ESPON

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Inspire Policy Making with Territorial Evidence

REPORT //

QGasSP – Final report

Quantitative Greenhouse Gas Impact Assessment Method for Spatial Planning Policy

Adjusted Final report // September 2022

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Abbreviations

ACEA	European Automobile Manufacturers Association
AFOLU	Agriculture, forestry and other land use (under LULUCF)
BASIC	a GHG inventory level by Greenhouse Gas Protocol
BASIC+	a GHG inventory level by Greenhouse Gas Protocol
BEI	the Baseline Emission Inventory
CARBINE	British model to estimate forest-related greenhouse gas emissions
C40	a network of the world's megacities committed to addressing climate change
CDP	County development plan
CH_4	methane
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CODEMA	Dublin's energy agency
COICOP	Classification of Individual Consumption by Purpose
COPERT	European tool for the calculation of emissions from the road transport
CRF	Common Reporting Format (under LULUCF national reporting requirements)
DEFRA	British department for Environment, Food & Rural Affairs
DfT	Department for Transport, UK
EEA	European Environment Agency
EEA39	EEA members and cooperating countries
EEIO	environmentally extended input-output approach
EIO	economic input-output approach
ESDAC	European Soil Database (European Soil Data Centre, 2013)
ESPON	The ESPON EGTC is a European Grouping on Territorial Cooperation
EU	European Union
FI	Finland
GGIA	Greenhouse Gas Impact Assessment, the name of the tool developed in QGasSP
GHG	Greenhouse Gas
GIS	Geographic Information System
CLC	CORINE Land Cover
GPC	Greenhouse Gas Protocol for communities
HBS	household budget survey
HWP	harvested wood products
ICCT	International Council on Clean Transportation
IE	Ireland
IO	input-output
IPCC	Intergovernmental Panel on Climate Change

LCA	Life Cycle Assessment
LPIS	EU Land Parcel Information System
LULUCF	Land-Use, Land-Use Change and Forestry
MapEire	Greenhouse gas quantification tool
MMU	minimum mapping unit
MRIO	multi-regional input-output database
NEDC	New European Driving Cycle, a test protocol for cars
NIR	National Inventory Report (on LULUCF emissions)
NPF	National Planning Framework
NUTS	Nomenclature of territorial units for statistics
P-LCA	process-based life cycle assessment
QGasSP	Quantitative Greenhouse Gas Impact Assessment Method for Spatial Planning Policy
RQ	Research question
SCATTER	Greenhouse gas quantification tool
SEA	Strategic Environmental Assessment
SEI	Stockholm Environment Institute
SEPA	The Scottish Environment Protection Agency
SPACE	Scottish tool for greenhouse gas quantification
SYKE	Finnish Environment Institute
TACCC	principles of transparency, accuracy, completeness, comparability and consistency
TalTech	Tallinn University of Technology
TRACCS	Transport data collection supporting the quantitative analysis -project
UI	User interface
UK	United Kingdom
UN	The United Nations
UNFCCC	(UN Climate Change) United Nations entity supporting the global response to climate change

Executive summary

The objective of the QGasSP project (2020–21) was to produce a tool with 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 planning 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. The key research questions for the QGasSP project were defined as follows:

> RQ1: How can consistent and comparable GHG baseline emissions data be collected at national, regional and local levels to assess the urban and land-use share of GHG emissions relevant for spatial planning policy and practice?
>
> RQ2: How can the efficacy of spatial plans and possible alternatives be systematically modelled, via standardised quantitative methodologies and accounting protocols, to determine their overall impact on GHG emissions, and aid cross-country, inter-regional and inter-municipality comparisons?
>
> RQ3: How can a better scientific understanding be developed of how national, regional and local planning authorities can prioritise relevant GHG mitigation strategies, including through enhancing the effectiveness of the SEA process, to rapidly build political will for climate action.

The tool created in this project was named GGIA Greenhouse Gas Impact Assessment.

Two approaches

The national GHG inventories apply a **territorial approach**, and this approach is also widely adopted for the GHG studies of cities and regions.

The territorial approach includes all direct CO_2e emissions within the area. This means that emission sources such as industry and transportation through the area may have a significant impact on the total CO_2e emissions. The volumes of industry, freight transport and the transportation of non-residents vary from region to region, and this makes the comparison of results very difficult.

The results of territorial studies are often reported as per citizen, even though this can be misleading: the total CO_2e emissions in this case are not caused by citizens alone, and any emissions outside the territory, but caused by it, are not captured in this approach. Moreover, when the cities and territories strive for carbon neutrality applying a territorial greenhouse gas quantification method, they will need to offset also the GHG emissions of freight transport and passengers who just travel through the area.

A **consumption-based** inventory includes all emissions arising from the residents' consumption of goods and services, no matter where the emissions arise globally, or where the residents are when causing emissions. In other words, emissions from goods produced elsewhere are allocated to the final user, as well as emissions of all travel regardless of if it takes place within the territory in question or outside. In Scotland, The Climate Change Act has required reporting on consumption-based emissions alongside progress of national production-based targets, since 2009. This approach is also recommended as a complementary analysis by C40 cities[1]. The cross-border comparison of results is justified, but the quantification methods are more complicated. In this approach, the land-use change impact does not refer to the land use within the area in concern, but the global land-use changes caused by the consumption of the residents.

[1] C40 is a network of the world's megacities committed to addressing climate change.

On the consumption side, the lack of a widely adopted and harmonised approach is more noticeable. Although being widely recommended in literature, this type of approach is still mostly compiled by academic researchers in institutions, rather than by the regions themselves that can instigate effective policy.

State of the art: methods and standards

Many cities and territories have announced ambitious climate commitments, but there is great variation in the scopes and methods applied. In the GHG quantification for cities and territories, the practices and methods are not harmonized, as they are for the national greenhouse gas inventories and for estimating the carbon footprint of construction works. Most of the cities and territories follow the guidelines of the Greenhouse Gas Protocol[2], which has become the unofficial standard for reporting of results. However, the Greenhouse Gas Protocol does not specify the methods for quantification, and therefore the studies applying these guidelines are not uniform.

The reporting categories of Greenhouse Gas Protocol are developed for inventory purposes and they are not designed to serve the needs of spatial planning or the needs of policy impact assessment. Reporting is based on three scopes which derive from the methodological point of view.

> **Scope 1:** GHG emissions from sources located within the target area boundary
>
> **Scope 2:** GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the area boundary
>
> **Scope 3:** All other GHG emissions that occur outside the area boundary as a result of activities taking places within the area boundary.

If a territory is divided into smaller areas, the direct GHG emissions accounted for each area (scope 1) can be summed up to get the total GHG emissions of the territory, but inclusion of indirect emissions (scope 3) would lead to double accounting. Therefore, emission reporting needs to be carried out by this “scope” method.

For spatial planning decisions, the method should enable comparisons of the most important climate impacts of alternative policies and new development proposals. To serve the local climate strategies and the needs of spatial planning, GHG studies should provide future projections. Currently, there is no common basis for creating these prognoses. This makes the comparison of territorial GHG quantifications even more difficult.

Currently, the GHG inventory results of cities and regions are very difficult to compare. This is partly due to the variation in methods and scopes, but it is also due to an in-built feature in the territorial approach that is typically applied in these studies, as explained below. There are a variety of national methods and tools developed independently by cities. These rely on the best available local data and cannot be applied, as such, in other countries.

It seems that the GHG quantification of cities and territories often borrow methods from national GHG inventories and the IPCC guidelines. In some cases this is problematic. For example, the method to quantify the impacts of land-use change for national GHG inventories is based on six land use categories, which do not have the resolution to distinguish the changes in land use in urban environments.

As the regional climate strategies typically aim at carbon neutrality, it would be also important to harmonize the quantification of measures for carbon offsetting and carbon sinks.

All in all, the project shows that there is a need for European harmonisation, which cannot be resolved within a tool development project. Cross-country and cross-region comparisons, enabled by harmonised approaches, could enhance the exchange and the implementation of best practices. Furthermore, this could help territories and cities in achieving their climate targets.

[2] https://ghgprotocol.org/

The challenge of pan-European applicability

Today, the most accurate data for GHG quantification of regions does not originate from European databases, but is collected locally. There are big differences in data availability. Forerunner countries in climate action provide national databases with comprehensive regional data. The land use types which include soil and vegetation, and transport activity per road type and municipality, can be collected from national databases for example in Finland, Ireland and the UK. However, not all European countries provide detailed regional data, and for this reason the best practises of the forerunner countries cannot be applied European-wide. Also, when the area of concern is small, there is usually no data available in databases, and accurate data needs to be created through questionnaires, GIS analyses and respective methods of bottom-up data collection.

European NUTS classification of regions provides a structure which could be utilised as a centralised European data collection for regions. Today, for example Eurostat provides datasets with NUTS2 and NUTS3 areas, but these datasets do not cover all the sectors needed in GHG quantification.

Developing and extending the datasets for NUTS1 and NUTS2 areas would be an improvement. However, it will not solve the challenge of pan-European applicability in spatial planning, because areas in spatial planning do not follow the NUTS classification.

There are also data gaps in the country-level (NUTS0) European data. For example, the vehicle occupancy rate is no longer an indicator which would be monitored and reported on a European level. In many datasets, the emission factor for national grid electricity is based on the energy generation, whereas GHG quantification would need to apply the emission factors for consumed electricity, which includes the transmission losses and imported electricity.

Tool review

A critical review of similar tools was undertaken in addition to the literature review. This was limited to tools available within the case study areas, with a total of five tools considered. It is important to stress that the tools differed substantially in terms of their scope, applications and complexity, which complicated the extent to which they could be directly compared. The factors considered included calculations for both territorial and consumption-based emissions, emission sectors (including how well land-use change is quantified), and whether both absolute and relative emissions are determined (such that a baseline inventory and subsequent policies could be considered). Moreover, the usability, communicability and pan-European applicability was also taken into account. Based on this analysis, none of the tools were found to adequately cover the project brief. A dichotomy was found between tools that primarily were for quantifying or accounting for the emissions occurring within an area, such as MapEire in Ireland or the Scatter tool in the UK, and those that more strongly emphasised the relative effects of plans and policies. Examples of the latter case were the SPACE tool, applicable to Scotland, and Ecocity Evaluator in Finland. On top of this, all of the tools were to a greater or lesser extent territorial only and with datasets covering only specific regions of Europe. Whilst additional datasets representing other areas could likely be produced in some cases, it does raise the possibility that the specific methodologies adopted may be most suited to modalities of the local data and less scalable to the whole of Europe. The lack of specific consumption modes, in addition, would serve to limit the comparability between regions.

The tools also differed in their usability and accessibility to non-experts. In this sense, Ecocity Evaluator was found to be closest to the centre of the project brief because it is a web-based application and user focused. SPACE, the other tool of a similar scope, was Excel based and rather more opaque, and this was found to limit its usability by non-experts. SPACE and Ecocity Evaluator also differed in being most suitable for the largest and smallest scales, respectively.

Methodology for the GGIA tool

In accordance with the best practice and the most recent recommendations, two separate methods for GHG quantification are applied in the GGIA tool. The territorial and consumption-based modes of the new tool, approach emissions quantification from different perspectives.

Both perspectives are important: a territorial approach is more sensitive to local data inputs and since they occur within the area considered, may cover emissions that can be captured easily by decision makers. In turn, the consumption-based approach allows for greater inter-region compatibility and may ultimately give a more accurate picture of emissions in developed economies. In reality, it would be necessary to compile both for a full picture of emissions.

Territorial GHG quantification includes calculation modules for land-use change, buildings and transport.

In land-use change sector, GGIA applies the IPCC methodology based on six land use categories and six carbon pools. In order to quantify the land-use change emissions, tool user has to analyse the land use types in the assessment area. National databases can be used to carry out the analysis. In the four pilot case studies, the researchers chose to demonstrate the use of tools and datasets that are applicable across Europe. The analyses utilized GIS data from CORINE Land Cover database and European Soil database. CORINE operates with 44 land use categories that need to be matched with the six IPCC categories. Some country-specific interpretations are needed, because European countries apply their own practises in the classification. The allocation principles are explained in the National Inventory Reports (NIR) that are published annually. This report presents the conversions for the four pilot case studies in Annexes 2–5, and explains the methodology in detail in Annex 1.

Buildings module models the expected future development of the buildings stock applying annual increase and demolition rates. It quantifies the GHG emissions from the energy use in commercial and residential buildings with the European Buildings Database data that provides the average energy consumption for dwellings and commercial buildings by country. The emission factors for fuels are extracted from the Covenant of Mayors dataset. The expected future development of the grid electricity emission factor is estimated with the annual decarbonisation rate according to the EU Reference Scenario 2016.

It is difficult to set default values for the emission factors for local district heating. There is great variation in the emission factors of district heating systems depending on the fuel types, but there is no European database on district heating systems available. There are also alternative methods for allocating the emissions of combined heat and power (CHP) plants that generate electricity and district heating. Moreover, any assumptions considering the future development have to be inserted through local datasets, as they are dependent on the market-driven decisions of local suppliers.

National and local datasets were utilized in the four case studies presented in this report. In GGIA tool, this can be repeated through the local dataset function where more accurate local data can be inserted to replace the national values from European databases.

Transport module quantification is based on the generic equation of GHG quantification, where activity data is multiplied by the relevant emission factors. The robust formula enables calculations also in areas which do not have fine-grained data on transport available. The road vehicle fleet operating in the area is assumed equal to the national car fleet according to Eurostat data. The differences in car engine sizes and propulsion in the national car fleets as well as the driving profiles, are accounted for in the emission factor.

The transport activity is expressed as annual vehicle-kilometres by mode of transport. Many guidelines prioritize the purchased fuel as the primary source of information, but in the regional territorial inventories, it is easier to allocate vehicle-kilometres to the area of concern.

The default values on transport activity from the national-level Eurostat data are scaled down by the population of the area and the settlement type. The tool has simple options with which planner user can adjust these top-down figures to match with the real transport activity in the region. For higher accuracy, transport activity data can be specified in the local dataset.

Consumption-based quantification applies an environmentally extended input-output approach (EEIO) with 'enhanced' data from selected sectors derived from process-based LCA. In the tool, the sectors to be covered in more detail were to do with electricity, traffic and energy use in buildings. The consumption-based approach enables inter-country, inter-regional, and inter-municipal comparisons. Today, the cities and territories are less familiar with this approach, but it is endorsed by many researchers.

Based on household expenditure information, consumption-based quantification can provide a holistic understanding of the total climate impacts caused by the consumption of the residents in a particular area. In policy quantification, it highlights the impact of lifestyles and consumption patterns on GHG emissions.

Features of the ESPON GGIA tool

A browser-based, open-source tool with a modular structure was produced. For the territorial approach, the project developed calculation modules for buildings, transport and land-use change. In the modular tool, the quantification modules can be updated and more modules for new CO_2e emission sectors can be included.

If international harmonisation is applied, the numerous tools developed by the cities and regions will cease to provide relevant results and need to be updated. The aim was to create a GHG quantification framework which is easy to adapt, update and future-proof.

The tool is designed for three kinds of users:

- **A Planner User,** who can quantify the GHG emissions of alternative spatial plans or policies without the need of an in-depth knowledge on GHG quantification.
- **An Expert User,** who is capable of creating and updating local set-ups (local datasets).
- **A Developer User,** who has (Python) programming skills and knowledge on GHG quantification methods **and** can view the source code of the tool and develop the functionality and/or the calculation methods further.

The tool uses built-in European default datasets (Annex 1), which enable GHG quantification even without local data. These European datasets will need to be updated regularly by the tool owner.

The local “bottom-up” data is inserted when a local dataset is created. A local dataset can be created for a region of any size by expert users.

Once the local set-up and the baseline analysis are done by an expert user, the GHG quantification of different kinds of policies and spatial plans within an area can be done without expert-level knowledge on GHG quantification. The user can be, for example, a planner who wants to evaluate the impacts of alternative solutions. The impact of the spatial plan/policy can be compared with the baseline and evaluated against the climate neutrality target.

In the calculations, the local datasets override the default data, and make both the baseline analysis and the quantification results reflect the local situation. If there is a limited number of local datasets available and they cannot replace all the default datasets, GHG emissions can still be quantified.

It is further stressed that bottom-up data is far more relevant on the territorial side of the calculations. For the consumption-side, the overarching data on emissions is at a country level, which makes sense given the globalised nature of supply chains. However, many modifications can be made by the user on economic consumption and the data on expected emissions.

In all emissions sectors, European countries and territories (and cities) have created their own databases with detailed information which is locally relevant. But the structure, the terminology and the taxonomy applied in these databases are not harmonized. Applying datasets with different kinds of structures makes the comparison of the baseline analyses and the quantification results more difficult. Moreover, these local datasets typically focus on locally originating territorial emissions, but leave out the global production and supply chains, and therefore, can lead to biased policy-guidelines.

Findings from the pilot case studies

The quantification model was tested in four case study pilots:

- County of Meath, Ireland
- City of Edinburgh, Scotland
- Rathlin Island, Northern Ireland
- Kymenlaakso, Finland.

The data collection for the baseline analysis revealed differences in data availability. The City of Edinburgh and the Kymenlaakso region had already compiled baseline scenarios for their GHG emissions, and the results were available as benchmarks for comparison. National statistics supported the baseline analyses for the City of Edinburgh, the County of Meath and the Kymenlaakso region, but the statistics do not provide information for smaller areas, such as Rathlin Island. The Rathlin Island baseline calculation utilised the data collected in recent surveys.

One key difficulty of policy impact quantification in all four cases was that the policy documents do not provide quantitative information that is necessary for GHG quantification. For example, if the policy is to promote active transport modes, assumptions on the expected impact on either modal shares or transport activity have to be specified in order to quantify the impact on GHG emissions. One approach is to evaluate the impact through various scenarios: for example by calculating the GHG emissions reductions with 1% increase, 5% increase and 10% increase in active transport. The results can also be utilised to set some targets for the policies.

The third finding from the case studies is the differences in the potential measures of spatial planning to reduce GHG emissions. Based on the findings of this study, it is likely that cities and regions are already aware that there are a number of important parameters in the GHG quantification that are outside of their control or influence. For example the decarbonisation of grid electricity is usually more dependent on the national strategies and investments than regional decision-making. The electrification of the car fleet is a market driven development which can be catalysed by regulation and economic incentives, but they are usually not regional steering mechanisms. Furthermore, in the areas where new construction and economic growth is limited, such as Rathlin Island, the number of economically feasible spatial planning policies that could deliver significant GHG reductions is also limited.

1 Introduction

1.1 Objectives of the 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. More specifically, the objective was to address the knowledge demands and technical requirements of the four stakeholders included within this Targeted Analysis Project:

- the Eastern and Midlands Regional Authority (IE)
- Scottish Government – Planning & Architecture Division (UK)
- Department for Infrastructure, Northern Ireland (UK) and
- Regional Council of Kymenlaakso (FI).

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 in three areas (buildings, land use, transport), and impacts arising from household consumption with possible post-project pan-European applicability. The purpose of this approach is to help inform 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. (ESPON, 2020)

1.2 Research questions

The key research questions for the QGasSP project were defined as follows:

RQ1: How can consistent and comparable GHG baseline emissions data be collected at national, regional and local levels to assess the urban and land-use share of GHG emissions relevant for spatial planning policy and practice?
RQ2: How can the efficacy of spatial plans and possible alternatives be systematically modelled, via standardised quantitative methods and accounting protocols, to determine their overall impact on GHG emissions, and aid cross-country, inter-regional and inter-municipality comparisons?
RQ3: How can a better scientific understanding be developed of how national, regional and local planning authorities can prioritise relevant GHG mitigation strategies for climate action, including through enhancing the effectiveness of the SEA process. (ESPON, 2020)

1.3 Tasks

The content of the assignment was described as follows:

1) Develop and deliver a flexible, user-centric web application which is simple to use in modelling GHG emissions from differing spatial planning policy options and in informing decision-making processes, including SEA. This includes the development of consistent and comparable GHG accounting parameters in quantifying urban and land-use based GHG emissions relevant to spatial planning. The goal was to develop a web-based model for pan-European application which has the potential to play a useful role in informing spatial policy decision-making, improving the SEA process and facilitating effective long-term climate action.

2) Test the model through pilot application in each of the stakeholder case study territories included in this Targeted Analysis Project. The purpose of the case study analyses shall be to iteratively test the operability of various stages of the model development through a bespoke quantitative evaluation specified by stakeholders' spatial plans and their likely effectiveness in respect of emissions abatement in differing sociopolitical contexts. The case studies shall also include a qualitative analysis, through focussed engagement and testing with key local stakeholders and partners at various

stages of the model development, to provide continuous practical feedback and insights from policymakers on practical deployment and usability in differing geographic contexts.

3) Produce a practical user guide for planners and SEA experts. The user guides aim to ensure that the value of the tool in the spatial planning process is maximised, including how it can be integrated into the SEA process and finally to enable decision makers to make informed decisions on reducing GHG emissions. (ESPON, 2020)

To this end, the following tasks were identified:

- Task 1: Methodological framework
- Task 2: Baseline analysis
- Task 3: Model development
- Task 4: Case Study pilots
- Task 5: User manual & guidance. (ESPON, 2020)

1.4 Authors/research team

The QGasSP project was carried out by a consortium of researchers and experts from

- Tallinn University of Technology, Academy of Architecture and Urban Studies, TalTech (service provider), Estonia
- Stockholm Environment Institute Tallinn Centre (SEI Tallinn), Estonia
- Codema - Dublin's Energy Agency, Ireland
- University of Iceland (as a sub-consult for the service provider), Iceland.

The QGasSP project was commissioned by ESPON in 2020–21. The ESPON EGTC is a European Grouping on Territorial Cooperation. ESPON started in 2002 and has continued since then to build a pan-European knowledge base related to territorial dynamics.

2 Methodological framework

2.1 Introduction: two main approaches on GHG quantification

The national GHG inventories apply a **territorial approach**, and this approach is also widely adopted for the GHG studies of cities and territories.

The territorial approach includes all direct CO_2e emissions within the area, no matter if they are caused by the residents or non-residents. This means that emission sources such as industry and transportation through the area may have a significant impact on the total CO_2e emissions. The volumes of industry, freight transport and the transportation of non-residents vary from region to region, and this makes the comparison of results very difficult.

The results of territorial studies are often reported as per citizen, even though this can be misleading: the total CO_2e emissions in this case are not caused by citizens alone, and some emissions may not be captured in this approach. Moreover, when the cities and territories strive for carbon neutrality applying a territorial greenhouse gas quantification method, they will need to offset also the GHG emissions of freight transport and passengers who just travel through the area.

A **consumption-based** inventory includes all emissions arising from the consumption of goods and services, no matter where the emissions arise globally, or where the residents are when causing emissions. In other words, emissions from goods produced elsewhere are allocated to the final user, as well as emissions of all travel regardless of if it takes place within the territory in question or outside. In Scotland, The Climate Change Act has required reporting on consumption-based emissions[3] alongside progress of national production-based targets, since 2009 (Scottish Parliament, 2009). This approach is also recommended as a complementary analysis by C40 cities (C40, 2019). The cross-border comparison of results is justified, but the quantification methods are more complicated. In this approach, the land-use change impact does not refer to the land use within the area in concern, but the global land-use changes caused by the consumption of the residents.

On the consumption side, the lack of a widely adopted and harmonised approach is more noticeable. Although being widely recommended in literature, this type of approach is still mostly compiled by academic researchers in institutions, rather than by the regions themselves that can instigate effective policy.

