ESPON

EUROPEAN UNION

Co-financed by the European Regional Development Fund

Inspire Policy Making with Territorial Evidence

ANNEX 4 – CASE STUDY REPORT //

Scotland Case Study Pilot

Quantitative Greenhouse Gas Impact Assessment Method for Spatial Planning Policy

Adjusted Annex // September 2022

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Table of contents

List of maps, figures, charts and tables

List of figures

List of tables

Abbreviations

BER	Building Energy Rating
CLC	CORINE Land Cover
CLMS	Copernicus Land Monitoring Service
COICOP	Classification of Individual Consumption by Purpose
CORINE	Coordinated Information on the Environment
CRF	Common Reporting Format
CSC	Carbon-Stock-Change Factors
EEA	European Environment Agency
EIO	Economic Input-Output
EPC	Energy Performance Certificate
ESDAC	European Soil Data Centre
FIPS	Forest Inventory and Planning System
FUA	Functional Urban Areas
GHG	Greenhouse Gas
GWP100	Global Warming Potential over 100 years
HBS	Household Budget Survey
ICE	Internal Combustion Engine
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LPIS	Land Parcels Information System
LULUCF	Land use, land-use change and forestry
MMR	Monitoring Mechanism Regulation
MMU	Minimum Mapping Unit
MRIO	Multi-Regional Input-Output
NEDC	New European Driving Cycle
NFI	National Forest Inventory
NIR	National Inventory Reports
NPF	National Planning Framework
p-LCA	Process-based Life Cycle Assessment
RDE	Real Driving Emissions
RSG	Reference Soil Groups
STL	Street Tree Layer
UNFCCC	United Nations Framework Convention on Climate Change
WRB	World Reference Base for Soil Resources

1 Introduction

GHG emissions were quantified for four case studies to test the GGIA tool methodology in a variety of contexts. The service providers have committed to use a range of spatial scales for the pilot case studies, this is shown through the case study selection that vary in their urban context i.e., rural, urban and suburban, whilst also differing in population sizes and geographic contexts.

Each case study consists of a baseline analysis, the quantification of selected policies and the evaluation of results. The case study pilots have been linked to relevant policy processes and the involvement of the stakeholders has been key to ensure that the link between case study and relevant spatial planning policy is present. The pilot case studies, where possible, reflect the stakeholders' envisaged use of the GGIA tool in each territory, this includes for example local authority spatial plans, development plans and national planning frameworks. The GHG analysis of the case study plans, follow key emission sectors:

- Buildings – changes in electricity and heating demands
- Infrastructure – changes in transport
- Land Use – changes in land use.

This report provides an insight into the GHG emission inventory for the City of Edinburgh as well as the data and methodologies applied for each sector.

2 Scotland Case Study Pilot – Edinburgh

The Scottish case study pilot is the capital city, Edinburgh, which is home to over 901,000 inhabitants who live in the council area, of which a population of over 518,000 live in the city. Choosing Edinburgh as a case study will allow the service providers to test the applicability of this approach based on datasets and typical characteristics for developed urban areas which have a relatively moderate density and contain a good mix of building uses and transport infrastructure.

Scotland has been very ambitious in its climate goals and has set a target to reach net zero emissions by 2045. The third National Planning Framework (Scottish Government, 2014) supports the planning system's role in meeting the Scottish climate goals and sets out a long-term vision for development and investment across Scotland over the next 20 to 30 years. It brings together all the Scottish Government plans and strategies in economic development, regeneration, energy, environment, climate change, transport and digital infrastructure to provide a coherent spatial vision of how Scotland should evolve over the next 20 to 30 years. Quantifiable actions from the Third National Planning Framework have been assessed with the methodology of the new GGIA tool.

2.1 Baseline

2.1.1 Consumption-based approach

The demand vector applicable to UK cities was applied for households in Edinburgh. The stakeholders indicated that household income was representative of the UK as a whole, so no further scaling was performed based on this factor. Information was provided by the stakeholders with regards to the average household occupancy and total population of the area, respectively, and this was used to determine the per capita and total emissions for the region.

Table 1. Description of the data situation utilised for the consumption calculations in Edinburgh.

Data situation: Edinburgh				
Demand Vector	Household occupancy	Household income level	Population	Further modifications / Notes
UK City	2.14	UK average	524,930	N/A

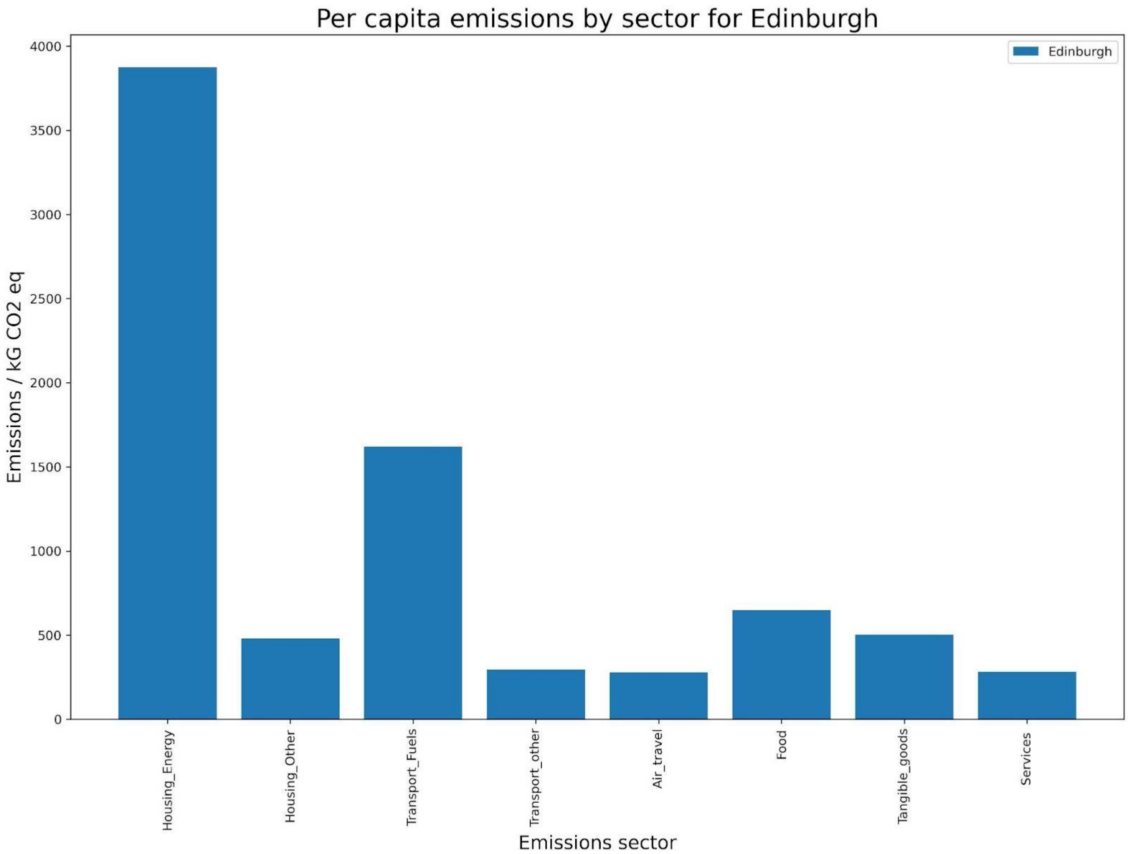

Figure 1. Per capita sectoral emissions for the city of Edinburgh (kgCO_2e/a) (2019)**.**

Figure 1 above shows the breakdown of emissions by sector for households in Edinburgh. Overall, the per capita emissions were approximately 8 tonnes CO_2e per annum. The total consumption emissions for the city were calculated to be approximately 4.2 MtCO_2e per annum. The largest contributions to the emissions came from residential energy demand and transport fuels, for which the largest contributions came from the direct use of fuels by the household. This also reflects the large proportions of space heating arising from direct combustion of fossil fuels. In the case of Edinburgh, this particularly arises through gas-based heating (around 3 tonnes of emissions per capita derive from gas-based heating). Transport emissions are also significant, which is somewhat surprising considering the location, and are higher than both Kymenlaakso and County Meath. This is despite the fact that households in both of these case areas spend more on transport fuels than Edinburgh. The reasons for this are two-fold. Firstly, in Finland there is a higher proportion of renewable fuels in the fuel mix (21%, whereas the corresponding figures for Ireland and the UK are both around 9%) and use-phase emissions for these have been set to zero. Secondly, the direct and indirect production phase emission intensities are somewhat lower for Ireland than Finland or the UK, which also serves to mitigate the higher expenditure in county Meath.

A further feature of the emissions is the roughly equal split between the use-phase and production phases. This contrasts with both Kymenlaakso and county Meath, for which emissions are primarily from the production phases and use-phase, respectively, but is similar to Rathlin Island, which reflects the similar emission factors used in both these cases (the only difference being the electricity sector). Food emissions are lower than for a rural area in the UK (Rathlin Island), with changes in occupation not entirely explaining this discrepancy. Household emissions are also still significantly higher in Rathlin Island than Edinburgh, although partly arises from differences in the electricity sector. Indeed, total household emissions independent of occupation level are similar to Kymenlaakso but lower than both County Meath and Rathlin island. When household occupancy is considered, Edinburgh, Kymenlaakso and County Meath all have rather similar carbon footprints. Total household expenditure in 2015 was comparable across all regions in Euro terms (higher values in Ireland are somewhat mitigated by the higher household occupancy levels). The results for Edinburgh are tabulated with greater sectoral detail in the following table. These results are also shown graphically along with those for the other case areas.

Table 2. Per capita sectoral emissions breakdown for Edinburgh (kgCO_2e/a) (2019).

