million, which creates a negative NPV (−£3.1 million) considering the monetary value's and quantity's confidence scores. It is important to realise that this study has minimal optimised bias, hence, the costs might be more likely outweighed.

The City of Edinburgh can start by installing a few green bus stops while exploring the available funding. This will raise public awareness, which is one of the biggest obstacles to GRs installation worldwide. By installing GR bus stops across the city, Edinburgh can benefit from all of the provided environmental services and reach the goals of various sustainability programmes quicker.

The methodological approach applied here is easily transferrable thanks to the B£ST tool, allowing for input of user's data; hence, other cities (both in the UK and worldwide) will benefit from a systematic assessment of the costs and ecosystem services resulting from GR installation.

Relevance to Resilience: Installing green roofs in urban areas contributes to air quality, sustainable drainage systems, carbon sequestration, mitigating urban heat islands, supporting biodiversity, and creating new habitats. These ecosystem services play an essential role in the mitigation of and adaptation to changing climate.

Author Contributions: Methodology, Z.K. and V.K.; Validation, Z.K.; Formal analysis, Z.K. and V.K.; Investigation, Z.K. and V.K.; Resources, Z.K.; Writing—original draft, Z.K.; Writing—review & editing, V.K. and Z.K.; Visualization, Z.K.; Supervision, V.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data Availability Statement: This research uses B£ST—a publicly available analysis tool developed by CIRIA—for analysis of publicly available data detailed in the methodology section.

Acknowledgments: The authors would like to thank Caroline Nichol for her encouragement, help and support with this project. We also thank all the companies willing to share the information, especially Andrew Renwick from Lothian Buses, David Zhao from Clear Channel, Chris Bridgman (Bridgman&Bridgman), Gary Grant (Green Infrastructure Consultancy), and Phil Smith (Autocross Euroshel). Comments of Jiří Šubrt and anonymous referees helped to improve the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

ADWP	antecedent dry weather period
AQMA	Air Quality Management Areas
BNG	biodiversity net gain
B£ST	Benefits Estimation Tool
CBA	cost-benefit analysis
CO_2	carbon dioxide
EGR	extensive green roof
GHG	greenhouse gas
GR	green roof
IGR	intensive green roof
LAI	leaf area index
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NPV	net present value
O_3	ozone
OM	organic matter
PM	particulate matter
PV	present value
SO_2	sulfur dioxide
SuDS	Sustainable Drainage Systems
UHI	urban heat island
UK	United Kingdom
WHC	water holding capacity

Appendix A

Complex B£ST guidance: https://www.susdrain.org/files/resources/BeST/w047b_bst_guidance_release_5_v0b_issued.pdf (accessed on 20 April 2022).

References

1. Miller, K.; Krivtsov, V.; Cohen, L. Inventory of Green Roofs within Edinburgh, Scotland. In *CIGOS 2021, Emerging Technologies and Applications for Green Infrastructure. Lecture Notes in Civil Engineering*; Springer: Singapore, 2022; pp. 1345–1353. [CrossRef]
2. Krivtsov, V.; Arthur, S.; Allen, D.; O'Donnell, E. *Blue-Green Infrastructure–Perspectives on Planning, Evaluation and Collaboration*; CIRIA: London, UK, 2019.
3. Arthur, S.; Krivtsov, V.; Allen, D.; Ahilan, S.; Guan, M.; Haynes, H.; Sleigh, A.; Wright, N. *Blue-Green Infrastructure–Perspectives on Water Quality Benefits*; CIRIA: London, UK, 2019.
4. EPA. *Estimating the Environmental Effects of Green Roofs: A Case Study in Kansas City, Missouri*; EPA: Washington, DC, USA, 2018; p. 26.

