ESPON

EUROPEAN UNION

Co-financed by the European Regional Development Fund

Inspire Policy Making with Territorial Evidence

ANNEX 1 – METHOD DESCRIPTION //

GGIA Methodology

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 Ratings
CH_4	Methane
CIBSE	The Chartered Institution of Building Services Engineers
CLC	CORINE Land Cover
CLMS	Copernicus Land Monitoring Service
CO_2	Carbon dioxide
COICOP	Classification of Individual Consumption by Purpose
CORINE	Coordinated Information on the Environment
CRF	Common Reporting Format
CSC	Carbon-Stock-Change Factors
DEFRA	Department for Environment, Food & Rural Affairs, UK
EEA	European Environment Agency
EIO	Economic Input-Output
EPC	Energy Performance Certificate
ESDAC	European Soil Data Centre
ETRS89	European Terrestrial reference System
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
N_2O	Nitrous oxide
NEDC	New European Driving Cycle
NFI	National Forest Inventory
NIR	National Inventory Reports
NPF	National Planning Framework

p-LCA	Process-based Life Cycle Assessment
PRIMES	Price-Induced Market Equilibrium System, a large scale applied energy system model
RDE	Real Driving Emissions
RNG	renewable natural gas
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

This annex describes the quantification methods implemented by the QGasSP research team for the GGIA tool and the case study pilots in the QGasSP project.

The objective of the QGasSP project (2020–21) was to produce a methodology that will allow competent planning authorities at national, regional and local administrative levels to quantify the influence of spatial planning policies on greenhouse gas (GHG) emissions in a consistent manner. The expected primary outcome of the QGasSP project was the development and delivery of a robust, simple and proportionate method for quantifying and forecasting the relative GHG impacts of alternative spatial planning policies, with pan-European applicability. The purpose of this method is to help inform strategic spatial policy alternatives at different administrative scales, and which can ultimately assist national, regional and local policy decision-makers across EU Member States and ESPON Partner States in meeting their GHG emission reduction targets.

In accordance with the C40 cities' guidelines, the QGasSP research team applied two approaches in the quantification of greenhouse gas emissions:

1) Today most cities and regions apply **territorial approach** that assesses the direct greenhouse gas emissions within the geographic boundary of the area in assessment, for example the city boundary. However, it is important to notice that all the greenhouse gas emissions within the area boundary are not caused by the residents. On the other hand, the consumption of the residents causes plenty of emissions outside the area boundary, all over the planet.

2) **Consumption-based approach** aims to assess the global greenhouse gas emissions of the local residents. This can be assessed for example with the statistical data on the economic consumption of households (household budget survey, HBS). Consumption-based results could be described as global carbon footprint of the citizens. It provides a holistic picture on total greenhouse gas emissions.

The two approaches open two different perspectives to the greenhouse gas emissions. Together they can provide a thorough understanding of the climate impacts caused by spatial plans and planning policies. An illustrative example of how consumption-based approach differs from the territorial picture is highlighted in the following diagram (Figure 1).

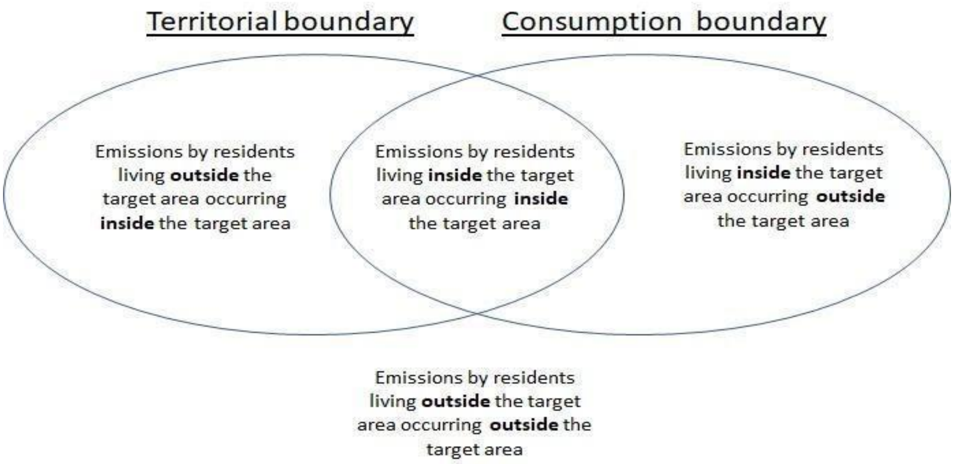

Figure 1. Conceptual differences between typical territorial and consumption emission boundaries.

2 Territorial quantification

2.1 Territorial approach: transport

2.1.1 Transport module in GGIA

Datasets included in the tool:

- A number of Eurostat datasets on transport activity (NUTS 0 level)
- TRACCS project dataset on car occupancy
- Future scenarios on the annual changes in transport activity: EU Reference Scenario 2016

Eurostat datasets have several data gaps: typically figures for Iceland, Liechtenstein and Norway are missing.

Planner User inputs:

To calculate the baseline and the indicative future projection, Planner User inserts values and selects menu options to describe the settlement types within the assessment area. When country level dataset is used, the statistical data on national transport activity and modal shares are down-scaled according to the population and settlement type. As the transport activity for metro and tram transport cannot be estimated this way, Planner User is expected to include or exclude (0–100%) metro and tram systems from the menu.

The policy quantification can include a new settlement or any policy that has an impact on transport activity, modal shares, shares of fuel types and/or the share of renewable energy in the electricity that is used in transport.

In addition, Planner User selects the time period (“policy period”) during which the policy is implemented.

Expert User inputs:

Expert user can adjust any default data value when creating a local dataset, including all CO_2e emission factors for all modes of transport. Expert User can specify of metro and tram systems that Planner User may choose to include or exclude.

Result:

The results show the policy impacts on the annual transport GHG emissions against the baseline scenario until 2050.

On the **Generate report** page, a summary of territorial quantification results is presented both as absolute GHG emissions (tCO_2e/a) and per capita ($tCO_2e/(capita,a)$).

The policies that can be quantified:

All spatial plans and policies that have an impact on passenger mobility, the intensity of freight transport, modal shares, fuel types in road transport and the CO_2e emission factor for the electricity used in transport.

In the territorial approach, the quantification of transport GHG emissions includes all transport activity within the boundaries of the target area, quantifying Tank-To-Wheels emissions for both freight and passenger transport.

Passenger transport includes

- buses and coaches
- passenger cars
- tram and metro

- passenger transport by rail
- passenger transport by in-land waterways.

Freight transport includes all haulage on roads, rails and water.

In the GHG emission quantification transport activity is multiplied by an emission factor. These two parameters are broken down in sub-factors which can be adjusted to quantify policy impacts.

Transport activity

Transport activity can be quantified either from the consumption of fuels or from the transport statistics, which are based on traffic counts or mobility surveys. In the baseline analysis, local datasets on vehicle kilometres (converted from passenger-kilometres or tonne-kilometres when necessary) are the primary source for transport activity data. As a rule, all GHG quantifications of planning policy impacts are carried out without specific traffic modelling.

Many sources prioritize fuel consumption as the source data for transport emissions calculation. However, in a territorial study it may be difficult to determine where the fuel is actually combusted - and only the fuel consumed within the selected area should be included.

The UK publishes statistics on fuel consumption by area of consumption (local authority level). This data also provides estimates of fuel consumption for each type of vehicle by road type (motorways, A roads and minor roads). The British methodology for calculating fuel consumption combines traffic activity data (from the Department for Transport's national traffic census) with fleet composition data and fuel consumption/emission factors (Sub-national consumption statistics, Methodology and guidance booklet, September 2021). However, respective data is not available for all European countries.

Transport activity defaults, proposed in the tool, are based on national-level (NUTS0) data which is scaled down by the number of residents and the settlement type. Passenger transport figures from the Eurostat database are first converted from passenger-kilometres into vehicle-kilometres by dividing them by average occupancy. Down-scaling and occupancy rate are two factors that cause high uncertainty in default values.

If the transport activity data would be available on NUTS1, NUTS2 or NUTS3 levels, this data could be applied directly in the quantification in some cases. Also, when the area in concern does not exactly match with the NUTS classification, the down-scaling of transport activity data would be more accurate than with national-level data.

There seems to be no up-to-date, comprehensive European statistics on vehicle occupancy rates. The accuracy of vehicle occupancy rate is important when the vehicle-kilometres are calculated from passenger-kilometre data.

Many sources, including a recent study by Fraunhofer institute, propose 1.6 as the European average for passenger cars (Fraunhofer, CE Delft, Ramboll, 2020). However, research literature indicates that there is significant variation in European car occupancy rates. In addition, the car occupancy rate depends on both the travel purpose and income level. As a default, the ESPON GGIA tool applies the national occupancy rates collected in the TRACCS project in 2011 (EEA, 2013). This seems to be the most recent comprehensive European dataset publicly available.

For example, the Finnish LIPASTO database (VTT, 2021) states that 1.7 is the average car occupancy rate. In Scotland the average passenger car occupancy is 1.5. The TRACCS figures differ from these slightly (EEA, 2013).

The ESPON GGIA proposes more accurate default values for tram and metro transport. The tool menu includes all European tram and metro systems, and they can be included either entirely or partially in the calculation.

For the default values in freight transport, GGIA applies national-level Eurostat transport activity data in vehicle-kilometres. This is down-scaled to the number of residents living in an area, and then fine-tuned with the menu options that require no expert knowledge on transport.

<u>Emission factors for modes of transport</u>

The GHG emissions from transport can basically be calculated with one average emission factor per mode of transport. For the policy quantification, it is necessary to provide a breakdown of factors which can be affected by the policies.

GGIA default values for emission factors

As a default, the emission factor for the electricity in transport is calculated with the national grid electricity emission factor including the imported electricity and transmission losses.

The most detailed breakdown is provided for passenger cars which typically cause the majority of the transport GHG emissions. The calculation of default emission factors starts with the specification of national emission factors for passenger cars with petrol and diesel engines. The calculation utilises the Eurostat data which provides the shares of small, mid-size and large engines per national car fleet. For various reasons, large engines are favoured in some countries, and this becomes visible in the average emission factor for petrol and diesel cars. The average emission factors for the three engine size categories were defined as in DEFRA 2019 (DEFRA, 2019), which provides conversion factors for these three categories in the British car fleet in 2002-2018. DEFRA 2019 was selected as it is the most recent available dataset on European car fleets for 2019. In reality, the average emission factor for each engine size category may differ from country to country. However, this simple method takes the national differences in petrol and diesel engine sizes into account.

Next, the average emission factor for passenger cars is calculated based on fuel shares in the national car fleet (Eurostat, Passenger cars by type of motor energy, 2019; for UK and Austria 2018 available). Together, the engine sizes and fuel shares cause significant variation in national average passenger car emission factors. The national differences are also reflected in the car occupancy rates which are applied when the transport activity data is calculated from passenger-kilometres.

Here the tool assumes that the annual kilometres driven for each engine type are in line with the respective share in the car fleet. This is a simplification, but the inaccuracy caused in the results can be considered minor.