Edinburgh	Direct Production kgCO_2e	Indirect Production kgCO_2e	Use Phase kgCO_2e	Total kgCO_2e
Shelter: Electricity, heating and fuels	873	429	2,573	3,874
Shelter: Actual and imputed rent	16	67	0	82
Shelter: construction	8	21	0	29
Shelter: Waste treatment, water supply and misc.	297	72	0	369
Transport fuels	86	256	1,280	1,621
Vehicle purchases	15	112	0	128
Other transport services	140	27	0	167
Air travel	219	59	0	278
Food: Plant-based	78	38	0	115
Food: Animal-based	29	289	0	318
Food nec	23	190	0	213
Clothing	31	90	0	121
Appliances	16	105	0	121
Furniture, household commodities and misc.	72	189	0	262
Services	67	215	0	283
Sum	**1,969**	**2,160**	**3,853**	**7,982**

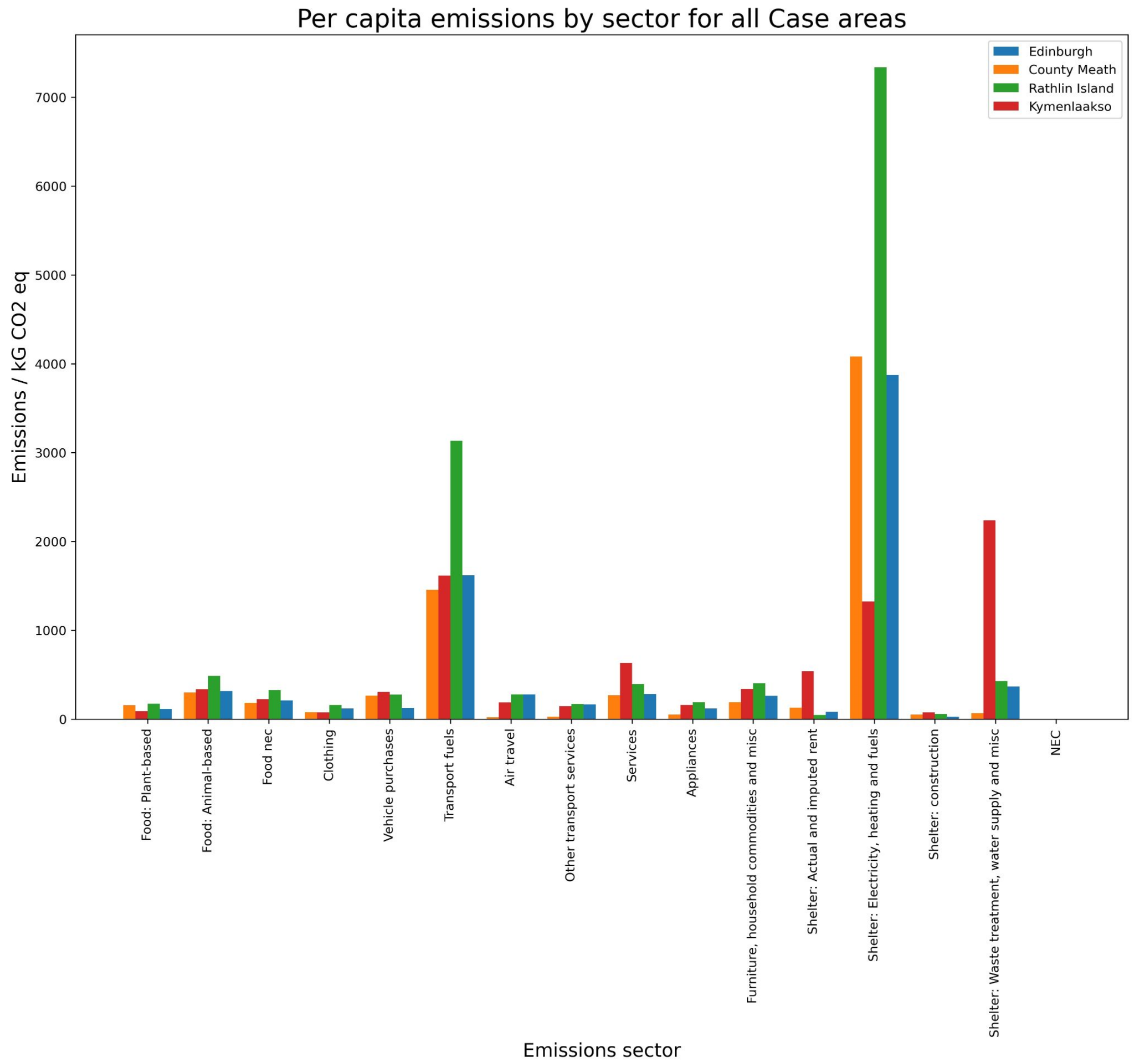

Figure 2. Per capita consumption emissions for all the case areas in 2020.

2.1.2 Territorial approach

2.1.2.1 Buildings

This section looks at the emissions arising from the building sector in Edinburgh, it includes both residential and commercial buildings, and also analysis results from the baseline, which gives insight into the current building stock for Edinburgh. This baseline information is then used to compare with emissions resulting from spatial planning policy changes.

The City of Edinburgh Council provided the service providers with a detailed inventory of energy use and greenhouse gas emissions for both residential and commercial buildings and facilities. This detailed inventory makes use of verified datasets published by the UK Government and is broken down by local authority area. It provides the energy use broken down by fuel and emission conversion factors for these fuels.

Residential sector

This methodology is based on the inventory provided by the council, data from the National Records of Scotland and the Energy Performance Certificate (EPC) database for the City of Edinburgh.

As explained in the previous section, the emissions inventory provided by the council gave the service providers detailed information on the energy use of the residential sector for 2018. Figures on types of housing in Edinburgh City were found from the National Records of Scotland[1]. Residential units were broken down into:

- Detached
- Semi-detached
- Terraced
- Apartments

An EPC is a certificate of energy efficiency of a property. EPC certificates are required if a house is being sold, let or is a new build. Properties which achieve an 'A' rating are the most efficient; meanwhile, properties which achieve a 'G' rating are the least energy efficient properties.

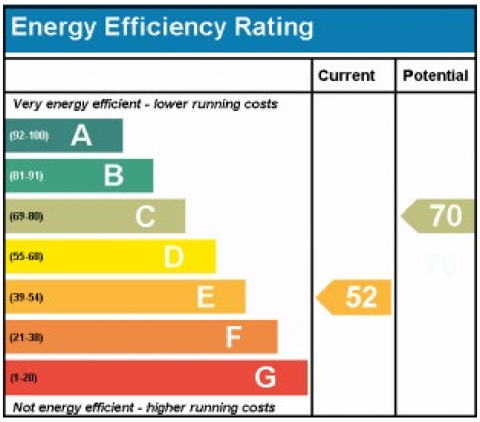

Figure 3. Energy performance certificate. Source: Gov.UK.

The EPC contains information on the property's energy use and typical energy costs, it also provides recommendations about how to reduce energy use. The EPC dataset for Edinburgh was used in this analysis for the calculation of energy required for normal use of space heating, hot water and lighting for a residential unit.

The EPCs analysed in this report were broken down by location and included the EPCs pertaining to the City of Edinburgh. This was done by filtering the data location and was then broken down further by type of dwelling (detached, semi-detached, terraced and apartments) and period built.

The drawback of the EPC is that a certificate is only required if a house is being sold or rented out, this means that it will not give a complete representation of all the housing stock in Edinburgh. However, this did give the service providers enough information to proportion the total residential energy use from the inventory into different dwelling types for Edinburgh, and also gave insight into the efficiency of the different residential dwellings.

Analysis

In 2018, the largest share of residential units were apartments; they made up 68% of the total residential housing stock in Edinburgh City. This was followed by terraced houses (12%), detached and semi-detached houses both accounted for 10% each of Edinburgh's housing stock.

[1] https://webarchive.nrscotland.gov.uk/20210313061311/https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/households/household-estimates/2018

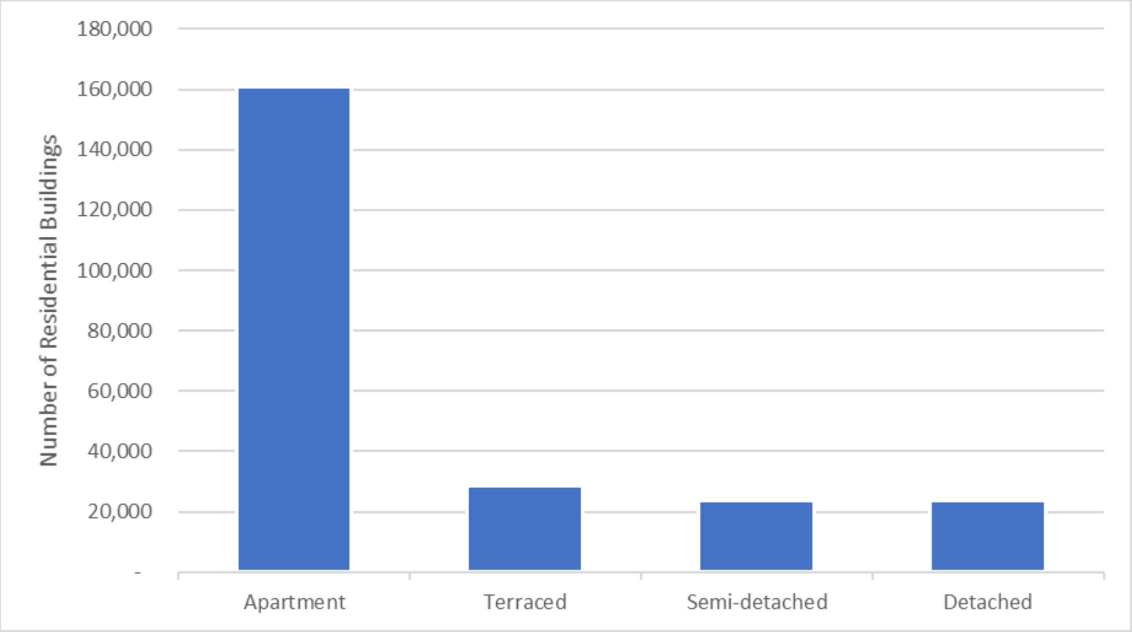

Figure 4. Total number of residential units in Edinburgh (2018).

Total energy use in the residential sector was 3,606 GWh. The residential fuel split mainly comes from natural gas, which makes up 78% of the total energy use in this region. Electricity is the second highest fuel in demand, making up 19% of the fuel mix.

Figure 5 shows the total final energy use broken down into the different energy demand areas. Most of the energy used was for space heating, accounting for 63% of the total, this was followed by water heating at 25%. Heating overall in the residential sector has the highest energy demand by far and creates potential for heat recovery from waste heat and district heating as a way of catering for this high heat demand. Lighting and pumps/fans are the least energy intensive, making up just 8% and 4% of the total demand, respectively.