5. Partnership, T.E. *Resilient Edinburgh-Climaze Change Adaptation Framework For Edinburgh 2014–2020*; Evidence Base and Risk Analysis; The Edinburgh Partnership: Edinburgh, UK, 2012.
6. Stovin, V.; Poë, S.; Berretta, C. A modelling study of long term green roof retention performance. *J. Environ. Manag.* **2013**, *131*, 206–215. [CrossRef] [PubMed]
7. Sutton, R.K. Introduction to Green Roof Ecosystems. In *Green Roof Ecosystems*; Sutton, R.K., Ed.; Springer International Publishing: Cham, Switzerland, 2015; pp. 1–25. [CrossRef]
8. DeNardo, J.C.; Jarrett, A.R.; Manbeck, H.B.; Beattie, D.J.; Berghage, R.D. Stormwater mitigation and surface temperature reduction by green roofs. *Trans. ASAE* **2005**, *48*, 1491–1496. [CrossRef]
9. VanWoert, N.; Rowe, D.; Andresen, J.; Rugh, C.; Fernandez, R.; Xiao, L. Green Roof Stormwater Retention: Effects of Roof Surface, Slope, and Media Depth. *J. Environ. Qual.* **2005**, *34*, 1036–1044. [CrossRef] [PubMed]
10. Carter, T.L.; Rasmussen, T.C. Hydrologic Behavior of Vegetated Roofs1. *JAWRA J. Am. Water Resour. Assoc.* **2006**, *42*, 1261–1274. [CrossRef]
11. Nawaz, R.; McDonald, A.; Postoyko, S. Hydrological performance of a full-scale extensive green roof located in a temperate climate. *Ecol. Eng.* **2015**, *82*, 66–80. [CrossRef]
12. Gong, Y.; Zhang, X.; Li, H.; Zhang, X.; He, S.; Miao, Y. A comparison of the growth status, rainfall retention and purification effects of four green roof plant species. *J. Environ. Manag.* **2021**, *278*, 111451. [CrossRef]
13. Soulis, K.X.; Ntoulas, N.; Nektarios, P.A.; Kargas, G. Runoff reduction from extensive green roofs having different substrate depth and plant cover. *Ecol. Eng.* **2017**, *102*, 80–89. [CrossRef]
14. Stovin, V.; Poë, S.; De-Ville, S.; Berretta, C. The influence of substrate and vegetation configuration on green roof hydrological performance. *Ecol. Eng.* **2015**, *85*, 159–172. [CrossRef]
15. Hamilton, I.; Stocker, J.; Evans, S.; Davies, M.; Carruthers, D. The impact of the London Olympic Parkland on the urban heat island. *J. Build. Perform. Simul.* **2014**, *7*, 119–132. [CrossRef]
16. United States Environmental Protection Agency. Heat Island Impacts. June 2014. Available online: https://www.epa.gov/heatislands/heat-island-impacts (accessed on 10 April 2022).
17. Carpentieri, M.; Kumar, P.; Robins, A. An overview of experimental results and dispersion modelling of nanoparticles in the wake of moving vehicles. *Environ. Pollut.* **2011**, *159*, 685–693. [CrossRef]
18. Yang, J.; Wang, Y.; Xiu, C.; Xiao, X.; Xia, J.; Jin, C. Optimizing local climate zones to mitigate urban heat island effect in human settlements. *J. Clean. Prod.* **2020**, *275*, 123767. [CrossRef]
19. Zhu, R.; Wong, M.S.; Guilbert, É.; Chan, P.-W. Understanding heat patterns produced by vehicular flows in urban areas. *Sci. Rep.* **2017**, *7*, 16309. [CrossRef] [PubMed]
20. Wong, N.H.; Chen, Y.; Ong, C.L.; Sia, A. Investigation of thermal benefits of rooftop garden in the tropical environment. *Build. Environ.* **2003**, *38*, 261–270. [CrossRef]
21. Cascone, S.; Arpón, J.C.; Gagliano, A.; Luque, G.P. The evapotranspiration process in green roofs: A review. *Build. Environ.* **2019**, *147*, 337–355. [CrossRef]
22. Jim, C.Y.; Peng, L.L.H. Weather effect on thermal and energy performance of an extensive tropical green roof. *Urban For. Urban Green.* **2012**, *11*, 73–85. [CrossRef]
23. Liu, K.; Minor, J. *Performance Evaluation of an Extensive Green Roof*; Presentation at Green Rooftops for Sustainable Communities: Washington, DC, USA, 2005; p. 14.
24. Pérez, G.; Vila, A.; Solé, C.; Coma, J.; Castell, A.; Cabeza, L.F. The thermal behaviour of extensive green roofs under low plant coverage conditions. *Energy Effic.* **2015**, *8*, 881–894. [CrossRef]
25. Susca, T.; Gaffin, S.R.; Dell'Osso, G.R. Positive effects of vegetation: Urban heat island and green roofs. *Environ. Pollut.* **2011**, *159*, 2119–2126. [CrossRef]
26. Tsang, S.W.; Jim, C.Y. Theoretical evaluation of thermal and energy performance of tropical green roofs. *Energy* **2011**, *36*, 3590–3598. [CrossRef]
27. Feng, C.; Meng, Q.; Zhang, Y. Theoretical and experimental analysis of the energy balance of extensive green roofs. *Energy Build.* **2010**, *42*, 959–965. [CrossRef]
28. Coutts, A.M.; Daly, E.; Beringer, J.; Tapper, N.J. Assessing practical measures to reduce urban heat: Green and cool roofs. *Build. Environ.* **2013**, *70*, 266–276. [CrossRef]
29. He, H.; Jim, C.Y. Simulation of thermodynamic transmission in green roof ecosystem. *Ecol. Model.* **2010**, *221*, 2949–2958. [CrossRef]
30. Bottalico, F.; Chirici, G.; Giannetti, F.; De Marco, A.; Nocentini, S.; Paoletti, E.; Salbitano, F.; Sanesi, G.; Serenelli, C.; Travaglini, D. Air Pollution Removal by Green Infrastructures and Urban Forests in the City of Florence. *Agric. Agric. Sci. Procedia* **2016**, *8*, 243–251. [CrossRef]
31. Hill, A.C. Vegetation: A sink for atmospheric pollutants. *Environ. Pollut.* **2017**, *231*, 207–218. [CrossRef] [PubMed]
32. Cai, M.; Xin, Z.; Yu, X. Spatio-temporal variations in PM leaf deposition: A meta-analysis. *Environ. Pollut.* **2017**, *231*, 207–218. [CrossRef]
33. Currie, B.; Bass, B. Estimates of air pollution mitigation with green plants and green roofs using the UFORE model. *Urban Ecosyst.* **2008**, *11*, 409–422. [CrossRef]