In addition to the national average emission factor, GGIA provides default values for two driving profiles: street and road driving. These two values are applied to define driving profiles for various kinds of settlement types (city/town/suburban/rural). An expert user can adjust the shares of street and road driving in the driving profiles for five settlement types. As default, the transport in the city environment is 100% urban driving (high emission factor for combustion engines) and rural environment is 100% rural driving. This has a significant impact on the GHG emissions, as a higher emission factor should be applied for combustion engines driving in urban environment, due to frequent acceleration and stops.

Finally, one average emission factor for the whole area is calculated as a weighted average of driving profiles in the area.

For combustion engines, the emissions factors are so called Tank-To-Wheel emission factors, which in GPC system would be reported as Scope 1 emissions. However, there are two exceptions for the rule:

1) The CO_2e emission factor for rechargable electric vehicles (battery electric vehicles i.e. BEVs) are based on the electricity consumption of the vehicle type and the national grid electricity emission factor (for consumed electricity). These are not Tank-to-Wheel emissions, but without this, the calculation would underestimate the climate impact of electric vehicles.

2) The CO_2e emission factor for biogas is not included as a default in the ESPON GGIA tool, but examined in one of the policies quantified in the Kymenlaakso case study. Biogas refers to biomethane as a fuel for renewable natural gas (RNG) vehicles.

   Tank-To-Wheel emissions from combustion of biomethane are high and would hide the benefits of RNG transport. Therefore the CO_2e emission factor for biomethane includes also Well-To-Tank aspect and thus it can be considered a low emission fuel, in accordance with several sources (IRENA, 2018). The CO_2e emission factor for biogas depends on the raw material and the gas mix. The biogenic carbon emissions can be calculated as zero, but biogas cannot be accounted for as zero-emission fuel. The case study applies 0.048 kgCO_2e/km as the CO_2e emission factor for RNG passenger cars (IRENA, 2018).

   Although biomethane is not included in GGIA as a default propulsion option, it can be added in the local dataset, for example to replace the category “alternative fuels” as in the Kymenlaakso case study.

This also shows why the reporting by Scopes is not emphasized in the GGIA tool. Limiting the calculation strictly to Scope 1 emissions would give a false indication on the climate impacts of various vehicle propulsion options. The emission factor for electric vehicles (EVs) would be zero, whereas in reality the emission factor of EVs depends on the grid electricity. In countries with carbon-intensive grid electricity, such as Estonia, electric vehicle has a higher emission factor in road driving than a car with a petrol engine.

Another option would be to extend the quantification to cover scopes 1-3 and so called well-to-wheels emissions instead of tank-to-wheel emissions. A holistic scope three calculation should also include the manufacturing of vehicles as well as the maintenance of infrastructure. Due to the time constraint of the QGasSP project and the limitations in data availability, this kind of all-inclusive quantification was not possible.

2.1.2 Calculation of transport GHG emissions for the case study pilots

Transport activity

The ESPON GGIA tool can make use of local data through local datasets. The pilot case studies were calculated using local data.

The case study pilots represent the different kinds of data collection situations. It is possible to collect transport activity data for the county of Meath from an advanced GIS-database. The city of Edinburgh and the Kymenlaakso region can utilize accurate national-level data provided on a local authority level, whereas Rathlin Island's transport activity data is based on a recent survey. All these are valid methods for the local datasets. When survey data is applied, it is important to estimate the vehicle-kilometres driven within the boundary of the selected area.

For the pilot case studies, the average occupancy rates applied are ones that are used by the relevant national sources.

Whenever possible, the vehicle-kilometres driven on roads and streets are shown separately, as there is a significant difference in fuel consumption between driving in an urban or rural environment. The GGIA tool defines the emission factors for both road and street driving, and uses them to define driving profiles for different settlement types.

Emission factors

In the local dataset, expert user can adjust any default value. Accurate emission factors for national car fleets could be calculated for example with the COPERT tool[1] (Emisia, 2021) that uses comprehensive and up-to-date datasets on European road transport. Because COPERT is not an open database, the GGIA tool cannot directly use that data.

In the pilot case studies, the national vehicle emission factor data is applied so that comparisons with previous baseline studies can be carried out. The national emissions factors for the city of Edinburgh and Rathlin Island are sourced from DEFRA (2020) *Greenhouse gas reporting: conversion factors 2020* (DEFRA, 2020). The Finnish case study baseline applies the emission factors from the Lipasto database (VTT, 2021).

[1] http://emisia.com/products/copert-4

2.2 Territorial approach: land-use change

2.2.1 Land-use change module in GGIA

Datasets included in the tool

- FAO FRA Year 2020: carbon stock change (CSC) factors for deforestation
- IPCC National Inventory Report (NIR) CRF tables 2021 (inventory year 2019): carbon stock change (CSC) factors for all other land use changes.

Some data gaps exist as the national CRF tables do not provide CSC factors for all land-use change categories.

Planner User inputs

Planner User makes two inputs to specify the land areas (in hectares) that are converted from one land-use category to another as a consequence of a plan or a planning policy. First input is the total area for each land-use change. The second input defines the share of organic soil in hectares. The share of mineral soil is calculated automatically. In addition, Planner User needs to select the year when the specified land-use change is expected to take place.

In practise, planner first needs to analyse the land area that is subject to change, allocating it to six IPCC land use categories. As described in chapter 2.4.2, CORINE Land cover database and European Soil database are examples of two data sources that can be used everywhere in Europe.

Expert User inputs

Expert user can add missing carbon stock change (CFC) factors or adjust the default factors collected from national inventory reports and the FAO database.

Result

The results can consist of both emissions and removals. CO_2 emissions are absolute figures, i.e. they display the land-use sector climate impacts of a planning policy. Increasing forestland typically leads to CO_2 removal. Each land use change causes highest impact during the year when the change is implemented, but the tool estimates also the future impacts until 2050. Impacts are country-specific, but typically highest CO_2 emissions are caused when forestland is converted to some other land-use category.

On the **Generate report** page, a summary of territorial quantification results is presented both as absolute GHG emissions (tCO_2e/a) and per capita ($tCO_2e/(capita,a)$).

The policies that can be quantified

All spatial plans and policies that cause changes in land use.

2.2.2 Calculation of land use GHG emissions for the case study pilots

The GGIA tool Land-use change module calculates the climate impacts that are caused when land is allocated to another purpose in spatial planning. Land use baseline analysis cannot be created with the GGIA tool. To demonstrate the methodology and the use of open European databases in this context, the research team calculated the Land use baseline emissions for the four pilot case studies by extending the tool methodology to land use. This chapter provides a detailed description of one method that can be used for the analysis of land use.

The Intergovernmental Panel on Climate Change (IPCC) Land use, land-use change and forestry (LULUCF) sector methodology (IPCC 2006) (IPCC 2019) was applied for estimating current land use baseline emissions in each case study pilot area.

LULUCF is an inventory sector defined by the IPCC that covers anthropogenic emissions and removals of greenhouse gases (GHG) resulting from changes in terrestrial carbon stocks. Thus, emissions and removals from (natural) unmanaged areas and marine/ocean ecosystems are excluded. The main GHG occurring in the LULUCF sector is CO_2, while non-CO_2 emissions (like CH_4, N_2O) are predominantly non-key categories, therefore only CO_2 emissions are estimated under the baseline analyses.

The IPCC methodology for emissions estimation uses activity data (usually areas of land) and emission factors which give emissions per unit of activity. Emission factors are derived from changes in carbon stocks. IPCC considers it as good practice for emissions estimates to relate as closely as possible to local conditions, but recognises that this may not always be possible. The IPCC methodology therefore provides for three Tiers of calculation of increasing complexity. Tier 1 methodology applies default emission factors provided by IPCC, Tier 2 methodology uses country-specific emission factors based on national data, and Tier 3 methodology uses more complex models to reflect more detailed variation in conditions within a country. In general, moving to higher tiers improves the accuracy and reduces uncertainty in the emission estimates, but also increases the complexity and resources required for conducting inventories. In short, information in terms of land use classification, land area and data on relevant emissions factors (or carbon-stock-change factors (CSC)) is needed for estimating CO_2 emissions and removals associated with activities in the land use sector.

IPCC provides the frame of six broad land-use categories (Table 1) and five carbon pools (Table 2) that form the basis of estimating emissions and removals from land use and land-use conversions. The categories are broad enough to classify all land areas in most countries and to accommodate differences in national land-use classification systems. The definitions of land-use categories may incorporate land cover type, land use based, or a combination of the two. Within each land-use category, emissions/removals resulting from carbon stock changes are estimated separately in the five carbon pools or may be based on the three aggregate carbon pools (i.e., biomass, dead organica matter (DOM) and soils) according to the IPCC methodology.

Table 1. IPCC Land-use categories.

Land-use category	IPCC description
Forest Land	This category includes all land with woody vegetation consistent with thresholds used to define forest land in the national greenhouse gas inventory. It also includes systems with a vegetation structure that currently fall below, but in situ could potentially reach the threshold values used by a country to define the Forest Land category.
Cropland	This category includes cropped land, including rice fields, and agro-forestry systems where the vegetation structure falls below the thresholds used for the Forest Land category.
Grassland	This category includes rangelands and pasture land that are not considered Cropland. It also includes systems with woody vegetation and other non-grass vegetation such as herbs and bushes that fall below the threshold values used in the Forest Land category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvi-pastural systems, consistent with national definitions.
Wetlands	This category includes areas of peat extraction and land that is covered or saturated by water for all or part of the year (peatlands and other wetland types) and that does not fall into the Forest Land, Cropland, Grassland or Settlements categories. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.
Settlements	This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent with national definitions.
Other Land	This category includes bare soil, rock, ice, and all land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

Table 2. IPCC LULUCF sector carbon pools.

Carbon pool		IPCC description
Biomass	Aboveground biomass	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage. In cases where forest understory is a relatively small component of the above-ground biomass carbon pool, it is acceptable to exclude it.
	Belowground biomass	All biomass of live roots. Fine roots of less than (suggested) 2mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.
Dead organic matter (DOM)	Dead wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10 cm in diameter (or the diameter specified by the country).
	Litter	Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for dead wood (e.g., 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.
Soils	Soil organic matter in mineral and organic soils	Includes organic carbon in mineral and organic soils to a specified depth chosen by the country and applied consistently through the time series. Live and dead fine roots and DOM within the soil that are less than the minimum diameter limit (suggested 2 mm) for roots and DOM, are included with soil organic matter where they cannot be distinguished from it empirically. The default for soil depth is 30 cm. Organic soils are identified on the basis of several criteria found in the IPCC guidelines, however, are mainly represented by Histosols (World Reference Base for Soil Resources). All other types of soils are classified as mineral.