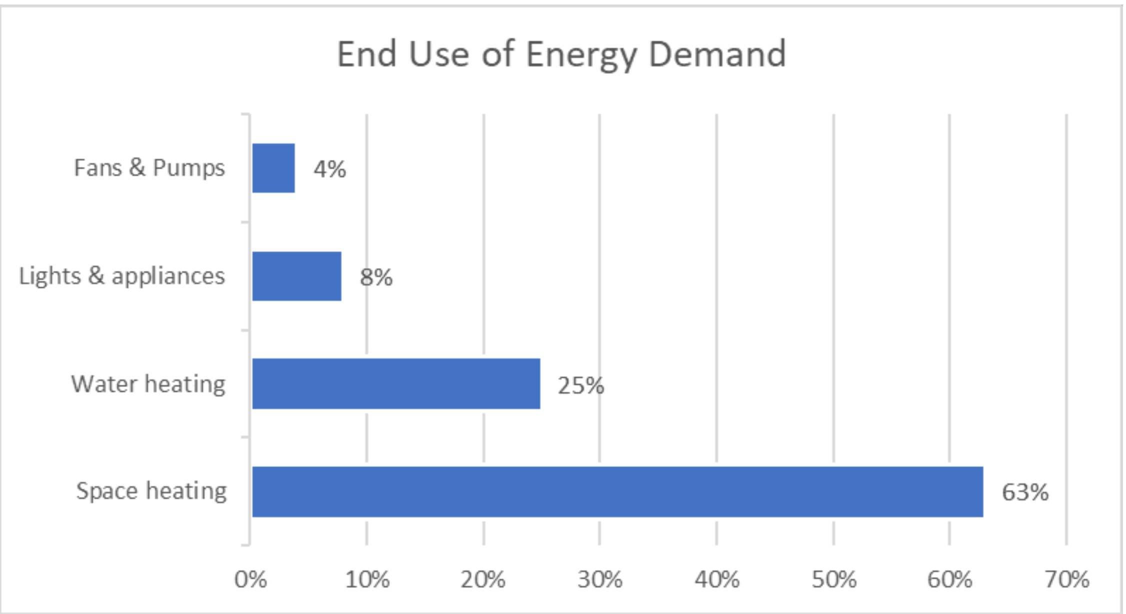

Figure 5. Share of residential energy demand in Edinburgh (2018).

Total emissions from the residential sector in Edinburgh amounted to 769,860 tonnes of CO_2 in 2018. Apartments had the highest emissions, accounting for 523,507 tonnes of CO_2, this was followed by terraced, detached and semi-detached houses.

The highest emissions in the residential sector come from natural gas and electricity, which contribute 67% and 31% respectively. There was very little oil, coal and biomass (mainly wood) used in the residential sector, only contributing to 1.8% of total emissions.

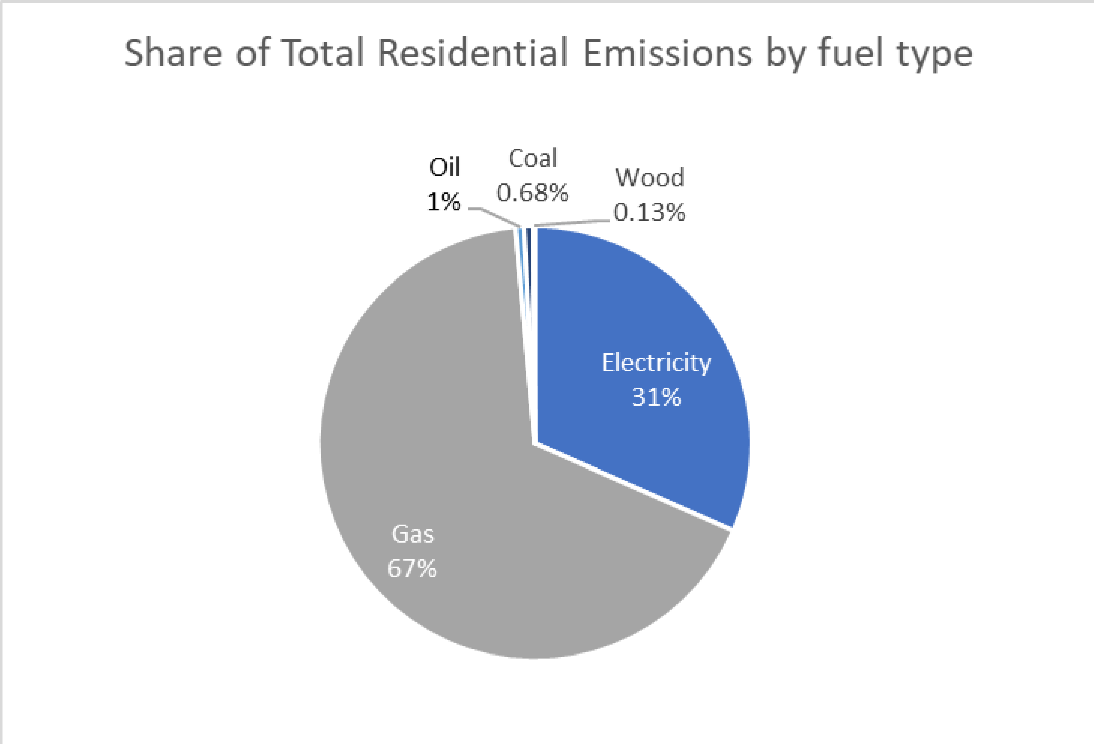

Figure 6. Share of total emissions in the residential sector by fuel type (2018).

Table 3. Total residential emissions in the City of Edinburgh (tCO_2e/a) (2018).

	Fuel						
Residential sector	Electricity	Gas	Oil	Coal	Peat	Wood	**Total**
Apartments	165,285	350,695	3,305	3,535	-	687	523,507
Terraced	29,168	61,887	583	624	-	121	92,383
Semi-detached	24,306	51,572	486	520	-	101	76,985
Detached	24,306	51,572	486	520	-	101	76,985
Total tCO_2e/a	243,066	515,727	4,860	5,199	-	1,010	769,861

Commercial

This methodology is mainly based on the inventory provided by the council. The emissions inventory gave the service providers detailed information on the energy use of the commercial sector for 2018.

Figures for total number of commercial buildings or floor areas for commercial properties could not be sourced for Edinburgh. However, some insight into the commercial sector was gained through the report produced by Edinburgh City Council in 2020, Edinburgh by Numbers[2]. From this report it was found that the majority of people in Edinburgh City, around 51,000 people, are employed in the health industry, followed by the hospitality and financial industry, each accounting for 33,000 employees. The commercial sector includes both the services and industrial sectors, industries that have a high level of employment in Edinburgh can be categorised as

- Health
- Hospitality
- Industrial Uses
- Offices
- Retail.

The total energy used in the commercial sector was 3,487 GWh. Natural gas (1,882 GWh) and electricity (1,380 GWh) accounted for the main share of this energy use. The commercial sector had a high use of heating oil, coal and biomass (wood) which all together made a total of 224 GWh.

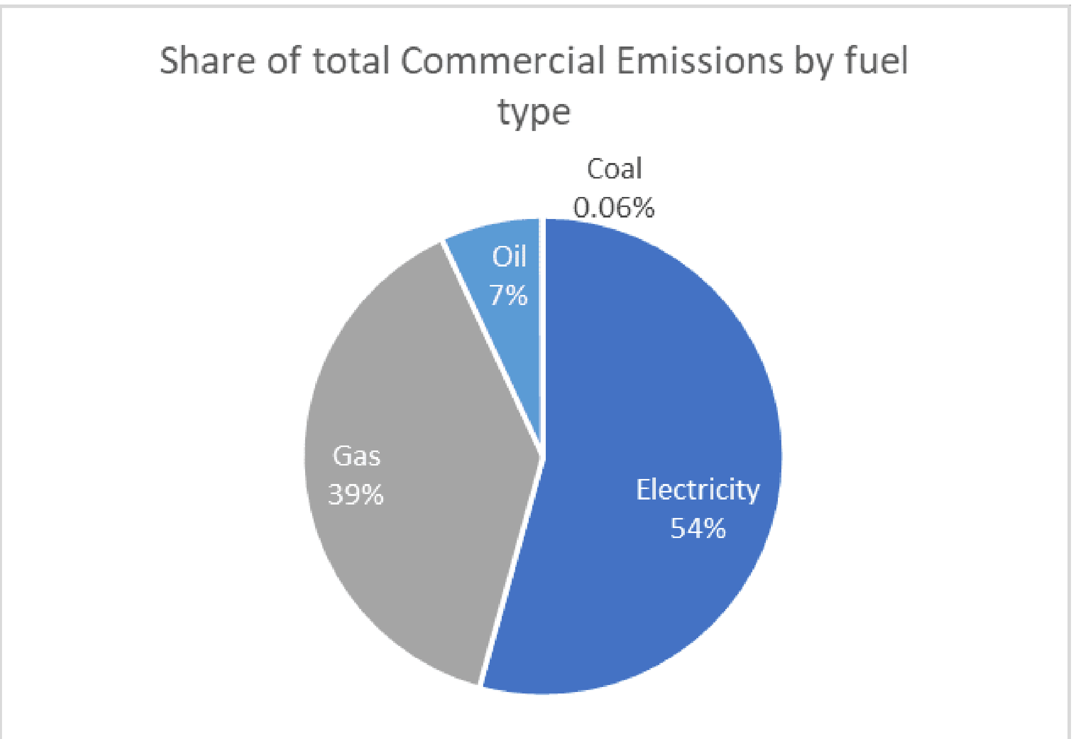

Figure 7. Share of total emissions in the commercial sector by fuel type (2018).

Total emissions from the commercial sector in 2018 amounted to 893,790 tonnes of CO_2. Of the total emissions emitted by the commercial sector, electricity accounts for the largest share of the total emissions (54%),

[2] https://www.edinburgh.gov.uk/downloads/file/29314/edinburgh-by-numbers-2020

followed by natural gas at 39%. Heating oil also produced significant emissions, contributing 7% to the total. It should be noted that Scotland's electricity mainly comes from renewable energy generation, however UK emission conversion factors have been applied to Scottish energy figures, the UK conversion factors do not accurately reflect the high penetration of renewables in electricity generation in Scotland and as a result electricity emission figures may tend to be higher.

Table 4. Total commercial emissions in the City of Edinburgh (tCO_2e/a) (2018).

	Fuel						
Commercial sector	Electricity	Gas	Oil	Coal	Peat	Wood	**Total**
Total tCO_2e/a	485,197	346,653	61,441	496	0	1	893,789

Total emissions

Total emissions from both the residential and commercial sectors in the City of Edinburgh accounted for 1,663,650 tonnes of CO_2 in 2018. The residential sector contributed 46% and the commercial sector 54% to the total emissions. The main source of emissions come from natural gas (52%), followed by electricity (44%) and heating oil (4%). The rest of emissions (approximately 0.4%) were made up of biomass (wood) and coal.