34. Speak, A.F. Quantification of the Environmental Impacts of Urban Green Roofs'. The University of Manchester. School of Environment and Development. 2013. Available online: https://www.research.manchester.ac.uk/portal/files/54539943/FULL_TEXT.PDF (accessed on 20 April 2022).
35. Zakrisson, A. Green Roof CO_2 Capture Explained. *Purple-Roof*. 2021. Available online: https://www.purple-roof.com/post/green-roof-co2-capture-explained (accessed on 15 April 2022).
36. Kuronuma, T.; Watanabe, H.; Ishihara, T.; Kou, D.; Toushima, K.; Ando, M.; Shindo, S. CO_2 Payoff of Extensive Green Roofs with Different Vegetation Species. *Sustainability* **2018**, *10*, 2256. [CrossRef]
37. Köhler, M.; Ksiazek-Mikenas, K. Chapter 3.14-Green Roofs as Habitats for Biodiversity. In *Nature Based Strategies for Urban and Building Sustainability*; Pérez, G., Perini, K., Eds.; Butterworth-Heinemannl: Oxford, UK, 2018; pp. 239–249. [CrossRef]
38. Thuring, C.; Grant, G. The Biodiversity of temperate extensive green roofs: A review of research and practice. *Isr. J. Ecol. Evol.* **2015**, *62*, 44–57. [CrossRef]
39. GRO. The GRO Green Roof Code. Green Roof Organisation. 2021. Available online: https://www.greenrooforganisation.org/wp-content/uploads/2021/03/GRO-Code-2021-Anniversary-Edition.pdf (accessed on 11 April 2022).
40. PAS. Biodiversity Net Gain | Local Government Association. Available online: https://www.local.gov.uk/pas/topics/environment/biodiversity-net-gain (accessed on 19 April 2022).
41. Prijs, M. Green-Roofed Bus Shelters | Closer Cities', *Closer Cities*. 2020. Available online: https://closercities.org/projects/green-roofed-bus-shelters#no-back (accessed on 20 April 2022).
42. Tomalty, R.; Komorowski, B. *The Monetary Value of the Soft Benefits of Green Roofs*; Smart Cities Research Services: Montreal, QC, Canada, 2010.
43. GSA. The Benefits and Challenges of Green Roofs on Public and Commercial Buildings. A Report of the United States General Services Administration. 2011. Available online: https://www.gsa.gov/cdnstatic/The_Benefits_and_Challenges_of_Green_Roofs_on_Public_and_Commercial_Buildings.pdf (accessed on 20 April 2022).
44. Andreoni, V.; Payne, K.; Sullivan, O. Promoting the Use of Green Roofs on Street-Level Surfaces to Improve Public Awareness about Stormwater Management in Boston. 2013. Available online: https://web.wpi.edu/Pubs/E-project/Available/E-project-101713-170426/unrestricted/Street-Level_Green_Roofs_to_Promote_Stormwater_Awareness.pdf (accessed on 20 April 2022).
45. ScienceToGo.org. ScienceToGo.org-Climate Change Awareness Boston, *Science To Go*. Available online: https://sciencetogo.org (accessed on 25 April 2022).
46. Márquez, M.I.V. Effectiveness of Green Roofs and Walls to Mitigate Atmospheric Particulate Matter Pollution in a Semi-Arid Climate. Pontificia un iversidad Catolica de Chile. School of Engineering. 2021. Available online: https://repositorio.uc.cl/xmlui/bitstream/handle/11534/61934/tesis%20MViecco11agosto_compressed.pdf (accessed on 20 April 2022).