Countries have their own definitions and grouping of land categories, which may or may not refer to internationally accepted definitions, such as those by FAO, Ramsar, etc, however, in order to apply the IPCC methodology, all land must be divided under the default IPCC land-use categories. Countries apply a variety and often a combination of national and global databases for estimating land cover, soil type and respective areas for the LULUCF inventory in national inventory reports (NIR) submitted under the United Nations Framework Convention on Climate Change (UNFCCC). For example, Ireland uses the National Forest Inventory (NFI), the Forest Inventory and Planning System (FIPS), the Land Parcels Information System (LPIS), Coordinated Information on the Environment (CORINE) Land Cover Maps and the General Soil Map of Ireland. The UK defines the area of different land use categories using NFI and 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. Finland uses NFI data supported by spatial data, e.g., aerial images, LPIS and Finnish georeferenced soil database for representing different land use and soil type areas. The combined country-specific land use and soil type identification approaches provide more accurate results than using general pan-European datasets, however, are often only applicable in the specific country. Open-source pan-European datasets (CORINE, European Soil Database) were applied in the current land use baseline analyses to demonstrate the usability of these standardised and harmonised databases. It should be noted that pan-European datasets are usually spatially coarse and not as accurate as local (country or smaller territorial unit) datasets, leading to greater uncertainty of the final emission estimates. These datasets are not integrated in the GGIA tool, but they are one method for quantifying the land area types within the area of assessment.

The Copernicus Land Monitoring Service (CLMS) was applied for determining the spatial distribution of land use classes and relevant areas for the case study pilots for the baseline analyses. CLMS provides CORINE

Land Cover (CLC) vector datasets that are based on the classification of satellite images produced by the national teams of the participating countries - the European Environment Agency (EEA) members and co-operating countries (EEA39). National CLC inventories are further integrated into a seamless land cover map of Europe. The resulting European database relies on standard methodology and nomenclature with following base parameters: 44 classes in the hierarchical 3-level CLC nomenclature (Copernicus Land Monitoring Service, 2018). The most detailed (level 3) classes were applied in the current analysis. There are different CLC datasets, like base status layers (minimum mapping unit (MMU) 25 hectares) and CLC-Change layers (MMU = 5 ha). Status layers synthesized with CLC-Change layers are called CORINE Land Cover 'CLC accounting layers' – 100 m raster datasets that comprise CORINE Land Cover status layers, modified for the purpose of consistent statistical analysis in the land cover change accounting system at EEA. The CLC 2018 accounting layers (Corine Land Cover Accounting Layers (CLC2018). European Environment Agency) were applied for determining current land use types in the case study pilots areas. In the case of Edinburgh, a more refined CORINE Urban Atlas Street Tree Layer (STL) 2018 (Urban Atlas: Street Tree Layer (STL) 2018) was applied to determine the area of urban trees within the Settlement land-use category. The Urban Atlas provides pan-European comparable land use and land cover data for Functional Urban Areas (FUA). The Street Tree Layer is a separate layer that includes contiguous rows or a patch of trees covering 500 m^2 or more and with a minimum width of 10 meter over "Artificial surfaces" (CORINE nomenclature class 1) inside FUA (i.e., rows of trees along the road network outside urban areas or forest adjacent to urban areas should not be included).

There are also several limitations to the CORINE maps: provided land classes are broad and do not cover all the LULUCF land use specialties, for example CORINE (class 412 Peatbogs) does not distinguish active peat extraction areas from natural peat bogs or restored wetlands, all of which are addressed separately according to the LULUCF methodology. Furthermore, 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 the current study, CORINE land classes were categorized into IPCC land-use categories and unmanaged land according to the land use definitions provided in the IPCC guidelines (IPCC, 2006), CLC nomenclature and information provided in national inventory reports (Ireland, 2021) (Finland, 2021) (United Kingdom of Great Britain and Northern Ireland, 2021). A list of the CORINE land cover classes determined in the four case study areas are shown in Table 3. More detailed definitions of the land classes can be found in the CORINE land cover nomenclature illustrated guide (Kosztra et al, 2017).

Table 3. CORINE land classes determined in the case study areas.

Class level 1	Class no (level 3)	Name
Class 1: Artificial areas	111	Continuous urban fabric
	112	Discontinuous urban fabric
	121	Industrial or commercial units and public facilities
	122	Road and rail networks and associated land
	123	Port areas
	124	Airports
	131	Mineral extraction sites. This class is not applicable for exploited peat bogs (class 412).
	132	Dump sites
	133	Construction sites
	141	Green urban areas. This class is applicable for parks inside settlements.

Class level 1	Class no (level 3)	Name
	142	Sport and leisure facilities
Class 2: Agricultural areas	211	Non-irrigated arable land
	222	Fruit tree and berry plantations
	231	Pastures, meadows and other permanent grasslands under agricultural use
	242	Complex cultivation patterns
	243	Land principally occupied by agriculture, with significant areas of natural vegetation
Class 3: Forest and semi-natural areas	311	Broad-leaved forest
	312	Coniferous forest
	313	Mixed forest
	321	Natural grassland
	322	Moors and heathland
	324	Transitional woodland/shrub
	331	Beaches, dunes, and sand plains
Class 4: Wetlands	411	Inland marshes
	412	Peatbogs. Both natural and exploited peat bogs.
	421	Coastal salt marshes
	423	Intertidal flats
Class 5: Water bodies	511	Water courses
	512	Water bodies
	522	Estuaries
	523	Sea and ocean

The spatial distribution and areas of different soil types were identified using the European Soil Database Maps (European Soil Database Maps). The applied European Soil Database Maps follow FAO World reference base (WRB) soil classification. The WRB is a comprehensive classification system that enables accommodation of national soil classification systems. The WRB is not intended to be a substitute for national soil classification systems, but rather to serve as a common denominator for communication at the international level. The WRB comprises two levels of categorical detail: the first level having 32 Reference Soil Groups (RSGs); the second level, consisting of the name of the RSG combined with a set of principal and supplementary qualifiers (FAO, 2014). In the current baseline analysis, data on WRB level 1 spatial distribution was used. Histosols were considered organic soils according to the IPCC guidelines, all other types of soils were classified as mineral. It was assumed that all managed organic soils are drained and result in CO_2 emissions. A list of the soil types present in the four case study areas are shown in Table 4. More detailed definitions of the soil types can be found in the World reference base for soil resources guide (FAO, 2014).

Table 4. WRB soil types determined in the case study areas.

Abbreviation	Soil type
CM	Cambisol
GL	Gleysol
HS	Histosols
LP	Leptosol
LV	Luvisol
PZ	Podzol
1	no soil/no information available for selected land parcel

Pilot case study administrative borders were obtained from OpenStreetMap.

All datasets were processed and analysed utilising QGIS. In the first step of GIS data processing all data layers were collected into a single GeoPackage (.qpkg). Each layer was projected according to the European Terrestrial reference System (ETRS89). The administrative borders of the area of interest were utilised to clip the base layers (CORINE accounting layers, European Soil Database layers; Figure 2) isolating all the single features from each layer and respective areas (in m^2) were calculated.

In the second step of GIS data processing, a relationship between land uses (extracted from CORINE land cover) and soil types (extracted from the European Soil Database) was set. The aim was to determine the total surface of a given land use, present on a certain soil type. For this purpose, the features from the European Soil Database were utilised to clip the CORINE land cover layers (Figure 2, Figure 3). Doing so, a subset of land-uses that fall within each typology of soil was obtained. Once the soil types were associated with land uses, the cumulative area of each land use type within all the different soil types was calculated.

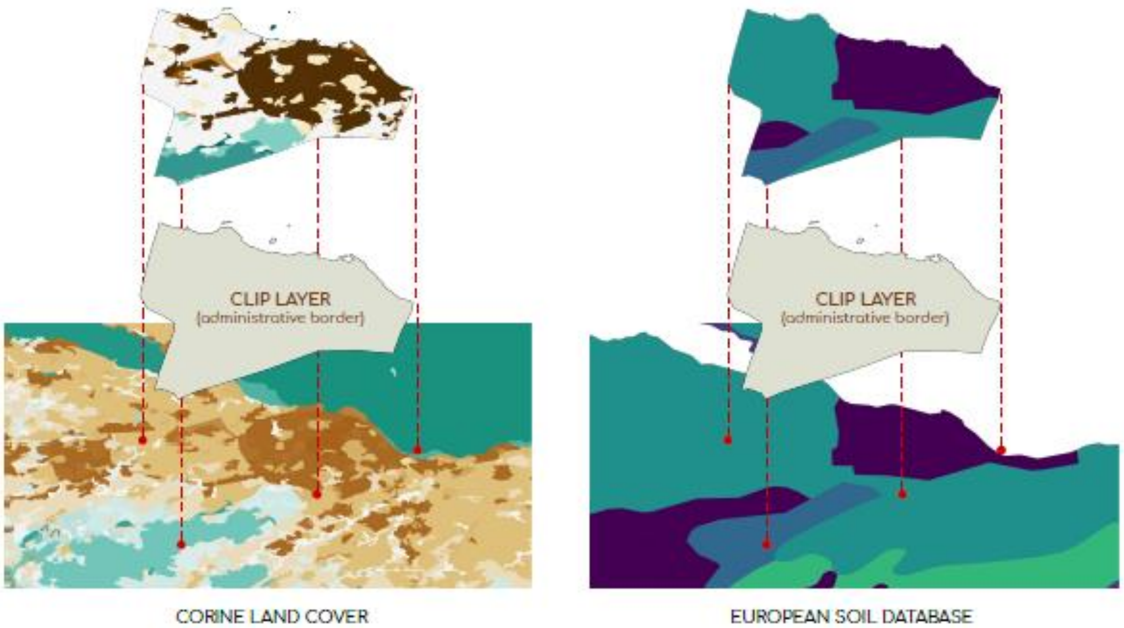

Figure 2. Example of GIS data processing (step 1).