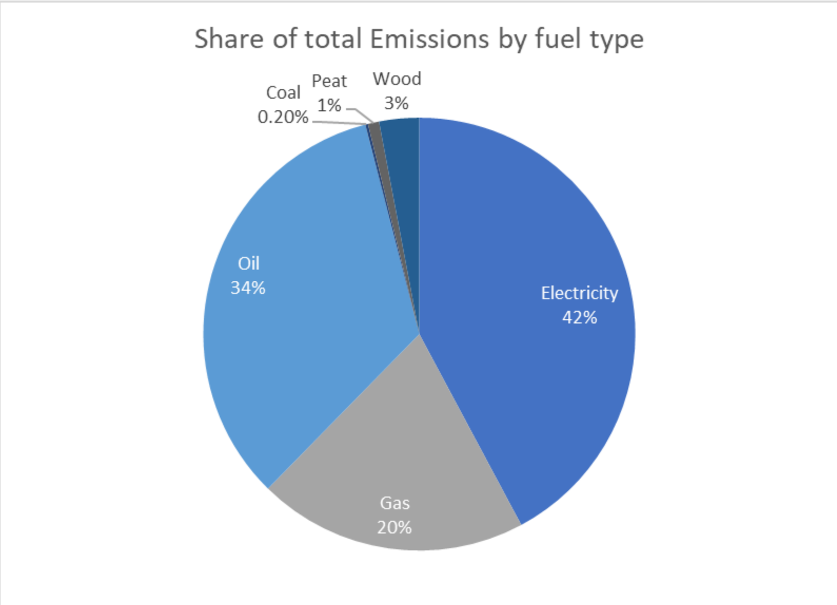

Figure 8. Share of total emissions in the building sector by fuel type (2018).

Table 5. Total emissions from the building sector in Edinburgh (tCO_2e/a) (2018).

	Fuels						
Building sector	Electricity	Gas	Oil	Coal	Peat	Wood	**Total**
Residential	243,066	515,727	4,860	5,199	-	1,010	769,861
Commercial	485,197	346,653	61,441	497	-	1	893,789
Total tCO_2e/a	**728,263**	**862,380**	**66,301**	**5,696**	**-**	**1,011**	**1,663,651**

2.1.2.2 Transport

Edinburgh is a major transport hub of East Central Scotland and is at the center of a multi-modal transport network with road, rail and air communications. The airport of Edinburgh serves over 12 million passengers per year. Edinburgh applies park and ride facilities at the outskirts of the city and the Union Canal provides an inland waterway link from Edinburgh to Falkirk.

Bus

There were 366 million bus journeys made in Scotland in 2019. The frequency of bus use was found to be higher in urban areas (54% of people in large urban areas used the bus at least once a month compared to 19% in small remote towns and 20% in remote rural areas.

Edinburgh is widely recognised as having one of the most extensive bus services in the country. Priority bus lanes on arterial routes into Edinburgh city centre are known as *Greenways* (because of the distinctive green tarmac used to surface them), these were introduced in 1997 and there are currently five main Greenways into the city. The Edinburgh Strategic Sustainable Transport Study – Phase 1 (Steer 2019) analysed ten possible corridors for public transport.

Edinburgh is actively working to decarbonize public transport, particularly buses. Edinburgh Transport is operating diesel-electric hybrid buses and has invested in new electric buses.

The vehicle kilometres for local bus services in the South East part of Scotland (Clackmannanshire, East Lothian, Falkirk, Fife, Midlothian, Scottish Borders, Edinburgh City, West Lothian) were 110 million vehicle-km in 2019 and 335 million vehicle-km in the whole of Scotland (Scottish Transport Statistics).

The average bus transport activity in Scotland was 61.3 bus-km/person. Since no specific data on Edinburgh is available, then the bus transport activity is estimated. In 2020, 1.46 billion vehicle miles were travelled on the roads of the City of Edinburgh. This equals 2349.6 million vehicle-km, of which passenger cars account for 1,771 million vehicle-km, light commercial vehicles account for 442 million vehicle-km, heavy goods vehicles account for 88 million vehicle-km. This leaves 48.6 million vehicle-km, of which buses are estimated to account for about 40 million vehicle-km. The average bus occupancy 16.2 was applied to convert the vehicle-km into passenger-km. This estimate will be updated when more accurate local data is made available.

The City of Edinburgh Council owns 91% of Lothian Buses, which is the largest municipal bus company in the UK. Lothian operates the majority of bus services in Edinburgh, according to Lothian bus, the average bus route covers 250–300 miles daily. Lothian buses operate 56 daytime routes and 12 night buses and the annual trips were 121 million in December 2017[3]. The bus fleet totals 909 (in 2019), of which 12 are electric buses (first six were Wright StreetAir electric buses introduced in 2017). All Lothian Buses have a tracking system for the bus fleet.

The DEFRA Conversion factors datasheet gives the following emission factors per passenger-km:

- Local bus (not London) 119.5 gCO_2e/passenger-km
- Average local bus 103.12 gCO_2e/passenger-km
- Coach 27.32 gCO_2e/passenger-km.

As the share of electric buses is still small, the average local bus factor is applied in this study.

Tram

The Edinburgh Tram[4] network, opened in 2014 and operates a fleet of CAF Urbos 3 low-floor trams that were specially designed to be used in the city. The capacity of a single tram is 250 passengers, 78 seated, 170 standing, and the Edinburgh tram fleet consists of 27 trams, but only half of them are required to operate

[3] Lothian Buses - Wikipedia

[4] Edinburgh Tram

during the peak hours[5]. Edinburgh also has a small suburban rail network, which runs in an east-west direction across the city.

The total tram-km in 2019/20 were 1.4 million vehicle-km (Light rail and tram statistics Table LRT0105). The length of the existing tramline is 14 kilometers and services operate for 19 hours per day (between 05:00 and 24:00) at 7–10 minute intervals 7 days a week[6]. There are approximately 300 one-way trips per day, which is the equivalent to 1.533 million tram-km/a. (Department for Transport Statistics, Light rail and tram statistics, Table LRT0105. Vehicle kilometers on light rail and trams and undergrounds by system: Great Britain – annual from 1983/84), which seems to be in line with current statistics.

The Edinburgh CAF Urbos 3 trams are equipped with three types of braking, with the normal service braking, the electro-dynamic regenerative brake is the priority braking mode. At speeds below 3 km/h, mechanical friction brakes are applied (Neil, 2016).

Since no accurate data on the electricity consumption of CAF Urbos 3 trams was available, the GHG emissions for the Edinburgh tram were calculated using person-kilometres instead of vehicle-kilometres.

In 2019/20 the transport activity for the Edinburgh tram was 57.3 million passenger-km (Light rail and tram statistics, Table LRT0105) with the average occupancy for the Edinburgh tram being 40.9 (Passenger-km/vehicle-km in 2019/20).

The DEFRA Conversion factors gives the emission factor of 29.91 kgCO_2e/passenger-km for light rail and tram (DEFRA, 2020).

This factor is higher than the reference values from other UK trams (2020 Government greenhouse gas conversion factors for company reporting):

- London tramlink 0.107 kWh/pkm, 27.19 gCO_2e/passenger-km
- Manchester Metrolink 0.078 kWh/pkm, 19.86 gCO_2e/passenger-km.

Manchester Metrolink network is operated by a fleet of Bombardier M5000s trams. Its occupancy in 2019/20 was 36 persons (Light rail and tram statistics, Table LRT0108). If a correction factor, based on the average occupancy (36.0/40.9), were to be applied to the emission factor of Manchester Metrolink (0.078 kWh/passenger-km, 19.86 gCO_2e/passenger-km), it would result in 17.48 gCO_2e/passenger-km for the Edinburgh tram.

Train

The main network rail station, Edinburgh Waverley, serves over 14 million passenger journeys per year. In 2018–19 the passenger train emissions were 36.6 gCO_2e per passenger kilometer, and the freight train emissions were 25.3 gCO_2e per tonne kilometer (Rail services decarbonisation action plan, pathway to 2035 (2020)). Recent investment in new electric rolling stock has increased the capacity on the Edinburgh to Glasgow route and reduced the CO_2 emissions by 69% (Rail services decarbonisation action plan, pathway to 2035 (2020)).

As the local data on the train-km within the city of Edinburgh was not available, the volume of transport on rails was estimated, using the primary source for passenger rail transport data from the Scottish Transport Statistics No 39, 2020 Edition, A National Statistics publication for Scotland.

23,088,000 journeys within Scotland started or ended in the city of Edinburgh (Scottish Transport Statistics, No 39, 2020 edition, page 118). This study assumes Edinburgh Waverley station was the starting point and divides the journeys as presented in Table 6.

[5] CAF Urbos 3 (Edinburgh) - Wikipedia
[6] Edinburgh Trams - Wikipedia

Table 6. Estimated train-km for the journeys ending or starting in Edinburgh (2019).

direction from/to Edinburgh Waverley station	tracks km	%	Passenger-km/a	Train-km/a
	15.6	20	72034560	1200576
North towards Dundee and Aberdeen	6.6	15	22857120	380952
South towards Tweedbank	7.4	5	8542560	142376
South-West towards Carlisle, Glasgow and West coast main line	14.9	10	34401120	573352
South-West towards Airdrie and Glasgow	14.8	10	34170240	569504
West towards Glasgow, Stirling, Perth and Inverness	14.9	40	137604480	2293408
total		**100**	**309610080**	**5160168**

With the average train occupancy of 60 passengers, this leads to 5.16 million train-km within Edinburgh. However, the baseline carried out calculations using the passenger-km estimate.

Outside the city boundary, the railroads leading to the North and South are not electrified, and the trains operating in those directions make use of diesel engines. (Rail services decarbonisation action plan, pathway to 2035 (2020)).

5,073,000 cross-border journeys started or ended in Edinburgh. This study assumes that 75% of these were from the Edinburgh Waverley station in the East direction[7] towards the East Coast Main Line, where the distance from the Edinburgh Waverley station to the border of the city of Edinburgh council is about 6.6 km. This accounts for 25,111,350 passenger-kilometers within the boundaries of the city of Edinburgh. 25% of cross-border journeys are assumed to be in the direction of South-West towards the West Coast Main Line (14.9 km), accounting for 18,896,925 passenger-kilometers. This equates to 44,008,275 passenger-km within the borders of the city. Accounting for the average train occupancy of 60 passengers, this results in 0.73 million train-km in the city of Edinburgh.

The Scottish journeys and cross-border journeys together total up to 354 million passenger-km per year and 5.89 million train-km per year (with a 60-passenger occupancy).

The final baseline calculation applies the total estimated passenger-km and the average UK emission factor for passenger rail transport 2019–20, which is 35.1 gCO_2e/passenger-km (Rail emissions 2019–20, Office of Rail and Road). Using the national average emission factor is justified since trains' power is drawn from the National Grid (Rail services decarbonisation action plan, pathway to 2035 (2020)).

For comparison, the DEFRA Conversion factors datasheet presents the following emission factors for trains (2020 Government greenhouse gas conversion factors for company reporting):

- National rail 36.94 gCO_2e/passenger-km
- International rail 4.97 gCO_2e/passenger-km

As the share of electric trains in the city of Edinburgh is rather high, the national average emission factor may be too high.

Cars, light commercial vehicles and heavy good vehicles

[7] Explore the UK by Rail with Our Route Map | CrossCountry (crosscountrytrains.co.uk

For the baseline analysis, the Edinburgh road transport activity data 2019 origins from the national statistics by the UK Government Department for Transport statistics[8]. This dataset provides vehicle-kilometres for cars, light commercial vehicles and heavy good vehicles.