47. USGS. Runoff: Surface and Overland Water Runoff | U.S. Geological Survey. 2018. Available online: https://www.usgs.gov/special-topics/water-science-school/science/runoff-surface-and-overland-water-runoff?qt-science_center_objects=0#overview (accessed on 19 March 2022).
48. ClearChannel. "Bee Bus Stops" Springing up in Leicester | Clear Channel UK. 2021. Available online: https://www.clearchannel.co.uk/latest/bee-bus-stops-springing-up-in-leicester (accessed on 30 April 2022).
49. SemperGreen. Green Bus Stops Ensure a Future-Proof City-Sempergreen. 2019. Available online: https://www.sempergreen.com/en/about-us/news/green-bus-stops-ensure-a-future-proof-city (accessed on 30 April 2022).
50. JCDecaux. State of the Art Bus Shelters for Manchester | JCDecaux UK. 9 November 2016. Available online: https://www.jcdecaux.co.uk/state-art-bus-shelters-manchester (accessed on 30 April 2022).
51. Murphy, S. Thriving Green Spaces Project, *The City of Edinburgh Council*. Available online: https://www.edinburgh.gov.uk/parks-greenspaces/thriving-green-spaces-project (accessed on 19 April 2022).
52. EFD. Cleaner air for Scotland: The Road to a Healther Future. List of Actions, *gov.scot*. 2015. Available online: http://www.gov.scot/publications/cleaner-air-scotland-road-healthier-future/pages/17/ (accessed on 26 April 2022).
53. CIRIA. B£ST. 2019. Available online: https://www.ciria.org/ItemDetail?iProductCode=W047AF&Category=FREEPUBS (accessed on 31 March 2022).
54. NRS. Edinburgh by Numbers 2021. The City of Edinburgh Council. National Records of Scotland. 2021. Available online: https://www.edinburgh.gov.uk/downloads/file/30669/edinburgh-by-numbers-2021 (accessed on 19 April 2022).
55. Buses, L. Lothian Buses: About Us. Available online: https://www.lothianbuses.com/about-us/ (accessed on 19 April 2022).
56. Yang, J.; Yu, Q.; Gong, P. Quantifying air pollution removal by green roofs in Chicago. *Atmospheric Environ.* **2008**, *42*, 7266–7273. [CrossRef]
57. Hamann, F.; Blecken, G.-T.; Ashley, R.M.; Viklander, M. Valuing the Multiple Benefits of Blue-Green Infrastructure for a Swedish Case Study: Contrasting the Economic Assessment Tools B£ST and TEEB. *J. Sustain. Water Built Environ.* **2020**, *6*, 05020003. [CrossRef]
58. Ashley, R.M.; Horton, B.; Digman, C.J.; Gill, E. Demonstrating the Multiple Benefits of SuDS—A Business Case—Literature Review. CIRIA. October 2013. Available online: https://www.susdrain.org/files/resources/ciria_guidance/ciria_rp993_literature_review_october_2013_.pdf (accessed on 20 April 2022).
59. Horton, B.; Digman, C.J.; Ashley, R.M.; McMullan, J. B£ST Guidance. Guidance to Assess the Benefits of Blue and Green Infrastructrie Using B£ST. CIRIA. 2019. Available online: https://www.susdrain.org/files/resources/BeST/ciria_best_online_help_190104.pdf (accessed on 15 April 2022).