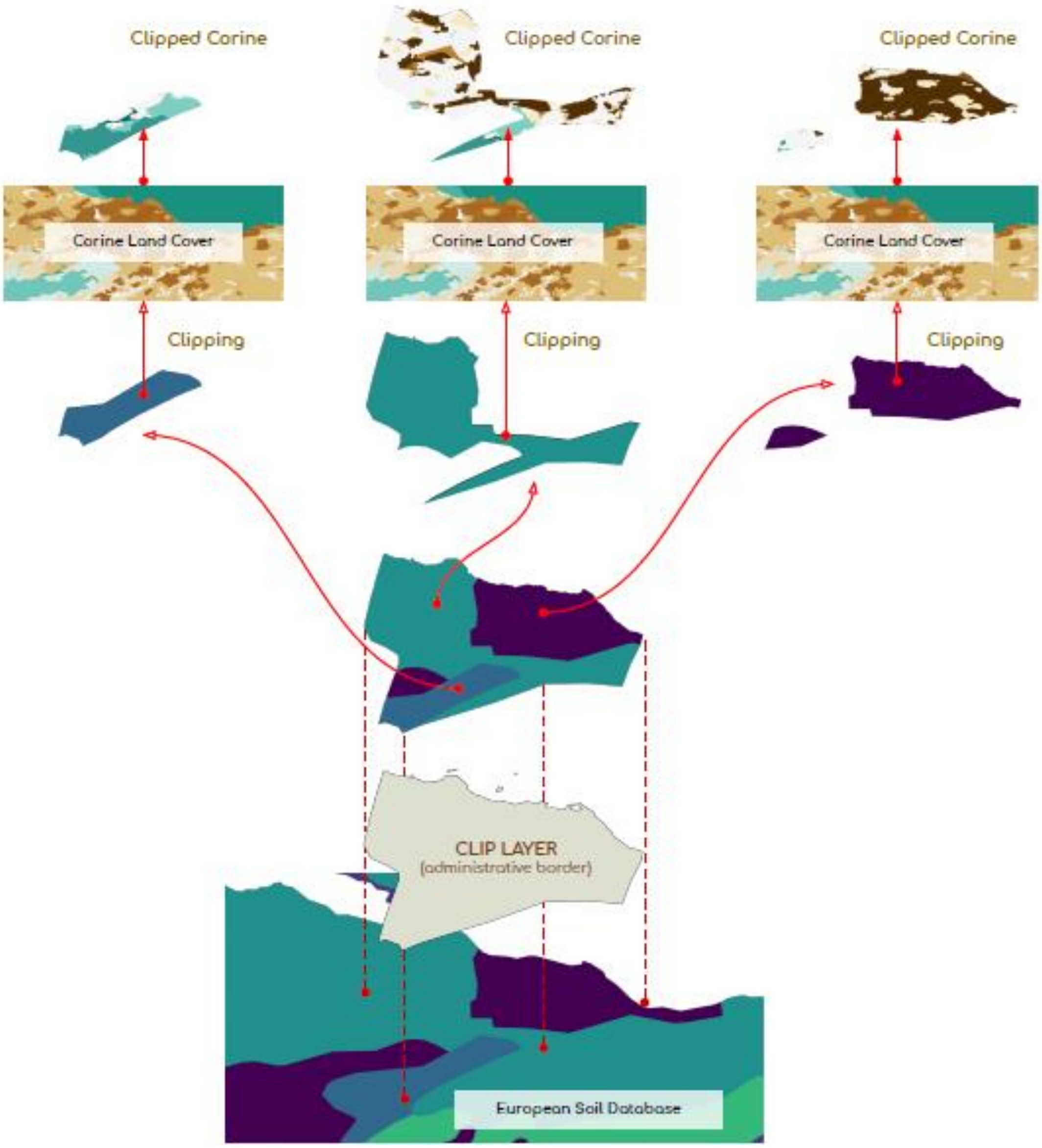

Figure 3. Example of GIS data processing (step 2).

Final emission estimates were calculated by multiplying the areas of land use and soil types with relevant carbon-stock-change factors (land remaining category) from the national inventory reports and common reporting format (CRF) tables from the latest available 2021 submissions (inventory year 2019) (Ireland, 2021) (Finland, 2021) (United Kingdom of Great Britain and Northern Ireland, 2021). Carbon-stock-change factors reflect the impact of current land use management practises on carbon stocks and are subject to change in time.

Net changes in carbon stocks were converted to CO_2 by multiplying with the ratio of CO_2/C molecular weights 44/12 and changing the sign for net CO_2 removals to be negative (-) and for net CO_2 emissions to be positive (+). IPCC LULUCF methodology divides land into two main subcategories: “lands remaining in the same land-use category” (by default for the last 20 years) and ”lands converted to present land use” (by default during the past 20 years). In the current baseline analysis, a simplifying assumption was used that the land use classes determined with CORINE datasets represent the “land remaining” category, which is mostly the predominant subcategory.

Not all emissions from the carbon pools of different land use categories are and must be estimated according to the IPCC guidelines. The reporting guidelines on annual greenhouse gas inventories stipulates that Parties may report emissions as not estimated if an activity occurs in the country, and either:

- the 2006 IPCC Guidelines do not provide methodologies to estimate the emissions/removals; or,
- a disproportionate amount of effort would be required to collect data for a gas from a specific category that would be insignificant in terms of the overall level and trend in national emissions.

Therefore, several country-specific carbon-stock-change factors and resulting emission estimates are missing, especially in the LULUCF sector that is inherently one of the most complicated sectors with highest uncertainty in the national inventory reports.

The IPCC land use category 'Settlements remaining settlements' (urban areas) is one of the most poorly reported LULUCF sector categories among the EU countries. Only 8 countries out of 29 (EU Member States, UK, Iceland) reported some quantitative estimates under the 'Settlements remaining settlements' category in their 2021 submission (EEA, 2021). The data gap is largely associated with the lack of IPCC methods for estimating GHG emissions, the assumption of equilibrium under Tier 1 methods, or the implementation of the insignificance provision in accordance with the Decision 24 CP/19. IPCC Tier 1 method assumes that under Settlements remaining settlements (that also includes changes within settlements) emissions and removals are balanced, thus no major emissions occur in biomass, dead organic matter or soil. For example, the IPCC guidelines state for biomass: "Tier 1 method assumes, probably conservatively, that changes in biomass carbon stocks due to growth in biomass are fully offset by decreases in carbon stocks due to removals (i.e., by harvest, pruning, clipping) from both living and from dead biomass (e.g., fuelwood, broken branches, etc.)". Similarly, it is assumed that soil C inputs equal outputs so that settlement soil C stocks do not change in the Settlements remaining category. Higher tiered IPCC methods could be applied to estimate emissions and removals under settlements; however, it requires country-specific data (extensive research and scientifically proven emission factors) which more than often is not available and not provided in national inventory reports.

The GGIA tool applies the IPCC tier 1 assumption for land converted from forest to another land-use category, which means that all biomass, dead wood and litter carbon losses occur in the year of land-use conversion. CSC factors from national CRF tables are used in the land use change sector, however, forest land conversion to other land categories (deforestation) is an exception and the biomass carbon stock data from FAO FRA database is applied for the following reason: Biomass CSC factors of deforestation reported in the CRF tables do not always reflect total carbon emitted due to flexible reporting requirements, e.g. in the case of UK 40% of forest above-ground biomass is assumed to be burnt and the remaining carbon stock in biomass is assumed to be immediately lost (instantaneous oxidation), thus CSC factors and emissions of deforestation are scattered.

The IPCC Tier 1 methodology simplification may largely underestimate urban vegetation as a carbon sink. Therefore, in the case of Edinburgh, a more comprehensive analysis was carried out - the CORINE Urban Atlas Street Tree Layer (Copernicus Land Monitoring Service, 2018) and i-Tree Eco survey information (Doick et al, 2017) was applied to provide indicative CO_2 removal estimates by urban forest.

Because of limitations to deriving default data sets to support estimation of some stock changes, IPCC Tier 1 methods include several simplifying assumptions that emissions are zero or in equilibrium under other land use categories as well. For example, Tier 1 methods assume that litter and dead wood pools are zero in all non-forest categories and under forest land remaining forest land. IPCC LULUCF guidelines also assume under Tier 1 that forest mineral soil C stocks do not change with management (under Forest land remaining Forest land). A Tier 1 approach assumes that biomass will be in an approximate steady-state (zero emissions) in Grassland Remaining Grassland where there is no change in either type or intensity of management etc. These simplifications are applied if implementing higher tiers (i.e., dynamic models) and country-specific data is not available.

The IPCC land-use category 'Other land' is considered unmanaged and not active in terms of potential for emissions or removals.

It must be emphasized that land use baseline emissions presented in this report are provided as general background information only - to demonstrate the applicability of the IPCC LULUCF methodology and usability of pan-European land-related datasets and emission factors (carbon-stock-change factors) provided in national greenhouse gas inventories and accompanying common reporting format tables. Total land use emissions calculated for each case study area are indicative rather than scientifically accurate and may differ from previously published reports (e.g., carbon neutral Kymenlaakso study) because: (i) pan-European land cover and soil datasets were applied following the recommendations of the QGasSP project terms of reference; (ii) general available information was used for reclassifying CORINE land classes into each case study

IPCC land categories; (iii) simplifying assumptions were applied, e.g. all land classes were considered as IPCC land remaining subcategories (impact of land-use changes were not taken into account, however land-use change function is included in GGIA), all managed organic soils were considered drained; (iv) only main LULUCF sector CO_2 source and sink categories that potentially have the greatest emission impact were included (countries may create additional land-use subcategories like undrained areas or report emissions from low carbon intensity areas like inland waters); (v) only CO_2 emissions were included (as in the SPACE tool); (vi) average country-level carbon-stock-change factors were applied.

Similarly, to the SPACE tool, creating a baseline scenario is not needed to quantify the potential climate impact of spatial planning policies in the land use sector.

2.3 Territorial approach: energy use in buildings

Territorial GHG quantification is a straight-forward way of estimating the direct emissions within the selected target area. This approach is applied in national GHG inventories and is also typical in the GHG analyses of territories and cities. However, comparisons between territories are not very informative from the GHG mitigation perspective since the amount of transport, industry activity, etc. differ from one area to another. A drawback of the territorial approach is that there is a possibility that not all GHGs within the territory are captured, and there might be an overlap of emissions that arise from activity within the region by non-residents.

The territorial GHG quantification can be used to monitor emissions within a single territory, city or area. The GGIA method includes Scope 1 and Scope 2 emissions (Greenhouse Gas Protocol), i.e., the direct GHG emissions which occur in the area and as a result of the electricity consumption in the area.

2.3.1 Buildings module in GGIA

Datasets included in the tool:

- Average energy consumption of residential and commercial building types by country: EU Buildings Database
- Emission factors for fuels: Covenant of Mayors dataset
- Future scenario on the annual changes in the carbon intensity of grid electricity by country: EU Reference Scenario 2016

European Buildings Database does not provide consumption data for Industrial buildings. For more detailed information on the data gaps, please see the last chapter of this report.

Planner User inputs:

To calculate the baseline and the indicative future projection for buildings GHG emissions, Planner User inserts the number of 1) residential units (dwellings) and 2) floor areas of commercial buildings.

The GGIA tool can quantify the GHG emissions caused by new development, densification of existing settlement, retrofitting and/or change of building use. Increase in renewable energy production may be included in each policy.

In addition, Planner User selects the time period ("policy period") during which the policy is implemented.

Expert User inputs:

Expert User can adjust any default data value when creating a local dataset.

The future changes in building stock (the annual new construction and demolition rates) can be included in the local dataset. Expert User can also set the CO_2e emission factors and future scenarios for energy carriers as well as values for average energy consumption per building type.

Result:

The results show the estimated annual GHG emissions with the policy impacts until 2050. They are compared against the baseline scenario (no policy impacts).

On the **Generate report** page, a summary of territorial quantification results is presented both as absolute GHG emissions (tCO_2e/a) and per capita ($tCO_2e/(capita,a)$).

The policies that can be quantified:

All policies with a major impact on the building stock, its energy consumption and renewable energy production.

The tool can make use of both national and local-level data; result accuracy from policy changes would depend on the accuracy of the input data.

The different spatial planning policies that can be quantified using the GGIA tool are outlined below:

1. Construction of new buildings, both residential and commercial buildings - user inputs required would relate to the number of new residential units (broken down by dwelling type) and floor area of new commercial units (broken down by building categories).

2. Retrofits of the building sector – which allows 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. User inputs required are the number of residential buildings being retrofit (broken down by dwelling type), the current BER or EPC rating and the expected new improved rating. As for commercial buildings, users would be need to input the floor area of commercial buildings to be retrofit (broken down by building category) and the expected reduction in energy demand (a percentage figure).