The average emission factor for passenger cars was calculated as a weighted average of the various engine types of the passenger car stock in the UK (Eurostat 2020). The emission factors for various fuel types were set in accordance with DEFRA (DEFRA, 2020) except for the electric vehicles. The average emission factor is 170 gCO_2e/km.

Electric passenger cars were assumed to have an electricity consumption of 0,15 kWh/km and they were assumed to run using the UK's grid electricity. The CO_2e emission factor for the UK's grid electricity mix was calculated from the EAA data (230 gCO_2e/kWh for UK in 2019), and the impact of cross-border trade and transmission losses were added as in Moro, A. et al. (2018), Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles[9]. After converting to 2020 grid emissions, this resulted in a grid electricity emission factor of 237 gCO_2e/kWh. For comparison, the DEFRA dataset announced CO2e emissions of 233.14 gCO_2e/kWh for the "electricity generated in the UK" in 2019, and advises to account for transmission and distribution losses 21.7 gCO_2e/kWh. This leads to an average CO_2e emission factor of 0.035573 $kgCO_2e/km$ for EVs. For comparison, the DEFRA datasheet presents values 0.01820–0.03338 $kgCO_2e/km$. The GHG emission factors for other road transport vehicles are:

- coach: 640 gCO_2e/vehicle-km
- light commercial vehicle: 247 gCO_2e/vehicle-km
- heavy goods vehicle: 658 gCO_2e/vehicle-km.

Total emissions

The results of the baseline analysis calculation are presented in Table 8 below. Conversions from passenger-kilometres to vehicle-kilometres or vice versa are avoided as they may cause more inaccuracy in the results.

Table 7. Transport activity, the CO_2e emission factors and the baseline transport emissions in Edinburgh (2019).

	Transport activity		Conversion factor		Emissions
Mode of transport	million pass-km/a	million vehicle-km/a	gCO_2e/ pass-km	gCO_2e/ vehicle-km	1000 tCO_2e/a
Passenger car		1,771.0		170	301.2
Bus	648.0	40.0	120		77.4
Tram	57.3	1.4	18		1.0
Passenger train	354.0		35		12.4
LGV		442.0		247	109.2
HGV		88.0		658	57.9
Freight on rails					
Total					**2,498**

[8] www.gov.uk/government/organisations/department-for-transport/series/road-traffic-statistics

[9] Transportation Research Part D 64 (2018) 5–14.

2.1.2.3 Land Use

The distribution of Edinburgh land cover classes and urban trees are shown in Figure 11 and Figure 12. Distribution of soil types is presented in Figure 13.

Figure 9. CORINE land cover classes in Edinburgh.

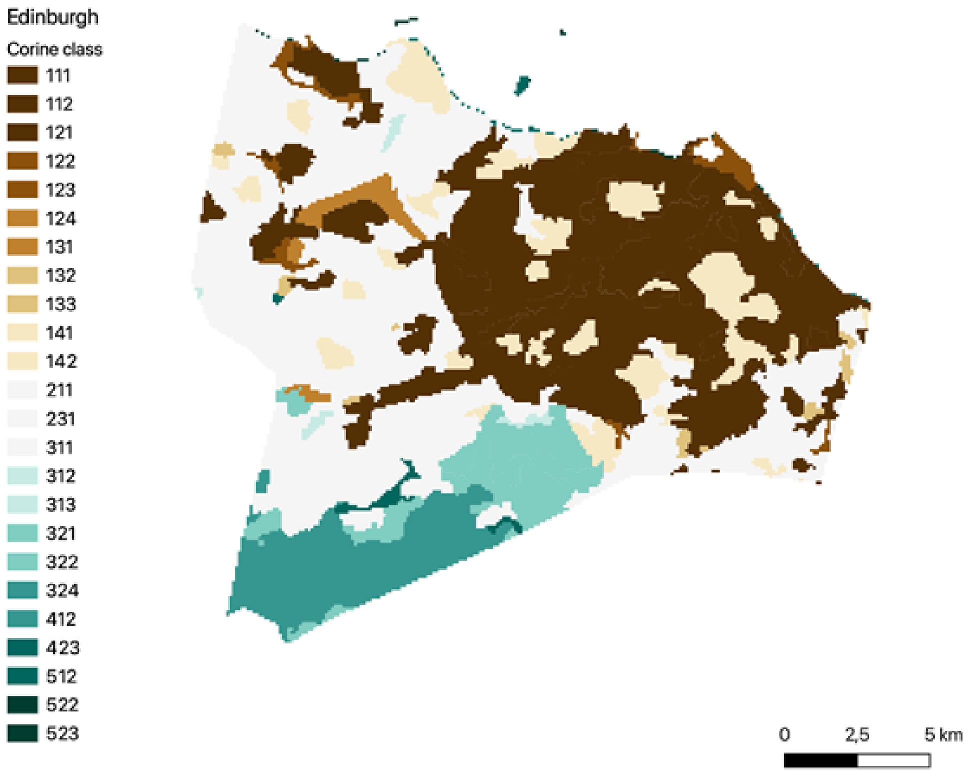

Figure 10. Tree cover in Edinburgh (CORINE Street Tree Layer).

Figure 11. Soil types in Edinburgh (European Soil Database).[10]

The dominant land cover is artificial areas (CORINE class 1 ≈ IPCC category Settlements) that constitute 47% of total Edinburgh area (Table 9). Agricultural areas (CORINE class 2 ≈ IPCC cropland, grasslands) cover 36% of total area, followed by forest and semi-natural areas (CORINE class 3 ≈ IPCC forest land, grassland, unmanaged land) and wetlands (CORINE class 4 ≈ IPCC peat extraction sites, unmanaged wetlands), both classes covering 8% of total Edinburgh area. The least represented land class (1%) is water bodies (CORINE class 5 ≈ IPCC unmanaged land). Deriving from the administrative borders of Edinburgh (Open Street Map) and the CORINE Street Tree Layer, the area of Edinburgh urban trees is approximately 2,612 ha[11] (9% of total administrative area). According to the European Soil Database, mineral soils constitute 65% and Histosols (IPCC organic soils) 4% of Edinburgh area, while the soil type is unknown for 31% of the area. Most of the unknown soil types (94%) are found under artificial areas such as under buildings, transport networks and other impermeable features.

[10] WRB soil classes: 1- no soil/no information available; CM - Cambisol; GL - Gleysol; HS - Histosol; PZ - Podzol; LP – Leptosol.

[11] Not presented separately in Table 10 because data is derived from a different CORINE layer, however the area of urban trees is most likely represented under CORINE classes 121 (Discontinuous urban fabric) and 141 (Green urban areas).

Table 8. Edinburgh land use and soil types.

CORINE land class		IPCC land-use category	IPCC soil type (ha)			Total area (ha)
			mineral	organic	not known	
Class 1: Artificial areas	111	Settlements	0	0	1,002	1,002
	112		2,238	45	5,118	7,401
	121		1,067	0	962	2,029
	122		270	0	0	270
	123		10	0	128	138
	124		302	0	0	302
	131		89	0	0	89
	132		29	0	0	29
	133		170	0	1	171
	141		48	0	654	702
	142		1,084	0	990	2,075
Class 2: Agricultural areas	211	Cropland	7,969	271	118	8,358
	231	Grassland	1,381	764	291	2,436
Class 3: Forest and semi-natural areas	311	Forest land	390	15	120	525
	312		47	0	0	47
	313		61	33	0	94
	321	Unmanaged land	615	21	0	636
	322	Grassland	1,112	0	0	1,112
	324	Forest land	2	45	0	47
Class 4: Wetlands	412	Unmanaged wetlands & peat extraction sites	2,268	5	0	2,272
	423	Unmanaged wetlands	12	0	23	35
Class 5: Water bodies	512	Unmanaged land	145	2	0	147
	522		5	0	0	5
	523		4	0	11	15
Total			**19,317**	**1,201**	**9,419**	**29,936**

The UK compiles and reports three different sets of CRF tables, each with a different geographical coverage of emissions to fulfil the reporting requirements of the EU Monitoring Mechanism Regulation (MMR), the Kyoto Protocol, and the UNFCCC (UK Greenhouse Gas Inventory 1990 to 2019 (UK Department for Business, Energy & Industrial Strategy, 2021)). In the current analysis, the implied carbon-stock-change factors from the Convention (UNFCCC) CRF tables were applied which corresponds directly to the framework of the IPCC LULUCF methodology. Although the UK has data sources available at the individual country level (England, Scotland, Wales and Northern Ireland), combined results are published in the CRF tables to give UK totals (UK Greenhouse Gas Inventory 1990 to 2019); United Kingdom. 2021 Convention Common Reporting Format (CRF) Tables), meaning carbon-stock-change factors are not provided separately for individual country level. Therefore, the combined CSC factors of UK[12] were implemented in the Scottish baseline analysis (Table 10).

According to the IPCC LULUCF guidelines only losses of C are associated with drainage of organic soils, whereas the respective UK's organic soil CSC factor for Forest land remaining Forest land subcategory has a positive value indicating C gains in organic soils. Thereby, it is stated in UK's NIR (Annex 3.4.1.7) that emissions from forest on drained organic soils are calculated using IPCC Tier 1 methodology. The default IPCC emission factor for drained organic soils in temperate managed forests[13] is 2.6 tCO_2-C/(ha,a) (IPCC, 2014). Additionally, results from the study by Evans et al. (Evans et al, 2017) that provides empirically-based and UK-specific IPCC Tier 2 peatland emission factors is implemented in the UK organic soil emission calculations. Emission factor of 2.0 tCO_2-C/(ha,a) from the latter study was used in the current analysis in order not to underestimate emissions from drained forest organic soils.

The UK reported CSC factor for organic soils under peat extraction sites combines both on- and off-site carbon stock changes, while in the current study only direct (on-site) CO_2 emissions are included (emissions resulting from the amount of peat extracted and used for horticulture are excluded). Therefore, the averaged on-site emission factor of domestic and industrial peat extraction sites is used.

According to the i-Tree Eco study (Doick et al, 2017) the estimated carbon sequestration by trees in Edinburgh is 2.51 tC/ha tree cover per year[14].

[12] UK reports carbon-stock-change factors separately for 'United Kingdom' (incl Northern Ireland) and 'Overseas Territories and Crown Dependencies' in its CRF tables. The values of the CSC factors for United Kingdom were applied in the current analysis.

[13] All UK forests are considered temperate (UK Greenhouse Gas Inventory 1990 to 2019: Annual Report for Submission under the Framework Convention on Climate Change. Department for Business, Energy & Industrial Strategy. April 2021)

[14] Calculated based on the characteristics of Edinburgh urban trees (crown cover, species, average diameter, growth of the tree genera etc). Sycamore features as the main contributor to the annual sequestration of carbon by Edinburgh's urban forest (Doick et al, 2017).