2.2 Review on reference tools

A review was conducted to analyse the available tools that could be applied within the case study areas. The tools were analysed with particular focus both on the outcomes of the review of the scientific literature, and the critical appraisal of the necessary features to embed the tool within SEA.

The first tool to be analysed was the **SPACE** tool, developed by the Scottish government (The Scottish Government, 2011, 2012) and SEPA, and applicable to Scotland. This tool was built directly for quantifying emissions associated with spatial planning decisions. Next, the **MapEire** tool, developed through a research project at Aarhus university in Denmark (Pledjerup, Nielsen, Bruun, 2018) (Pledjerup, Nielsen, Bruun, 2019) (Pledjerup, Nielsen, Bruun, 2019) (Nielsen et al, 2020) was also considered. MapEire is a geospatial tool for desegregating and allocating emissions from the Irish national GHG inventory. A relatively similar model has been developed in Finland (GISPO, 2018) (Hastio, 2019) (Mäkinen, 2019) (UBIGO, 2019). The **SYKE** tool was built through a collaboration between the Tampere government and two Finnish software companies (‘Ubigo’ and ‘Gispo’). It has also so far only been applied in the Tampere region. A final tool applied within the case study areas is known as **SCATTER** (Nottingham City Council et al, 2019)**.** Although this tool can only be used within the United Kingdom, since it implements the GHG Protocol for Cities (GPC) methodology

[3] Section 37 requires the Scottish Ministers to lay a report before the Scottish Parliament in respect of each year in the period from 2010 to 2050 setting out, in so far as reasonably practicable, the emissions of greenhouse gases, whether in Scotland or elsewhere, which are produced by or associated with the consumption and use of goods and services in Scotland during that year.

it was taken as a representative tool for several others that have been applied to different regions, such as the 'local GHG inventory tool' by the environmental protection agency in the US, or the 'Environmental insights explorer' by Google). Additionally, the reference tool for the project, **Ecocity Evaluator** was also included in the comparative analysis. This was developed by Epecci Ltd in collaboration with Oivan (formerly IWA).

These tools differ substantially in scope, complexity and purpose, which complicates the extent to which they can be directly compared. For example, whilst SPACE and Ecocity Evaluator are essentially tools for comparing different spatial planning decisions, SCATTER is first and foremost a tool for compiling a baseline inventory. The other factors considered were the emission types and sectors included, with a separate section for land use as this was judged to be an element only partially included in many of the tools. Besides these factors, it was also important whether the tools considered emissions from a territorial or consumption perspective, how widely they could be applied across Europe and integrated within SEA, and the nature of their user interface and its appropriateness for both expert and non-expert users. Finally, the communicability of the results was also considered. The results from the comparative analysis are summarised in the following table, which also included a consideration of the new tool, the details of which are further elaborated in the following section.

Table 1. Comparative analysis of tools within the case study pilots.

	SPACE	**Ecocity Evaluator**	**MapEire**	**SYKE**	**Scatter** (representative GPC)	**GGIA**
GHG	GHG only	GHG only	GHG+.	GHG only	GHG only	GHG only*
Sectors (exc LULUCF)	Building energy use, transport and waste.	Building life-cycle, building energy use, infrastructure and transport	All sectors from UNFCCC national reporting	Building life-cycle, building energy use, transport	building energy use, transport, waste, industrial processes and product use	Building life-cycle, building energy use, infrastructure and transport
Land use (LULUCF)	Land-use change only; only four land categories	Land-use change only, 3 Land categories, outdated data	All sectors and land types from UNFCCC national reporting (6 Land categories). Includes sources and sinks.	Land-use change and carbon sinks	IPCC LULUCF methodology, 6 land categories	IPCC LULUCF methodology, 6 land categories
Baseline inventory	✗	✗	✓	✓	✓	✓
Comparative assessment	✓	✓	✗	~	~	✓
Production account	✓	✓	✓	✓	✓	✓

Consumption account**	✗	✗	✗	✗	✗	✓
Model design and interface (incl any geospatial components)	Excel based. No geospatial component.	Web-based application. Limited Geospatial component	Application based. Geospatial component	Application based. Geospatial component	Web-based application. No Geospatial component	Web-based application
Pan-European applicability	✗	✗	✗	✗	✗	✓
Linkages with SEA report	✓	~	✗	✗	✗	✓
Usability and communicability	Expert use; no automated reports	non-export use; automated reports	expert use; no automated reports	Expert use; no automated reports	non-expert use; automated reports	non-expert use; automated reports

* The new tool can be modified in the future to include additional functionalities relevant to spatial planning.
** Whilst some tools include aspects of consumption accounting, none do so in a complete or systematic manner.
~ refers to an element of a particular tool judged to be partially fulfilled, or valid in certain cases.

It can thus be seen that no existing tool adequately covers the range of applications envisioned within the project brief. However, it is clear that Ecocity Evaluator sits closer to the centre of the project brief than any of the other tools reviewed. The tool is browser based and easy to use, aggregates emissions into a single number and projects the emissions into the future. Moreover, it allows comparative emissions between different spatial planning choices, though perhaps not to the extent of SPACE, and the automatic reports are valuable since many users may be non-experts. Ecocity Evaluator suffers, however, when applied to the largest scales such as whole regions, where a prospective user may wish to look at changes in policy components over wide areas, rather than any single area or development. Evidently, to work at different scales, the tool needs to assess specific changes within local developments, perhaps reaching down to the single component level, and also to assess how changes in circumstances or a policy (e.g. building regulations) might lead to changes in a range of sites. Ecocity Evaluator is also considered to represent the land-use sector relatively poorly, only has data suitable within Finland/Netherlands, and, whilst it may include some consumption aspects, it does not include a separate systematic assessment of consumption-based emissions. SPACE was also seen to have many of the aspects considered important within the tool. However, it further suffered in relation to Ecocity in terms of the usability assessment, the emission sources considered and the lack of aggregation of the results into a single number. Critically, all of the tools suffered in the sense that they were only designed or included data for subsections of Europe.

The first tool to be considered was SPACE. In relation to others that will subsequently be described, such as MapEire or the SYKE tool, SPACE only considers a limited number of emissions sectors, as well as mostly, but not exclusively, calculating emissions occurring during the lifetime of the building. That is, it is mainly territorial-based. These sectors are respectively defined as energy use, including electricity, waste, land-use change and transport. Used as standard, the tool effectively only assesses CO_2 equivalent based emissions (unlike the SYKE tool and MapEire) and also generalises building emissions into broad categories; Housing, Commercial and other buildings, such as schools and hospitals. Housing and Commercial buildings can further be subdivided into components, which for housing are flats, terraces, or (semi-) detached houses. Additionally, further greenhouse gases that may also be important for specific developments could be included, effectively through placeholders. However, the value of this is uncertain given that the tool does not aggregate emissions into a single number, instead leaving separate the results from each sector. Emission reductions are projected into the future through reduction in electricity and fuel emission factors, but not through any changes to lifestyle.

In contrast, the emissions considered within MapEire are extensive, encompassing 32 pollutants from 138 sectors, including all 7 GHG mandated by the UNFCCC and all non-GHG pollutants required under the European CAFE and CLRTAP directives. This makes it applicable to other factors important in spatial planning, such as air quality. It adds additional value by considering carbon sequestration through the LULUCF sector, which is not included in SPACE.

In further contrast to SPACE, MapEire does not directly calculate emissions per se. Instead, it seeks to determine relative emissions from different geographical regions for each of the sectors considered, and then assign a proportion of the Irish national emissions inventory based on known pollutant or activity data, or proxies if these are not available (it is thus a top-down methodology). The emissions are assigned to a map of Ireland with a resolution of 1 by 1 km, with higher resolutions also feasible and demonstrated in the Dublin area. It can be moreover envisaged that similar data could also be used based on other extensive national or regional inventories, whilst the geographical desegregation is also clearly of value in spatial planning, as well as potentially making the results obtained in a potential comparative analysis easily communicable to relevant stakeholders.

A relatively similar model has been developed in Finland (Hastio, 2019) (GISPO, 2018) (Mäkinen, 2019) (UBIGO, 2019). The SYKE tool was built through a collaboration between the Tampere government and two Finnish software companies ('Ubigo' and 'Gispo'). It has also so far only been applied in the Tampere region. The tool runs as an extension to an open-source GIS programme (QGIS) and is mostly based on national and regional level data, although with a framework provided for including more accurate local level data if available.

The tool considers a greater number of sources than SPACE and appears to follow a more life-cycle based approach, for example considering construction, repair and demolition emissions for buildings. It is also strongly focussed on future emissions, which are considered through different parameters representing a range of policy engagements towards minimising and mitigating carbon emissions, and feasible scenarios for population growth within the city. The user therefore has a greater degree of control over how emissions will progress into the future than in SPACE. This is a key strength given the timescale of building development and use and the subsequent 'lock-in' of harmful or positive aspects. As discussed, this is therefore something that should be considered a useful component to be included in the new tool.

A final, recent on-line tool is known as SCATTER (Nottingham City Council et al, 2019). This was developed for UK-wide application by local governments in Nottingham and Manchester, along with the Tyndall centre for climate research and 'Athesis', a company from the private sector. Scatter is a browser-based tool for establishing a carbon inventory based on the GPC methodology at the BASIC level. The authors further note that similar tools for establishing a GPC inventory are also available for different regions.

It is broadly based on UK national statistics subsequently assigned to local authority regions (and is thus largely top-down and production-based). In contrast to some of the published literature, this also points to the feasibility of the GPC methodology. Moreover, like SYKE the tool provides emissions trajectories until 2050 that can be modified by a large number of different macroscopic policy scenarios. Whilst this would not be appropriate for the more detailed, project-specific developments, it could be beneficial when considering the larger spatial scales. It is also the only tool that provides a clear basis for developing systematic baseline inventories without requiring a high-level of expertise by the end user.

Ecocity Evaluator

In Ecocity Evaluator, specific developments are computed, and emissions are considered from buildings (including the life-cycle emissions), infrastructure, energy (heating of air and water, ventilation and electricity), traffic and land use. Infrastructure is determined based on the existing street network of the region considered for the development. Emissions from electricity (and any electric heating) are established based on an understanding of the regulations followed, in order to determine consumption, scaled by pan-Finnish emission factors. Alternatively, district heating emissions follow municipality-specific fuel distributions. Traffic is separated into commuting and freight categories, (to our best understanding) with surveys used to determine activities at the target region, and Finnish-specific emission factors (including emission from production). Finally, land use emissions are determined using global values for deforestation.

Consequently, the methods applied are actually similar to SPACE, with some exceptions – for example including building life cycle emissions. As with SPACE electricity and heating emissions are seen to decrease through decreased emission factors (although Ecocity Evaluator does include a separate solar energy calculation, unlike SPACE), but there are additional considerations in terms of traffic, where social aspects such as a greater uptake of low emissions vehicles and changes in travel habits are considered. Moreover, individual building designs can be imported into the software to improve the accuracy of calculations, as well as a basis for determining results for future developments of a similar type. In practice, this means that for most emission factors, there are 3 additional multiplier sets that can be applied in the UI, that reflect the (technological or behavioral) development either pessimistically, conservatively, or optimistically.

Usability and Suitability

Considering the tools in the context of the QGasSP brief, they differ in many important aspects, with no single tool apparently suitable to cover the breadth of applications targeted. For example, whereas MapEire and the SYKE tools have graphical user interfaces and are essentially stand-alone applications, the SPACE tool is excel-based, and SCATTER has an online interface but no geospatial component.

Looking first at SPACE, one advantage is that it is highly comparative as different scenarios can be quickly produced and considered against each other in real time. This is of clear value when used by non-experts by making prospective changes communicable. The SCATTER tool also appears to have a comparative aspect, at least at the policy level. Moreover, both SPACE and SCATTER appear to have much lower data and computational requirements than MapEire or SYKE. Finally, SPACE is the only analysed tool with direct application to SEA built into the development process (for which assessment of reasonable alternatives is a key aspect).

However, it is also limited in several respects. For one, it does not allow emissions to be aggregated into a single number, and this critically hinders comparability between different regions, or even different developments. It also makes it harder for the tool to be used by non-experts due to the lack of advice on how to interpret the respective weights of the individual components. Moreover, future emissions over time are only considered very generally through perceived changes to electricity and transport emission factors (and have to be built as separate calculations by the user for each year considered). Turning again to SCATTER, although this is clearly a useful tool for allowing regions to understand their GHG emissions, it is currently only applicable and indeed accessible to local governments in the UK. Furthermore, given the requested Europe-wide use of the tool, the UK specific methodology would require some modifications for other regions, whilst attribution of top-down national data may limit the level of granularity when applied to the smallest scales. Moreover, like SPACE and unlike the reference Ecocity Evaluator, it again does not include a consumption-based approach. It also does not seem appropriate to SEA practitioners or seemingly allow the degree of flexibility necessary for more advanced or region-specific policy analysis, although it is expected this could be easily introduced.

The geospatial components of MapEire and SYKE have benefits for interpreting results along with promoting stakeholder engagement. The levels of detail, moreover, have clear advantages, but can also be seen as a hindrance in comparison to SPACE and SCATTER. For example, calculations in MapEire can take up to a day to calculate data for a single year, at least for the baseline calculations. This also calls into question the usability of the tool by non-experts, and the computational requirements preclude a web-based tool unless the calculations are sent to an external server. No information is provided on the time taken for calculations in SYKE, but the similarity to MapEire, albeit over a much smaller area, also suggests a longer timeframe.

More critically, it does not appear that either tool includes any facile method for performing comparative analysis between different scenarios. In practice, they are tools for geographically desegregating emissions, and not something directly applicable to spatial planning as envisaged in the project brief.

2.3 Key findings of the literature review

Robust accounting protocols for carbon emissions exist at the national level across Europe. For instance, GHG inventories are produced annually at this scale through the IPCC methodology (IPCC, 2019). Here, emissions occurring within a country are designated into different categories and subcategories dependent on their source of origin, where for each the amount of emissions is determined by multiplying the frequency of an activity by a coefficient, the emission factor, describing the expected emission from a normalised unit of activity. Such factors are in turn determined by a hierarchy of calculation methods, known as tiers. These are respectively tier 1, which is based on average factors and readily available statistics, tier 2, based on more country or region-specific data, and tier 3, involving detailed local calculations and expected to afford the greatest level of accuracy in the final values.

Whilst such inventories are well established and with rigorous reporting standards to aid inter-state comparability, the procedures followed at smaller scales are more diffuse. This is partly a result of how changing the spatial scale changes the validity of any method applied. At the largest scales envisioned for the QGasSP tool, adopting the IPCC national methodology may indeed be appropriate, but it becomes progressively insufficient at the more local level since a greater number of emissions are outsourced beyond the considered geographical region (Chen et al, 2020). At these smaller scales, for example at the level of a single building, inventories are typically determined through variants of life cycle analysis (LCA), which systematically accounts for embodied emissions in used resources (Sharma et al, 2011). Cities sit between these two extremes and given their importance in the global economy and as sources of emission, as well as nodes of innovation, a great proportion of the published scientific literature has focused on this level (Arioli et al, 2020). Although this does not cover all of the spatial scales envisaged here, it serves as an appropriate point for evaluating the current state of the art in GHG inventories and harmonising an approach that can work at all scales relevant in QGasSP.

The differences in methodology applied at the widest and smallest scales, and as discussed in the introduction, also points to a broader conceptual distinction in accounting methodology. This is between traditional, ‘territorial’ based approaches that assign emissions occurring within a given area, and a more recent trend for ‘consumption’ inventories that account for all relevant emissions regardless of their geographical origin. According to Heinonen et al. (2022) the consumption-based method allocates to a consumer the GHG emissions caused by their consumption regardless of the geographic location of the occurrence of the emissions. For example, this might mean that emissions intrinsic to the extraction, processing and transport of fuel, as well as its subsequent combustion are included in an inventory. In this sense it represents an effective translation of the source associated with a particular emission from a geographical point to the end user.

This general dichotomy is also seen in the published literature. For example, in their systematic review published in 2020, Arioli et al. broadly grouped inventory methods at the city level into two categories reflecting these distinctions in methodological framework, although in reality many individual approaches applied at the city level will include aspects of both (Arioli et al, 2020). Both territorial and consumption approaches should be equivalent on a global level, but at more regional scales they can differ substantially. Indeed, Broekhoff et al (Broekhoff et al, 2019) reported that actual emissions can be a factor of 2 to 3 times the size of those reported through production-based accounting[4]. Chen et al also noted a similar proportion in their account of carbon metabolism in global cities (Chen et al, 2020). In practice, however, territorial and consumption-based inventories should be viewed as complementary. Given the conceptual similarity, territorial

[4] Production-based accounting allocates the emissions by the place of occurance, respectively to direct emissions (Scope 1) in territorial approach.

approaches are more easily harmonised with national accounting, are generally easier to perform at the larger scales using local (or bottom-up) data and more easily avoid any double counting of emissions (Chen, Long, et al, 2020). They may also present a range of emissions that can more easily be controlled through local action. Consumption-based approaches, on the other hand, not only provide a more accurate picture of actual emissions, but also can be more clearly defined on a per-capita or per unit of wealth basis, making them more communicable to individual citizens and other stakeholders (Dodman, 2009), and more comparable between different regions.

Given the overlap with national accounts, territorial inventories are more developed, and follow to varying degrees an IPCC-type methodology. Such approaches are often predominantly (though not necessarily exclusively) top-down in nature and may for instance rely on the scaling of the national inventory to match the activities taking place in the city or other region. Attempts have been made to better harmonise the approaches between cities, and in this context the Global Protocol for community-scale greenhouse gas emissions inventories (GPC), published in 2014, is of interest (Greenhouse Gas Protocol, 2014). GPC groups emissions into different scope standards reflecting the geographical location of the emissions:

> **Scope 1:** GHG emissions from sources located within the target area boundary
>
> **Scope 2:** GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the area boundary
>
> **Scope 3:** All other GHG emissions that occur outside the area boundary as a result of activities taking places within the area boundary.

In most cases scopes 1 and 2 are applied, with scope 3 being more in-line with a consumption-based methodology. Emissions are also reported at either a so-called BASIC or BASIC+ level, depending on the number of sources reported. GPC broadly follows the categorisation of emissions and guidelines found in national reporting, and so widespread adoption would allow more easy comparison to national values, as well as between individual cities within and between countries. Indeed, in their comparison of the GHG accounting methodologies of Helsinki, Stockholm and Copenhagen, Dahal and Niemelä concluded that "*a common emissions calculation method is necessary, such as the method derived from the GPC standard platform…Alternatively, in order to establish a robust, transparent, and qualitative system boundary, cities may develop comprehensive calculation methods in collaboration with governmental agencies, other municipalities, universities, and research institutions that include both direct and indirect emissions of GHG. However, we recommend that cities adopt GPC standards with an expanded reporting level. To adopt these standards globally, we also recommend updating the EU and United Nations reporting guidelines."* (Dahal & Niemelä, 2017)

Conversely, the GPC is also viewed as a complicated protocol (Erickson & Morgenstern, 2016) and an additional layer to be applied below BASIC to assist with limited data variability has also been suggested (Arioli et al, 2020). This problem may also be alleviated by the limited emission sources considered within this project. A second widely used methodology is the Baseline Emission Inventory (BEI), updated in 2018 and applied by several cities in Europe (European commission, 2020). Both GPC and BEI are of similar scope, including imported electricity emissions and exported waste (Balouktsi, 2020) (although BEI does also provide a framework for LCA type calculations). As a result, utilisation of one of these methodologies would also ensure a clear framework for the addition of further emission sources beyond the ones considered here in the future. Finally, it is expected that both of these methodologies could be scaled up to a regional assessment given their compatibility with the IPCC guidelines.

Harmonisation is less developed when it comes to consumption-based approaches (Heinonen et al, 2020). Accounting for emissions through a full consumption approach can essentially be accomplished bottom-up through process-based LCA, top-down by using economic Input-Output (IO) matrices that track the embodied emissions through supply chains, or through a hybridisation of the two (Balouktsi, 2020). This discrepancy in approaches poses challenges for harmonisation. Moreover, the varying spatial scales required in the GGIA tool also provide a complication given that each of these methods is most appropriate at the smallest and largest scales, respectively. Indeed, it is not expected to be practical to perform full LCA at the level of a city or larger, whilst despite multiple benefits, the issues associated with applying IO tables are well-known, such as the age of the data used in any analysis, or aggregation errors. Heinonen et al reviewed over 100 consumption-based approaches, showing them to be applied at a variety of range scales including the entire range relevant for the tool. However, they also comment on a lack of standard terminology and it is not necessarily clear what is included in each of the methodologies (Heinonen et al, 2020). In this context, the attempts to establish standardised consumption methodologies, for example the PAS 2070 (BSI, 2013) or the consumption-based extension to the GPC (C40, 2018) are promising. However, these will still broadly rely on the accuracy and suitability of any regional IO tables available in a given area.

Heinonen has applied environmentally extended input-output (EEIO) methods, for example the **tiered hybrid LCA method**, with the aim of combining the benefits of the two main types of LCA: the comprehensive range of input-output-LCA and the precision of process-LCA. Like an input-Output approach, instead of solely collecting the most recent sectoral datasets available, the tiered hybrid method utilises economic consumption data, overarching all aspects of consumption.

The tiered hybrid LCA method has provided results that have challenged many assumptions of the science community. For example, at Aalto University, the PhD projects applying the tiered hybrid LCA method have questioned the benefits of urban densification strategies and highlighted the importance of embodied emissions i.e. so called “carbon spike” of new construction. The results of professor Junnila’s research team were also notified in the 5th IPCC report (IPCC, 2014).

EEIO approaches, such the tiered hybrid LCA method, can provide solutions to some crucial challenges related to a pan-European methodology, including one of the three key research questions: how to collect consistent and comparable GHG baseline emissions data at national, regional and local levels. The industries (consumption categories) of input-output-LCA would create obvious placeholders for all aspects of consumption for the future development of the tool. Harmonised input-output tables, such as Exiobase[5] (Stadler, 2018), also exist for the whole of Europe, and help to solve issues related to pan-European data availability that are likely to persist into the future. Since the tool is designed to be updated and expanded beyond the end of the current project, grounding the results around such a database, that will itself evolve through future iterations, can help to mitigate these issues.

Taken together, it is clear from the published literature that there are a number of methodologies available that can be potentially used as the basis for the tool.

It is noted that aligning with the existing methodologies will aid uptake, particularly something similar to the GPC for the territorial-based approach. On the consumption side, the wide spatial scales envisaged in the tool pose complications, and so a hybridised approach, such as the tiered-hybrid method, is targeted aligned to the tool hierarchy.

2.4 Model development

In accordance with the best practise and the most recent recommendations, two separate methods for GHG quantification were developed. The territorial and consumption-based modes of the new tool, approach emissions quantification from two different perspectives. Both perspectives are important: a territorial approach is more sensitive to local data inputs and since they occur within the area considered, may cover emissions that can be captured easily by decision makers. In turn, the consumption-based approach allows for greater inter-region compatibility and may ultimately give a more accurate picture of emissions in developed economies. In reality, it would be necessary to compile both for a full picture of emissions.

The objective of pan-European applicability means that it is not possible to just adopt the best practises in the tool. Best practises tend to apply methods and tools which are designed on the local data. Respective data would not be available in all regions of Europe. Therefore, it is more important to define in each module

[5] EXIOBASE is a global, detailed Multi-Regional Environmentally Extended Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT) developed by a consortium of research institutes in projects financed by the European research framework programs.

the core calculation that has a major impact on the total GHG emissions. This calculation can be utilized by the European regions which do not have extensive datasets available, and may be just starting their climate action. Also in the countries with advanced quantification systems, spatial plan or policy may concern an area which does not have the data for a baseline analysis available.