60. CIRIA. CIRIA RP1074: Making B£ST Better B£ST Evidence Review Summary. CIRIA. June 2018. Available online: https://www.susdrain.org/files/resources/BeST/making_best_better_evidence_review_summary_june_2018_.pdf (accessed on 15 April 2022).
61. Ashley, R.; Gersonius, B.; Digman, C.; Horton, B.; Smith, B.; Shaffer, P. Including uncertainty in valuing blue and green infrastructure for stormwater management. *Ecosyst. Serv.* **2018**, *33*, 237–246. [CrossRef]
62. Getter, K.L.; Rowe, D.B.; Robertson, G.P.; Cregg, B.M.; Andresen, J.A. Carbon Sequestration Potential of Extensive Green Roofs. *Environ. Sci. Technol.* **2009**, *43*, 7564–7570. [CrossRef] [PubMed]
63. HMT. The Green Book: Appraisal and Evaluation in Central Government, *GOV.UK*. November 18 2022. Available online: https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent (accessed on 2 September 2023).
64. Air Quality Appraisal: Damage Cost Guidance; GOV.UK. 2021. Available online: https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance (accessed on 21 April 2022).
65. Heusinger, J.; Weber, S. Extensive green roof CO_2 exchange and its seasonal variation quantified by eddy covariance measurements. *Sci. Total. Environ.* **2017**, *607–608*, 623–632. [CrossRef] [PubMed]
66. Statista. UK: Projected Carbon Values 2018–2035, *Statista*. 2019. Available online: https://www.statista.com/statistics/720295/uk-projected-carbon-value-price/ (accessed on 18 April 2022).
67. Stovin, V.; Vesuviano, G.; Kasmin, H. The hydrological performance of a green roof test bed under UK climatic conditions. *J. Hydrol.* **2012**, *414–415*, 148–161. [CrossRef]
68. SEPA. Flood Risk Management (Scotland) Act 2009: Local Flood Risk Management Plan. Forth Estuary Local Plan District. The City of Edinburgh Council. 2016. Available online: https://www.edinburgh.gov.uk/downloads/file/22751/local-flood-risk-management-plan (accessed on 25 April 2022).
69. Greenspace Scotland. The Third State of Scotland's Greenspace Report. February 2018. 2018. Available online: https://drive.google.com/file/d/1aQLMu60G5WRi4QKBCuZJ92oT8eM2sxd3/view (accessed on 25 April 2022).
70. Wilson, J. Thermal Properties Of Building Materials | Electronics Cooling, *Electronics-Cooling*. 2008. Available online: https://www.electronics-cooling.com/2008/02/thermal-properties-of-building-materials/ (accessed on 21 April 2022).
71. Engineering ToolBox. Specific Heat of Common Substances. Available online: https://www.engineeringtoolbox.com/specific-heat-capacity-d_391.html (accessed on 21 April 2022).
72. MetOffice. Royal Botanic Garden Edinburgh (Edinburgh) UK Climate Averages', *Met Office*. Available online: https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/gcvwqum6h (accessed on 21 April 2022).
73. Berardi, U. The outdoor microclimate benefits and energy saving resulting from green roofs retrofits. *Energy Build.* **2016**, *121*, 217–229. [CrossRef]
74. Scotland, G. Greenspace Use and Attitudes Survey 2017. Research Findings: Executive Summary. 2017. Available online: https://drive.google.com/file/d/1jGifcDnC1izChhrzmmv3mAZqLgxfvzLg/view?usp=embed_facebook (accessed on 21 April 2022).
75. A National Statistics Publication for Scotland. Scottish Transport Statistics. No. 39 2020 Edition. 2020. Available online: https://www.transport.gov.scot/media/49177/scottish-transport-statistics-2020-publication-final-version.pdf (accessed on 15 April 2022).
76. Loder, A. 'There's a meadow outside my workplace': A phenomenological exploration of aesthetics and green roofs in Chicago and Toronto. *Landsc. Urban Plan.* **2014**, *126*, 94–106. [CrossRef]
77. Farrell, C.; Mitchell, R.E.; Szota, C.; Rayner, J.P.; Williams, N.S.G. Green roofs for hot and dry climates: Interacting effects of plant water use, succulence and substrate. *Ecol. Eng.* **2012**, *49*, 270–276. [CrossRef]
78. LAQM. *Air Quality Annual Progress Report*; Local Air Quality Management: Sacramento, CA, USA, 2020.
79. Alexandri, E.; Jones, P. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Build. Environ.* **2008**, *43*, 480–4938. [CrossRef]
80. Arbid, Y.; Richard, C.; Sleiman, M. Towards an experimental approach for measuring the removal of urban air pollutants by green roofs. *Build. Environ.* **2021**, *205*, 108286. [CrossRef]
81. Lovett, G.M. Atmospheric Deposition of Nutrients and Pollutants in North America: An Ecological Perspective. *Ecol. Appl.* **1994**, *4*, 629–650. [CrossRef]
82. Cook-Patton, S.C.; Bauerle, T.L. Potential benefits of plant diversity on vegetated roofs: A literature review. *J. Environ. Manag.* **2012**, *106*, 85–922. [CrossRef]
83. Pugh, T.A.M.; Lindeskog, M.; Smith, B.; Poulter, B.; Arneth, A.; Haverd, V.; Calle, L. Role of forest regrowth in global carbon sink dynamics. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 4382–4387. [CrossRef] [PubMed]
84. Speak, A.F.; Rothwell, J.J.; Lindley, S.J.; Smith, C.L. Urban particulate pollution reduction by four species of green roof vegetation in a UK city. *Atmos. Environ.* **2012**, *61*, 283–293. [CrossRef]
85. Bridgman & Bridgman. Bridgman and Bridgman | Living Roof Services-We Create Sustainable Living Roofs. Available online: https://bridgmanlandscapes.co.uk/#services (accessed on 29 April 2022).
86. Getter, K.L.; Rowe, D.B.; Andresen, J.A. Quantifying the effect of slope on extensive green roof stormwater retention. *Ecol. Eng.* **2007**, *31*, 225–231. [CrossRef]
87. Mentens, J.; Raes, D.; Hermy, M. Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? *Landsc. Urban Plan.* **2006**, *77*, 217–226. [CrossRef]