3. Changes in urban densification - users will need to input the current amount of residential and commercial building (broken down by dwelling type and commercial categories), and the expected densification (as a percentage).

4. Change in building use (from commercial to residential or vice versa) - users will be asked to indicate the change in building use whether form a residential to a commercial property or vice versa.

5. Increase in renewable energy generation from retrofits and new buildings - users will be asked about renewable energy sources and the percentage of energy that is expected to be delivered from renewable energy.

Open-source data has been prioritised and pan-European datasets have been used, where applicable, to allow replicability across EU regions. These pan-European datasets were found to be more useful for regional analyses, and more specific local data-sets are required for more realistic local development plan assessment. When different levels of data are available, the higher level of quality data is selected.

The buildings considered at a European level are classified as commercial and residential, the EU Buildings Database was used to give information on the total floor area and number of buildings for both the residential and commercial sector. It also provides information on average energy demand per m^2 floor area for the different building types. This data was broken down by fuel type and is used to quantify the energy demand from both commercial and residential buildings. National emission factors for heating fuels and electricity are used to convert the energy demand into emissions

At a local/ regional level, local level data is used to analyse the energy use and emissions from the following buildings:

- Residential
- Commercial.

Utilising national datasets means less relevant results, which reflect the problems and opportunities on the national level rather than territorial, regional or local level. However, it is important that GHG quantification is also possible when the local data is not available.

Residential

The methodology to quantify emissions from the residential sector includes firstly, identifying the total number of housing units in an area, this information is located in the EU Database and has residential buildings grouped by housing type i.e., apartments, detached, semi-detached and terraced houses.

Average energy use for different developments broken down into different fuel categories such as different fossil fuels, electricity, renewable energy sources and district heating, these figures are also sourced from the EU Buildings Database. The average energy figures for the different dwelling types are applied to the total housing stock, which results in a total energy demand for a specified country broken down by fuel and dwelling type. These figures are then multiplied by national emission factors to produce total CO_2 emissions generated from the residential sector.

Commercial

The methodology used for the calculation of the commercial baseline includes two main data sources - commercial buildings broken down into building use and floor areas, and energy consumption figures for commercial buildings or energy benchmarks for different commercial properties. All this data for different EU countries is sourced from the EU Buildings Database.

These energy figures provide typical energy usage per square metre of floor area for different business categories. Commercial building energy use per m^2 is broken down into different fossil fuels, electricity, renewable energy sources and district heating. To calculate the energy use for each property, each 'property use' must be matched to a typical energy use. The energy use for the different property uses must then be multiplied by the corresponding floor area, which gives a total energy demand for the different commercial building uses. This total energy demand, broken down by fuel type (fossil fuels, electricity, etc.), is then multiplied by national emission factors to provide total emissions from the commercial sector.

Future projections

By default, the future projections in GGIA utilize the data from the EU Reference Scenario 2015 (Capros et al, 2016), based on PRIMES modelling. All parameters related to future scenarios can be updated in a local dataset.

2.3.2 Calculation of buildings GHG emissions for the case study pilots

This section looks at the emissions arising from the building sector in the pilot case study areas, it includes both residential and commercial buildings. This methodology was used to quantify energy and emissions baselines, which give insights into the current building stock for the case study pilots. This baseline information is then used to compare with emissions resulting from spatial planning policy changes. The stakeholders involved in this project were instrumental in providing detailed inventories of energy use and greenhouse gas emissions for both residential and commercial buildings and facilities. It should be noted that the methodologies outlined below can vary for the different pilot case studies; a detailed methodology for each case study area is included in the Pilot Case Study Report Annex.

Case study pilots make use of local-level data, specifically the national legislation on energy use in new buildings, the energy use of retrofit buildings (this stems from EPC or BER information available for the case study pilots) and local-level inventories on typical energy consumption for different building related policy options.

Residential

The residential methodology at a local-level, is similar to the national-level methodology, with the exception that this quantification makes use of local-level information. Local-level data on number of buildings broken down by period built, building type (apartment, terraced, semi-detached and detached) and location, are sourced from national census and inventories. As for detailed energy usage, for the different building types, are gathered either from national energy records or alternatively, the service providers quantified average energy usage by analysis in-depth the Energy Performance Certificate (EPC) database for Edinburgh and Kymenlaakso or the Building Energy Rating (BER) database for Ireland.

An EPC or BER is a certificate of energy efficiency of a property. EPCs and BERs 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.

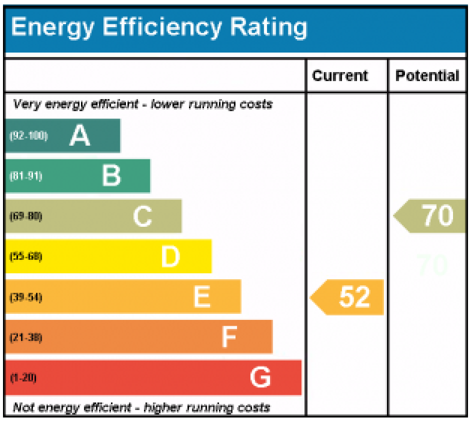

Figure 4. Energy performance certificate. Source: Gov.UK.

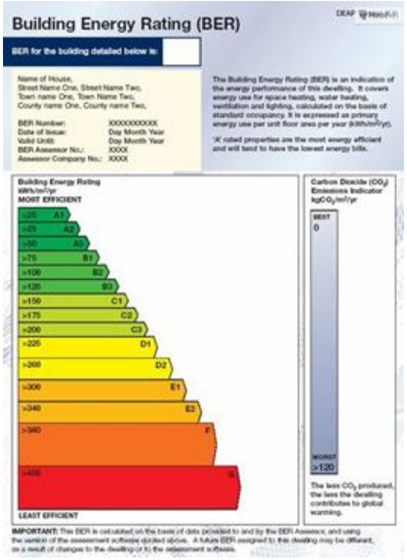

Figure 5. Building energy rating. Source: SEAI.

The EPC contains information on the property's energy use and typical energy costs, it also provides recommendations about how to reduce energy use. Meanwhile the BER Research Tool, developed by SEAI in 2009, contains similar information as the EPC and was used in this analysis for the calculation of energy required for normal use of space heating, hot water, ventilation and lighting per metre squared area of a residential unit. The final energy rating given to a household is in kWh/m^2/year, and an energy efficiency scale from A to G is applied. It also provides an insight into other data, such as type of household, year of construction, location, floor area, and fuel use.

The average energy figures for the different dwelling types are then applied to the total housing stock, which results in a total energy demand for a specified area broken down by fuel and dwelling type. These figures were then multiplied by national emission factors to produce total CO_2 emissions generated from the residential sector.

Commercial

The methodology used for the calculation of the commercial baseline includes two main data sources – a detailed breakdown of different commercial property floor areas and energy consumption benchmarks from the Chartered Institution of Building Services Engineers (CIBSE) was used for Ireland and Northern Ireland. The UK CIBSE Guide F: Energy Efficiency (CIBSE, 2006) and TM46 (CIBSE, 2012) provide typical energy usage per square metre of floor area for different business categories, amalgamated from numerous UK surveys. The advantage of using CIBSE energy benchmarks is that they are based on a large sample set, and as Irish building regulations follow UK regulations, the energy figures are applicable in the Irish context. There are certain limitations, however; climate in the UK is more severe than in Ireland and can affect results when applied to the Irish sector.

Whilst for Scotland and Finland, local level information on commercial buildings is already gathered every few years by local agencies and/or at a national level. The energy benchmarks for different commercial buildings (or energy information provided by the stakeholders) are matched to the relevant floor areas. The CIBSE energy figures are only split into either fossil fuels or electricity. Therefore, due to a lack of data at a local level, the national breakdown of fossil fuels and electricity for energy use in commercial buildings was used for Ireland and Northern Ireland.

The energy use for the different property uses must then be multiplied by the corresponding floor area, which gives a total energy demand for the different commercial building uses. This total energy demand broken down by fuel type (fossil fuels, electricity, etc.) is then multiplied by national emission factors to provide total emissions from the commercial sector.

Emission factors

Emission factors used by the building sector are sourced from the EU Covenant of Mayors for Climate and Energy: Default Emission Factors for Local Emission Inventories (Koffi et al, 2017). The expected decarbonisation of grid electricity is based on the PRIMES modelling from the EU Reference Scenario 2016 that published a prognosis for each EU member state (Capros et al, 2016).

3 Consumption-based quantification

3.1 Consumption-based approach

The consumption-based quantification applies a form of tiered-hybrid life cycle assessment (LCA) methodology. In general, tiered-hybrid applies a combination of two types of life cycle assessment, with an environmentally extended economic input-output approach (EEIO) being 'enhanced' by using data for selected sectors derived from process-based LCA (p-LCA). The procedure amounts to modifying the basic EEIO to increase specificity towards the target area and the relevant emissions sectors covered by the tool. Additionally, the tool also considers the final 'use-phase' emissions, for example emissions associated with the private combustion of fuels. These are not considered as standard in EEIO calculations.

Such a method models the whole economy included in the EEIO and therefore, minimises the 'truncation errors' present in some calculations by fully accounting for the supply chain, irrespective of geographic area. P-LCA in turn allows greater detail to be used in the calculations should such data be available. Problems involved in down-scaling the national picture are also reduced by considering the circumstances of the local area, such as the urban density or relative income level of the residents.

These modifications help to overcome the typical EEIO weakness of limited resolution at the subnational level. As with all approaches based on input-output (IO) matrices, however, the approach will be most appropriate at larger scales and under the assumption that household consumption is closely aligned to expected values. Partly as a result of this, when compared to the territorial calculations it is also a feature of the approach to more readily be based on top-down data sources.

Emissions scope and boundary

All three of the most important greenhouse gases (GHGs) are accounted for in the EEIO database (CO_2, CH_4, N_2O) in terms of global warming potential over 100 years (GWP100). In total, 19 different types of emissions are included, representing both combustion and non-combustion sources. Annual emissions are reported per capita (in units of $kgCO_2e$) and can be compared between different regions. Emissions for the total area are also given in tonnes CO_2e.

All emissions are assigned to the end user and are generated by all economic activity of private persons residing in the target area, regardless of the location in which the emissions themselves originate. Indeed, for many products with lengthy global supply chains, a high proportion of these emissions will occur outside the target area (Chen et al, 2020). On the other hand, local emissions caused by the activity of residents living outside the target area are not included. This is irrespective of whether they result from the global supply chain (e.g., exports) or through visits to the target area by non-residents (traffic transiting through the target area is also not counted). Moreover, the emissions caused by other economic agents within the target area, such as governmental and capital expenditure, are not included (the tool computes a personal carbon footprint, rather than areal carbon footprint (Heinonen et al, 2020).