On the other hand, the forerunner territories and cities would not apply a tool which is less accurate than their current practises. For this reason, the ESPON GGIA tool is designed to provide an opportunity to conduct also more detailed GHG analyses with more fine-grained data.

The methodology of the GGIA tool is described in detail in Annex 1.

2.4.1 Buildings

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 datasets required for more realistic local development plan assessment. When different levels of data were available, the higher level of quality was selected.

The buildings considered at a European level were classified as commercial and residential. The EU Buildings Database[6] was used to give information on average energy demand per m^2 for the different building types. This data was broken down by fuel type and helped to quantify the energy demand from both commercial and residential buildings. National emission factors for heating fuels and grid electricity were used to convert the energy demand into emissions

Building Emissions

Residential

The methodology to quantify emissions from the residential sector includes firstly, identifying the total number of housing units in an area. This information was located in the EU Database, or provided by the stakeholders for case studies, 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 were also sourced from the EU Buildings Database, or sourced from the Energy Performance Certificate Database analysis done by the service providers. 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 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 was sourced from the EU Buildings Database.

These energy benchmarks 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

[6] EU Buildings Database | Energy (europa.eu)

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.

2.4.2 Transport

In the territorial approach, the quantification of transport GHG emissions includes all transport activity within the boundaries of the area, quantifying direct emissions for both freight and passenger transport.

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

The modal shares included in passenger transport are

- bus
- passenger car
- tram and metro
- passenger transport by rail.

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

Transport activity

Transport activity is usually 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.

Many sources prioritize fuel consumption as the source data for transport emissions calculation, as the purchase of fuels is always accurately documented. However, in a territorial study it may be difficult to determine where the fuel is actually combusted.

GGIA default values for transport activity

The default values for transport activity are based on national-level (NUTS0) data which is scaled down by the number of residents and the type of settlement. 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 uncertainty in default values.

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. GGIA tool applies national occupancy rates as defined in the TRACCS project in 2011 (EEA, 2013). The occupancy rates change by the time so updated European datasets on occupancy rates would be welcome. There is not enough data available to evaluate the impact of settlement type in these figures.

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. The list of European tram and metro systems was collected in the QGasSP project.

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.

Local data for transport activity

The case study pilots represent 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 share of vehicle-kilometres driven within the boundary of the selected area.

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. In the GGIA tool, each settlement type has a specific driving profile, in which the share of road and street driving varies.

Emission factors for modes of transport

The GHG emissions from transport are basically 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.

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 average emission factors for passenger cars with petrol and diesel engines, which dominate the car fleet in all European countries. 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, which provides conversion factors for these three categories in the British car fleet in 2002–2018 (DEFRA, 2019). 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.

The average emission factor for passenger cars is calculated based on the fuel shares in the national car fleet (Eurostat, Passenger cars, by type of motor energy, 2019). 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.

In addition to the national average emission factor, GGIA provides default values for two driving profiles: rural and urban driving. The tool user specifies the shares of various kinds of transport environments (metropolitan/city/town/suburban/rural). An expert user can adjust the shares of urban and rural driving profiles allocated for 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.

In the local dataset, expert users can adjust any default value described above. This provides an opportunity to utilize for example COPERT[7] data (Emisia, 2021) that is in many occasions considered as the most comprehensive and up-to-date data on European road transport. COPERT data is not applied in GGIA by default because it is not free of charge.

The pilot case studies apply the emission factors from national databases so that the results can be compared with previous baseline studies. The national emissions factors for the city of Edinburgh and Rathlin Island are sourced from DEFRA *Greenhouse gas reporting: conversion factors 2020* (DEFRA, 2020). The Finnish case study baseline applies the emission factors from the Lipasto database (VTT, 2021).

2.4.3 IPCC LULUCF method

QGasSP service providers implemented the Land Use, Land-use Change and Forestry (LULUCF)[8] sector methodology according to the IPCC guidelines (Eggleston H S, 2006) (Hiraishi, 2014) (Calvo Buendia et al (eds.), 2019) for quantifying territorial carbon emissions under land use. LULUCF is an inventory sector defined by the IPCC that covers anthropogenic (not natural) emissions and removals of GHGs resulting from

[7] COPERT is a Microsoft Windows software program which is developed as a European tool for the calculation of emissions from the road transport sector. The technical development of COPERT is financed by the European Environment Agency (EEA).

[8] LULUCF is also referred to collectively as agriculture, forestry and other land use (AFOLU). In the QGasSP project the land use sector is limited to the scope of LULUCF methodology.

changes in terrestrial carbon stocks. It covers the carbon pools of living biomass (above- and below ground), dead organic matter (dead wood and litter) and organic soil carbon for six broad land categories: forest land, cropland, grassland, wetlands, settlements (urban areas) and other land. In addition, wood products such as timber used in construction or furniture, referred to as harvested wood products (HWP) can be reported as an additional pool, however it was not included in the tool in the current stage. Both emissions and removals of GHGs can be estimated according to the LULUCF methodology. The relevant GHG occurring in the LULUCF sector is mainly CO_2, therefore non-CO_2 emissions (nitrous oxide, methane) were not incorporated into the GGIA tool in the first approximation. The regular inventory reports on LULUCF emissions (NIR)[9] to UNFCCC are developed at country level, and rarely at lower level of administration.

The LULUCF sector has numerous inherent characteristics that complicate reporting and GHG mitigation activities. Managed land is strongly influenced, but not entirely controlled by human intervention. A complex set of processes in terrestrial vegetation and soil cause both carbon emissions and removals, which can result in either net emissions or removals over an area of land. Furthermore, the capacity for terrestrial vegetation and soil to remove carbon from the atmosphere saturates because ultimately, a steady state will occur in the balance of emissions and removals for a given area of land. As a consequence of saturation, the potential to mitigate greenhouse gas emissions through vegetation management is finite. Emission reductions or increased removals achieved through mitigation activities in the LULUCF sector are also potentially reversible due to a phenomenon known as impermanence. In addition, agriculture and forestry measures can indirectly contribute to GHG mitigation through growing and harvesting of biomass to substitute for GHG intensive materials and fossil fuels (Kuikman, 2011).

Justification for applying the IPCC LULUCF methodology for land use sector in the QGasSP project is the following:

- The IPCC methodology is applied worldwide, including among the EU countries, and serves as the basis for reporting GHG emissions under the UNFCCC and the Paris Agreement. All the QGasSP case study pilot countries already implement the IPCC methodology for reporting annual GHG emissions, however this is usually done at a national scale.
- The IPCC methodology and related national inventory reports (NIR) follow the TACCC principles - transparency, accuracy, completeness, comparability and consistency; meaning the methodology is harmonized across countries and allows adequate comparison of GHG emissions from land use between countries and regions which was one of the aims of the QGasSP project.
- All land use categories, carbon pools, as well as the carbon sinks and sources are accounted for, thus the full potential of CO_2 reduction can be estimated when comparing the climate impact of different spatial planning documents and strategies.
- Six broad IPCC land-use categories form the basis of estimating GHG emissions and removals from land use and land-use conversions. The land uses may be considered as top-level categories for representing all land-use areas, with sub-categories describing special circumstances significant to emissions estimation, and where data are available. The categories are broad enough to classify all land areas in most countries and to accommodate differences in national land-use classification systems.
- National inventory reports with accompanying common reporting format (CRF) tables (with implied emission factors) are updated annually and reviewed by UNFCCC. Thus, NIR and CRF tables provide up-to-date land use data that can be integrated into the spatial planning GHG quantification tool database.
- Although the IPCC LULUCF methodology has been developed to estimate GHG emissions and removals at a national level, the structure, data requirement and GHG quantification is also applicable at smaller scales.

Two essential data needs are identified in the IPCC guidance:

1. Area or area change data for the land use categories

[9] https://unfccc.int/ghg-inventories-annex-i-parties/2021

2. Information on associated carbon stocks and relevant GHG emissions factors depending on the soil (mineral or organic) and land use category.

Obtaining the above mentioned data, however, might be difficult to acquire. Reporting of land use emissions is a technically complex matter, which is subject to ongoing improvement, refinement and gap-filling both for determining spatial land-use changes and accompanying emissions. There are several limitations and difficulties when applying the LULUCF methodology in the GGIA tool, some of which are addressed as following:

- Land representation and defining land use categories: Geographically explicit data is needed for calculating land use emissions and removals. Countries use various methods to obtain land area data, including annual census, periodic surveys and remote sensing. Each of these methods of data collection will yield different types of information. For example UK uses a mix of National Forest Inventory (NFI) data, Land Cover Map 2015, UK Directory of Mines and Quarries and Google Earth imagery, digital map of RB209 soil types; Ireland uses a combination of CORINE land cover data set, NFI, maps and aerial photography, EU Land Parcel Information System (LPIS), Indicative Soils Map of Ireland; Finland uses NFI, LPIS, aerial images, Finnish georeferenced soil database etc. The service provider acknowledges that the approaches and applied databases are appropriate for each country, however, the aim of the QGasSP project is to develop a robust, simple and standardised tool for quantifying GHG impacts of spatial planning policies, with pan-European applicability. Hence, the use of open source pan-European datasets is recommended. In the pilot case studies, the QGasSP service providers have applied the Copernicus Land Monitoring Service (CLMS), specifically the CORINE Land Cover (CLC 2018) vector database for determining spatially explicit land use classes and relevant areas for the case study pilots for the baseline analysis.

  CLC datasets are based on the classification of satellite images produced by the national teams of the participating countries - the EEA members and cooperating 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; minimum mapping unit (MMU) for status layers is 25 hectares; minimum width of linear elements is 100 metres (Copernicus Land Monitoring Service, 2021). There are also several limitations to the CORINE maps: provided land classes are broad and do not cover all LULUCF land uses, for example CORINE does not distinguish active peat extraction areas. 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 6 IPCC land use classes. Also the mapping unit of 25 ha might limit the accuracy of determining land classes on small scale planning.

- LULUCF methodology requires to determine general soil type (organic or mineral soil) for each land use class, while only a few EU countries have spatially explicit soil maps. In the case studies the QGasSP researchers have applied the ESDAC European Soil Database (European Soil Data Centre, 2013).

- Availability and accuracy of emission factors: The IPCC guidelines define three "tiers" to indicate different levels of accuracy, whereby the tier three method is the most accurate and the tier one method the least accurate. National GHG inventories comprise data with different levels of accuracy. By default, country-specific implied emission factors were applied for case study pilots. The service providers acknowledge that this top-down approach has the drawback that applied emission factors reflect the national average for a certain emission source but not necessarily the actual local emissions. To overcome this drawback, the user of the GHG quantification tool can replace the top-down emission factors by local (bottom-up) data.

- Data uncertainty: Land use sector comprises highly complex and dynamic ecological systems which translates in uncertainties of the estimates and of their attribution. Uncertainties associated with land use are significantly higher than those in the energy and industrial sector. For example, the combined uncertainty of emission factor and activity data of CO_2 emissions exceeded 100% for forest land, cropland, grassland and wetlands in Ireland's 2020 national GHG inventory submission. At sector level, LULUCF emissions estimates have the highest uncertainty also in the UK's and Finland's 2020 national inventory reports.

- Temporal variability of emission factors: In the current tool development stage, land use baseline scenario and subsequent emissions and removals due to land use are calculated based on a simple linear function: Emissions = (activity data) x (emission factor). The most up-to-date implied emission factors from national GHG inventory reports are applied by default. The emission factors reflect current environmental state and are subject to change due to technical corrections as well as constant dynamic changes in the environment (carbon density). While changes in soil C stocks are relatively slow and occur over decades, changes in the biomass carbon stocks are rapid, e.g. due to the sigmoid growth of a stand of trees. Thus, it is highly recommended to update the emission factors in the course of future use of the tool. Furthermore, the time period of the transition from old to new land-use category is assumed by default 20 years. IPCC Tier 1 method assumes that biomass, dead wood and litter pool carbon losses occur entirely in the year of the transition (e.g. deforestation), while relevant carbon stocks increase over a period of 20 years after land-use change (e.g. afforestation). Soil C emissions and sequestration is assumed to continue for 20 years after land-use change. Thus, in order to quantify the total impact of land-use change, a 20-year time period should be taken into account. However, countries that use higher tiers and complex models (e.g. UK's CARBINE model) might apply shorter or longer time periods than the default IPCC 20 year period, thus calculating total land use impact over the default transition period of 20 years might introduce a bias.

Baseline quantification process

Land use baseline scenario was constructed by determining current land use classes in the case study pilots using Corine Land Cover (CLC) 2018 dataset and the European Soil Database as far as applicable. In the city of Edinburgh Copernicus Urban Atlas 2018 and Street Tree Layer 2018 datasets were applied. Carbon emissions and removals are subsequently quantified using the LULUCF sector implied emission factors of the relevant case study pilot's national inventory reports submitted in 2021 to the UNFCCC.

2.5 Consumption-based approach

2.5.1 EEIO method

The consumption-based quantification applies an environmentally extended input-output method (EEIO) inspired by the 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 emissions, typically in which individuals themselves burn fossil fuels. These are hereby called 'use-phase' emissions, and for example are associated with the private combustion of fuels. These are not considered as standard in EIO 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. This is an abridged version of the text found in the methodological report. Interested readers are referred there for more detail on the method applied in GGIA.

2.5.2 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 kg CO_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). An illustrative example of how this differs from the territorial picture is highlighted in the following diagram (Figure 1). 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 an areal carbon footprint) (Heinonen et al, 2020).

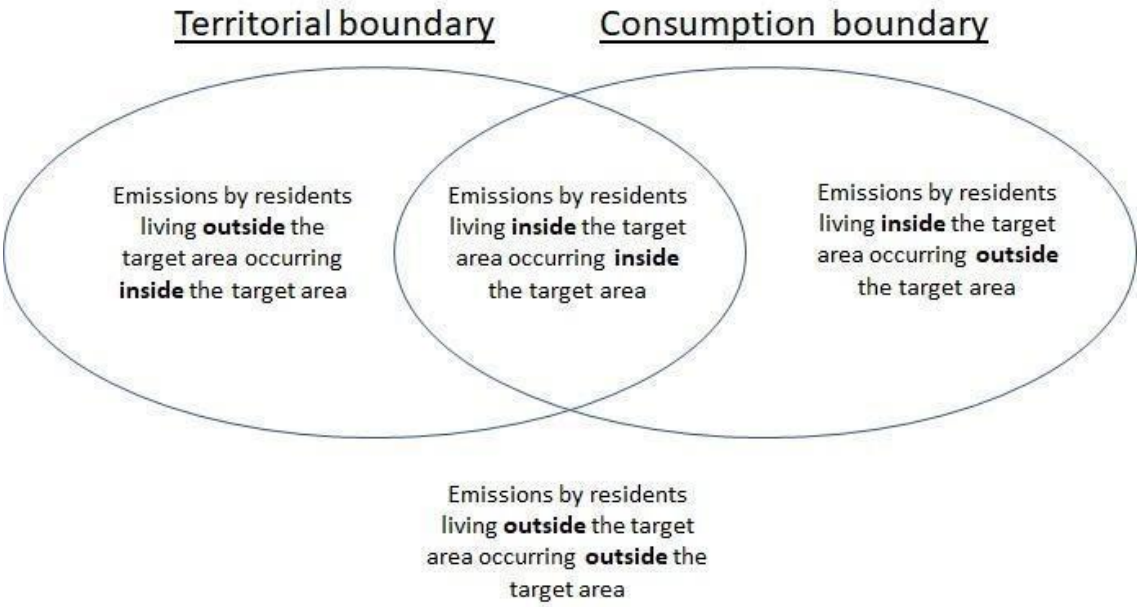

Figure 1. Conceptual differences between typical territorial and consumption emission boundaries.

2.5.3 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 used 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.

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 9800) 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. In all cases, emission intensities are determined (in units of kg CO_2/€) for a total of 200 'products' representing the whole economy.

This initial calculation describes the expected emissions for each euro spent on each 'product' 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 1500 inhabitants per km^2, at least 50000 residents), urban clusters (density greater than 300 inhabitants per km^2, at least 5000 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.

These modifications do not change the fundamental calculation for the carbon footprint. Performing the calculation 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 can act as place holders for future modules within the tool.

The output of these calculations is annual emissions distributed into different emission sectors. Results and changes can be tracked within the same area, or comparatively between different regions across Europe.

3 Tool development

3.1 Introduction

In accordance with the task description, the research team developed a browser-based open-source to quantify GHG emissions of spatial planning in any European region in two modes: 1) applying **territorial approach** or 2) applying **consumption-based approach.**

For the territorial approach, the project developed calculation modules for buildings, transport and land-use change. In the modular tool, the quantification modules can be updated and more modules for new CO_2e emission sectors can be included.

The aim was to create a GHG quantification framework that is easy to adapt, update and is future-proof.

3.2 Functionalities of the GGIA tool

The tool is designed for three kinds of users:

- **A Planner User,** who can quantify the GHG emissions of alternative spatial plans or policies without the need of an in-depth knowledge on GHG quantification.
- **An Expert User,** who is capable of creating and updating local set-ups (local datasets).
- **A Developer User,** who has (Python) programming skills and knowledge on GHG quantification methods **and** can view the source code of the tool in Github and develop the functionality and/or the calculation methods further.

The tool uses built-in European default datasets, which will need to be updated regularly by the tool owner.

The local “bottom-up” data can be inserted when a local dataset is created. A local dataset can be done for a region of any size by expert users. The tool collects local datasets and they are available for all users of the tool. Once selected, local dataset replaces the national data, and makes both the baseline analysis and the quantification results reflect more the local situation.

Once the local set-up and the baseline analysis are done by an expert user, the GHG quantification of different kinds of policies and spatial plans within this region can be done without expert-level knowledge on greenhouse gas quantification. The user can be, for example, a planner who wants to evaluate the impacts of alternative solutions. The impact of the spatial plan/policy can be evaluated against the baseline and the climate neutrality target.

It is further stressed that bottom-up data is more relevant on the territorial side of the calculations. For the consumption-side, the overarching data on emissions is at a country level, which makes sense given the globalised nature of supply chains. However, many modifications can be made by the user to make the data on economic consumption and the data on expected emissions.

Territorial calculation consists of three modules: transport, land-use change and buildings. Consumption-based module is one module covering all aspects of consumption.

The impact of planning policies can be assessed against the baseline created in the tool. The tool also creates a simple future projection of baseline emissions based on the PRIMES modelling.

The QGasSP project aimed at introducing a new tool with at least respective functionalities than existing national tools, such as Scottish SPACE, but with European applicability. The objective was also to take the functionalities one step further in order to better serve the needs of spatial planning. Table 2 below presents a comparison of the functionalities of the GGIA tool and the reference tool (SPACE). EcoCity Evaluator is no longer available and therefore it was not considered a meaningful reference.

Table 2. The comparison of GGIA and the reference tool (SPACE).

	SPACE	GGIA
Technical realization	Excel spreadsheet	browser-based
Methodological approach	territorial	territorial consumption-based
Sectors included	Energy use in buildings Transport Land-Use Change Waste	Energy use in buildings Transport Land-Use Change Consumption-based (all-inclusive)
Emissions to be quantified	relative emissions only	absolute emissions (baseline) relative emissions (policies)
Buildings types / Energy Use in Buildings quantification	residential commercial other	residential commercial Other
Modes of transport / Transport quantification	passenger car HGVs (lorries)	passenger car bus tram metro passenger train HGVs (lorries) freight train freight on inland waterways
Land-Use Change quantification	based on the IPCC method from six categories to one	based on the IPCC method from six categories to six
Future projections	for specified years	trajectory until 2050
Default data	Scottish	European 32 countries included

3.3 Use of the tool

The structure of GGIA is based on established sectoral GHG quantification methodologies. Territorial quantification can include all sectors (transport, land-use change, buildings) or just one single sector. Consumption-based assessment is always all-inclusive.

In Territorial mode, GGIA first estimates the sectoral baseline emissions and builds up a simplified future projection until the year 2050 with a minimum number of non-expert user inputs.

Next the impact of a new settlement can be assessed based on the user inputs.

- In the Transport module these inputs are 1) the number of new residents and 2) the settlement type. The latter describes the type of new environment constructed (metropolitan, urban, suburban, town, rural) which has an impact on the default transport activity values and the emission factors of road transport.
- In the Land-use module the impact of a new settlement is quantified based on the conversions between six land use categories.
- In the Buildings module the user inserts the numbers of new residential units and the floor areas of new commercial buildings.

Finally, the policy impact section quantifies the changes that may have a significant impact on the territorial GHG emissions and calculates the relative GHG emissions.

In the Transport module, spatial planning policies may for example

- reduce the need for mobility (for example increasing remote working, or promoting active modes of transportation);
- reduce freight transport in the area;
- adjust the modal share (for example better provision of public transport or mobility as a service solutions);
- adjust the fuel share for road transport vehicles (service stations for low-carbon fuels or EV charging stations);
- increase the share of renewable energies in the electricity for transport.

In the Land-use change module, all policy changes are conversions between the land-use categories. Calculation applies the CSC factors from the national inventory reports (NIR) and the FAO database, assessing also the long-term the impacts of conversions in land-use.

In the Buildings module, the quantification options cover the retrofits and conversions that have an impact on the energy consumption of buildings. The share of renewable energy can be adjusted.

The user is expected to define the policy period for each policy. This is the timing for the policy that divides the impact over the selected years.

Respectively, the consumption-based module first creates a baseline of total GHG emissions for the residents of the area. Based on a compact set of inputs, the impacts of new settlements and planning policies are quantified and displayed over the baseline scenario graph

Europe aims to be carbon neutral by 2050, and the action plans of European territories and cities typically aim at reaching carbon neutrality before that. Therefore the time span from present to year 2050 provides the time frame in which the planning policies are expected to contribute to climate action.

The use of the tool is instructed in detail in the User manual and the Video guides that can be accessed directly from the GGIA tool.

3.4 Future-proofing

In order to future-proof both the methodology and tool, the research team has created an open source tool with a modular structure, where the calculation modules can be updated and developed.

Open source means that the software's source code is available for users to download, examine and modify. Most open source projects have a public code repository on a website, that contains the full history of the project (code changes), documentation, possibility to download the full project and often, also a link to the actual live and running version of the project's code (working application).

An open source approach enables the use of best practises even as the methodology of GHG quantification would still be developing. The modular structure allows for updates on sectoral calculation models, for example when a methodology is standardised or widely adopted by professionals, then this can be updated. In principle, a region or city can implement its own, unique quantification methodology in the tool and continue using it for GHG quantification, but this would then mean that the opportunity of comparison would be lost.

3.5 Web hosting and maintenance of the tool

The tool will need hosting and maintenance. The **version control system** allows users to view changes and go back to the earlier versions of the tool, providing an access to the full history of changes made to the code. The version control system allows the developers to remove problematic changes, track issues, and merge changes made by multiple developers to the same files in the code base. **Code repository** contains the current code version and all its historical incremental iterations. A platform like Github can offer the project a location where the code can be safely stored and shared, documentation published.

The maintainer of the open source project acts as the moderator and gatekeeper for any changes, and and takes care of physically updating the code repository with only the changes that actually benefit the project.

3.6 Use of GGIA in SEA

The main aim of the GGIA tool is to support planners in their work by providing an opportunity for quick quantification of climate impacts. The tool enables an easy start with no expert knowledge but can also crease assessments with high accuracy to support the decision-making. When used systematically in planning, the GGIA tool can be expected to provide transparency regarding the climate impacts of various plans and planning policies. Due to its Europe-wide applicability, the tool has the potential to become a platform for sharing best practises.