88. Moran, A.; Hunt, B.; Smith, J. Hydrologic and water quality performance from green roofs in Goldsboro and Raleigh, North Carolina. July 2005. Available online: https://www.osti.gov/etdeweb/biblio/20861933 (accessed on 14 April 2022).
89. Voyde, E.; Fassman, E.; Simcock, R. Hydrology of an extensive living roof under sub-tropical climate conditions in Auckland, New Zealand. *J. Hydrol.* **2010**, *394*, 384–395. [CrossRef]
90. Simmons, M.T.; Gardiner, B.; Windhager, S.; Tinsley, J. Green roofs are not created equal: The hydrologic and thermal performance of six different extensive green roofs and reflective and non-reflective roofs in a sub-tropical climate. *Urban Ecosyst.* **2008**, *11*, 339–348. [CrossRef]
91. Teemusk, A.; Mander, Ü. Rainwater runoff quantity and quality performance from a greenroof: The effects of short-term events. *Ecol. Eng.* **2007**, *30*, 271–277. [CrossRef]
92. Villarreal, E.L.; Bengtsson, L. Response of a Sedum green-roof to individual rain events. *Ecol. Eng.* **2005**, *25*, 1–7. [CrossRef]
93. Getter, K.L.; Rowe, D.B. The Role of Extensive Green Roofs in Sustainable Development. *HortScience* **2006**, *41*, 1276–1285. [CrossRef]
94. Rowe, D.B.; Monterusso, M.A.; Rugh, C.L. Assessment of Heat-expanded Slate and Fertility Requirements in Green Roof Substrates. *HortTechnology* **2006**, *16*, 471–477. [CrossRef]
95. Zheng, X.; Zou, Y.; Lounsbury, A.W.; Wang, C.; Wang, R. Green roofs for stormwater runoff retention: A global quantitative synthesis of the performance. *Resour. Conserv. Recycl.* **2021**, *170*, 105577. [CrossRef]
96. Berndtsson, J.C. Green roof performance towards management of runoff water quantity and quality: A review. *Ecol. Eng.* **2010**, *36*, 351–360. [CrossRef]
97. Seters, T.; Rocha, L.; Smith, D.; MacMillan, G. Evaluation of Green Roofs for Runoff Retention, Runoff Quality, and Leachability. *Water Qual. Res. J.* **2009**, *44*, 33–47. [CrossRef]
98. Kasmin, H.; Stovin, V.R.; Hathway, E.A. Towards a generic rainfall-runoff model for green roofs. *Water Sci. Technol.* **2010**, *62*, 898–905. [CrossRef] [PubMed]
99. Stovin, V. The potential of green roofs to manage Urban Stormwater. *Water Environ. J.* **2010**, *24*, 192–199. [CrossRef]
100. Krivtsov, V.; Birkinshaw, S.; Yahr, R.; Olive, V. Comparative Ecosystem Analysis of Urban Ponds: Implications for Synergistic Benefits and Potential Trade-Offs Resulting from Retrofitting of Green Roofs in Their Catchments. *Int. J. Environ. Impacts: Manag. Mitig. Recover.* **2021**, *4*, 323–339. [CrossRef]
101. Krivtsov, V.; Arthur, S.; Buckman, J.; Kraiphet, A.; Needham, T.; Gu, W.; Gogoi, P.; Thorne, C. Characterisation of suspended and sedimented particulate matter in blue-green infrastructure ponds. *Blue-Green Syst.* **2020**, *2*, 214–236. [CrossRef]