Data collection and calculation procedure

The method applied in this project is predominately based on two data sources. The 2020 version of Exiobase, (Stadler, 2018) (EXIOBASE Consortium, 2021), a widely used EEIO, is applied to determine emission intensities. This is a 'multi-regional' input-output database (MRIO), which means it is more accurate and covers many regions/countries within a single matrix. In total, Exiobase represents 49 countries/regions, including virtually all of Europe at country-level, and the rest of the world with lower resolution. In all cases, emission intensities are determined (in units of $kgCO_2/€$) for a total of 200 'products' representing the whole economy. This includes, amongst others, separate 'products' representing different forms of electricity generation, different fuels for space heating and private and public transport modalities. Intensities are determined by assigning a proportion of emissions for each product-region combination (a total of 9,800) to all other product-region combinations. A proportion of these emissions are assigned to the original product-region and correspond to the emissions caused by the direct production of each product, with the other emissions capturing different aspects of the global supply chain.

This initial calculation describes the expected emissions for each euro spent on a 'product' found within each country. The total emissions are then found by multiplying by the average expenditure on each of these within the case area. Such expenditure is derived from Eurostat household Budget surveys (HBS). These surveys are collated every 5 years and illustrate both total value and expenditure purpose, based on the Classification of Individual Consumption by Purpose (COICOP) system. The resultant expenditure is thereafter assigned to the Exiobase product categories using the procedure of Ivanova et al (Ivanova & Wood, 2020), along with subsequent modification as outlined below.

The national HBS describes the average picture for an average household in each country. The household expenditure is made more specific to different sub-national regions by first using Eurostat HBS that describe the distribution of expenditure in cities, towns, and rural areas. These distinctions represent different levels of population density and geographical contiguity (Eurostat, 2011). Initial assignments are made based on population density, in which 1 km x 1 km divisions are classified as high-density clusters (population density 1,500 inhabitants per km^2, at least 50000 residents), urban clusters (density greater than 300 inhabitants per km^2, at least 5,000 residents) or rural grid cells (all cells not classified as high-density or urban clusters). Urban types are thereafter defined based on the following criteria:

- Cities: At least 50% of the population live in high-density clusters (certain other criteria also apply to cities).
- Towns: Less than 50% of the population live in rural grid cells and less than 50% also live in high-density clusters.
- Rural areas: More than 50% of the population live in rural grid cells.

Next, this can be further modified by a second survey describing how the total expenditure in Euros is dependent on the income quintile of the household. For example, this means that a high-income area in a city would replace the average national HBS with the distribution of expenditure based on the city-specific HBS for that country, and the total overall expenditure by the budget survey describing the total expenditure for the richest income quintile. All data was used at the household level. The most recent HBS was from 2015. A new HBS was expected for 2020 but has yet to be released. Ideally, the newer HBS could be incorporated within the tool once available.

The HBS is given in purchaser prices (I.e., it includes taxes), whereas basic prices are required for Exiobase. As such, the data was converted from purchaser to basic prices using supply and use tables found in Eurostat (NAIO_10_CP15). Moreover, product-specific inflation multipliers were used to update the values to 2019 (PRC_HICP_AIND). The average annual inflation over the last 5 years was then used as a further multiplier to put the HBS in 2020 values without the depreciation associated with the COVID-19 pandemic. As such, the use of slightly outdated data is somewhat mitigated, assuming that the projections to 2020 are accurate. In this case, the structure of the HBS is what is important as it informs what percentage of household expenditure is given to certain products (i.e. it answers the question, what percentage of household expenditure is given to different types of food? What proportion is given to gasoline for private travel etc.). It is assumed that the structure of this expenditure would be relatively similar between 2015 and 2020. That is, although the total amount spent in 2020 may be different to 2015, the proportion of that total spent on each product is rather similar in these two cases. However, it would still be better to update the tool to include the 2020 data once it is made available.

Specific HBS surveys used:

HBS_STR_T211 – Household expenditure by consumption purpose (per mille)

HBS_EXP_T136 – Household expenditure by consumption purpose by urban area (per mille)

HBS_EXP_T133 – Mean household consumption expenditure by income quintile (per Euro)

The influence of these changes is to increase the specificity to the target area. For example, the below shows the changes in amount spent on fuels for private transportation in the UK and Finland at different levels of urban density, after conversion to Exiobase product categories. It can be seen that the expenditure is below average for city residents (high density), but well above average for residents of rural areas. It is also clear from the numbers below that in Finland there is a higher contribution from biofuels than is found in the UK.

Table 5. Comparison of fuel expenditure for private transport at different urban densities for Finland and the United Kingdom.

UK	Motor Gasoline	Gas / Diesel oil	Biogasoline	Biodiesels
Average	262	546	25	53
City	226	470	22	46
Town	301	627	29	61
Rural	355	739	34	72
Finland	**Motor Gasoline**	**Gas / Diesel oil**	**Biogasoline**	**Biodiesels**
Average	169	476	46	129
City	134	377	36	102
Town	170	478	46	129
Rural	214	600	58	162

The data is given in the Exiobase format and with household income equal to the national average in all cases. It should be noted that this is just an example, and that similar data is available for all countries in the tool. This figure was used to highlight the general trend that residents in higher urban density areas typically have lower fuel purchases.

These modifications do not change the fundamental calculation for the carbon footprint, which is given by:

$$Emissions = B\,(I - A)^{-1}k \qquad (1)$$

where:

k = Final demand vector, describing the monetary value of different products spent by the household. This is derived using the Eurostat HBS.

A = Input-output matrix. A matrix describing the normalised flows between each ‘industry’ or ‘product’ considered. For Exiobase, the database used here, there are ~ 200 products in ~ 170 different industries that describe different areas of the economy.

I = Identity matrix. This is a matrix of the same dimensions as A, with the values down the main diagonal equal to exactly 1, and all other values being equal to 0.

B = Vector describing emissions from a unit of output from each industry. The three most important GHGs are considered covering both combustion and non-combustion sources.

Modifications and use-phase emissions

The previous section describes all emissions up to product delivery to the household (cradle-to-gate). The final ‘use-phase’ emissions are subsequently added onto these values for the relevant sectors considered within the tool. Furthermore, modifications are also made for these sectors to increase the accuracy of the calculation following the procedures outlined below.

Electricity

The electricity sector, including transmission and distribution, is represented by 14 different products within the Exiobase matrix. Different emission intensities are assigned to different types of electricity generation, such as via coal combustion or PV cells. On the other hand, the HBS only assigns expenditure (in euros) to electricity, without distributing it into different forms of production. The Exiobase sectors could be replaced by a single value representing the average national emission intensity for electricity in each country (typically given in gCO_2e/kwh), but this would mean the upstream emissions could no longer be tracked through the IO approach. Moreover, electricity production in each country may not equal demand, with an excess or dearth of production being covered through trade with other countries.

Household electricity expenditure in euros was first converted to kWh using standardised price statistics from Eurostat (NRG_PC_204). Next, this was distributed to electricity sources in Exiobase using data on the electricity mix of each country (based on data from EMBER (EMBER, 2020)). The effects of trade between countries were then considered. This was based on a 2013 paper by Moro and Lonza (2013), which described resultant carbon intensities for combustion only at low voltage (utilised by households). The values were finally scaled to 2019 based on the ratio of carbon intensities between 2013 and 2019 given by EEA (EEA, 2020), under the assumption that the proportional role of trade remained constant in this time period. The final values derived from this procedure replaced the direct production emission intensities in Exiobase, with the upstream emissions being converted from units of euros to kWh, but otherwise left as standard. Moreover, this procedure was also carried out for the demand associated with different population densities (cities, towns and rural areas) for each country found in the tool.

Transport emissions

In contrast to the territorial approach, emissions from transport can be tracked directly through the expenditure of residents in the target area, since no distinction is necessary based on the location. Household expenditure is designated in the HBS in terms of types of public transport, and fuels and vehicle purchases/maintenance for private transport. Based on the distribution of engine types in each country, the expenditure on fuel was first divided into Gasoline and Diesel proportions. This was achieved using data from Eurostat (ROAD_EQS_CARPDA). No distinction was required for hybrid vehicles, since this should show up in reduced fuel expenditure in the HBS (the share of electric vehicles was rounded to zero for each case area). Next, the share of renewable transport fuels (assumed to be constant between petrol and diesel engines) was deduced from a separate Eurostat database (nrg_ind_ren) and was taken as biofuel in all cases. Finally, these values were distributed into four different Exiobase products representing gasoline, biogasoline, diesel and biodiesel, respectively. In all cases, the emission intensities were left unchanged, but additional 'use-phase' emission intensities were determined for gasoline and diesel based on the combustion emissions associated with 1 Litre of each and representative fuel prices based on the European weekly oil bulletin (European Commission, 2019) (separately collected for the UK (UK gov, 2019) and Norway (statistics Norway, 2019).

The use-phase emission intensities are thus, in economic units, following conversion of results obtained from the work of Cherubini et al (Cherubini et al, 2009). The Biofuel use-phase emissions are taken to be zero.

Residential space heating emissions

The HBS describes energy expenditure in terms of electricity (described above), liquid fuels, solid fuels, gas and heat, respectively. Heat was directly distributed into a single Exiobase product category and represents centralised or district heating. The remaining categories were subdivided based on Eurostat data describing final residential fuel consumption at the national level (NRG_D_HHQ). The expenditure on solid fuels was divided into wood and solid fossil fuels (either coal or peat, depending on region). In turn, gas expenditure was split between natural gas and biogas, respectively, whilst liquid fuels were in turn disaggregated into Exiobase products representing heavy fuel oil, kerosene, natural gas liquids and other biofuels. For each of these separations, it was assumed that energy consumption was proportional to expenditure, since no relevant data could be found at a Europe-wide level. No further data was available describing how these subdivisions varied by urban area or household income, and so were taken to be constant (although the HBS expenditure in each of the broader categories did depend on the urban-type, and so would be reflected in the final emissions).

Finally, the use-phase emission intensities associated with each fuel type was calculated. For liquid fuels, this is based on fuel price statistics from the European weekly oil bulletin (European Commission, 2019) and separate databases for the UK (UK Gov, 2019) and Norway (Statistics Norway, 2019), and standard results for the emissions associated with 1 L of each fuel. The same method was used for gas fuels (NRG_PC_202). No good data could be found for solid fuels, so the values were estimated using the country-wide total household energy consumption to estimate fuel use per household, and then dividing this by the average household expenditure on solid fuels in the HBS. This gave values in terms of energy per Euro that in turn could be converted into emissions per Euro.

3.1.1 Sectoral emissions and spatial planning policy

The final emissions calculation is given as:

$$Emissions = B\,(I - A)^{-1}k + Uk \qquad (2)$$

where:

U = the use-phase emission intensities and all other terms are defined as above.

Performing the calculation above yields a table of emission for all 200 products defining the economy for a region under study. Similar products are grouped together to obtain emissions from a smaller number of sectors, some of which are aligned to the territorial sectors, whilst others act as place holders for future modules within the tool. Dividing by the average household size, which is found either from Eurostat for different urban types (HBS_CAR_T315), or directly from information on the case areas, generates annual emissions on a per capita basis that can be compared between regions. Subsequent multiplication by population gives the total emissions for the case area.