3.6.1 SEA as the vehicle for the GHG mitigation within spatial planning

According to the SEA Directive (2001/42/EC) (European Commission, 2001), the main role of SEA is to avoid and reduce environmental impacts arising from the implementation of a spatial or sectoral plan or programme. SEA provides alternative scenarios for public debate and helps the process of decision making by decision makers of the strategic documents. A SEA report is usually a supplementary document to the strategic document.

Today SEA is recognised as the vehicle for the implementation of climate protection within spatial planning.

SEA is a systematic process for evaluating the likely environmental implications of a proposed policy, plan or programme and provides means for looking at cumulative effects and appropriately addressing them, at the earliest stage of decision making, along with economic and social considerations. It should be noted that public engagement into the stages of the SEA process is a key factor.

SEA and spatial planning processes are intertwined and complement each other. Wende et al. stated as early as in 2012 that "*In Europe, land use, residential and commercial development and the development of the transportation infrastructure are as a rule controlled by means of spatial planning instruments, for which Strategic Environmental Assessments (SEA) must generally be carried out under the terms of a European Union Directive European Parliament and Council of the European Union, 2001*" (Wende et al, 2012).

SEA assesses the environmental consequences and mitigation potential of a prospective development and consists of several distinct stages. These are respectively known as screening, scoping, environmental report, and adaption and monitoring, and are summarised below:

Screening stage	Here, the responsible authority assesses the likely environmental impacts of a plan and considers the need for SEA. Also, a decision not to conduct SEA can be verified with the GGIA tool.
Scoping stage	The range of environmental issues to be considered by SEA is defined, and 'reasonable alternatives' are determined. The reasonable alternatives can subsequently be assessed against the proposed development plan.
Environmental report	The environmental consequences of the proposal are assessed against a baseline. An assessment is made against the reasonable alternatives and measures to mitigate potential drawbacks.
Adaptation and monitoring	The decisions taken are subsequently assessed following the development.

3.6.2 Benefits of GGIA in SEA

The GGIA tool can be used (possibly by a non-expert using generic datasets at the design level) during screening and scoping to inform on the necessity of continuing with the subsequent stages. SEA can be required for all urban developments, and the existence of a trusted and communicable methodology for assessing GHG emissions would help to build stakeholder engagement and trust before commencing the later stages.

More specifically, the tool will be targeted for widespread adoption **during the preparation of the SEA report**. At this stage the tool is likely used by SEA experts, and may involve the use of specific regional datasets directly relevant for the envisioned development that have been compiled by the expert during the project. The tool can provide a Pan-European methodology for the assessment of GHG emissions within the SEA process. Although the impacts of plans and policies differ from country to country, sharing of best practises on a single European platform may develop into a valuable toolkit of GHG mitigation strategies in spatial planning.

The key advantages of the GGIA tool for SEA are hereafter listed:

Ease of use: The tool is a browser-based online application. Little specific knowledge is needed to generate results, whilst also allowing a more experienced user to tailor the results to the specific area under investigation.

Coverage: 32 countries within ESPON are included in the tool by default. Users can provide more specific dataset to different regions within these countries. Local dataset functionality enables also adding more countries in the tool, whenever the necessary datasets are available.

Homogeneity and comparability: The tool utilises the same methodology regardless of where the calculations are performed. The consumption-based method allows results to be compared across these regions and at different spatial scales. This helps the results to be trusted.

Absolute and relative emissions: The baseline allows absolute emissions to be generated for the area. The relative emissions differences between this, the plan and the reasonable alternatives can be clearly seen and quantitatively compared. This provides a sense of perspective to the results, and also allows them to be contextualised within different carbon neutrality targets.

Future prognosis: Results are projected into the future. The effects of altering the year of implementation can be seen. This also helps to integrate the tool within the final stage of SEA by assessing the actual development against those estimated by the tool.

The GGIA tool can also be used to support back-casting in planning, that is to test what kind of changes would lead to the desired GHG emission reductions in the future. The results can help to design climate strategies and to set sectoral step-by-step targets for GHG emissions.

As the research team recognized a trend towards more holistic consumption-based quantification, it decided to aim at having two calculators included in the GGIA tool, in order to provide a complete picture of GHG emissions.

3.7 Promotion and Development

The ESPON GGIA tool needs to be actively promoted so that it is adopted by territories and cities in GHG quantification. In the best case, GGIA could be developed a platform for sharing best practices and enhancing international and interregional comparisons, in accordance with the QGasSP project objectives.

The crowd sourcing principle could be utilized to develop the tool properties and methodology. At first place, GGIA would need additional modules on embodied emissions (of buildings and infrastructure) and waste emissions.

The continuation projects should tackle the questions related to data harmonization and methodology as described above. The GIS integration or the integration in digital urban twins could be a long term target that could aim at fully integrating the quantification in digital planning processes.

4 The pilot case studies

4.1 Introduction

The scope of the case studies was to test the tool methodology in a variety of contexts. The service providers committed to use a range of spatial scales for the pilots, this is shown through the case study selection that vary in their urban context i.e., rural, urban and suburban, whilst differing in population sizes and geographic contexts. In order to ensure the tool is robust and applicable to different countries, the selection process of the case study pilots has ensured a diverse variety of situations that might be encountered by spatial planners. These case study areas cover a range of different urban types, spatial scales, and with both high quality and more limited data availability.

The case study pilots were linked to relevant policy processes and the involvement of the stakeholders has been key to ensure that the link between case study and relevant spatial planning policy is present. The case studies include a qualitative analysis, through focussed engagement with key local stakeholders at various stages, to provide continuous feedback and insights from policymakers on practical deployment and usability in differing geographic contexts.

To deliver these case study pilots, the service providers had to engage with the stakeholders early on in the project through group and one-to-one meetings between the stakeholders and service provider representatives, this was done to better understand the needs of the stakeholders and to also help with the process of selecting the pilot case studies, datasets required for each area, policy processes and policy documents.

Using local data, where possible, has been a priority in the emission quantification method. Utilising national datasets would mean less relevant results, at least on the territorial side, as these reflect the problems and opportunities on the national level rather than on the territorial, regional or local level. On the consumption side, the use of a pan-European dataset as the basis for calculations ensures good comparability between regions. However, even with the territorial mode, it is important that emission quantification is possible also when the local data is not available. To gather the regional datasets which capture these local characteristics, the service providers have engaged with the stakeholders to discuss the data availability and detailed lists of datasets were gathered for the four case study areas.

The pilot case studies, where possible, reflect the stakeholders' envisaged use of the tool in each territory, this includes for example national planning frameworks, regional spatial strategies, and local authority development plans. The GHG analysis of the case study plans follow key emission sectors:

Buildings - changes in electricity and heating demands

Transport - including changes in transport activity, modal shares and fuel types

Land Use - changes in land use.

The following section provides an insight into each case studies' current emission targets, emission inventories and outlines the spatial planning policies, objectives and actions quantified by the tool and their results. More detailed information on each case study pilot can be found in the Annexes 2–5.

4.2 Climate mitigation and targets in each region studied

As a starting point, it is important to understand what each country/region developing the tool is trying to achieve at a national level in terms of ambitions, targets for GHG reductions and their drivers. In some jurisdictions there are more ambitious targets at National level when compared to EU wide targets, and again even higher targets at local municipality level.

In the **UK**, the UK Climate Change Act (UK Climate Change Act, 2008) commits the UK to an ambitious target of reducing emissions by at least 100% by 2050 from 1990 baseline levels. This includes reducing emissions from the devolved administrations (Scotland, Wales and Northern Ireland). This was increased recently from an 80% target by 2050, and is one of the most ambitious national targets in Europe. Northern Ireland and Scotland, therefore, must at least achieve these targets.

In **Northern Ireland**, there is no separate climate change legislation, but greenhouse gas emissions from Northern Ireland contribute to the UK total under the Climate Change Act 2008 (UK Climate Change Act, 2008), and it has a key role to play in meeting their obligations under the Paris Agreement. This consortium notes the findings of the Northern Ireland Committee on Climate Change report in 2019 (Committee on Climate Change, 2019), which outlines the challenges these targets bring for Northern Ireland given its unique characteristics in comparison to the rest of the UK - such as the large proportion of GHGs from agriculture (30%), they are interconnected to the electricity system of the Republic of Ireland, they do not have an extensive gas grid (mostly oil heating) and degraded peatland adding to carbon sources. Latest GHG inventories (2017) show Northern Ireland has decreased emissions by 18% since the baseline year, which is the lowest % decrease of any UK country (England 45%, Wales 25% and Scotland 48%).

Scotland has gone one step further in terms of ambition, and has really become a leading country in terms of tackling climate change. The Scottish Government has set a target of net zero emissions by 2045, with defined interim targets of 56% by 2020, 75% by 2030, and 90% by 2040. The Planning (Scotland) Act 2019 (Scottish Parliament, 2019) introduces six outcomes that the National Planning Framework in Scotland (NFP3, 2014) will contribute towards, one of which is meeting targets relating to emissions reductions arising from the Climate Change (Scotland) Act 2009 (as updated) (Scottish Parliament, 2009). The 2019 Planning Act also introduces the requirement that the impact of lifecycle greenhouse gas emissions from national developments on achieving national greenhouse gas emissions reduction targets is assessed. It also embeds the principles of a 'Just Transition', which means reducing emissions in a way which tackles inequality and promotes fair work at the heart of Scotland's approach to reaching net-zero. It will be interesting to see how spatial planning can help to contribute to national targets, while also trying to address these other economic aspects of the transition. The Scottish Environment Protection Agency (SEPA) has produced a lot of guidance and advice for planning authorities in relation to development plans and their impact on the environment (e.g. waste and energy proposals), including GHG impact. One of the existing tools investigated for this project, SPACE, was also developed in conjunction with the Scottish government for application in Scotland.

Ireland has set national targets under various EU directives that have been transposed as statutory instruments. These require that certain targets for energy efficiency, renewable energy and GHG reductions are achieved by 2030 and 2050. In Ireland, the Climate Action and Low Carbon Development (Amendment) Act was published in 2021 to provide for the approval of plans by the Government in relation to climate change for the purpose of pursuing the transition to a climate resilient, biodiversity rich and climate neutral economy by no later than the end of the year 2050. The Climate Action Plan 2021 commits Ireland to a legally binding target of net-zero greenhouse gas emissions no later than 2050, and a reduction of 51% by 2030. The Plan lists the actions needed to deliver on the country's climate targets and sets indicative ranges of emissions reductions for each sector of the economy. It will be updated annually, including in 2022, to ensure alignment with legally binding economy-wide carbon budgets and sectoral ceilings. This Plan makes Ireland one of the most ambitious countries in the world on climate.

In line with the Climate Action Plan is the Regional Spatial & Economic Strategy (RSES) for the Eastern & Midland Regional Assembly (EMRA) (EMRA, 2019). The strategy includes a number of climate Regional Policy Objectives (RPOs). One of the RPOs to be noted is RPO 3.6 which states that 'City and county development plans shall undergo assessment of their impact on carbon reduction targets and shall include measures to monitor and review progress towards carbon reduction targets'.

Finland aims to become carbon neutral by 2035. A central pillar in climate action is the national climate legislation, which entered in force in 2015, introducing a legal commitment to cut down the national CO_2 emissions by 80% from the reference year 1990. Furthermore, the national Climate Change Act[10] is also currently being reformed and aims to reinforce climate change legislation to achieve a carbon neutral target by 2035.

Achieving the target of a carbon neutrality by 2035 requires significant measures to reduce emissions in the energy and transport sectors, as well as emission reductions in the land use sector and strengthening carbon

[10] https://ym.fi/en/climate-change-legislation

sinks and reservoirs. The current Government Programme contains a number of climate measures concerning agriculture, forestry and land-use changes that will in future be incorporated into the climate plan for the land use sector. The preparation of the new energy and climate strategy, commenced by the ministry of Economic Affairs and Employment in April 2020, will take into account and coordinate the Government Programme's energy and climate policies, the long- and medium-term climate change policy plans referred to in the Climate Change Act (Climate Change Act Finland 609/2015, 2015), and the EU's energy and climate targets for 2030.

Besides the national climate commitments, also cities and regions have prepared their own actions plans and climate targets. The Towards Carbon Neutral Municipalities (Hinku) network brings together municipalities, businesses, citizens and experts to create and carry out solutions to reduce greenhouse gas emissions. The municipalities in the network are committed to an 80% reduction in greenhouse gas emissions from 2007 levels by 2030. There are over 70 Hinku municipalities and five Hinku regions in the network, all committed to the same emission reduction target. The network is coordinated by the Finnish Environment Institute (SYKE). The most ambitious climate target was recently introduced by the city of Lahti, aiming at carbon neutrality already by 2025.

In municipal level, various tools and methodologies have been developed for GHG accounting. A new, non-commercial, open-source GHG quantifying tool developed by the Finnish Environment Institute was published in 2020.

4.3 Pilot case study 1: County of Meath, Ireland

4.3.1 Introduction of the pilot area

The Irish case study pilot is County Meath, which lies on the border of Dublin. Meath's close proximity to Dublin, makes it a commuter region and provides a good mix of spatial attributes, having both rural, urban and suburban areas. Over the recent years, Meath has experienced a rapid growth in population which has resulted in an increase in land-use change, traffic and has boosted the economy in the area.

It is worth noting that the county has been proactive in the area of climate action and this is showcased in Meath's Climate Action Strategy (which covers the period from 2019 to 2024) (Meath County Council, 2019), which is both ambitious and pragmatic with the ability to enable others to take action and inspiring them to lead on climate action. Meath is currently in the final process of developing their Meath County Development Plan 2021–2027, and their Climate Action Strategy is very much linked to their County Development Plan. The service providers have tested the tool on the Meath County Development Plan 2021–2027.

4.3.2 Baseline for GHG emissions

4.3.2.1 Buildings

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

<u>Residential</u>

Total energy use in the residential sector was 1,454 GWh. The residential fuel split mainly comes from heating oil, which makes up 48% of the total energy use in this region. Natural gas is the second highest fuel in demand, making up 34% of the fuel mix, followed by electricity at 15%. Most of the energy used was for space heating. Space heating had by far the highest energy demand, accounting for 76% of the total. This is followed by water heating at 19%. Heating overall in the residential sector has the highest energy demand by far, lighting and pumps/fans are the least energy intensive, making up just 4% and 1% of the total demand, respectively.

Total emissions from the residential sector in Meath amounted to 404,590 tonnes of CO_2 in 2016, this equates to 6.3 tCO_2 per dwelling in Meath which is slightly higher than the national average in Ireland, which was reported to be 5.5 tCO_2 for 2020 (SEAI). This can be due to a number of factors, some of which are; different baseline figures (2016 as opposed to 2020 SEAI figures) and the high prevalence of detached dwellings in Meath, which tend to emit more emissions per m^2 floor area than other types of dwellings. The figure below depicts the total emissions grouped by fuel and dwelling type. Detached houses had the highest emissions, accounting for 287,750 tonnes of CO_2 (and they also account for the highest share of dwellings (54% of all dwellings are detached houses). This was followed by semi-detached houses, terraced houses and apartments, all of which accounted for 77,100, 26,070 and 13,700 tonnes of CO_2 respectively, of the total emissions in the residential sector in 2016.

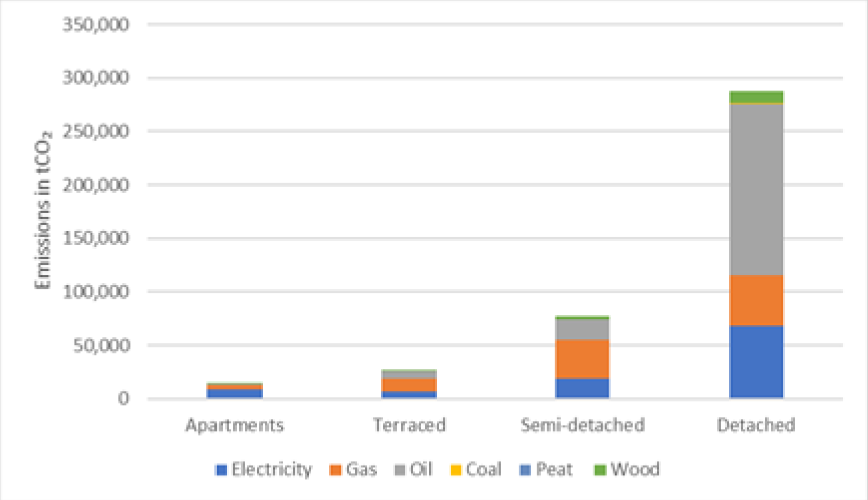

Figure 2. Total Emissions in tCO_2 in the Residential Sector by Fuel Mix and Dwelling Type (2019).

The highest emissions in the residential sector come from heating oil, electricity and natural gas, which contribute 46%, 26% and 25% respectively. There was very little peat, coal and biomass (mainly wood) used in the residential sector, only contributing to 3.4% of total emissions.

<u>Commercial</u>

The total energy used in the commercial sector was 741 GWh. Electricity (390 GWh) and natural gas (175 GWh) accounted for the main share of this energy use. The commercial sector had a high use of heating oil, peat and biomass (wood) which all together made a total of 176 GWh.

Total emissions from the commercial sector in 2021 amounted to 267,105 tonnes of CO_2. The commercial properties that produced the most emissions were industrial uses, retail, hospitality and offices are the main CO_2 emitters, as altogether they made up 96% of the commercial sector's total emissions.

- Industrial uses: 162,684 tCO_2
- Hospitality: 61,772 tCO_2
- Retail: 20,113 tCO_2.

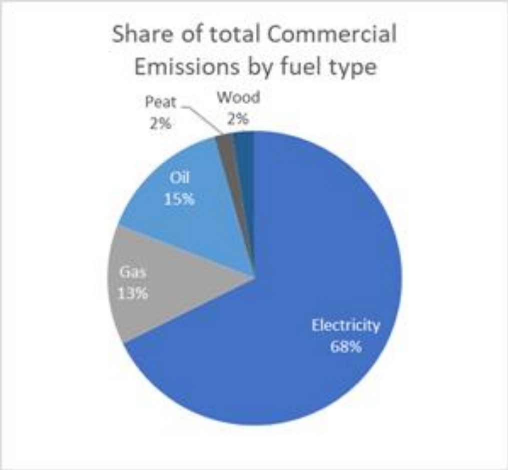

Figure 3. Share of Total Emissions in the Commercial Sector by Fuel Type (2019).

Of the total emissions emitted by the commercial sector, electricity accounts for the largest share of the total emissions (68%), followed by heating oil at 15%. Natural gas also produced significant emissions, contributing 13% to the total.

Total Emissions from Buildings

Total emissions from both the residential and commercial sectors in Meath accounted for 671,690 tonnes of CO_2 in 2016. The residential sector contributed 60% and the commercial sector 40% to the total emissions. The main source of emissions come from electricity (42%), followed by heating oil (34%) and natural gas (20%). The rest of emissions (approximately 4.2%) were made up of biomass (wood), peat and coal.

Table 3. Total Emissions from the Building Sector in County Meath (2019).

Building Sector	Electricity	Gas	Oil	Coal	Peat	Wood	Total
Residential	102,526	100,117	186,812	1,345	358	13,432	404,590
Commercial	180,766	35,429	39,026	-	5,211	16,673	267,105
Total tCO_2	**283,292**	**135,545**	**225,838**	**1,345**	**5,569**	**20,105**	**671,695**

4.3.2.2 Transport

Road transport volumes for buses and passenger cars are derived from a draft version of the ERM (Eastern Region Model) Model Development Report (not published) (NTA). The allocation of transport volumes on the road network of Meath would otherwise be rather difficult. Now the model can also report the transport activity divided to driving on roads and streets, which makes the quantification more accurate.

For train transport, respective sources are not available, and therefore the vehicle kilometres were estimated by measuring the tracks within the boundary of Meath and applying the statistical data on daily train services in the county.

A unique component in the Meath transport baseline is the Tara Mines transport. Tara is Europe's largest zinc mine and also one of the largest in a global comparison. Around 2.6 million tonnes of ore are mined annually for the production of zinc and lead concentrates.

Although the railway tracks within the borders of Meath are not long, the high loads, use of diesel engines and the intensity of ore transport make the freight on rails a significant component in the baseline emissions.

Total emissions from transport

The summary of the transport emissions is presented in Table 4 below.

Table 4. Total Emissions from the Transport Sector in County Meath (2019).

Mode of transport	Driving profile	Million vkm/a	$kgCO_2e/vkm$	tCO_2e/a	tCO_2e/a
Passenger car	road	5.946	0.131	779	1,039
	street	1.294	0.201	259	
Bus, aver. occupancy 16	road	0.028	0.557	16	21
	street	0.008	0.651	5	
Passenger train		0.520	2.216	1	1
Road freight		0.804	0.865	696	696
Freight on rails		0.029			742
Total					**2,498**

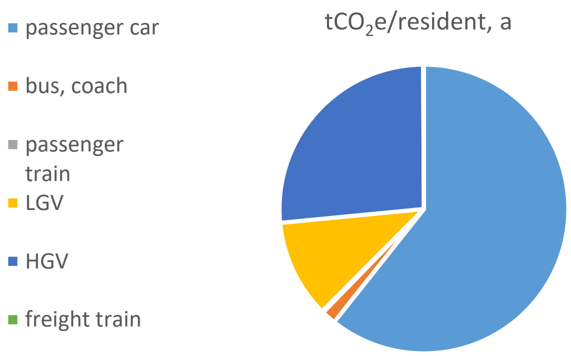

Figure 4. The shares of transport modes in total transport GHG emissions, County Meath (2019).

4.3.2.3 Land-use

The distribution of Meath land cover classes and soil types are shown in Figure 5 and Figure 6.

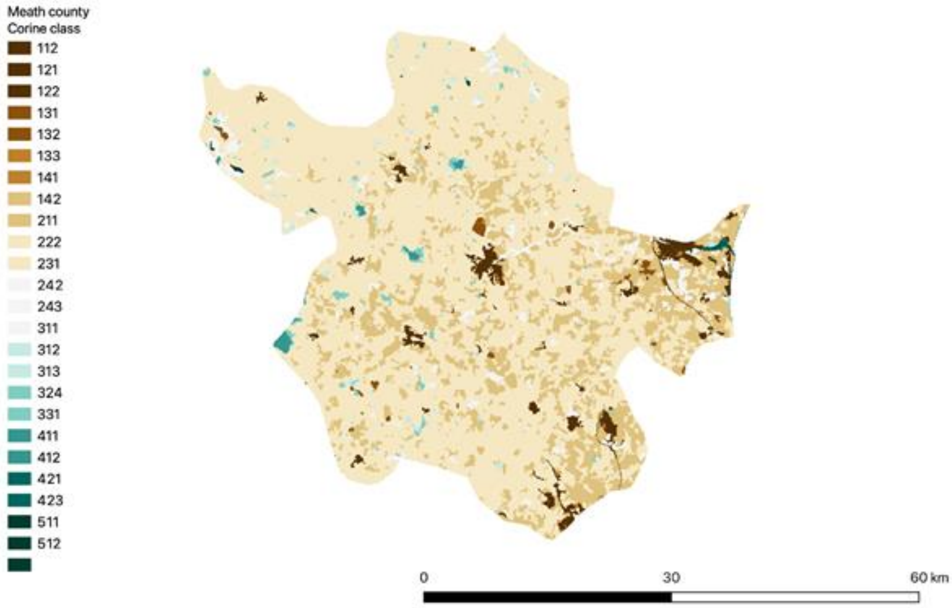

Figure 5. CORINE land cover classes in County of Meath. [11] [12]

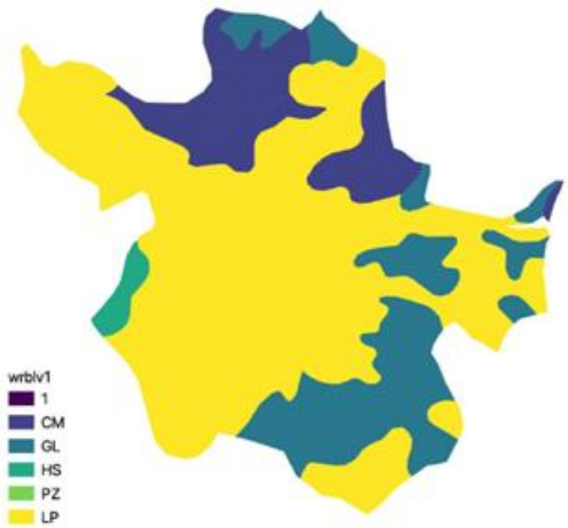

Figure 6: Soil types in County of Meath (European Soil Database). [13]

[11] More detailed description can be found in Annex 1 – METHOD DESCRIPTION, Table 4 and Table 5.