Table 9. UK's land use carbon-stock-change factors (Submission 2021, inventory year 2019).

Carbon-stock-change factors	Biomass		Dead organic matter		Soil	
tC/(ha, a)	above-ground	below-ground	dead wood	litter	mineral	organic
Forest land remaining forest land	0.75	IE[15]	0.31	0.04	0.40	-2.00
Cropland remaining cropland	-0.0003	IE	NO	NO	-0.33	-8.19
Grassland remaining grassland	-0.003	IE	NA	NA	0.39	-1.09
Peat extraction remaining peat extraction	NO	NO	NO	NO	NO	-2.24
Settlements remaining settlements	2.51	IE	NA	NA	-0.43	-0.18

NO – not occurring/no emissions.
IE – included elsewhere.
NA – not applicable/reporting not required.
Negative CSC factors denote decrease and positive increase in the C pool.

Land use emission estimates in Edinburgh are presented in Table 10. The land use sector in Edinburgh is estimated to be currently a net sink of -1,176 tCO_2. Annual CO_2 removals are mainly related to carbon sequestration by urban trees that demonstrates the importance of urban vegetation in mitigating climate change among other benefits such as reducing the risk of flooding, reducing the 'urban heat island' effect, improving the health and comfort of urban residents etc. Major emissions result from cultivation of cropland soils in Edinburgh. Total emission estimate does not include potential emissions from peat extraction sites that however might be a minor underestimation if any at all. CORINE class 412 'Peatbogs' includes both natural and exploited peat bogs, thus the area of peat extraction sites cannot be determined based on CORINE maps. However, the area of organic soils in class 412 is only 5 hectares, thus it is unlikely that industrial peat extraction sites are present in Edinburgh.

Table 10. Baseline land use emission estimates in Edinburgh (tCO_2/a) (2019).

	Biomass		Dead organic matter		Soil		
IPCC Land use category	above-ground	below-ground	dead wood	litter	mineral	organic	**Total**
Forest land	-1,954	IE	-806	-93	-728	688	-2,892
Cropland	10	IE	0	0	9,681	8,136	17,828
Grassland	38	IE	0	0	-3,596	3,052	-506
Peat extraction sites (wetlands)	0	0	0	0	0	NE	NE
Settlements	-23,997	IE	0	0	8,362	29	-15,606
Total	**-25,903**	**0/IE**	**-806**	**-93**	**13,719**	**11,906**	**-1,176**

Emissions have positive and removals negative signs.
IE – included elsewhere.
NE – not estimated.

[15] Included under aboveground biomass.

2.2 Spatial planning policies

Scotland's Third National Planning Framework (NPF3) is a long-term strategy and a national vision of what is expected of the planning system and the actions that it must deliver for the people of Scotland. It is accompanied by an Action Programme, which describes the implementation of NPF3. Scottish Planning Policy is thematic national planning policy and sets out how nationally important land use planning matters should be addressed across the country.

2.2.1 Actions to be addressed

NPF3 is an ambitious plan which aims to achieve at least an 80% reduction in greenhouse gas emissions by 2050. It has highlighted that most of the energy infrastructure, and the majority of Scotland's energy consumers, are located in close proximity to cities. Thus, cities are a focus to improve the energy efficiency of the built environment, which is both a challenge but also an opportunity for reducing emissions.

Actions from NPF3 that the tool will aim to quantify for the building sector relate to the promotion and facilitation of energy efficient building design, as well as actions that promote the use of lower carbon fuels in buildings. While no numerical proposals are highlighted, nevertheless, the following policies and objectives from the NPF 3 can be quantified:

A successful, sustainable place:

- 2.5: Significant increase in house building to ensure housing requirements are met across the country
- A low carbon place:

  3.16: Retrofitting efficiency measures for the existing building stock.

  3.17: We believe that there are significant opportunities for the cities in particular to use renewable and low carbon heat energy.
- We will apply building standards to improve the energy efficiency of existing and new buildings.
- A natural, resilient place:

  4.14: A more integrated approach and 'greening' of the urban environment through green infrastructure and retrofitting.

The tool developed will quantify the impacts on emissions from:

1) Retrofits of the building sector – which will also allow for changes in the current buildings' space and water heating to account for changes in technologies such as changing from boilers to heat pumps or alternatively to account for connections to low carbon heat
2) Changes in urban densification
3) Change in building use (from commercial to residential or vice versa)
4) Increase in renewable energy generation from retrofits and new buildings.

Scotland's Third Land Use Strategy 2021–2026 main goals in the land use sector is to increase the rate of afforestation and peatland restoration. Given the data provided in NIR the following actions can be quantified:

- afforestation: cropland/grassland/settlement conversion to forest land
- deforestation: forest land conversion to cropland/grassland/peat extraction/settlements
- peatland restoration (rewetting)
- land conversion to peat extraction
- grassland/settlements conversion to cropland
- cropland/settlements conversion to grassland
- cropland/grassland conversion to settlement.

2.2.2 Quantifying actions

2.2.2.1 Building related policies

New buildings

There are no indicative numerical proposals in the NPF, however when addressing construction of new buildings the Housing statistics 2019: Key Trends Summary[16] that is published by the Scottish Government, indicates a national increase of 1% in new dwellings. It has been assumed that new dwellings in Edinburgh will also increase by 1% annually, thus this would result in a total of 18,928 new houses to be built over the NPF lifetime.

Territorial emissions

The construction of 18,928 new houses over eight years can be categorised as 12,871 new apartments, 2,271 terraced, 1,893 semi-detached and 1,893 detached houses. This breakdown assumes that the new residential buildings built are in the same proportion as those constructed in the same period. This increase in residential units would result in an additional 18,842 tCO_2. When considering densification, accounting for the same increase in housing units (18,928 additional units) the emissions from building energy use would have the same increase as new construction in a new settlement (18,842 tCO_2), however the impact that the densification would have, can be clearly seen in the transport sector.

It was assumed that a total of 1,989,347 m^2 of floor space was created through this policy. Assuming this led to a total development of buildings with an equivalent spatial footprint (200 ha), the total expected emissions in the year of the development would be 0.39 $MtCO_2e$. This was assuming that the original land was split between forest land and grassland and between mineral and organic soils. The original land-use was assumed to already be of settlement land type for the densification policy, and so no additional land-use change emissions would be expected.

Consumption-based emissions

The calculations were performed in 2030. The same assumptions were applied as the territorial side, indicative of 18928 new houses with the same average house size as the whole of Edinburgh. The average income level of the residents was assumed to be equivalent to the national average. The new houses were assumed to be built to an energy class B, whereas the existing stock was assumed to be D. For the development of a new settlement, the demand vector for an average density (town) was applied. Considering the expected energy savings for the new developments leads to per capita emissions for the new residents of 6.7 tCO_2e (against 6.5 tCO_2e per capita in the baseline scenario for 2030). The total increase in emissions as a result of these new residents would be 0.27 $MtCO_2e$.

For the alternative example of densification, the situation was more complicated since the city demand vector was already used for the baseline. No demand vector is available for higher density areas (although this could be developed in the future) and a simplification was therefore applied. It is known that the use of private transport fuel (in units of MJ) generally decreases as density increases. A quantitative relationship can be fitted to data describing the per capita private fuel use for residents of different global cities that have different urban densities (Kenworthy, 2018). The urban density of Edinburgh as a whole is 1,800 residents/km^2. Based on this relationship, If this was increased to 3,600 residents/km^2 then the fuel use would be reduced by 42%. If this was applied along with a 20% increase in public transport expenditure, then the expected per capita emissions would be 5.2 tCO_2e. In this case the total increase in emissions would be 0.21 $MtCO_2e$.

It is important to stress that the entire profile of consumption is different when demand vectors representing different urban densities are used. This means that each HBS tracks the changes in expenditure on all products, such as food, electricity, air travel and so on, whereas here the expenditure on fuel is only reduced and (partly) covered by an increase in public transport. The results here do not represent the whole changes that would be expected from an increase in urban density. Indeed, there are multiple examples in the academic literature where residents of more dense urban areas have higher carbon footprints than residents of less dense areas (Heinonen, 2011) In the future more detailed analyses may be possible that were not

[16] https://www.gov.scot/publications/housing-statistics-scotland-2019-key-trends-summary/pages/5/

feasible within the timeframe of the project. The stakeholders should be aware of these significant limitations when analysing the results.

Retrofitting

To determine the number of retrofits that will be carried out over the eight-year timeframe of the NPF, the service providers made use of the Draft Edinburgh 2030 Climate Strategy - Delivering a Net Zero Climate Ready Edinburgh[17]. This draft strategy identifies that approximately 42% of homes have an EPC rating of D or lower. '*Regulations proposed by the Scottish Government in the national draft Heat in Buildings Strategy would mean that by 2035, all domestic properties will need to have an EPC rating of C or higher. For Edinburgh, this could be as many as 100,000 homes in Edinburgh that will require retrofitting.'*

Territorial emissions

From the analysis carried out on Edinburgh's residential sector, it was found that most buildings had an average EPC rating of D (apartments, terraced, semi-detached and detached housing were analysed separately to find the average energy rating for the different dwelling types). Assuming that approximately 100,000 homes have to be retrofit by 2035, then over the NPF timeframe, this would result in 53,000 homes to be retrofit from a D to a C rating, of which 36,040 are apartments, 6,360 terraced, 5,300 semi-detached and 5,300 detached houses. This assumes that the number of buildings retrofitted by type of dwelling are in the same proportion as the current existing housing stock. The total emission reduction from these retrofits equate to 101,894 tonnes of CO_2.

Consumption-based emissions

The calculation was applied in 2035 with 53,000 houses to be retrofitted. This represents approximately 21% of the housing stock, based on the population of Edinburgh and the average household occupancy given by the stakeholders. The improved energy efficiency was assumed to be from a D to C rating, representing a reduction in energy use of around 30%. Applied to the whole building stock this leads to energy use being reduced by an approximate scale factor of 0.94. Applying this leads to pan city per capita emissions of 5.9 tCO_2e in 2035 (the equivalent value for the baseline was 6.1 tCO_2e). Applied across the whole of Edinburgh, this leads to total emissions savings of 0.85 $MtCO_2e$.

Renewable energy generation

Territorial emissions

Renewable energy (RE) generation for the building sector comes from the RE generated in new buildings and retrofitted ones. Assuming that all new houses include a 20% RE generation and that houses retrofitted to a C EPC rating generate 10% of RE, this results in an increase of 5,706 MWh of RE. No information on new commercial buildings and retrofits could be found in the National Planning Framework 3. However, it should also be noted that the tool can quantify construction of new commercial developments, retrofits, changes in building use and the effects of urban densification.