102. Krivtsov, V.; Birkinshaw, S.; Forbes, H.; Olive, V.; Chamberlain, D.; Lomax, J.; Buckman, J.; Yahr, R.; Arthur, S.; Takezawa, K.; et al. Hydrology, ecology and water chemistry of two suds ponds. In *Urban Water Systems and Floods III, Proceedings of the 7th International Conference on Flood and Urban Water Management, FRIAR 2020', Valencia, Spain, 28–30 September 2020*; WITPress: Billerica, MA, USA, 2020; pp. 167–178. [CrossRef]
103. Krivtsov, V.; Birkinshaw, S.; Olive, V.; Lomax, J.; Christie, D.; Arthur, S. Multiple Benefits of Blue-Green Infrastructure and the Reduction of Environmental Risks: Case Study of Ecosystem Services Provided by a SUDS Pond. In *Civil Engineering for Disaster Risk Reduction*; In Springer Tracts in Civil Engineering; Springer: Berlin/Heidelberg, Germany, 2021; pp. 247–262. [CrossRef]
104. Krivtsov, V.; Forbes, H.; Birkinshaw, S.; Olive, V.; Chamberlain, D.; Buckman, J.; Yahr, R.; Arthur, S.; Christie, D.; Monteiro, Y.; et al. Ecosystem services provided by urban ponds and green spaces: A detailed study of a semi-natural site with global importance for research. *Blue-Green Syst.* **2022**, *4*, 1–23. [CrossRef]
105. Förster, J. Variability of roof runoff quality. *Water Sci. Technol.* **1999**, *39*, 137–144. [CrossRef]
106. Pizzol, M.; Christensen, P.; Schmidt, J.; Thomsen, M. Impacts of "metals" on human health: A comparison between nine different methodologies for Life Cycle Impact Assessment (LCIA). *J. Clean. Prod.* **2011**, *19*, 646–656. [CrossRef]
107. Roehr, D.; Fassman-Beck, E. *Living Roofs in Integrated Urban Water Systems*; Taylor & Francis Group: London, UK, 2015; Available online: http://ebookcentral.proquest.com/lib/ed/detail.action?docID=1983421 (accessed on 12 April 2022).
108. Berndtsson, J.C.; Emilsson, T.; Bengtsson, L. The influence of extensive vegetated roofs on runoff water quality. *Sci. Total. Environ.* **2006**, *355*, 48–63. [CrossRef]
109. Van Metre, P.C.; Mahler, B.J. The contribution of particles washed from rooftops to contaminant loading to urban streams. *Chemosphere* **2003**, *52*, 1727–1741. [CrossRef] [PubMed]
110. Berndtsson, J.C.; Bengtsson, L.; Jinno, K. Runoff water quality from intensive and extensive vegetated roofs. *Ecol. Eng.* **2009**, *35*, 369–380. [CrossRef]
111. Emilsson, T.; Berndtsson, J.C.; Mattsson, J.E.; Rolf, K. Effect of using conventional and controlled release fertiliser on nutrient runoff from various vegetated roof systems. *Ecol. Eng.* **2007**, *29*, 260–271. [CrossRef]
112. Santamouris, M. Cooling the cities—A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Sol. Energy* **2014**, *103*, 682–703. [CrossRef]
113. Tabares-Velasco, P.C.; Srebric, J. Experimental quantification of heat and mass transfer process through vegetated roof samples in a new laboratory setup. *Int. J. Heat Mass Transf.* **2011**, *54*, 5149–5162. [CrossRef]
114. Kershaw, T.; Sanderson, M.; Coley, D.; Eames, M. Estimation of the urban heat island for UK climate change projections. *Build. Serv. Eng. Res. Technol.* **2010**, *31*, 251–263. [CrossRef]
115. Dunnett, N.; Roofs, R.G. *Green Roof Ecosystems*; Sutton, R.K., Ed.; Springer International Publishing: Cham, Switzerland, 2015; pp. 233–255. [CrossRef]