[12] CORINE classes: artificial areas (112–142); agricultural areas (211-243); forest and semi-natural areas (312–331); wetlands (411-423); water bodies (511– 512).

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

The dominant land cover is agricultural areas (CORINE class 2 ≈ IPCC cropland, grassland) that constitute 93% of total Meath area. Grasslands (CORINE class 231) cover 71% of total Meath area, which is in good alignment with the overall land use distribution in Ireland. Grassland is the dominant land-use category in Ireland, and the anthropogenic management of grasslands is long standing and profound due to the long-term trends towards livestock production in Ireland since the mid-1800s (NIR Ireland, 2021). Artificial areas (CORINE class 1 ≈ IPCC settlements) cover 4% of total Meath area, followed by forests and semi-natural areas (3%) (CORINE class 3 ≈ IPCC forest land, other (unmanaged) land). Wetlands (CORINE class 4 ≈ IPCC unmanaged wetlands, peat extraction sites) and water bodies (CORINE class 5 ≈ IPCC unmanaged land) account for 0.4% and 0.1%, respectively, of total Meath area. According to the European Soil Database, Histosols (IPCC organic soils) constitute 1.5% and mineral soils 98.5% of total area.

Land use emission estimates in the County of Meath are presented in Table 5. The total annual emission estimate (net removal) of -53,151 tCO_2 does not include emissions from potentially significant sources such as peat extraction sites and cropland organic soils. The presence of cropland organic soils is debatable due to the discrepancies of data provided in different databases (Indicative Soil Map of Ireland vs European Soil Database). The approximate emissions from drained cropland organic soil could be around 16,000 tCO_2 if the organic soil area (551 ha) from European Soil database and the default IPCC emission factor (7.9 tCO_2-C/(ha a) for boreal and temperate croplands; (IPCC, 2014) is used. Another potential underestimation of emissions occurs in the peat extraction category, specifically due to drainage of organic soils. Despite the efforts made by the QGasSP service providers (official queries sent to Bord na Móna) and by the case study stakeholder (EMRA), no information on the current area of active peat extraction sites in the County of Meath was obtained. CORINE class 412 'Peatbogs' includes both natural bogs and peat extraction sites, therefore the area of class 412 cannot be equated to the area of peat extractions and respective emissions cannot be estimated in the current baseline analysis.

Table 5. County of Meath baseline land use emission estimates (tCO_2/a) (2019).

IPCC Land use category	Biomass		Dead organic matter		Soil		Total
	above-ground	below-ground	dead wood	litter	mineral	organic	
Forest land	-20,988	-3,491	4,236	-252	1,124	255	-19,116
Cropland	464	NO	NO	NO	-7,424	NE	-7,047
Grassland	NO	NO	NO	NO	-80,423	53,347	-27,076
Peat extraction sites (wetlands)	NE	NE	NE	NE	NO	NE	NE
Settlements	NO	NO	NO	NO	NE	NE	NE
Total	**-20,524**	**-3,491**	**4,236**	**-252**	**-86,723**	**53,602**	**-53,151**

Emissions have positive and removals negative signs.

NO – no (zero) emissions are assumed.

NE – not estimated.

4.3.2.4 Consumption-based Emissions

The demand vector representing the average household across the Republic of Ireland was used to describe county Meath. This was to accommodate the varying urban densities present in the area. The stakeholders indicated that the average income of the area is similar to Ireland as a whole, and so no further scaling was performed based on this factor. Information was provided by the stakeholders with regards to the average household occupancy and total population of the area, respectively, and this was used to determine the per capita and total emissions for the region.

Table 6. Description of the data situation utilised for the consumption calculations in County Meath.

Data situation: County Meath				
Demand Vector	Household occupancy	Household income level	Population	Further modifications / Notes
Irish average	3.03	Irish average	194942	N/A

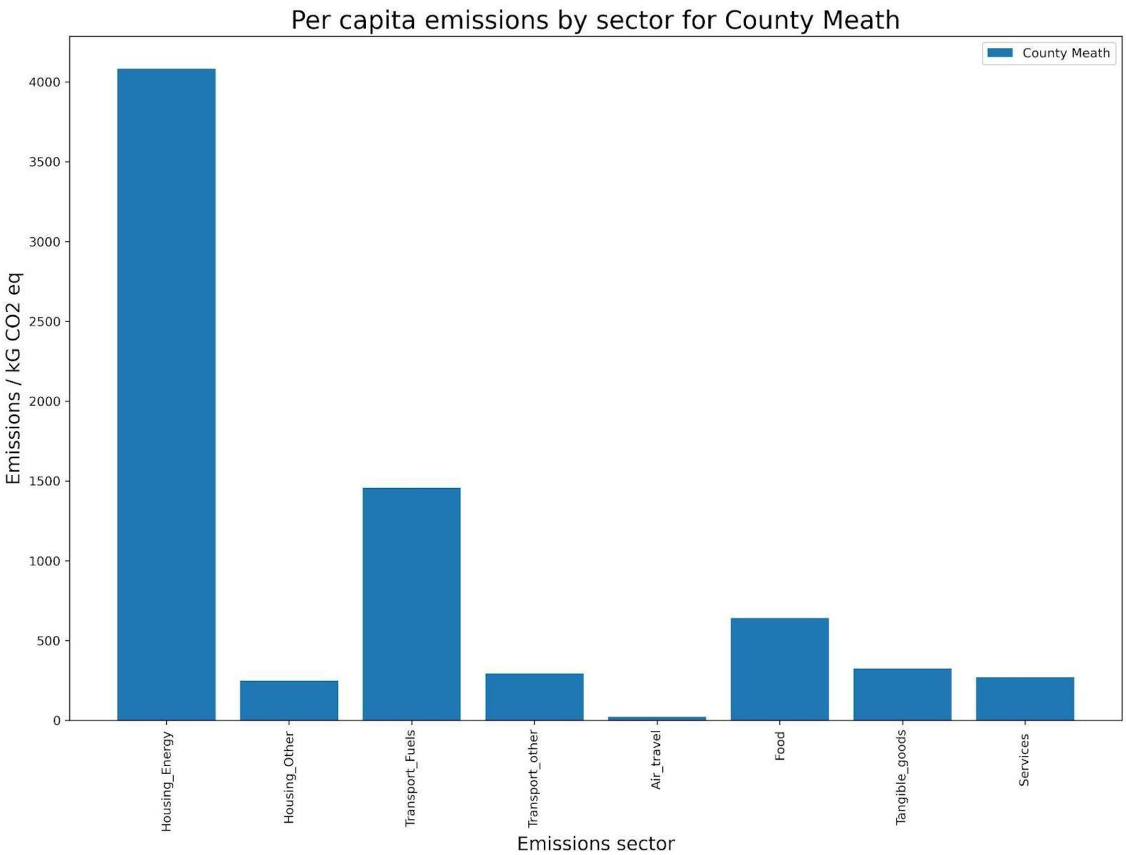

Figure 7. Annual per capita sectoral emissions for County Meath (2019).

Figure 7 above shows the breakdown of emissions by sector for households in County Meath. Overall, the per capita emissions were around 7.3 tonnes CO_2e per annum. The total consumption emissions for the region were calculated to be approximately 1.4 $MtCO_2e$ per annum. The largest contributions to the emissions came from residential energy demand and transport fuels. In turn, residential energy is dominated by so-called 'use phase' emissions, which reflects the large proportion of space heating arising from direct combustion of fossil fuels in the household.

4.3.3 Case Study

The adopted Meath County Development Plan 2021–2027 sets out the policies and objectives and the overall strategy for the development of the County over the plan period. This Plan provides a pathway for Meath which will enable the county to continue to make significant contributions to national economic growth recovery by promoting sustainable development and facilitating stable economic growth, and thus, delivering long term benefits for the citizens of the county.

4.3.4 Results

Buildings

The County Development Plan (CDP) highlights the importance of reducing the county's reliance on imported fossil fuels and encourages the replacement of these fuels with regionally generated renewable energy in an effort to ensure security of energy supply. In so doing, it promotes the use of lower carbon fuels in the home and highlights, where feasible and practicable, the provision of photovoltaic solar panels in new residential developments, commercial developments, and public buildings for electricity generation/storage and/or water heating purposes so as to minimise carbon emissions and reduce dependence on imported fossil fuels and reduce energy costs.

It also seeks to improve the energy efficiency of the County's existing building stock in line with good conservation practice and to promote energy efficiency in all buildings in the County. The CDP also promotes and facilitates the design of new energy efficient buildings and helps to support the use of heat pumps as an alternative to gas boilers, where appropriate, for domestic and commercial development.

Actions from the CDP that the tool will quantify for the building sector relate to the promotion and facilitation of energy efficient building design, as well as actions that promote the use of lower carbon fuels in buildings.

Transport

The emphasis of the CDP is to encourage a modal shift towards walking and cycling, however it is also important to recognise that some essential travel will continue to be made by cars and goods vehicles and the CDP facilitates improvement in road infrastructure to cater for the required improved efficiencies. It is a strategic aim of the CDP to create efficient compact settlements which reduce the need to travel. Maintaining and improving transport networks remains a priority, particularly in relation to the delivery of important infrastructural development and transport measures which support the economic development strategy for the County.

Achieving sustainable patterns of transport in accordance with national and regional policies will enable settlements to function more efficiently and effectively. Increased public transport provision, coupled with enhanced cycling and walking facilities in the urban areas, will provide the means to cater for much of the increased travel demand.

Land use

The main focus of Meath CDP is on urban areas - towns and villages - but it provides also policies and objectives for rural areas. Information is also provided for Natura 2000 network sites within and adjacent to settlement boundaries, however Natura sites are protected areas and generally not subject to development. Land Use Strategies are rather generic and most often suggest to regenerate and enhance the natural and physical environment of the settlements.

Meath Climate Action Strategy 2019–2024 sets GHG emission reduction targets and provides County Meath Carbon Baseline for 2012 based on energy consumption in different sectors. Emissions relating to direct land management, e.g. exploitation of soils, peatland or forest management are not included in the baseline methodology. The Climate Action Strategy also sets out eight thematic areas where actions will be taken: economy, mobility, built environment, clean energy, resource management, water, natural resource and planning. Specific actions do not specify recommendations for possible land-use changes in the area.

Taking into account the information provided in these policy documents, it is difficult to quantify specific actions relating to land-use change. However, the territorial quantification mode enables the quantification of relevant emissions and removals.

Consumption-based

The results of the policy quantification are summarised in the following table. In general, there was a lack of quantitative numbers linked to specific policies in the reference document, meaning assumptions were required to perform the calculations. Further details, including the key assumptions taken, are given in the pilot case study report (Annex 2).

The construction of the new buildings would lead to total life-cycle emissions of 0.9 Mt CO_2e in 2026. Assigned to the new residents, this gives each a footprint of 29 tCO_2e in 2026 in the case of a new settlement and 28 tCO_2e in the case of densification.

Table 7. Quantifying Planning Policies for County Meath. Building-related policies.

policy	impact	module	quantification in GGIA	CO_2e increase / decrease (tCO_2)	Emissions per capita (tCO_2/capita)
1.1 New construction as new settlement	2022-26	energy use in buildings	additional floor area in all building categories	15,338	
		land-use change	land use change (ha) from greenfield (land use type forest and grassland) to settlement	3,400	
		consumption-based	increase in the number of residents, Town demand vector, Improved building efficiency	18,000 (additional 94,000 construction emissions)	New residents 4.7 (in 2026) 29 (including construction)
1.2 New construction as densification	2022-26	energy use in buildings	additional floor area in all building categories	15,338	
		land-use change	no impact		
		consumption-based	increase in the number of residents, Town demand vector, Improved building efficiency	15,000 (additional 94,000 construction emissions)	New residents 4.0 (in 2026) 28 (including construction)
2. Retrofitting	2022-26	energy use in buildings	change in energy consumption profile of existing buildings	-86,000	
		consumption-based	change in expenditure on energy	66,000	6.8 (in 2026)
3. Increase in renewable energy generation	2022-26	energy use in buildings	change in energy consumption profile of existing buildings	11,178 MWh	
		consumption-based	increase in the share of renewable energy	2,400	7.1 (in 2026)

Table 8. Quantifying Spatial Planning Policies for County Meath. Transport-related policies.

policy	impact	module	quantification in GGIA	CO_2e increase /decrease (tCO_2)	Emissions per capita (tCO_2/capita)
4.1 Improving the provision of public transport	2022-26	transport	reduce passenger car transport; increase bus transport respectively	54,989	
		consumption-based	part of the transport expenditure moves from passenger cars to public transport	59,000	6.9 (in 2026)
4.2 Enhancing cycling and walking facilities	2022-26	transport	reduce transport activity (active modes excluded)	62,901	
		consumption-based	decrease private transport expenditure	60,000	6.9 (in 2026)
4.3 Provision of park-and-ride facilities	2022-26	transport		20,570	
		consumption-based	part of the transport expenditure moves from passenger cars to public transport	55,000	6.8 (in 2026), 7.0
4.4 Increasing remote working	2022-26	transport		15,275	
		consumption-based	increase in the share of renewable energy	6,000 17,000 (with 5% increased household energy use)	6.8 (in 2026) 7,100 (with 5% increased household energy use)
4.5 Phase II of the Navan Railway line	2022-26	transport		19,625	
		consumption-based	part of the transport expenditure moves from passenger cars to public transport	59,000	6.9 (in 2026)

4.4 Pilot case study 2: City of Edinburgh, Scotland

4.4.1 Introduction of the pilot area

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

Scotland has been very ambitious in its climate goals and has set a target to reach net zero emissions by 2045. The third National Planning Framework (NFP3, 2014) supports the planning system's role in meeting the Scottish climate goals and sets out a long-term vision for development and investment across Scotland over the next 20 to 30 years. It brings together all the Scottish Government plans and strategies in economic development, regeneration, energy, environment, climate change, transport and digital infrastructure to provide a coherent spatial vision of how Scotland should evolve over the next 20 to 30 years. Quantifiable actions from the Third National Planning Framework have been tested by the tool.

4.4.2 Baseline for GHG emissions

4.4.2.1 Buildings

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

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

Residential Sector

Total energy use in the residential sector was 3,606 GWh. The residential fuel split mainly comes from natural gas, which makes up 78% of the total energy use in this region. Electricity is the second highest fuel in demand, making up 19% of the fuel mix. Most of the energy used was for space heating, accounting for 63% of the total, this was followed by water heating at 25%. Heating overall in the residential sector has the highest energy demand by far and creates potential for heat recovery from waste heat and district heating as a way of catering for this high heat demand. Lighting and pumps/fans are the least energy intensive, making up just 8% and 4% of the total demand, respectively.

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

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

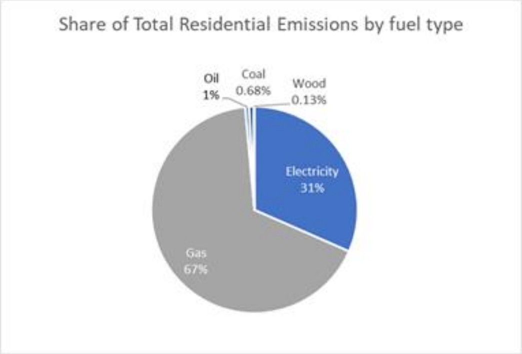

Figure 8. Share of Total Emissions in the Residential Sector by Fuel Type (2019).

Commercial

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

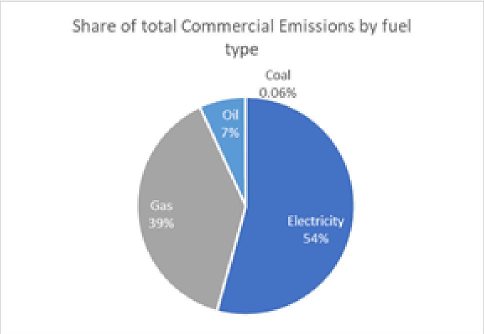

Figure 9. Share of Total Emissions in the Commercial Sector by Fuel Type (2019).

Total emissions from the commercial sector in 2018 amounted to 893,790 tonnes of CO_2. Of the total emissions emitted by the commercial sector, electricity accounts for the largest share of the total emissions (54%), followed by natural gas at 39%. Heating oil also produced significant emissions, contributing 7% to the total.

Total Emissions from Buildings

Total emissions from both the residential and commercial sectors in the City of Edinburgh accounted for 1,663,650 tonnes of CO_2 in 2017. The residential sector contributed 46% and the commercial sector 54% to the total emissions. The main source of emissions come from natural gas (52%), followed by electricity (44%) and heating oil (4%). The rest of emissions (approximately 0.4%) were made up of biomass (wood) and coal.

Table 9.Total Emissions from the Building Sector in Edinburgh (tCO_2/a) (2019).

Building Sector	**Electricity**	**Gas**	**Oil**	**Coal**	**Peat**	**Wood**	**Total**
Residential	243,069	515,727	4,860	5,199	-	1,010	769,861
Commercial	485,197	346,653	61,441	497	-	1	893,789
Total tCO_2	**728,263**	**862,380**	**66,301**	**5,696**	**-**	**1,011**	**1,663,651**

4.4.2.2 Transport

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

The data availability on the City of Edinburgh is very good. The result of the baseline analysis is presented in Table 10 below.

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

	Transport activity		**Emission factor**		**Result**
Mode of transport	Million passenger-km/a	Million vehicle-km/a	gCO_2e/p-km	gCO_2e/v-km	$ktCO_2e$/a
Passenger car		1,771.0		170.0	301.2
Bus	648.0	40.0	119.5		77.4
Tram	57.3	1.4	17.5		1.0
Passenger train	354.0		35.0		12.4
Light commercial vehicle		442.0		247.0	109.2
Heavy goods vehicle		88.0		658.0	57.9
Freight train					
Total	**1,059.3**	**571.4**	**172.0**	**905.0**	**257.9**

4.4.2.3 Land-use

Figure 10. Tree cover in Edinburgh (CORINE Street Tree Layer).[14]

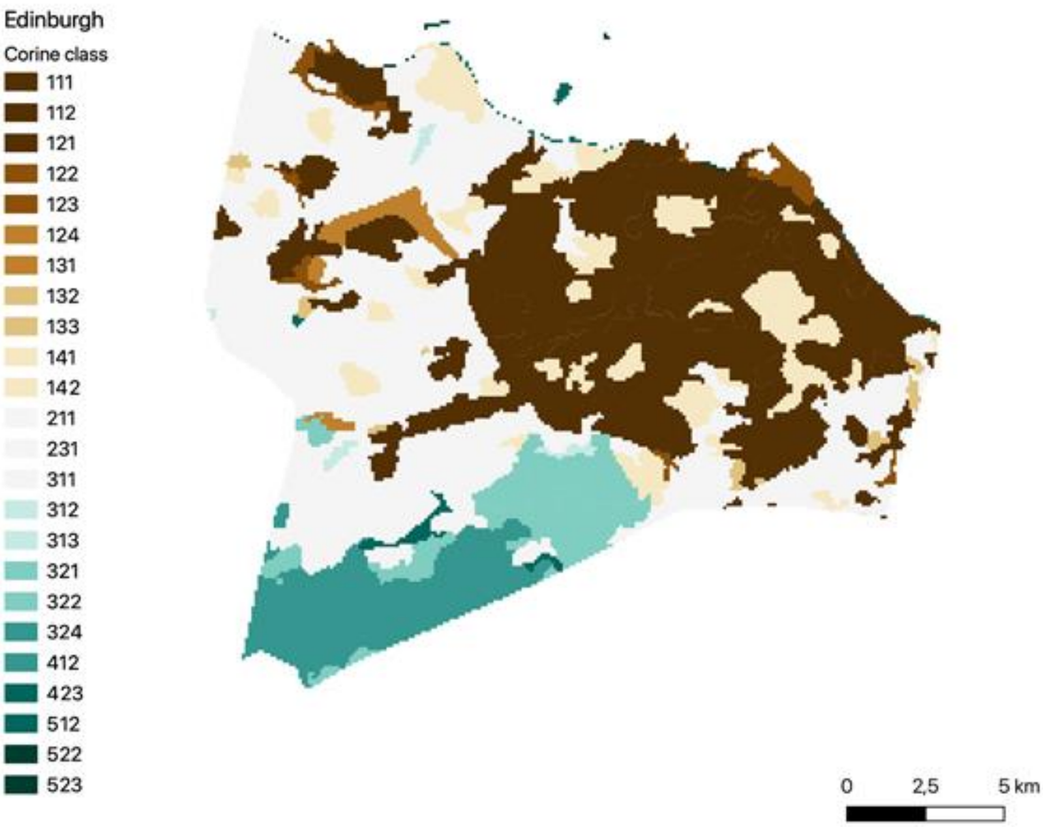

Figure 11. CORINE land cover classes in Edinburgh.

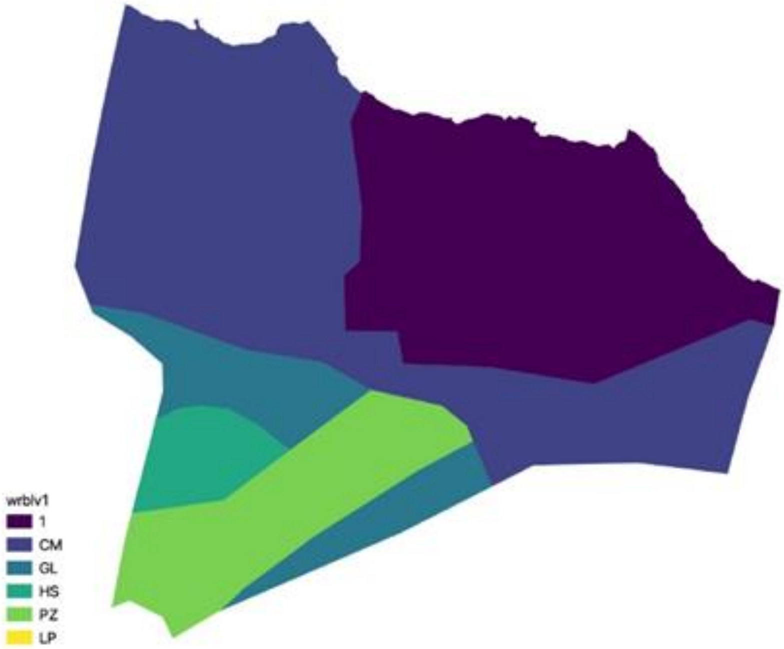

Figure 12. Soil types in Edinburgh (European Soil Database).[15]

The dominant land cover is artificial areas (CORINE class 1 ≈ IPCC category Settlements) that constitute 47% of total Edinburgh area (Table 11). Agricultural areas (CORINE class 2 ≈ IPCC cropland, grasslands) cover 36% of total area, followed by forest and semi-natural areas (CORINE class 3 ≈ IPCC forest land, grassland, unmanaged land) and wetlands (CORINE class 4 ≈ IPCC peat extraction sites, unmanaged wetlands), both classes covering 8% of total Edinburgh area. The least represented land class (1%) is water bodies (CORINE class 5 ≈ IPCC unmanaged land). Deriving from the administrative borders of Edinburgh (Open Street Map) and the CORINE Street Tree Layer, the area of Edinburgh urban trees is approximately 2,612 ha[16] (9% of total administrative area). According to the European Soil Database, mineral soils constitute 65% and Histosols (IPCC organic soils) 4% of Edinburgh area, while the soil type is unknown for 31% of the area. Most of the unknown soil types (94%) are found under artificial areas such as under buildings, transport networks and other impermeable features.