Consumption-based emissions

The policy was applied in 2035 to the retrofitted buildings, using the same assumptions as the territorial calculations of 10% of energy coming from rooftop PV. This amounts to 2.1% of electricity coming from rooftop PV when applied to the whole building stock. This leads to per capita emissions of 6.0 tCO_2e in 2035, and total reduction in emissions of 5.0 $ktCO_2e$.

[17] https://consultationhub.edinburgh.gov.uk/ce/2030-climate-strategy/supporting_documents/080621%20FINAL%20Edinburgh%202030%20Climate%20Strategy.pdf

2.2.2.2 Transport related policies

Comparison: densification vs. new settlement

In this comparison, densification is assumed to guide the new residents to areas with excellent provision of public transport, whereas new settlement is expected to have a suburban character and higher car-dependency. In both cases the transport activity is assumed the same than the baseline average.

The number of residents for the new settlement is in this calculation 66,300, which will form 10.9% of the total population of Edinburgh. Thus, 89% of the citizens will have no changes in modal shares. The results are presented in the table below.

Table 11. New development as densification or as extension towards suburban areas; estimated impact on modal shares and the passenger transport GHG emissions.

	Passenger-km			tCO_2e/a		
	average	urban	suburban	average	urban	suburban
Passenger car	5,222	4,178	6,267	555	543	567
Bus	1,194	1,542	555	143	147	134
Tram	106	454	49	2	3	2
Passenger train	652	1,001	303	23	24	22
Total	**7,175**	**7,175**	**7,175**	**723**	**717**	**725**

The urban profile with less passenger car kilometers and more public transport reduces the GHG emissions in transport sector by 3,426 tCO_2/a, assuming that the new population is about 11%. With more car-dependent, suburban profile, the GHG emissions will increase by 1,438 tCO_2/a.

The benefits of densification will become even more evident when the embodied emissions are included in the comparison.

High speed rail

Due to lack of data on completion dates and expected changes in modal shifts, a number of assumptions were made. These results should then not be taken as indicative of the expected changes in emissions following these changes, but rather illustrative of how the tool can quantify such changes should such data be available. The calculation was performed in 2035.

<u>Consumption-based emissions</u>

The consumption approach looks at the carbon footprint of private residents. This means that the emissions from freight transport are not directly considered. However, given that the approach models the whole supply chain, a proportion of the freight travel that can be related to products purchased by the residents of the area will in principle be considered. This policy was illustratively modelled via a 20% reduction in private transport fuel consumption, and a 20 % increase in expenditure on public transport. The share of rail in public transport expenditure was also increased from 0.54 to 0.6 and private vehicle purchases and maintenance were reduced by 10%. The effects of these changes yielded per capita emissions of 5.8 tCO_2e. The total emissions reduction was 0.12 $MtCO_2e$.

The Borders railway line

Given the lack of quantitative detail, this policy was modelled in the same way as High speed rail, but with the policy introduced in 2040.

<u>Consumption-based emissions</u>

This policy led to per capita emissions across the whole of Edinburgh of 5.4 tCO_2e (the equivalent per capita emissions in the baseline were 5.7 tCO_2e). This would lead to an equivalent emissions reduction of 0.11 $MtCO_2e$.

Promotion of active travel (biking, walking)

As with the other policies, the lack of key numbers prohibits the true quantification of the expected changes following this policy. Hence, the changes are again illustrative and serve how the quantification would be expected to proceed should such information have been made available.

Consumption-based emissions

This policy was assumed to lead to a reduction in purchases of fuel for private transport of 20% and purchases of vehicles and vehicle maintenance of 10%. No changes were made to the expenditure on public transport. This policy was applied in 2030. The annual per capita emissions across the whole of Edinburgh were found to be 6.2 tCO_2e (the equivalent emissions in the baseline scenario were 6.5 tCO_2e in this year). This leads to a total emissions reduction of 0.14 $MtCO_2e$ in 2030.

2.2.3 Results

The results of the policy quantification are summarised in Table 12. In general, there was a lack of quantitative numbers linked to specific policies in the reference document, meaning assumptions were required to perform the calculations.

Table 12. Quantifying spatial planning policies for the City of Edinburgh.

policy	impact	module	quantification in the tool	CO_2e increase /decrease (tCO_2)	Emissions per capita (tCO_2/capita)
1. Construction of new buildings			Comparison – new developments vs densification		
a) new construction as new settlement	2022-30	energy use in buildings	additional floor area in all building categories	19	N/A
		transport	adjusting modal shares	1,438	
		land-use change	land use change (ha) from greenfield (land use type forest and grassland) to settlement	39,000	N/A
		consumption-based	increase in the number of residents. Change of demand vector from city to town. Improved building efficiency.	270,000	6.7 (in 2030) New residents only.
b) new construction as densification	2022-30	energy use in buildings	additional floor area in all building categories	19	N/A
		transport	adjusting modal shares	-3,426	
		land-use change	no impact		N/A
		consumption-based	increase in the number of residents. Decrease in private travel consumption. Improved building efficiency.	210,000	5.2 (in 2030) New residents only.
2. Retrofitting	2022-30	energy use in buildings	change in energy consumption profile of existing buildings	-100,000	N/A
		consumption-based	change in expenditure on energy	85,000	5.9 (in 2035)
3. Increase in renewable energy generation	2022-30	energy use in buildings	change in energy consumption profile of existing buildings	5706 MWh	N/A
		consumption-based	increase in the share of renewable energy	5,000	6.0 (in 2035)

The construction of the new buildings would lead to total life-cycle emissions of 1 $MtCO_2e$ in 2030. Assigned to the new residents, this gives each a footprint of 204 tCO_2e in 2030 in the case of a new settlement, and 2,102 tCO_2e for densification.

3 Conclusions

This section identifies the key findings from the different carbon emitting sectors for both the consumption and territorial-based approaches, and also discusses the actions from the quantified spatial planning policies that can contribute the most to emission reductions in Edinburgh.

3.1 Key findings from the baseline

It should be noted that both approaches for estimating emissions, have identified the transport and building sectors as having the highest emissions and consumed more fossil fuels than the other sectors. Thus from this analysis, these sectors should be the main targets of energy and emission reduction initiatives.

3.1.1 Consumption-based approach

- The per capita emissions were approximately 8 tonnes CO_2e per annum.
- The total consumption emissions for the city were calculated to be approximately 4.2 $MtCO_2e$ per annum.
- The largest contributions to the emissions came from residential energy demand and transport fuels, for which the largest contributions came from the direct use of fuels by the household. This also reflects the large proportions of space heating arising from direct combustion of fossil fuels. In the case of Edinburgh, this particularly arises through gas-based heating (around 3 tonnes of emissions per capita derive from gas-based heating).
- Transport emissions are also significant.

3.1.2 Territorial approach

3.1.2.1 Buildings

- Total emissions from both the residential and commercial sectors in the City of Edinburgh accounted for 1,663,650 tonnes of CO_2 in 2017.
- The residential sector contributed 46% and the commercial sector 54% to the total emissions.
- The main source of emissions come from natural gas (52%), followed by electricity (44%) and heating oil (4%).

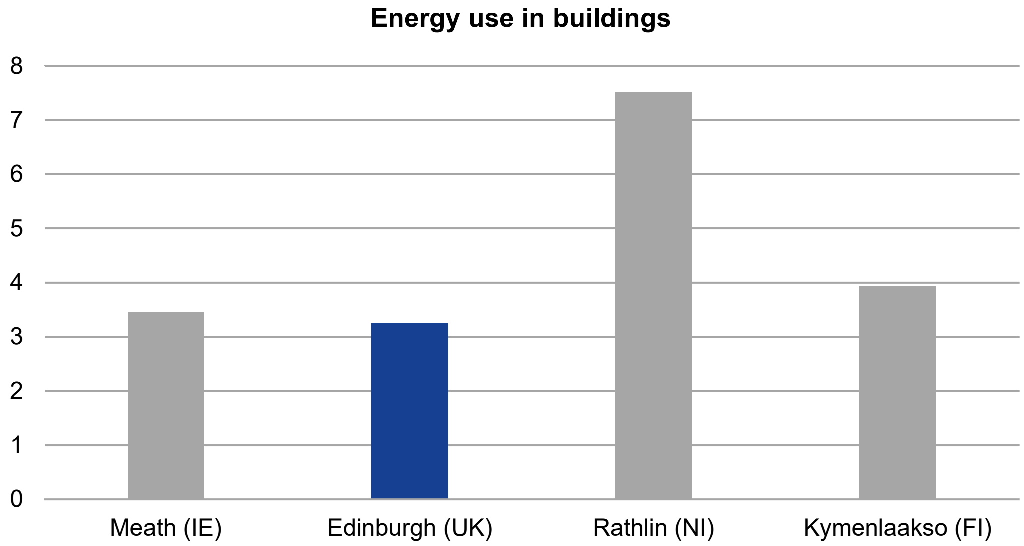

Figure 12. Annual buildings baseline emissions per capita ($tCO_2e/(capita,a)$) (2019).

3.1.2.2 Transport

- The City of Edinburgh is a major transport hub in Scotland and in the whole UK. Edinburgh is also a forerunner in GHG mitigation, which is also visible in transport data, including the electrification of a main railway line and the investments on a tram system and electric buses of a bus operator owned by the city.
- The baseline emissions are also characterised by excellent provision of public transport.
- Emissions from transport in Edinburgh come from:

  Passenger cars 301.2 ktCO_2e/a

  Light commercial vehicles 109.2 ktCO_2e/a

  Busses 77.4 ktCO_2e/a.

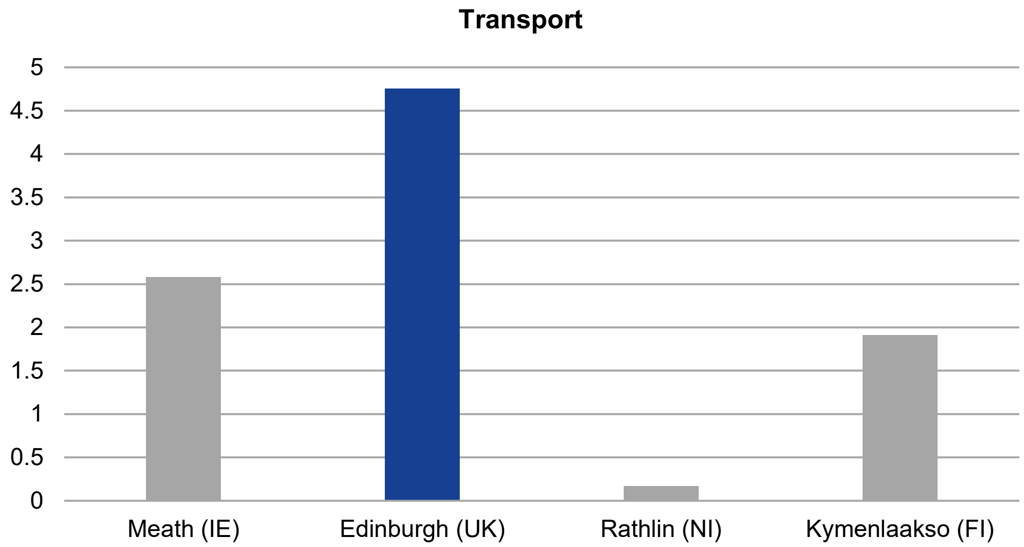

Figure 13. Annual transport baseline emissions per capita (tCO_2e/(capita,a)) (2019).