Changes arising from spatial planning policy will be quantified through changes to the demand vector (k in the equation above). This means that it will be modelled through changes in amounts that the residents are spending on different things, and the ratios that exist between these things. These ratios can be readily calculated from the household budget surveys, or other data available in Eurostat. For example, an increase in the utilisation of biofuels in land transport will be modelled by changing the ratio between diesel and biodiesel, and, gasoline and bio gasoline. This means the residents are effectively spending more on biofuels and less on pure gasoline and diesel. The ratio that is changed is the ratio between biogasoline and gasoline and biodiesel and diesel, which were originally derived from (nrg_ind_ren) as detailed above. Widespread penetration of electric vehicles will be considered through a reduction in demand for all transport fuels, along with a proportional increase in the expenditure on electricity. So in effect, the residents would be spending less on gasoline and diesel (and their bio-equivalents) and more on electricity. Improved residential building efficiency can be similarly quantified through a reduction on the proportion of the different energy sources allocated to heating, whilst the ratio of these (derived originally from the HBS and the Eurostat database (NRG_D_HHQ) can also be modified to characterise a reduction in direct combustion as a source of heating. So the residents may spend less overall on heating fuels and electricity. At the same time, the relative amount they spend on more sustainable options, such as electricity for heat pumps or district heating may increase when considered in relation to the amounts that are being spent on combustible fuels.

Other policies will be computed by changes to the emission intensities (the expected emissions for each euro the residents spend). This will, for example, be the case when it comes to locally distributed electricity production, such as expanding rooftop solar installations.

The output of these calculations is annual emissions distributed into different emission sectors. Changes can be tracked within the same area, or comparatively between different regions across Europe. For example, the following graph provides a comparison of the per capita emissions in each sector across the four case areas in 2020. Note that emissions from air travel have not been fully accounted for due to difficulties in determining the final 'use-phase' emissions.

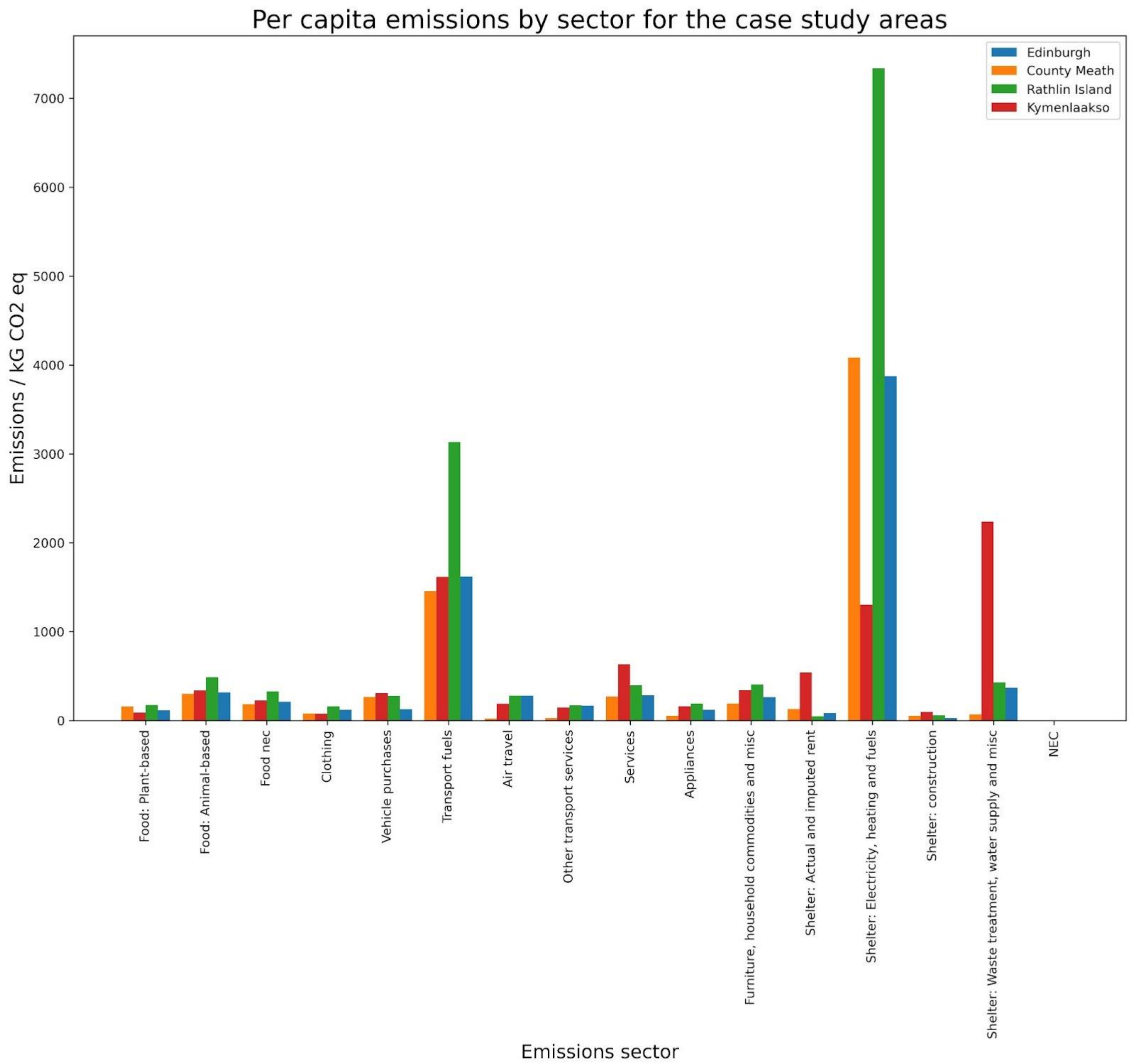

Figure 6. Per capita sectoral emissions for each of the case areas in 2020.

Future projection of emissions

The emissions are also projected into the future. This is done by performing the same calculation for every year between the baseline year and 2050. The values are changed based on 3 factors:

1. The expected annual rate of global decarbonisation

The default value is 3% per year. Here, the emission intensities (the expected global emissions for each euro spent on different products) are reduced by 3% every year. This value was taken based on IEA estimations that fossil fuels are globally expected to decrease by 4% each year, and the assumption that the burning of fossil fuels ultimately account for 75% of global emissions

2. The expected annual growth in income levels of households

There are separate values for each country, as well as separate values for each decade up to 2050. This value is important because as households or residents' income increases, they will spend more money, and so their consumption-based emissions are likely to increase. Here, the demand vector increases every year by the expected annual income growth rate.

3. The expected annual change in household size

Again there are separate values for each country, as well as separate values for each decade. This is important because the calculations are performed at an individual household level, but the per capita level is more relevant for comparing between regions. As discussed above, the emissions are divided by the household size in order to determine the per capita emissions. In most cases, the average household size is expected to decrease between now and 2050.

The expected annual growth in income level and the expected annual change in household size are taken from the PRIMES modelling, as described in the EU reference scenario report 2016, which describes future expected trends in Energy, transport and GHG emissions up to 2050.

It is extremely important to stress that the future projections should not be taken as accurate predictions of the future. To give one simple example, these projections were made before the coronavirus pandemic. However, they are included to give an insight into a plausible scenario of what the future could look like if the situation used in the baseline is broadly maintained. It can therefore give some insight into what scale of changes may be needed in order for future emission targets to be met. It is also useful because it allows for changes in the year that policies are introduced to be considered.

Calculation output

The output of the calculations are two graphs, one shows a stacked bar chart of the per capita emissions leading to 2050, and the second shows the cumulative per capita emissions up to 2050. The cumulative emissions are generated by summing up all annual per capita emissions up to that point. In this way, the advantages of introducing policies earlier (and seeing the consequent emissions reductions sooner) can be seen.

In this example emissions were calculated for an arbitrarily defined region of Berlin. Note that this should in no way be taken to represent any particular region of Berlin. The results are purely generated to illustrate the future projections included in the tool.

The first graph (Figure 3) shows the annual emissions for a single resident under the baseline scenario. Each bar in the bar graph represents the annual per capita emissions, which are broken down within the bar into different emissions sectors. These sectors are the same as shown in Figure 2. It can be seen that the effect of the future projections is a gradual reduction of emissions under the baseline scenario. This is driven by the global decarbonisation included in the tool. A lower factor for this decarbonisation could lead to emissions growing from year to year, since the average house size and household income are projected to decrease and increase, respectively.

The second graph (Figure 4) shows the cumulative emissions of a single resident between 2020 and 2050 for the baseline scenario and two policy interventions. That is, it shows the total emissions that have occurred up to that point, for the baseline (shown in blue) and two different policies (shown in orange and green, respectively). If climate neutrality was achieved in a certain year, such as 2040, then the respective curve in this graph would be flat after this point, as no further emissions are accumulating in the atmosphere. These are retrofits of the residential housing stock that lead to a 50% reduction in average energy use for heating, 50% of electricity utilised by the residents being generated locally by solar PV, and 50% of the energy from heating being generated from electrical sources. The difference in the policies are the years of implementation. In RFx50_2025 (green curve) the retrofits are completed in 2025 and in RFx50_2035 (orange curve) they are completed in 2035. In all other cases, the emissions reflect the baseline scenarios, such that there are no further changes to the consumption profiles of the residents. It can be seen that, although in both cases the cumulative emissions are much lower than those in the baseline scenario, and the per capita annual emissions in 2050 are approximately the same (less than 6 tonnes, compared to 8.5 tonnes in the baseline scenario), there is still a large difference between these two scenarios. As such, it highlights the value of earlier interventions in mitigating emissions, by allowing fewer total emissions to accumulate in the atmosphere. The cumulative emissions would be around 255 tCO_2e per capita for the policies implemented in 2025 and 287 tCO_2e per capita if the policies were delayed until 2035. The baseline scenario leads to cumulative emissions of 334 tCO_2e. It is important to stress that even under the more aggressive retrofitting policy the per capita emissions are still extremely high, and further reductions would certainly be necessary. Currently the tool can modify transport policies; in subsequent versions of the tool other aspects of consumption, such as food and waste could also be considered. Finally, it should be reiterated that this area and these policies are purely illustrative, and should not be taken to represent any real area of Berlin, or any real policies that may be under consideration.