Land use emission estimates in Edinburgh are presented in Table 11. The land use sector in Edinburgh is estimated to be currently a net sink of -1,176 tCO_2. Annual CO_2 removals are mainly related to carbon sequestration by urban trees that demonstrates the importance of urban vegetation in mitigating climate change among other benefits such as reducing the risk of flooding, reducing the ‘urban heat island’ effect, improving the health and comfort of urban residents etc. Major emissions result from cultivation of cropland soils in Edinburgh. Total emission estimate does not include potential emissions from peat extraction sites that however might be a minor underestimation if any at all. CORINE class 412 ‘Peatbogs’ includes both natural and exploited peat bogs, thus the area of peat extraction sites cannot be determined based on CORINE maps. However, the area of organic soils in class 412 is only 5 hectares, thus it is unlikely that industrial peat extraction sites are present in Edinburgh.

[14] CORINE classes: artificial areas (111–142); agricultural areas (211–231); forest and semi-natural areas (311–324); wetlands (412–423); water bodies (512–523).

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

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

Table 11. Baseline land use emission estimates in Edinburgh (tCO_2/a) (2019).

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

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

4.4.2.4 Consumption-based

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

Table 12. Description of the data situation utilised for the consumption calculations in Edinburgh.

Data situation: Edinburgh				
Demand Vector	Household occupancy	Household income level	Population	Further modifications / Notes
UK city	2.14	UK average	52,4930	N/A

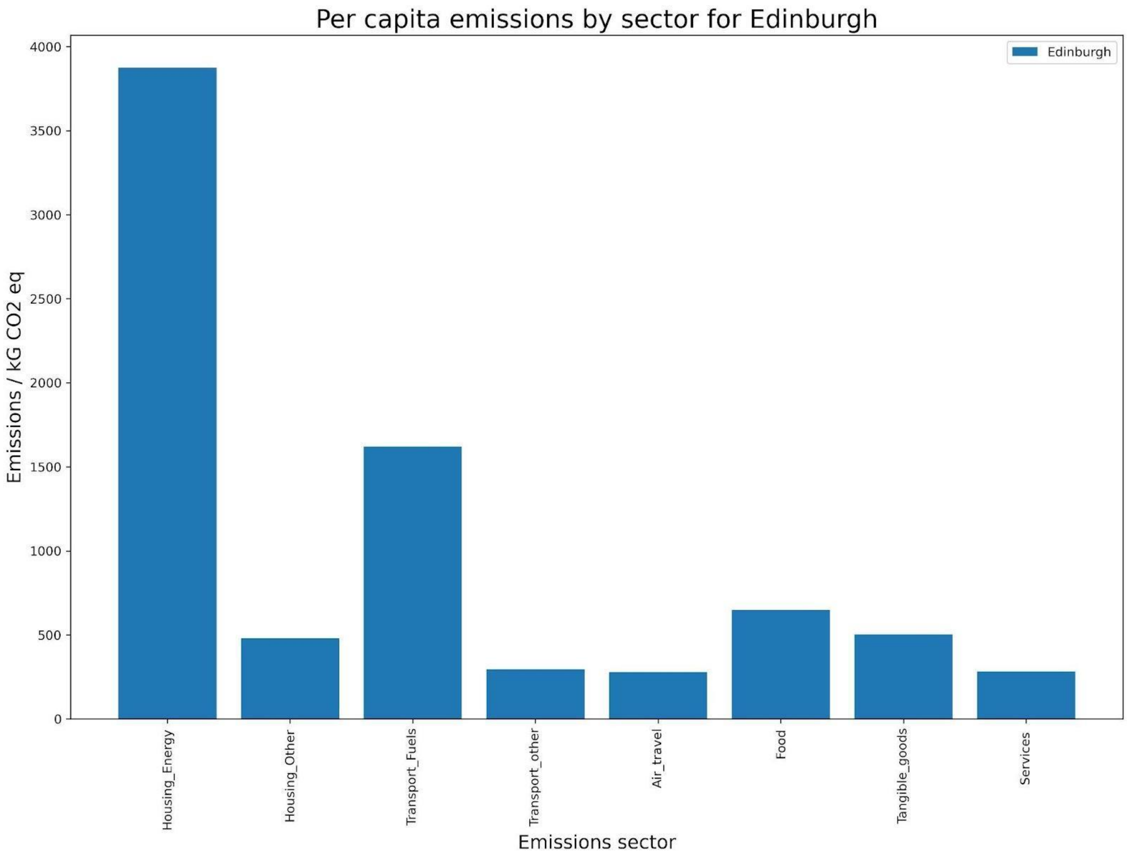

Figure 13. Per capita sectoral emissions for the city of Edinburgh (2019).

Figure 13 above shows the breakdown of emissions by sector for households in Edinburgh. The emissions were calculated for the year 2020. Overall, the per capita emissions were approximately 8 tonnes CO_2e per annum. The total consumption emissions for the city were calculated to be approximately 4.2 Mt CO_2e per annum. The largest contributions to the emissions came from residential energy demand and transport fuels, for which the largest contributions came from the direct use of fuels by the household. This also reflects the large proportions of space heating arising from direct combustion of fossil fuels. In the case of Edinburgh, this particularly arises through gas-based heating (around 3 tonnes of emissions per capita derive from gas-based heating). Transport emissions are also significant.

4.4.3 Case study

Scotland's Third National Planning Framework (NFP3, 2014) is a long-term strategy and a national vision of what is expected of the planning system and the actions that it must deliver for the people of Scotland. It is accompanied by an Action Programme, which describes the implementation of NPF3. Scottish Planning Policy is thematic national planning policy and sets out how nationally important land use planning matters should be addressed across the country.

Actions to be Addressed

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

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

- A successful, sustainable place:
  2.5: Significant increase in house building to ensure housing requirements are met across the country
- A low carbon place:
  3.16: Retrofitting efficiency measures for the existing building stock.
  3.17: We believe that there are significant opportunities for the cities in particular to use renewable and low carbon heat energy.
  We will apply building standards to improve the energy efficiency of existing and new buildings.
- A natural, resilient place:
  4.14: A more integrated approach and 'greening' of the urban environment through green infrastructure and retrofitting

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

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

4.4.4 Results

The results of the policy quantification are summarised in the following table. In general, there was a lack of quantitative numbers linked to specific policies in the reference document, meaning assumptions were required to perform the calculations. Further details, including the key assumptions taken, are given in the pilot case study report.

Table 13. Quantifying Spatial Planning Policies for the City of Edinburgh.

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

The construction of the new buildings would lead to total life-cycle emissions of 1 $MtCO_2e$ in 2030. Assigned to the new residents, this gives each a footprint of 204 tCO_2e in 2030 in the case of a new settlement, and 202 tCO_2e for densification.

4.5 Pilot case study 3: Rathlin Island, Northern Ireland

4.5.1 Introduction of the pilot area

The case study pilot for Northern Ireland is Rathlin Island. Rathlin is Northern Ireland's only offshore inhabited island, is mainly rural; its population has been steadily increasing and currently has a population of approximately 160 inhabitants. Rathlin Island lies within the Antrim Coast and Glens Area of Outstanding Natural Beauty and it has a number of natural energy resources, including wind, biofuel and geothermal; these renewable energies, however, are not being used to their full potential.

The Northern Area Plan 2016 (NAP), developed by the former Department of the Environment, is the current statutory plan for Rathlin Island. The NAP forms the basis of land use planning, decisions on planning applications and sets out to inform the general public, statutory authorities, developers and other interested parties of the policy framework and land use proposals that will be used to guide development decisions within the Plan area.

The Rathlin Island Policy (Department for Regional Development, 2010) recognises that the challenges faced on Rathlin are different to those experienced on the mainland and may have to be addressed differently. The spatial planning policy that the tool has tested out for Rathlin is the Northern Area Plan 2016.

4.5.2 Baseline for GHG emissions

4.5.2.1 Buildings

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

Residential

From data provided, energy use in the residential sector was found to total 2.40 GWh. The residential fuel split mainly comes from heating oil, which makes up 75% of the total energy use in this region. Oil boilers were found to be the most common main source of heating on the island, followed by stoves and solid fuel boilers.

Electricity had the second highest energy demand, making up 13% of the fuel mix. In 2018 Rathlin Island had a total of 128 electrical connection points in 2018, of which 101 connections were domestic connection points and accounted for 320 MWh. Most of the energy used was for space heating. Space heating had by far the highest energy demand, accounting for 61% of the total. This is followed by water heating at 26%. Heating overall in the residential sector has the highest energy demand by far and creates potential for heat recovery from waste heat and district heating as a way of catering for this high heat demand. Lighting and appliances are the least energy intensive, making up 13% of the total demand, it should be noted that Lights & appliances also include energy demand for fans and pumps.

Total emissions from the residential sector in Rathlin amounted to 726 tonnes of CO_2 in 2018. The figure below depicts the total emissions grouped by fuel and dwelling type. Semi-detached houses had the highest emissions, accounting for 305 tonnes of CO_2. This was followed by detached houses, terraced houses and apartments, all of which accounted for 276, 116 and 29 tonnes of CO_2 respectively, of the total emissions in the residential sector.

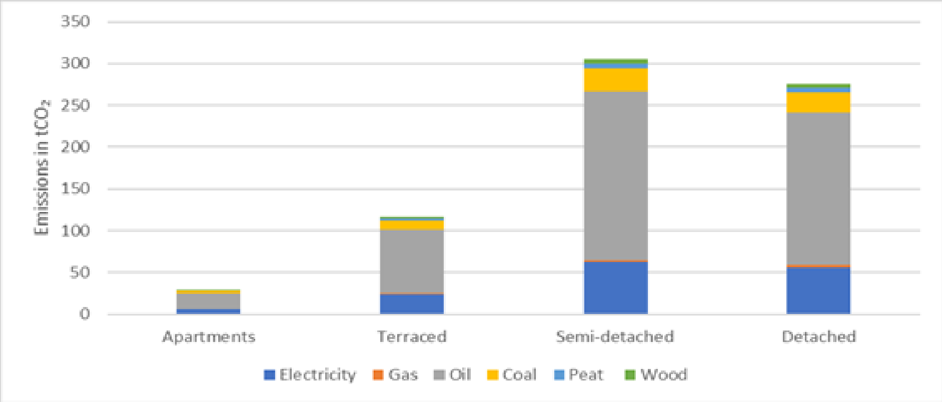

Figure 14. Total Emissions in tCO_2 in the Residential Sector by Fuel Mix and Dwelling Type (2019).

The highest emissions in the residential sector come from heating oil, electricity and coal, which contribute 66%, 20% and 9% respectively. There was very little peat, biomass (mainly wood) and bottled gas used in the residential sector, only contributing to 5% of total emissions.

Commercial

From data provided, it was found that Rathlin Island had a total of 128 electrical connection points in 2018, 27 of which were commercial connection points, thus, it was assumed that commercial buildings totalled 27. Local level information on the types of buildings present on the island was used to create a dataset of typical commercial floor areas for different property categories. The total energy used in the commercial sector was 1.4 GWh. Bottled gas (660 MWh), heating oil (371MWh) and electricity (364 MWh) accounted for this energy use.

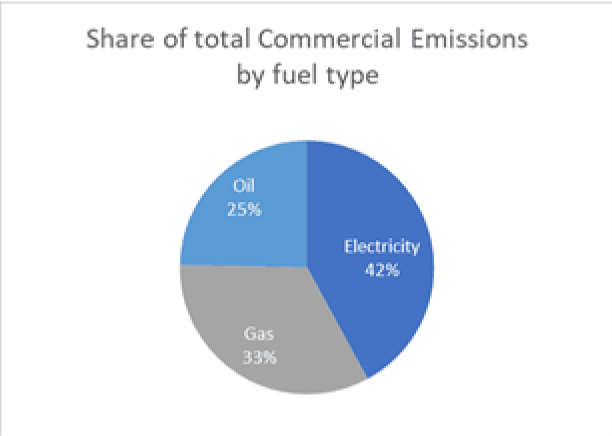

Figure 15. Share of Total Emissions in the Commercial Sector by Fuel Type (2019).

Total emissions from the commercial sector in 2018 amounted to 401 tonnes of CO_2. Of the total emissions emitted by the commercial sector, electricity accounts for the largest share of the total emissions (42%), followed by bottled gas at 33% and heating oil (25%).

Total Emissions from Buildings

Total emissions from both the residential and commercial sectors in Rathlin accounted for 1,127 tonnes of CO_2 in 2016. The residential sector contributed 64% and the commercial sector 36% to the total emissions. The main source of emissions come from heating oil (51%), followed by electricity (28%) and bottled gas (13%). The rest of emissions (approximately 7%) were made up of coal, biomass (wood) and peat.

Table 14. Total Emissions from the Building Sector in Rathlin Island (2019).

Building Sector	Electricity	Gas	Oil	Coal	Peat	Wood	Total
Residential	148	7	480	65	14	12	726
Commercial	169	133	99	-	-	-	401
Total tCO_2	**317**	**140**	**579**	**65**	**14**	**12**	**1,127**

4.5.2.2 Transport

The transport activity data for Rathlin Island is based on a recent study on sustainable transport strategy (McLaughlin, 2019), which included a transport survey for the residents. The thesis project applies a consumption-based approach in the GHG quantification of transport including all transport by the residents of Rathlin Island. However, the territorial assessment includes only the transportation on the Rathlin Island. The island has a ferry connection to the mainland and has no transit transport at all. Therefore, the estimate on the annual number of vehicle-kilometres for this calculation is smaller than in previous studies.

Rathlin Island had about 70 cars, 11 vans and 16 4x4s in 2019. According to the transport survey, 50% of the vehicles are in daily use. 31% of the vehicles are in use most days, and 19% only once or twice a week. Based on this information, the average number of car trips was estimated 378/week on the island. This equals to 19,656 trips per year. For vans and 4x4s, an assumption of one trip per day was applied. As most of the settlement is located quite close to the ferry port, an average length of one trip (on Rathlin) was assumed 5 kilometres only.

80% of vans and cars have diesel engines and 20% petrol engines. 4x4s were assumed diesel-fuelled.

In addition, the island fleet includes tourist minibuses.

The transport emissions of Rathlin Island are presented in Table 15 below.

Table 15. Transport activity and annual road transport emissions on Rathlin Island (2019).

Vehicle type	Fuel type	Number of vehicles	Vehicle-km/a	Emission factor gCO_2e/km	Total emissions tCO_2e/a
Passenger car	diesel	56	78624	168	13.2
	petrol	14	19656	174	3.4
4x4	diesel	16	29200	191	5.6
Van	diesel	9	16425	241	4.0
	petrol	2	3650	210	0.8
Minibus	diesel	4	1960	300	0.6
Total					**27.6**

4.5.2.3 Land-use

The distribution of Rathlin Island land cover classes and soil types are shown in Figure 16 and Figure 17.

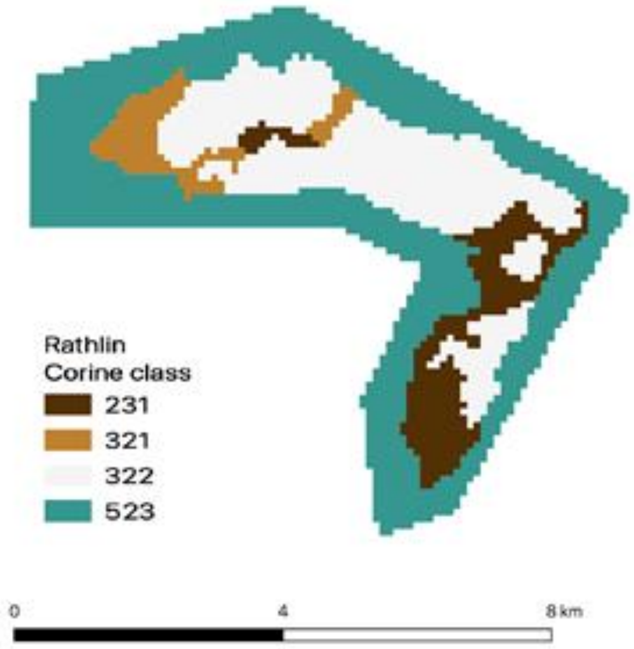

Figure 16. CORINE land cover classes in Rathlin Island.[17]

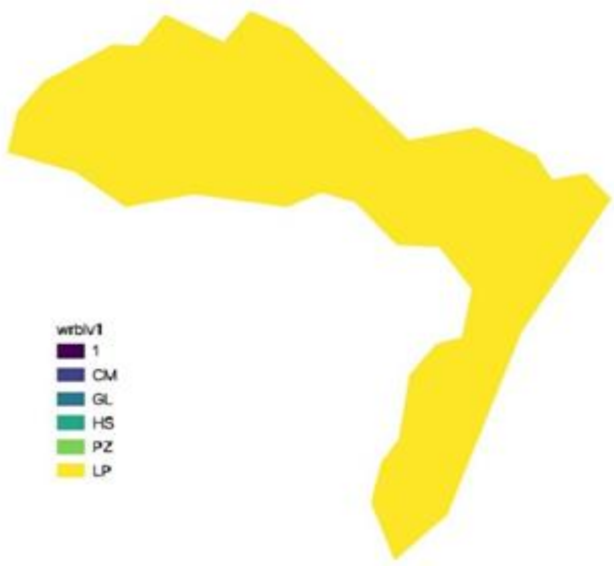

Figure 17. Soil types in Rathlin Island (European Soil Database).[18]

[17] CORINE classes: 231 - pastures, meadows and other permanent grasslands under agricultural use; 321 - natural grassland; 322 - moors and heathland; 523 - Sea and ocean.

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

There are four level 3 CORINE land cover classes that can be categorised into grasslands and unmanaged land according to IPCC land-use categories in Rathlin Island. The dominant land cover is semi-natural areas (CORINE class 3 ≈ IPCC category grasslands, natural grasslands as unmanaged land) that constitute 69% of total Rathlin area.. Agricultural areas (CORINE class 2 ≈ IPCC grasslands) cover 20% of total area, followed by water bodies (CORINE class 5 ≈ IPCC unmanaged land). According to the European Soil Database there are only Leptsosol soils that are classified as IPCC mineral soils.

Table 16. Baseline land use emission estimates in Rathlin Island (tCO_2/a) (2019).

IPCC Land use category	Biomass		Dead organic matter		Soil		Total
	above-ground	below-ground	dead wood	litter	mineral	organic	
Grassland	12	IE	0	0	-1,624	0	-1,612
Total	**12**	**IE**	**0**	**0**	**-1,624**	**0**	**-1,612**

* Emissions have positive and removals negative signs. IE – included elsewhere.

The land use sector in Rathlin Island is estimated to be currently a net sink of -1,612 tCO_2. Annual CO_2 removals are related to carbon sequestration in managed grassland mineral soils, while grassland biomass is estimated to decrease slightly causing minor emissions. Rathlin has a large share of designated conservation and protected areas, some of which probably fall under the CORINE class 322 Moors and heathland. The latter are considered as managed grasslands according to the UK's NIR, however might be unmanaged in Rathlin. IPCC methodology does not take into account emissions/removals from natural and unmanaged areas; thus, the total carbon sink might be overestimated in Rathlin case study.

4.5.2.4 Consumption-based

The UK rural demand vector was applied for households in Rathlin Island. The stakeholders indicated that the average income of the area did not differ from the UK as a whole, and so no further scaling was performed based on this factor. Information was provided by the stakeholders with regards to the average household occupancy and total population of the area, respectively, and this was used to determine the per capita and total emissions for the region. Moreover, the UK electricity sector in the model was fully replaced with the Irish electricity sector (although total demand was left unchanged) to account for the integration of the electricity sector across the island of Ireland. Accounting for trade, the Irish electricity grid is around 50% more carbon intensive than the UK equivalent, upstream emissions notwithstanding.

Table 17. Description of the data situation utilised for the consumption calculations in Rathlin Island.

Data situation: Rathlin Island				
Demand Vector	Household occupancy	Household income level	Population	Further modifications / Notes
UK rural	1.74	UK average	160	Irish electricity sector used

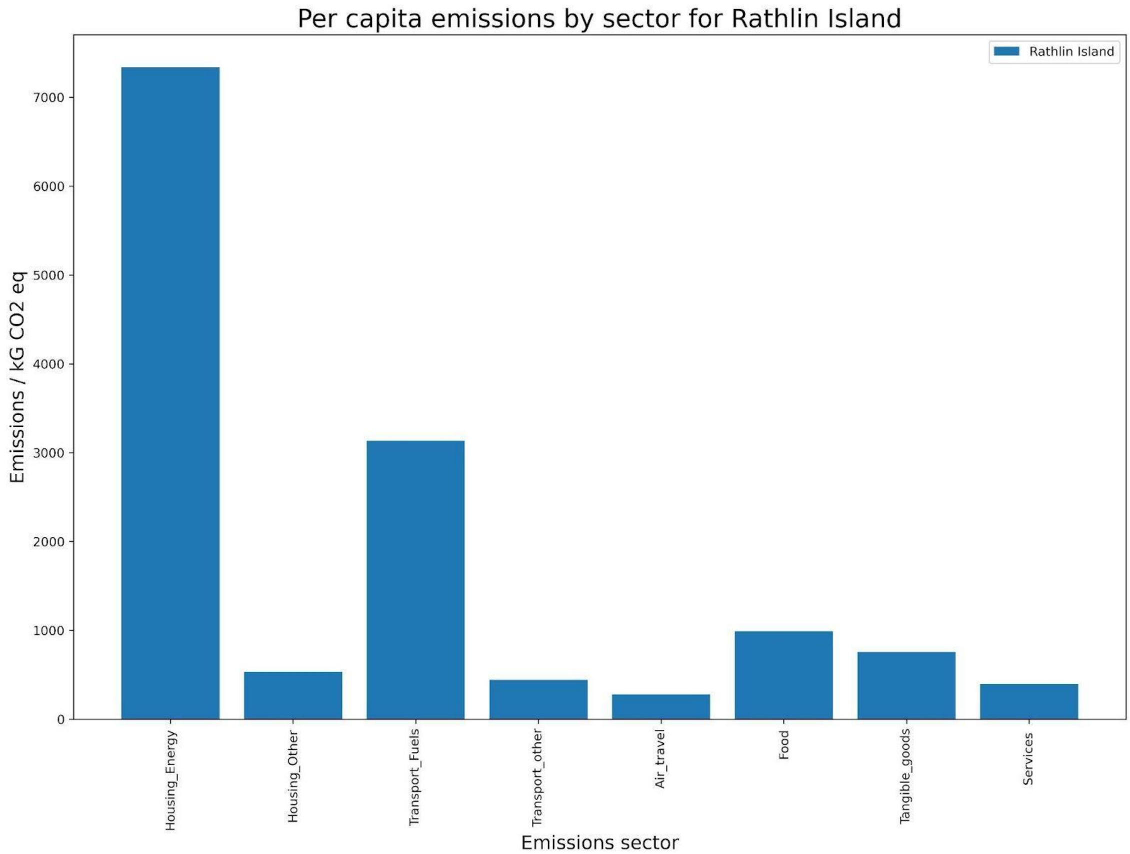

Figure 18. Per capita sectoral emissions for Rathlin Island (2019).