The total transportation emissions deviate from the existing Edinburgh baseline by -15%. This is partly explained by the fact that the existing Edinburgh baseline analysis includes all types of motorized road vehicles, whereas the method developed for the GGIA tool focuses on passenger cars, buses and road freight transport. The main methodological difference between this study and the current baseline is related to activity data. The current Edinburgh baseline applies the data on fuel consumption, which is typically well-documented. However, the GGIA methodology does not use fuel consumption data, because it is difficult to allocate fuel consumption in territorial and city scale: although we know the amount of petrol sold in one city, we don't know if this petrol was combusted in driving in this city or outside the city boundary. On a national level, transport activity in vehicle-kilometres can be sourced from Eurostat datasets.

3.1.2.3 Land use

- The land use sector in Edinburgh is estimated to be currently a net sink of -1,176 tCO_2.
- Annual CO_2 removals are mainly related to carbon sequestration by urban trees that demonstrates the importance of urban vegetation in mitigating climate change among other benefits such as reducing the risk of flooding, reducing the 'urban heat island' effect, improving the health and comfort of urban residents etc.
- Major emissions result from cultivation of cropland soils in Edinburgh.
- Total emission estimate does not include potential emissions from peat extraction sites that however might be a minor underestimation if any at all.

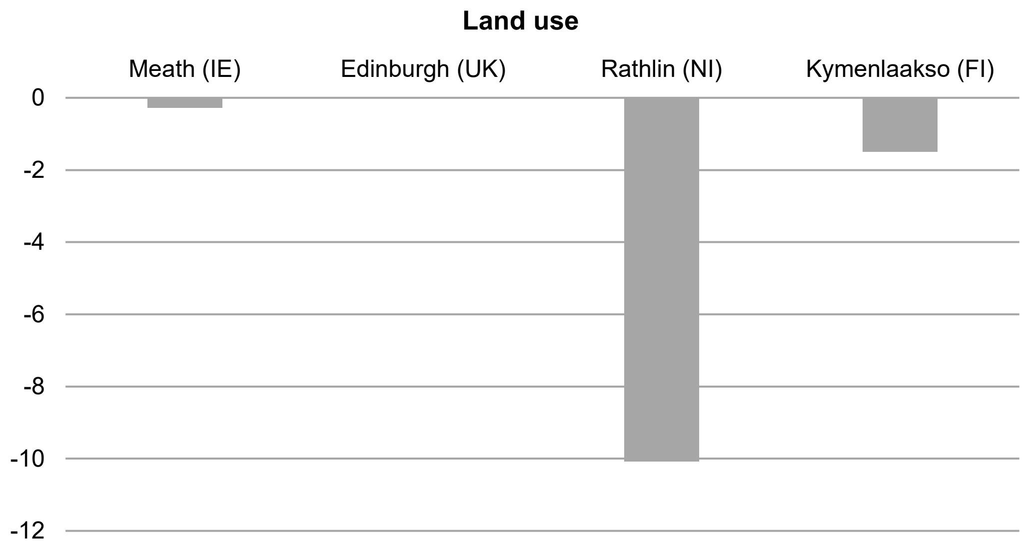

Figure 14. Annual land use baseline emissions per capita (tCO_2e/(capita,a)) (2019).

The GHG emissions from land-use deviate quite significantly from the existing baseline analysis for the City of Edinburgh. Both assessments are based on the IPCC methodology and the carbon stock change factors from the CRF-tables annexed to UK's national inventory report. The deviation mainly results from land use analysis methodology, which apparently had led to different kind of classification for land use. The key differences in this analysis are:

1) The assessment of this report demonstrates a robust, simplified method and databases that can be applied European-wide, also in those regions where refined local data is not available.

   Therefore the report analysis utilizes CORINE Land Cover database and European Soil Database. UK defines its land use categories and the areas of different land use categories using national forest inventory, Northern Ireland Woodland Base Map, UK Agricultural Census, ONS Standard Area Measurement, UK Directory of Mines and Quarries and Google Earth imagery (peat extraction sites), Peat condition maps, and Land Cover Map 2015.

2) A full-scale land use GHG emissions inventory needs to be simplified in order to make the method applicable in a tool.

   Land use emissions were calculated based on the carbon-stock-change factors provided in national CRF tables, while UK applies CARBINE carbon accounting model, that delivers detailed emission estimates for different carbon pools (biomass, litter, dead wood) for each year. Furthermore, the land-use changes are excluded from the baseline analysis of this report; in other words land use emissions are calculated with carbon stock change factors “forest land remaining forest land”, “cropland remaining cropland” etc.

3) The current land use emissions for the Edinburgh baseline derive from the UK-wide GHG inventory. The analyses for the UK Inventory cover the whole Great Britain and therefore apply a grid size of 20 x 20 km (partly 1 x 1 km) (BEIS 2021). The resolution of the GIS analysis for this report is much higher: it applies the most detailed (level 3) CLC classes for land cover analysis, based on a 100 x 100 m grid.

4) The IPCC LULUCF methodology allows countries to have flexibility in defining the six land use classes, which makes it difficult to align the 44 CORINE land classes according to the six IPCC land use categories. In general, the interpretation is based on the UK NIR but may, however, cause deviation in the results.

5) The quantification of this study includes CO_2 emissions only. The existing baseline analysis for land use in Edinburgh includes all GHG emissions (CO_2e).

6) UK, including the referred BEIS Edinburgh analysis, is following the IPCC LULUCF methodology. UK does not estimate biomass emissions/uptake under the “Settlements remaining Settlements”

category, however carbon uptake by urban trees was estimated in the current baseline analyses according to data obtained from the i-Tree Eco study and CORINE Urban Atlas Street Tree Layer (STL) 2018. According to our estimation, urban trees act as a major carbon sink that had a large impact on the total emissions for Edinburgh.

Thus, the source data of the QGasSP study is less country-specific but applies a higher resolution. On one hand it excludes some emissions but on the other hand is more accurate in accounting the impact of urban greeneries.

Despite the methodological simplifications, the result of this study seems to indicate that a more detailed analysis of specific land use emissions in Edinburgh (similar to the one carried out by the region of Kymenlaakso for example) might actually prove the land use sector in Edinburgh a carbon sink that can provide direct savings when carbon offsets are procured for carbon neutrality.

In this context it is important to stress again that the GHG quantification method for land-use was developed for national GHG inventories, and is not well-suited for urban environments, where much higher number of land use categories would be needed to reflect the climate impact for various kinds of urban environments.

3.2 Key findings from the action quantification of spatial planning policies

From the actions that were quantified for the Third National Planning Framework (NPF3), retrofitting and transport related actions had the greatest potential to reduce emissions.

From the analysis carried out on Edinburgh's residential sector, it was found that most buildings had an average EPC rating of D, assuming that approximately 100,000 homes have to be retrofit by 2035, then over the NPF timeframe, this would result in 53,000 homes to be retrofit from a D to a C rating. The total emission reduction from these retrofits equate to 101,894 tonnes of CO_2. Renewable energy (RE) generation for the building sector comes from the RE generated in new buildings and retrofitted ones. Assuming that all new houses constructed include a 20% RE generation and that houses retrofitted to a C EPC rating generate 10% of RE, this results in an increase of 5,706 MWh of RE.

Comparing densification against new settlements, densification is assumed to provide the new residents with a good provision of public transport, whereas new settlements are expected to have suburban characteristics and higher car-dependency. The number of residents for the new settlement is estimated to be 66300, which will form 10.9% of the total population of Edinburgh. Thus, 89% of the citizens will have no changes in modal shares. The urban profile with less passenger car kilometres and more public transport reduces the GHG emissions in the transport sector by 3,426 tCO_2/a, assuming that the new population is about 11%. With a more car-dependent, suburban profile, the GHG emissions will increase by 1,438 tCO_2/a.

The benefits of densification will become even more evident when the embodied emissions are included in the comparison.

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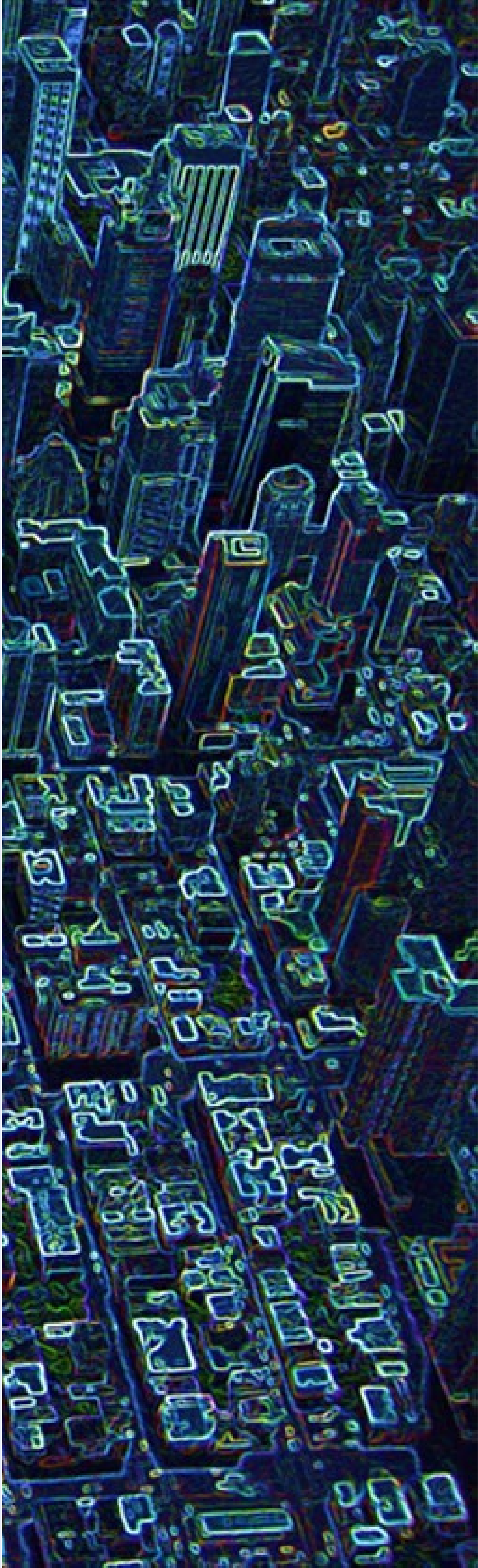

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