116. Köhler, M. Long-Term Vegetation Research on Two Extensive Green Roofs in Berlin. *Urban Habitats* **2006**, *4*, 3–26.
117. Ramage, W. LocalGov.co.uk-Your Authority on UK Local Government-Encouraging Biodiversity in UK Cities: Bee Bus Stops and More. 7 September 2021. Available online: https://www.localgov.co.uk/Encouraging-biodiversity-in-UK-cities-Bee-Bus-Stops-and-more/52893 (accessed on 29 April 2022).
118. SmartCitiesWorld. Brighton Bus Shelter Becomes Home to Upcycled Living Roof, *Smart Cities World*. 2019. Available online: https://www.smartcitiesworld.net/news/news/brighton-bus-shelter-becomes-home-to-upcycled-living-roof-4546 (accessed on 29 April 2022).
119. Lowson, J. Dozens of New Carbon Reducing Green Bus Shelters to be Created in Milton Keynes. 2021. Available online: https://www.miltonkeynes.co.uk/news/politics/dozens-of-new-carbon-reducing-green-bus-shelters-to-be-created-in-milton-keynes-3177215 (accessed on 29 April 2022).
120. Biswas, M.H.A.; Dey, P.R.; Islam, M.; Mandal, S. Mathematical Model Applied to Green Building Concept for Sustainable Cities Under Climate Change. *J. Contemp. Urban Aff.* **2021**, *6*, 36–50. [CrossRef]
121. Dizdaroglu, D. Developing Design Criteria for Sustainable Urban Parks. *J. Contemp. Urban Aff.* **2022**, *6*, 69–81. [CrossRef]
122. Dipeolu, A.A.; Ibem, E.O.; Oriola, O.A. Influence of Green Infrastructure on Residents' Endorsement of the New Ecological Paradigm in Lagos, Nigeria. *J. Contemp. Urban Aff.* **2022**, *6*, 159–173. [CrossRef]