Figure 18 above shows the breakdown of emissions by sector for households in Rathlin Island. Overall, the per capita emissions were 13.9 tCO_2e per annum. The total consumption emissions for the region were calculated to be approximately 2.2 $ktCO_2e$ per annum. The largest contributions to the emissions came from residential energy demand and transport fuels. 'Use-phase' emissions significantly contribute to the residential energy demand, which reflects the large proportion of space heating arising from direct combustion of fossil fuel combustion in the household. Electricity emissions are also significant (2 tonnes CO_2e per annum) due to the high carbon intensity of the Irish grid combined with UK demand being somewhat higher than in Ireland. Transport emissions were also significant.

4.5.3 Case study

The aim of the Northern Area Plan (NAP) (Department of the Environment (NI), 2016) is to provide a framework for development throughout the area, conforming with the strategy and guidance set out in the Regional Development Strategy 2035 (RDS) (Department for Regional Development, 2012), facilitating sustainable growth, meeting the needs of communities and protecting environmental attributes.

Policies from the NAP that the tool will aim to quantify for the building sector relate to the promotion and facilitation of energy efficient building design, as well as the use of lower carbon fuels in buildings. While no numerical proposals are highlighted, nevertheless, the following policy from the NAP can be quantified:

- Regional Planning Context - Promoting more sustainable development within existing urban areas and ensuring an adequate and available supply of quality housing to meet the needs of everyone

Policies of NAP are examined in the light of the sustainable transport strategy study provided by McLaughlin (McLaughlin, 2019).

Northern Area Plan. Rathlin Island has a large share of areas of international and national conservation importance (Ballycarry, Ballygill North, Rathlin Island Coast, Kebble, Kinramer South). The importance of conserving the landscape and natural resources of the rural areas and protecting it from excessive, inappropriate or obtrusive development is recognised. NAP does not propose any direct land-use changes in Rathlin

Island. According to CORINE maps grassland is the dominant managed land category in Rathlin. The most realistic land-use changes are grassland conversion to cropland and grassland conversion to settlements that can be quantified.

Land use

Rathlin Island Action Plan 2016–2020 aims to conserve the island's exceptional environmental heritage. The local environmental policy priority is to safeguard the island's environmental beauty and heritage, to support the island's agricultural and aquaculture sectors to develop and maintain sustainable practices, and maintain its environmental designations. Large parts of Rathlin Island are designated as the Natura 2000 network sites. Rathlin has been designated as a Special Area of Conservation and a Special Protection Area under the Habitats and Birds Directives, due to which major urban developments are limited in the area. Furthermore, current Rathlin Action Plan's policy actions do not suggest any planned land-use changes.

Rathlin Island European Marine Site Management Scheme provides key management guidance that is applicable to the designated marine areas surrounding Rathlin Island plus areas of the Rathlin Island Special Protection Area. Coastal development on the island has been limited in recent years to around the harbour and Church Bay area. No major new developments are presently anticipated for the immediate coastal area of Rathlin. Establishing tidal stream renewable energy devices up to 200 MW in an area off the north east coast of Rathlin Island is being negotiated, however this action is not included as part of the land use (LULUCF) methodology, the latter covers anthropogenic emissions in terrestrial carbon pools. Actions related to renewable energy are addressed under buildings and transport sectors.

4.5.4 Results

The results of the policy quantification are summarised in the following table. In general, there was a lack of quantitative numbers linked to specific policies in the reference document, meaning assumptions were required to perform the calculations. Further details, including the key assumptions taken, are given in the pilot case study report.

Table 18. Quantifying Spatial Planning Policies for Rathlin Island.

policy	impact	module	quantification in the tool	CO_2e increase /decrease (tCO_2)	Emissions per capita (tCO_2/capita)
1. Retrofitting	2016-26	energy use in buildings	change in energy consumption profile of existing buildings	48	N/A
		consumption-based	change in expenditure on energy	24 (E to C) 36 (E to B)	12.1 (in 2026) 12.0 (in 2026)
2. Increase in renewable energy generation	2016-26	energy use in buildings	change in energy consumption profile of existing buildings	1.68 MWh	
		consumption-based	increase in the share of renewable energy	1.80E + 00	12.2 pc (in 2026)
3. Transport-related policies					

policy	impact	module	quantification in the tool	CO_2e increase /decrease	Emissions per capita
3.1 Improving the provision of public transport	2016-26	transport	adjusting modal shares		
		consumption-based	part of the transport ex-penditure moves from passenger cars to public transport	8.70E+01	11.6 (in 2026)
3.2 Enhancing cycling and walking facilities	2016-26	transport	reduce transport activity		
		consumption-based	decrease in transport ex-penditure	9.20E+01	11.6 (in 2026)
3.3 Provision of park-and-ride facitlities	2016-26	transport	adjusting modal shares		
		consumption-based	part of the transport ex-penditure moves from passenger cars to public transport	8.40E+01	11.6 (in 2026)
3.4 Increasing remote working	2016-26	transport	reduce transport activity		
		consumption-based	decrease in transport ex-penditure	88.3 48 heating incl	11.6 (in 2026) 11.9 (in 2026)

4.6 Pilot case study 4: Kymenlaakso Region, Finland

4.6.1 Introduction of the pilot area

The region Kymenlaakso, in South-East Finland, has a population of 174,000. The largest cities are the harbour city Kotka (55,000 inhabitants), Kouvola (88,000 inhabitants) and the old bastion town Hamina (20,000 inhabitants).

Kymenlaakso is part of the Finnish *Towards Carbon Neutral Municipalities* (Hinku) (Carbonneutralfinland.fi, 2013) network which brings together municipalities, businesses, citizens and experts to create and carry out solutions to reduce GHG emissions. The 70 municipalities involved are committed to reduce emissions at a more rapid pace than EU targets require. The network aims to create solutions that have economic and social benefits as well as environmental advantages. The GHG emission reduction target is 80% for the period between 2007–2030.

The Kymenlaakso region aims to become carbon neutral by 2035. To this end, the region of Kymenlaakso has compiled a roadmap which includes detailed information on the region's GHG emissions, carbon sinks (LULUCF sector) and the main measures that need to be implemented in different sectors such as industry, forestry and traffic. According to the roadmap, the region of Kymenlaakso has to decrease GHGs mainly from transport, energy production and agriculture sectors. LULUCF sector's carbon sinks need to be increased in forests and soils. Measures in the roadmap include for example eco-innovations, cleantech, circular economy approach in all sectors, climate wise forestry, increasing the share of renewable energy, compact urban structure and environmental education and comprehensive cooperation between all sectors.

The spatial planning policy that the tool has been tested on for Kymenlaakso is the Carbon Neutral Kymenlaakso 2040 plan.

4.6.2 Baseline for GHG emissions

4.6.2.1 Buildings

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

Residential

Total energy use in the residential sector was 2,729 GWh. The residential fuel split mainly comes from electricity, which makes up 54% of the total energy use in this region. It should be noted that households that are heated by electricity generally tend to make use of air source heat pumps, which have become quite common in Finnish households. District heating contributes 16% to the total energy demand, followed by wood (biomass) at 15% and geothermal energy (8%). Most of the energy used was for space heating. Space heating had by far the highest energy demand, accounting for 67% of the total. This was followed by water heating at 20%. Heating overall in the residential sector has the highest energy demand by far and creates potential for heat recovery from waste heat. It should be noted that compared to the other case study pilot areas, Kymenlaakso has colder winters, thus a higher need for space and water heating. Lighting and appliances are the least energy intensive, making up just 13%.

Total emissions from the residential sector in Kymenlaakso amounted to 507,640 tonnes of CO_2. The figure below depicts the total emissions grouped by fuel and dwelling type. Detached houses had the highest emissions, accounting for 440,000 tonnes of CO_2. This was followed by apartments and terraced houses, all of which accounted for 49,623, and 18,017 tonnes of CO_2 respectively, of the total emissions in the residential sector.

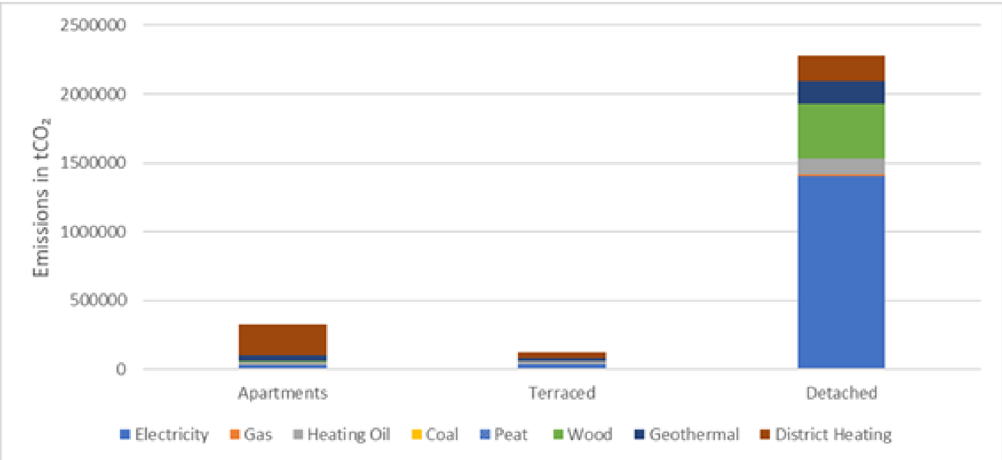

Figure 19. Total Emissions in tCO_2 in the Residential Sector by Fuel Mix and Dwelling Type (2019).

The highest emissions in the residential sector come from electricity, biomass and district heating, which contribute 45%, 32% and 14% respectively. Heating oil, gas, coal and peat contributed to 9% of total emissions.

Commercial

The total energy used in the commercial sector was 971,441 GWh. District heating (595 GWh) and electricity (152 GWh) accounted for the main share of this energy use. The commercial sector had a high use of heating oil, 147 GWh, meanwhile gas, geothermal and biomass (wood) all together made a total of 77 GWh.

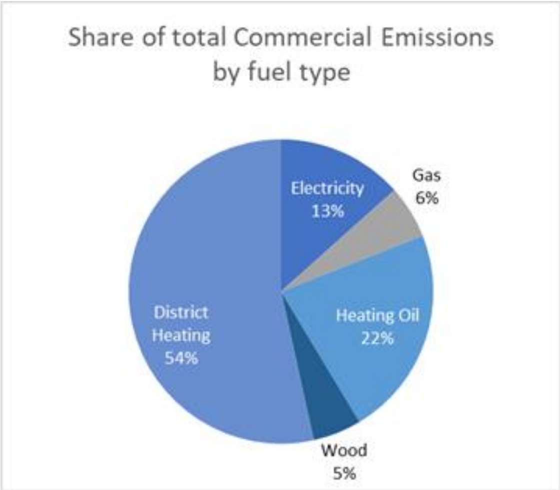

Figure 20. Share of Total Emissions in the Commercial Sector by Fuel Type (2019).

Total emissions from the commercial sector amounted to 175,898 tonnes of CO_2. Of the total emissions emitted by the commercial sector, district heating accounts for the largest share of the total emissions (54%), followed by heating oil at 22%. Electricity also produced significant emissions, contributing 13% to the total.

Total Emissions from Buildings

Total emissions from both the residential and commercial sectors in Kymenlaakso accounted for 683,540 tonnes of CO_2 in 2016. The residential sector contributed 74% and the commercial sector 26% to the total emissions. The main source of emissions come from electricity (37%), followed by wood (25%) and district heating (24%). The rest of emissions were made up mainly from heating oil (12%) and gas (2%).

Table 19. Total Emissions from the Building Sector in Kymenlaakso (2019).

Building Sector	Electricity	Gas	Oil	Coal	Peat	Wood	District Heating	Total
Residential	227,415	4,813	40,831	23	454	163,157	70,948	507,640
Commercial	23,530	9,923	39,349	0	0	9,087	94,010	175,898
Total tCO_2	**250,944**	**14,736**	**80,180**	**23**	**454**	**172,244**	**164,958**	**683,538**

4.6.2.2 Transport

In GHG analyses, the Kymenlaakso area is characterised on one hand by the intensive transit transport and, on the other hand, by large forest areas with carbon sinks. One special feature of Kymenlaakso is the transport on water and the harbour activities, which cannot be analysed in detail in this study.

The baseline analysis utilises the transport activity data collected for the Carbon neutral Kymenlaakso roadmap, created by Ramboll and Regional Council of Kymenlaakso in 2019 (Savikko, Hokkanen, Koutonen, Haanpää, 2019) and the LIPASTO database by VTT (LIPASTO, 2021). LIPASTO provides the road transport activity and the respective CO_2e emissions by municipality.

The rail transport activity figures are from the Carbon neutrality roadmap baseline data. The road transport was divided into street kilometres (in an urban environment) and roads (rural environment) utilising the information from the Kymenlaakso carbon neutrality roadmap.

Total Transport Emissions

The results of the GHG emissions calculation for the transport in Kymenlaakso are presented in Table 20 below.

Table 20. The baseline emissions for transport in Kymenlaakso (2019).

Mode of transport	million vehicle-km/a	tCO_2e/a	%
Passenger car	1,142	163,242	49.1
Bus	16	13,168	4.0
Passenger train		2	0.0
Passenger transport on water		1	0.0
LGV (vans)	162	25,159	7.6
HGV (lorries)	114	131,148	39.4
Freight on rails			
Freight transport on water		32	0.0
Total		**332,751**	**100.0**

4.6.2.3 Land-use

The distribution of Kymenlaakso land cover classes and soil types are shown in Figure 21 and Figure 22.

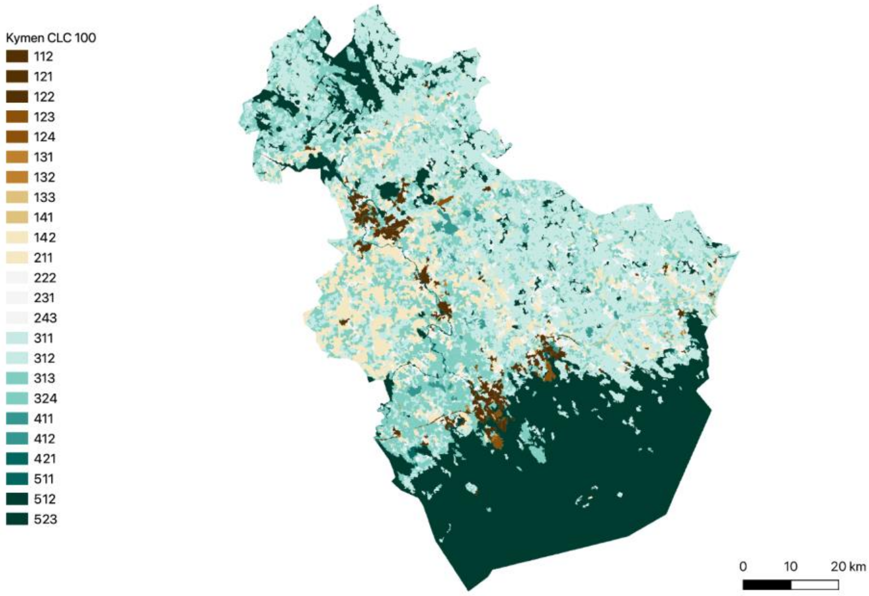

Figure 21. CORINE land cover classes in Kymenlaakso.[19]

Figure 22. Soil types in Kymenlaakso (European Soil Database).[20]

[19] CORINE classes: artificial areas (112–142); agricultural areas (211–243); forest and semi-natural areas (311–324); wetlands (411–421); water bodies (511–523).

[20] WRB soil classes: CM - Cambisol; HS - Histosol; LP - Leptosol; PZ - Podzol.

The dominant land cover is forest and semi-natural areas (CORINE class 3 ≈ IPCC forest land) that constitute 65% of total Kymenlaakso area (Table 21). This is in very good agreement with the overall land use distribution in Finland – forest land represents 65% of total Finland area (Finland's National Inventory Report 2021)). Agricultural areas account for 20% (CORINE class 2 ≈ IPCC cropland, grassland) while grasslands account less than 0.1% of Kymenlaakso area. It's also described in NIR that there are no large grazing land areas or permanent grasslands in Finland. Water bodies have a share of 11% (CORINE class 5 ≈ IPCC unmanaged land). Artificial areas (CORINE class 1 ≈ IPCC settlements) constitute 3%, followed by Wetlands 1% (CORINE class 4 ≈ IPCC peat extraction sites, unmanaged wetlands). According to the information provided by the case study stakeholder (Regional Council of Kymenlaakso) there were 2 020 hectares of peat production areas that have environmental permits in Kymenlaakso in 2018.

According to the European Soil Database, Histosols (IPCC organic soils) constitute 3% and mineral soils 97% of total area.

The land use sector in Kymenlaakso is estimated to be currently a net sink of -259,593 tCO_2 mainly due to the large share of carbon sequestering forest land. The emissions from forest organic soils might be overestimated here because emissions from forest organic soils are assessed only in the drained organic soils, while the carbon stock changes of soils in undrained peatlands is assumed to be in a steady state (equal to zero) in Finland. In the current analysis all managed organic soils were considered drained, which is a conservative approach according to the IPCC the guidelines and common assumption among countries reporting under the UNFCCC. Major emissions result from peat extraction sites and cultivation of cropland organic soils.

Table 21. Baseline land use emission estimates in Kymenlaakso (tCO_2/a) (2019).

IPCC Land use category	Biomass		Dead organic matter		Soil		Total
	aboveground	belowground	dead wood	litter	mineral	organic	
Forest land	-226,347	IE	IE	IE	-111,911	5,138	-333,121
Cropland	-120	IE	IE	IE	21,492	21,393	42,764
Grassland	-9	IE	0	0	0	0	-9
Wetlands (peat extraction sites)	51	IE	0	0	0	30,722	30,773
Settlements	0	0	0	0	0	0	0
Total	**-226,426**	**0**	**0**	**0**	**-90,420**	**57,252**	**-259,593**

Emissions have positive and removals negative signs.

IE – included elsewhere.

4.6.2.4 Consumption-based

The demand vector representing the average household was used to describe Kymenlaakso. This was to accommodate the varying urban densities present in the area. There was no data provided by the stakeholders to suggest the relative income level differed from the average picture for Finland, and so no further scaling was performed based on this factor. Additionally, no information was provided with regards to the average household occupancy level, and so the consumption picture for Kymenlaakso therefore represents the typical situation for Finland as a whole. Two small modifications were made to the emission intensity side. The values for heat energy (district heating) and aviation fuel were replaced with the Swedish values, since they led to erroneously large errors in the calculation.

The data situation applied to Kymenlaakso is summarised in the following table.

Table 22. Description of the data situation utilised for the consumption calculations in Kymenlaakso.

Data situation: Kymenlaakso				
Demand Vector	Household occupancy	Household income level	Population	Further modifications / Notes
Finnish average	Finnish average (2.02)	Finnish average	174,167	2 sectors replaced by Swedish values due to unrealistic values in the IO table

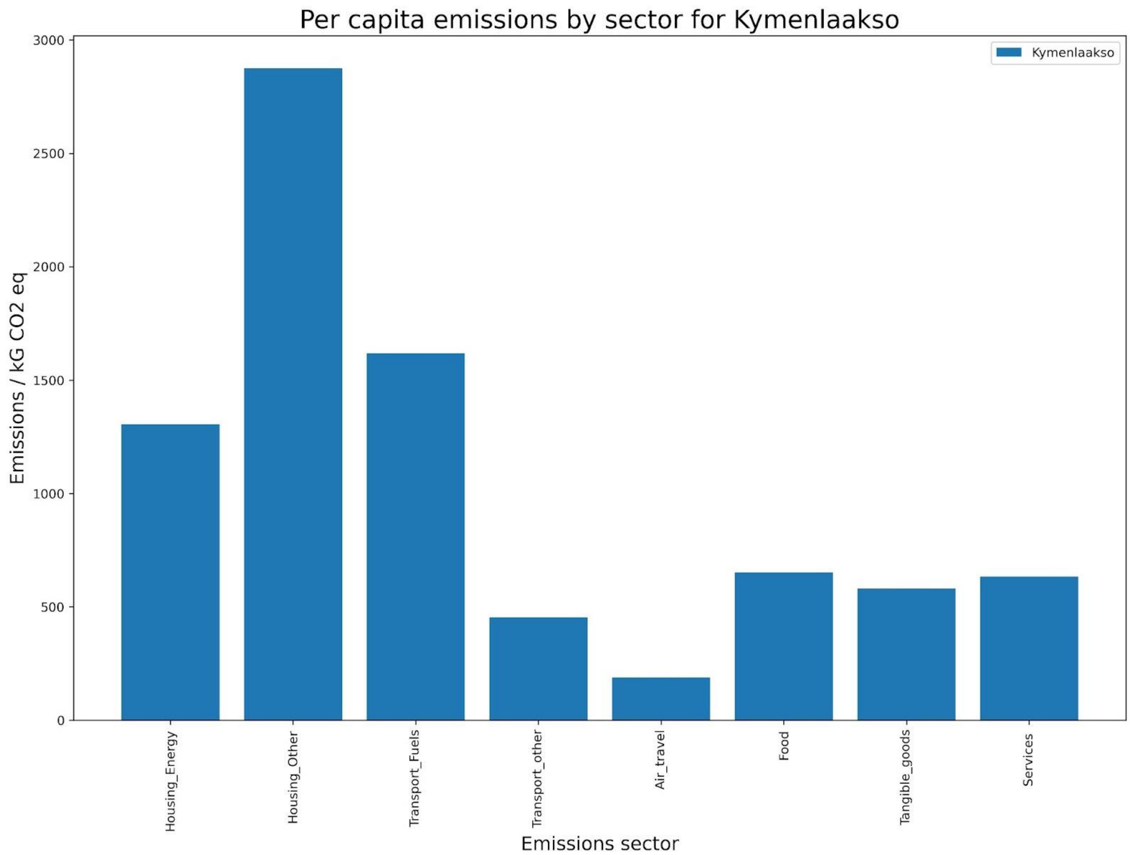

Figure 23. Annual sectoral emissions per capita for Kymenlaakso (kgCO_2e/a) (2019).

The preceding graph (Figure 23) displays the estimated per capita emissions for Kymenlaakso for the year 2020. Overall, the per capita emissions were 7.9 tonnes CO_2e per annum. The total consumption emissions for the region were calculated to be approximately 1.4 MtCO_2e per annum. A feature of the emissions from the region is the small contribution from the electricity sector, as well as the relatively higher contribution from electricity and renewables in household heating.