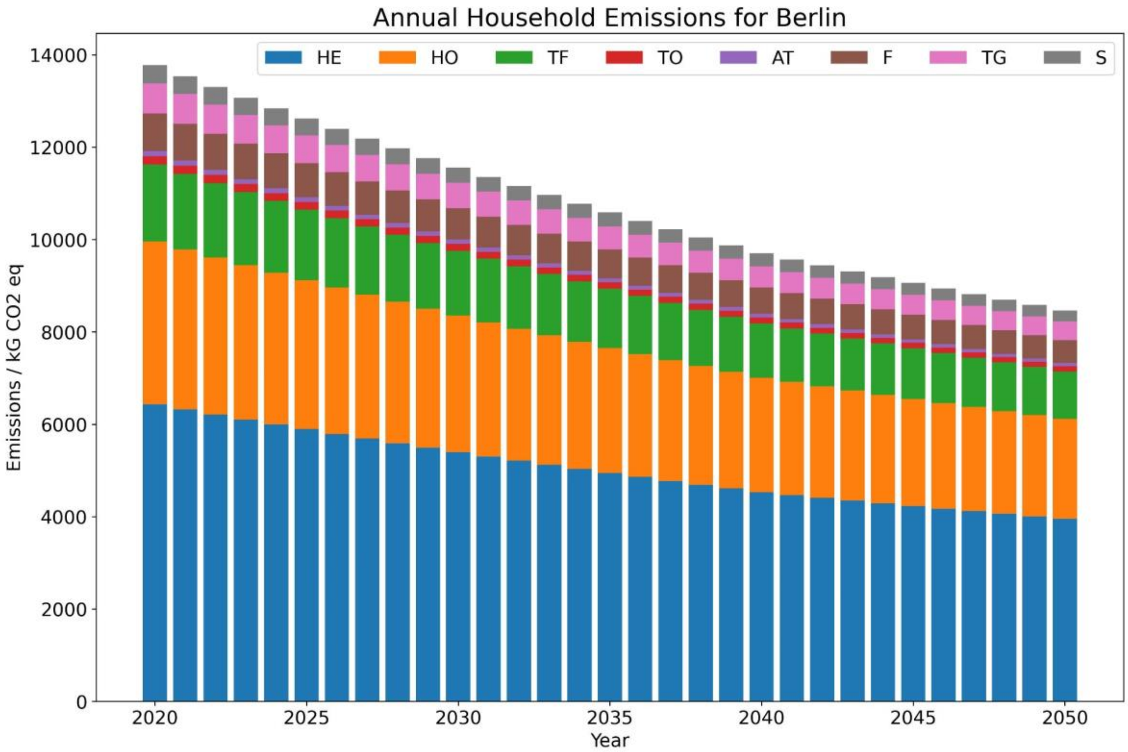

Figure 7. Baseline emissions for a region of Berlin, showing the annual emissions to 2050 and the breakdown of emissions by sector.

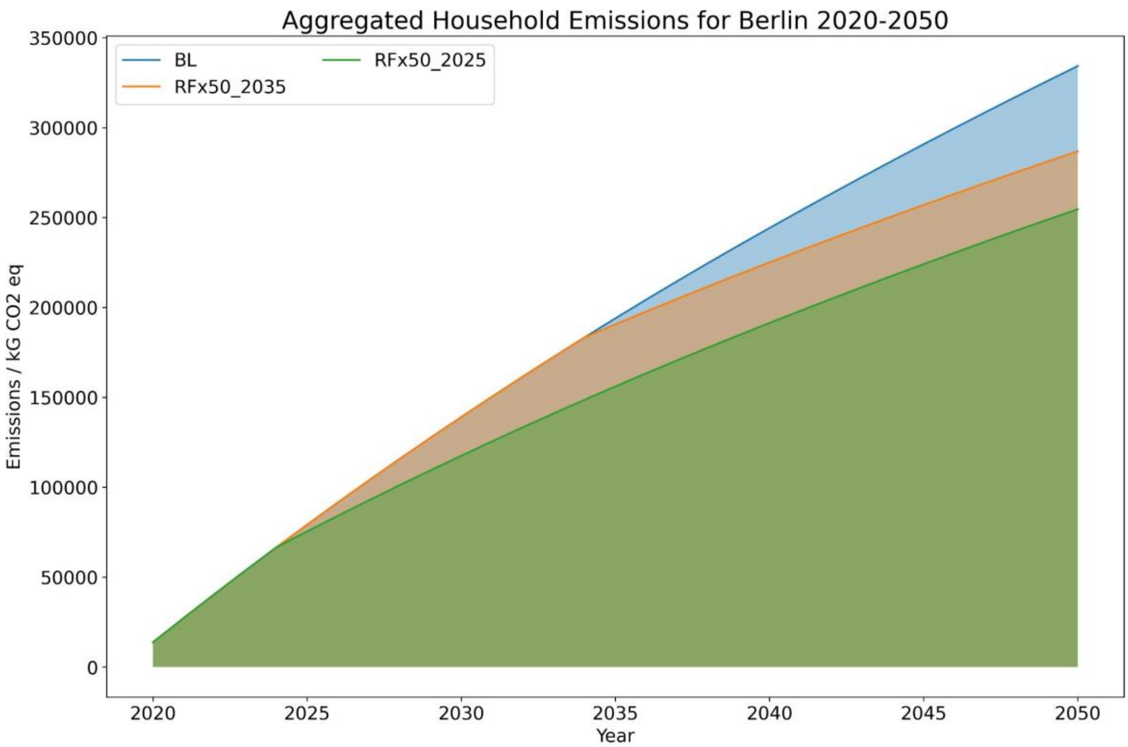

Figure 8. Cumulative emissions of a region of Berlin for the baseline scenario, and for an aggressive retrofit carried out in 2025 and 2035.

4 Data overview

This chapter provides an overview on the gaps in the datasets that are applied in the GGIA tool. It also explains why the most up-to-date data was not available for some modules.

Road transport emissions

Up-to-date emission factors for national car fleets could be calculated with the COPERT tool[2] (Emisia, 2021) that uses comprehensive and up-to-date datasets on European road transport. Because COPERT is not an open database, the GGIA tool cannot directly use that data.

Vehicle occupancy rates

Currently there seems to be no up-to-date, comprehensive European statistics on vehicle occupancy rates. The accuracy of vehicle occupancy rate is important when the vehicle-kilometres are calculated from passenger-kilometre data.

Many sources, including a recent study by Fraunhofer institute, propose 1.6 as the European average for passenger cars (Fraunhofer, CE Delft, Ramboll, 2020). However, research literature indicates that there is significant variation in European car occupancy rates. In addition, the car occupancy rate depends on both the travel purpose and income level. As a default, the ESPON GGIA tool applies the national occupancy rates collected in the TRACCS project in 2011 (EEA, 2013). This seems to be the most recent comprehensive European dataset publicly available.

However, the data collected in 2011 cannot be considered entirely up-to-date, as the occupancy rates keep changing. An advance tool could also take into account the differences between urban and rural areas, but at the moment there is not enough data available to create this type of weighting in a reliable way.

Future Scenarios

For future projections, GGIA applies the EU Reference Scenario 2016 that published prognoses for a number of key developments in each EU member state (Capros et al, 2016). The key figures are based on the PRIMES modelling, providing figures outlining the expected changes in transport activity, the share of electric vehicles in road transport and the carbon intensity of grid electricity. An update for the EU reference scenario was published in 2021, but unfortunately it provides no numeric information on the assumptions concerning the future developments, such as in annual change rates published in the 2016 version.

Table 6 presents the data gaps discovered in the European datasets that are applied in the GGIA tool.

Table 6. Data gaps (missing values) in the European datasets applied in GGIA.

Module	Database	Dataset	Missing data
General	Eurostat	Population on 1 January by age and sex	Liechtenstein, UK
	EU Reference Scenario 2016	Population change scenario	Iceland, Liechtenstein, Norway, Switzerland
	EU Reference Scenario 2016	Grid electricity decarbonisation scenario	Iceland, Liechtenstein, Norway, Switzerland
Consumption-based	Exiobase	Technical coefficient matrix	-
		Final demand vector	-

[2] http://emisia.com/products/copert-4

Module	Database	Dataset	Missing data
	HBS	Household Budget Survey	-
Transport	Transport in Figures 2020 Part 2.	Performance of Passenger Transport expressed in passenger-kilometers	Liechtenstein
	EU Reference Scenario 2016	Public road transport, annual change	Iceland, Liechtenstein, Norway, Switzerland
	Eurostat	Motor coaches, buses and trolley buses, by type of motor energy 2019	Austria, Bulgaria, Iceland, Liechtenstein, UK
	EU Reference Scenario 2016	Share of electric vehicles, scenario	Iceland, Liechtenstein, Norway, Switzerland
	EU Reference Scenario 2016	Passenger car transport, scenario	Iceland, Liechtenstein, Norway, Poland, Slovenia, Switzerland
	TRACCS project dataset	Passenger car occupancy	Liechtenstein
	Eurostat	Passenger cars, by type of motor energy and size of engine 2019	Austria, Bulgaria, Denmark, Greece, Iceland, Lithuania, Luxembourg, Slovakia, UK
	Eurostat	Passenger cars by type of motor energy 2019	Bulgaria, Iceland
	EU Reference Scenario 2016	Trams & metros, passenger transport volume, scenario	Iceland, Malta, Norway, Poland, Slovenia, Switzerland
	Eurostat	Share of locomotives by propulsion (diesel / electricity)	Belgium, Bulgaria, Croatia, Cyprus, Denmark, Estonia, France, Germany, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Netherlands, Norway, Romania, Spain, Sweden, Switzerland, UK
	EU Reference Scenario 2016	Passenger train transport, scenario	Iceland, Liechtenstein, Norway, Switzerland
	Eurostat	Freight transport in vehicle-km	Italy, Liechtenstein, Norway, Spain, Switzerland
	EU Reference Scenario 2016	Road freight transport, scenario	Iceland, Liechtenstein, Norway, Switzerland
	ACEA Report	Vehicles in use 2021, LGV and HGV	Bulgaria, Cyprus, Iceland, Liechtenstein, Malta

Module	Database	Dataset	Missing data
	Eurostat	Lorries by type of motor energy	Belgium, Bulgaria, Czechia, Germany, Greece, Iceland, Lithuania, Slovakia, Slovenia
	EU Reference Scenario 2016	Inland navigation, change	Iceland, Liechtenstein, Norway, Switzerland
Land-use change	FAO FRA Year 2020	Deforestation	-
	NIR CRF tables 2021 (inventory year 2019)	Peatland restoration (re-wetting)	Austria; Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Greece, Hungary, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, UK
		Forest land converted to other wetlands / flooded land	Cyprus, Estonia, France, Hungary, Iceland, Italy, Latvia, Malta, Netherlands, Poland, Slovakia
		Cropland converted to other wetlands / flooded land	Cyprus, Estonia, France, Hungary, Iceland, Italy, Latvia, Malta, Netherlands, Poland, Slovenia
		Grassland converted to other wetlands / flooded land	Cyprus, Estonia, France, Hungary, Italy, Latvia, Malta, Netherlands, Poland, Slovakia
Buildings	EU Buildings database	Average energy consumption of renewables in residential buildings	Portugal
		Average energy consumption, Retail buildings	All 32 countries

Module	Database	Dataset	Missing data
		Average energy consumption, Health buildings	Belgium, Bulgaria, Croatia, Cyprus, Czechia, Estonia, Finland, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Norway, Poland, Portugal, Slovakia, Slovenia, Switzerland
		Average energy consumption, Hospitality buildings	Belgium, Bulgaria, Croatia, Cyprus, Czechia, Estonia, Finland, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Norway, Poland, Portugal, Slovakia, Slovenia, Switzerland
		Average energy consumption, Office buildings	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Estonia, Finland, France, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Switzerland
		Average energy consumption, Industrial buildings	All 32 countries
		Average energy consumption, Warehouses	Belgium, Bulgaria, Croatia, Cyprus, Czechia, Estonia, Finland, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Norway, Poland, Portugal, Slovakia, Slovenia, Switzerland

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