Allied to this initial finding, a relatively greater proportion of the Finnish carbon footprint arises from direct and indirect production of products, rather than the household use phase, in comparison to the other case study areas. For example, the services sector is notably higher than the other case study areas. Moreover, waste makes a large contribution to the Finnish footprint (recorded under 'household other') with significant contributions coming from landfill. Note that waste corresponds to a 'place-holder sector' in the tool, so the values are distributed in the same way for each country and region, and is also not well differentiated in the initial HBS. This means that although the waste sector may very well be different for Kymenlaakso than the average European picture, it was not considered here. This was because waste was not a sector included in this version of the tool.

4.6.3 Case study

Buildings

Actions from the roadmap that the tool will aim to quantify for the building sector relate to the use of low carbon fuels and energy efficient technologies in buildings. While no numerical proposals are highlighted, nevertheless, the following measures from the roadmap can be quantified:

- Replacing fossil fuels with renewables
- The phasing out of peat as an energy source.

Transport

The territorial transport system plan implements the national transport plan on a territorial level. The transport plan of Kymenlaakso aims to follow and implement the Carbon neutrality roadmap. The case study quantifies some impacts of

- Transport 12, the national transport system plan 2021–32 (Vayla, 2021)
- Kymenlaakso transport system plan (Kymenlaakson Liitto, 2021).

The territorial transport system plan implements the national transport plan on a territorial level. The transport plan of Kymenlaakso aims to follow and implement the Kymenlaakso carbon neutrality roadmap. The actions were specified by cross-examining the transport-related actions in the Kymenlaakso Carbon Neutrality Roadmap and the regional transport system plan. They include:

- Developing a distribution network for biogas (biomethane) vehicles in 2025–2035
- Improvements of main rail connections 2025–2040
- The improvements of Kotka-Kouvola highway in 2022–2029.

Land Use

The stakeholder of Kymenlaakso did not request quantifying any spatial planning policy actions in the land use sector. However, given the data provided in Finland's NIR the following actions can be quantified:

- afforestation: cropland/grassland/wetlands/settlements conversion to forest land
- deforestation: forest land conversion to cropland/grassland/settlements
- land conversion to peat extraction
- grassland/wetlands/settlements conversion to cropland
- cropland/wetlands conversion to grassland.

4.6.4 Results

The results of the policy quantification are summarised in the following table. In general, there was a lack of quantitative numbers linked to specific policies in the reference document, meaning assumptions were required to perform the calculations. Further details, including the key assumptions taken, are given in the pilot case study report.

Table 23. Quantifying Spatial Planning Policies for Kymenlaakso.

policy	impact	module	quantification in the tool	CO_2e increase /decrease (tCO_2)	Emissions per capita (tCO_2/capita)
1. Biogas station network	2025-35	transport	share of biogas fuel in passenger cars increases; petrol and diesel reduces	-6,569	-0.04
		consumption-based	shares of fuel types are adjusted	48,000	6.5 (in 2030)
2. Improvement of main rail connections	2025-40	transport	shares of passenger and freight transport on rails increase; road transport reduces	-5,977	
		consumption-based	part of the transport expenditure from passenger cars to passenger train	45,000	6.5 (in 2030)
3. Improvement of Road 15 from Kouvola to Kotka	2022-29	transport	adjusting driving profiles to quantify the impact of less congestion on Road 15	-3,040	-0.02
		consumption-based	increase in private transport, decrease in public transport but increas in bus share	-45,000	7.0 (in 2030)
4. Retrofitting	2022-26	energy use in buildings	change in energy consumption profile of existing buildings	-51,000	
		consumption-based	change expenditure on energy	27,000	7.1 (in 2026)
5. Increase in renewable energy generation	2022-26	energy use in buildings	change in energy consumption profile of existing buildings	324,049 MWh	
		consumption-based	increase in the share of locally produced and used renewable energy	12,000	7.2 (in 2026)

4.7 Comparison of results

Figures 24, 25 and 26 present a comparison of the territorial GHG quantification results for the four pilot case studies. The GHG emissions are announced per capita, which makes the comparison more justified.

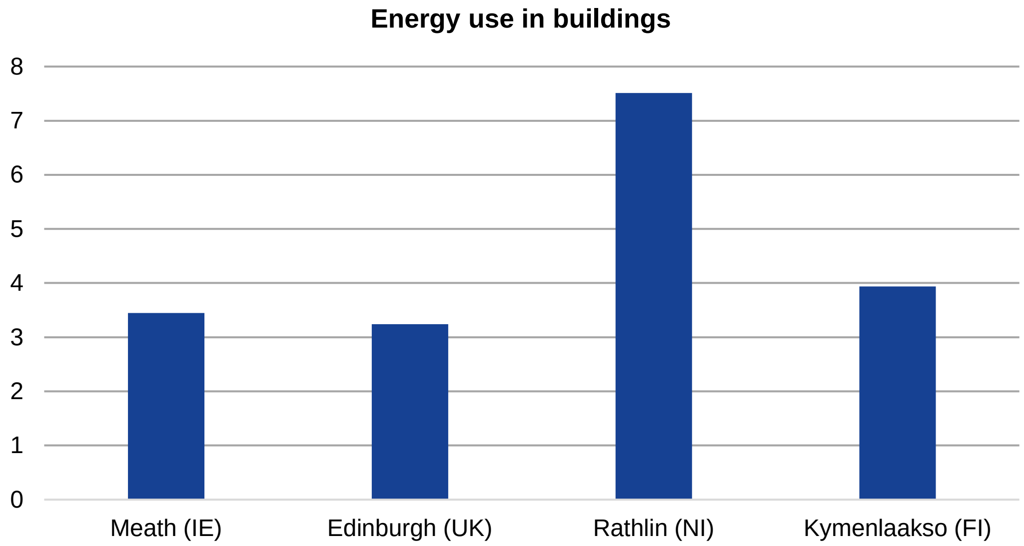

Figure 24. Annual Buildings baseline emissions per capita ($tCO_2e/(capita,a)$) (2019).

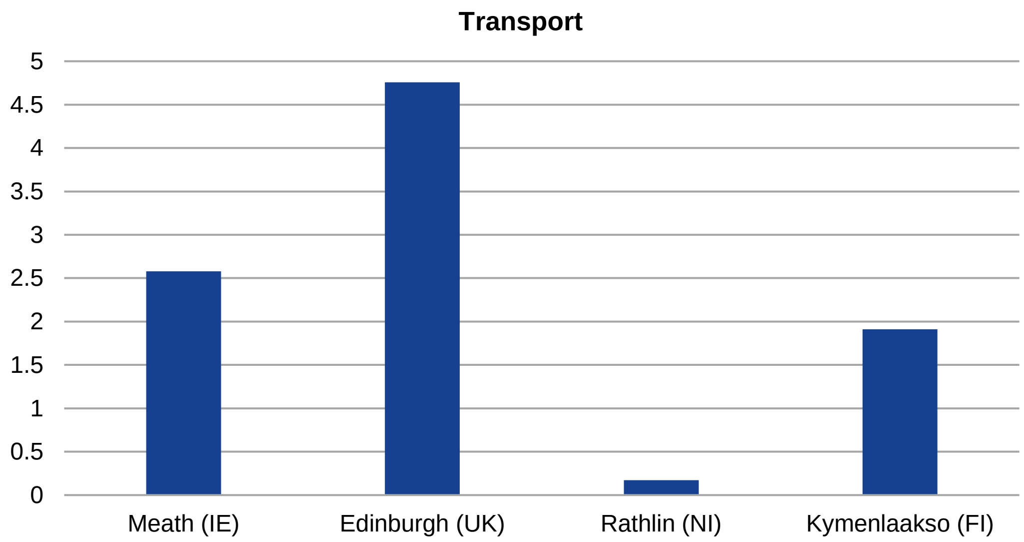

Figure 25. Annual Transport baseline emissions per capita ($tCO_2e/(capita,a)$) (2019).

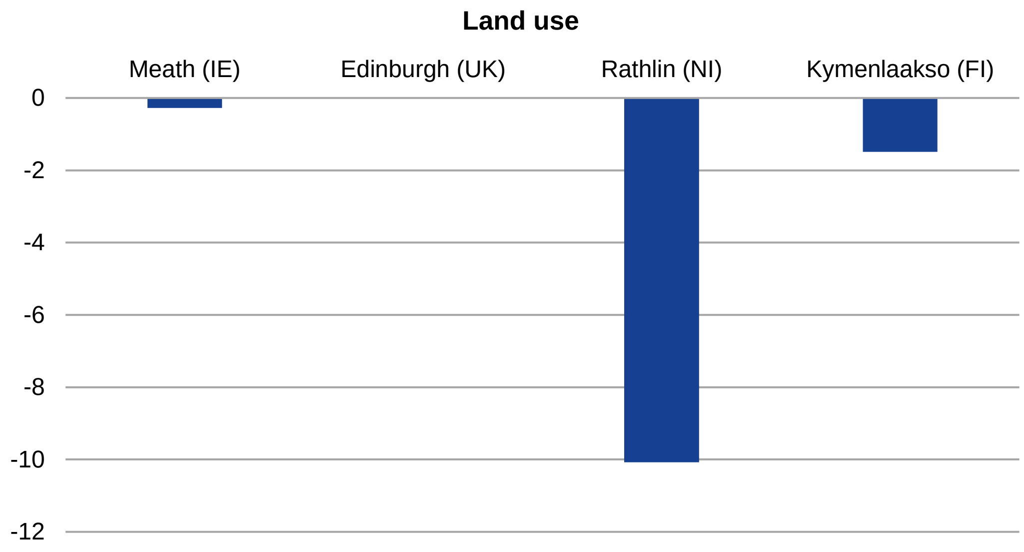

Figure 26. Annual Land use baseline emissions per capita ($tCO_2e/(capita,a)$) (2019).

In Transport sector, high territorial emissions tend to reflect the transport infrastructure within the area and its intensive use rather than the provision of public transportation for example.

Energy use in buildings is one sector where the two different approaches come rather close to each other (Figure 27). However, these figures reflect two slightly different components of total GHG emissions. The territorial result includes all types of buildings within the area and applies the statistical average energy consumption per building type for the quantification of GHG emissions. The total emissions are then divided by the number of residents. The consumption-based result is based on the residents' average expenditure on housing.

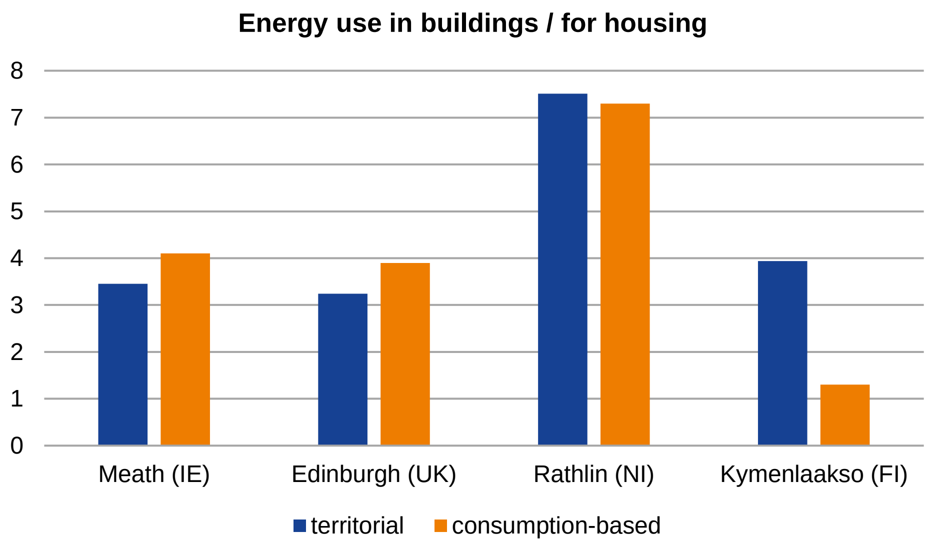

Figure 27. Annual baseline emissions for energy use in buildings (territorial) and energy use for housing (consumption-based) per capita ($tCO_2e/(capita,a)$) (2019).

5 Conclusions

5.1 Responses to RQ1 – enabling comparisons

RQ1: How can consistent and comparable GHG baseline emissions data be collected at national, regional and local levels to assess the urban and land-use share of GHG emissions relevant for spatial planning policy and practice?

5.1.1 Comparability of results

As described in this report, the problems in comparing baseline emissions quantification results are fundamental. As an allocation principle, the commonly used territorial approach generates results which are difficult to compare directly. In fact, there are good reasons to ask whether the climate neutrality targets relying on territorial quantification are justified, when

a) All the GHG emissions of the residents are not accounted for.

b) Carbon neutral cities and territories will not compensate the GHG emission of the residents but the GHG emissions caused within their territory. In this sense, the amount of offsets is arbitrary: the high intensity of industry or the high volume of transit transport may significantly increase the GHG emissions to be compensated. Is it a justified investment to purchase compensations for GHG emission which are not caused by the residents and over which the local authorities have very little control?

c) Respectively, some regions have large forested areas with a carbon sink that helps to achieve carbon neutrality. Also in this sense, the comparison of the baselines of large rural municipalities and densely populated cities is not justified.

Furthermore, the practise of announcing territorial results per resident can be considered misleading. The result of territorial quantification does not present the greenhouse gas emissions caused by the residents. However, territorial allocation is a justified approach for the GHG inventories of cities and territories in order to monitor and steer the development within their region.

As a response to RQ1 - and following the guidance of C40 cities as well as the requirement set by the Scottish Climate Change Act - the QGasSP team concludes that consumption-based GHG quantification should be applied as a complementary analysis. With consumption-based approach, the global GHG impacts of cities and territories of any size can be directly compared. The difficulty of the consumption-based approach is that the global GHG emissions of the residents are difficult to trace, and today there are no established methodologies applied by cities and territories. The QGasSP team has applied environmentally extended input output method (EEIO) utilizing the Exiobase data. These types of methods – until today – have been mostly applied in academic research.

As the climate crisis is escalating, the approaches in GHG quantification can be expected to rapidly evolve. There is now ample evidence that emissions are driven by consumption, with little evidence of the proposed decoupling from GDP when considered on a global scale. Truly successful mitigation efforts, therefore, can only succeed if policy makers are aware of this full scope of emissions and then leverage the necessitated responses.

In order to enhance the comparison of regional strategies and the exchange of best practises, GGIA tool is designed to collect local datasets, which are available for all users.

5.1.2 Uniform data collection for the baselines

The absence of commercial tools for international use demonstrates that the methods for GHG quantification are fragmented and diverse. The national and regional tools are designed to make use of locally available data, and therefore they are applied only in this specific country or area. The best practises of GHG quantification for cities and territories are applying local datasets that are rather accurate but not necessarily comparable.

European datasets can provide harmonized top-down source data, but today they cannot reach the accuracy of the local datasets. It would be controversial to ask the forerunner cities and territories to adopt quantification practises that utilise less accurate data than they have available.

The data that needs to be collected locally includes for example the future scenarios on grid electricity emissions, vehicle occupancy rates and CO_2e emission factors for district heating systems. There are alternative methods for creating future scenarios or allocating the emissions for a local CHP power plant producing district heating and power.

In principle, the primary measure for the harmonisation of local data collection should be European standardisation. This is not always enough: for example each European country that plans to introduce a regulatory framework to assess the carbon footprint of buildings, has created its own unique assessment framework - despite the comprehensive European standardisation. Publications such as The European Reference Scenario 2016 (Capros et al, 2016) could provide a common basis for the future projections if the data is accessible. The example of COPERT tool (Emisia, 2021) shows that a research project or a tool development project can provide harmonising sectoral approaches on greenhouse gas quantification, but they need constant development and active hosting.

5.1.3 Proposals on the next steps

The QGasSP project team proposes the following initiatives to harmonise the data collection:

a) Preparing a continuation project for the QGasSP, to develop an on-line platform for sharing the most relevant datasets and best practises of local data collection for spatial planning.

b) Preparation of a new European standard or an ESPON guide on local data collection to make the datasets of cities and territories uniform and compatible; in a respective manner than e.g. the standardisation of environmental product declarations has been applied.

c) Creating European datasets on transport and buildings on NUTS1, NUTS2 and NUTS3 levels, including also local datasets on household budgets to support the consumption-based inventories.

d) Elimination of the data gaps in the current NUTS0-level (countries) datasets (See Annex 1).

e) Initiatives to create comprehensive European datasets on the parameters that are crucial for the future-oriented GHG quantification according to best practises: for example future scenarios related to energy and transport, emission factors for district heating networks, vehicle occupancy rates.

5.2 Responses to RQ2 – application in spatial planning

RQ2: How can the efficacy of spatial plans and possible alternatives be systematically modelled, via standardised quantitative methodologies and accounting protocols, to determine their overall impact on GHG emissions, and aid cross-country, inter-regional and inter-municipality comparisons?

5.2.1 Special features of GHG quantification for spatial planning

The GHG quantification for spatial planning differs from national GHG inventories in many ways. Considering the baseline analysis, the following aspects should be highlighted:

- The area in concern may be of any size. Quantification data is often not directly available from statistics and may be difficult to compile (e.g. land use sector).
- Spatial planning is future-oriented. The quantification is not monitoring the past development but impacts that span over a longer period of time in the future. The GHG quantification for spatial planning requires future projections based on realistic assumptions and scenarios.

Considering the impact assessment on planning policies, the following features should be highlighted:

- Quantitative information on the policies is typically generic or missing. Policies and ideas will materialize in the future. Spatial planning leaves many options open.
- The most important climate impacts may fall on various scopes. For example the impact assessment of densification strategy (probably the most common spatial strategy for GHG mitigation) requires comparison of alternative solutions, where the comparison of the impacts on land use, transport and embodied emissions reveal the benefits of the strategy.

5.2.2 Bridging the policy documents and GHG quantification

One key finding from all four pilot case studies is the lack of quantitative targets in spatial plans and policy documents. Without numeric values, the person who conducts the quantification needs to make assumptions considering the expected impact of each policy. This further increases uncertainty in the quantification results.

In the pilot case studies of this project, the research team has made assumptions considering the impact of policies. For example: if a policy aims at promoting the active modes of transportation, we have to apply two assumptions:

- How much this policy is expected to reduce the volume of motorized passenger transport?
- Will this change be achieved throughout the area in assessment, or just some parts of it?

In principle, it would be possible to build in the tool some assumptions on the policy impacts regarding the abovementioned questions. However, the same policy may have a very different kind of impact in urban and rural areas, not to mention the difference between the countries. This would likely make the results look arbitrary, and the linkage between the inserted data and the results would be hidden from the users.

The practise of setting numeric targets for the policies would support systematic assessment of GHG emissions as well as the cost-benefit analyses supporting the decision-making. The impact assessment can also utilize a range of values that the GGIA tools converts into GHG emissions.

5.2.3 Proposals on the next steps

The QGasSP project team proposes the following initiatives to develop the practises of GHG quantification for spatial planning:

a) Developing a consistent LULUCF sector quantification method for cities and territories, i.e. for any area smaller than country. This method should be detailed enough to make a difference between various land use types in urban environments, including the carbon sinks of urban vegetation.

b) Creating and maintaining a new European dataset to provide a coherent basis for reliable future projections of GHG emissions, with a respective content than the EU reference scenario 2016 report (Capros et al, 2016).

c) Develop a method to reliably allocate the transport activity by the boundaries of regions and cities; similar to *British Sub-national consumption statistics, Methodology and guidance booklet, September 2021* (UK Department for Business, Energy & Industrial Strategy, 2021) or the Finnish ALIISA database which provides data on transport activity per vehicle type and per municipality (VTT, 2021). This could be based on GIS or urban digital twins.

d) Promote cities and regions to conduct their own local HBS following the COICOP classification. This would allow the global emissions to be assessed purely for their region. This could uncover specific modalities in the consumption-profiles of residents that differ from the national picture.

e) Develop ESPON handbook on the GHG quantification in SEA.

Concerning the GGIA tool development, the following steps should be considered:

a) Provide support to compare different policy scenarios.

b) Provide geographical support to create the necessary input values for the land use module, using existing land-use and soil maps;.

c) Provide more extensive support to create a local dataset including metadata with background information on the local datasets.

d) Testing the tool more extensively in practice with regional and/or local stakeholders, for example, by using the C40 cities network.

e) Add a territorial quantification module for waste.

f) Add a territorial quantification module for embodied emissions.

5.3 Responses to RQ3 – prioritisation of local strategies

RQ3: How can a better scientific understanding be developed of how national, regional and local planning authorities can prioritise relevant GHG mitigation strategies, including through enhancing the effectiveness of the SEA process, to rapidly build political will for climate action.

Climate impacts assessment should be systematically integrated in the planning process. When various options are quantified in an early stage of the process, it is possible to seize the most feasible and efficient mitigation strategies. For decision-making, climate impacts shall be evaluated against other relevant aspects such as costs and public acceptance.

GGIA tool supports the use of back-casting method to evaluate a single policy in the context of other developments and climate commitments. When the future target is set, the tool can be used to specify alternative paths to reach step-by-step the climate target by the selected year. On the territorial side, the weighting of the climate action in various emission sectors can also be varied.

As the strategic environmental assessment is being applied throughout Europe and as the SEA Directive sets out a common procedure for spatial and strategic sectoral plans, it can be considered as one of the principal ways by which GGIA tool can gain widespread adoption.

Similarly to the GHG quantification of policies in the case study pilots, GHG quantification can help to choose between alternative policies and to prioritize the local strategies. Here the application of local data is crucial: if GHG quantification is carried out with national average data, the results also reflect the policy impacts on a national level, and some unique territorial or local GHG mitigation potentials may not be recognized.

References

Afionis et al (2017) Consumption-based carbon accounting: does it have future?. Wiley Interdisciplinary Reviews: Climate Change, 8 (1) (438).

Arioli et al (2020) The evolution of city-scale GHG emissions inventory methods: A systematic review. Environmental Impact Assessment Review.

Balouktsi M (2020) Carbon metrics for cities: production and consumption implications for policies. Buildings and Cities, Volume 1 (1), pp. 233–259.

Broekhoff et al (2019) Estimating consumption-based greenhouse gas emissions at the city scale. A guide for local governments. Stockholm Environment Institute. Available at: https://www.sei.org/wp-content/uploads/2019/03/estimating-consumption-based-greenhouse-gas-emissions.pdf (Accessed 26 April 2022).

Brunet-Navarro P, Jochheim H and Muys B (2016) Modelling carbon stocks and fluxes in the wood products sector: a comparative review. Global Change Biology, Volume 22, pp. 2555–2569.

BSI (2013) PAS 2070:2013 specification for the assessment of greenhouse gas emissions of a city - Direct plus supply chain and consumption-based methodologies.

C40 (2018) Consumption-based GHG emissions of C40 cities.

C40 (2019) Defining Carbon Neutrality for Cities & Managing Residual Emissions. Cities' Perspective & Guidance., New York/London: NYC Mayor's Office of Sustainability; C40 Cities Climate Leadership Group.

Capros P (2016) EU Reference Scenario 2016. Energy, Transport and GHG emissions. Trends to 2050. European Commission. Directorate-General for Energy, Directorate-General for Climate Action and Directorate-General for Mobility and Transport.

Chen et al (2020) Physical and virtual carbon metabolism of global cities. Nature Communications, Volume 11(1), pp. 1–11.

Chen et al (2020) Urban carbon footprints across scale: Impoartant considerations for choosing system boundaries. Applied Energy, Volume 259.

Cherubini F (2009) Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. Resources, Conservation and Recycling, Volume 53(8), pp. 434–447.

Climate Action Plan 2019 (2019). Available at: https://www.gov.ie/en/publication/ccb2e0-the-climate-action-plan-2019/ (Accessed 23 October 2021).

Climate Change Act Finland 609/2015 (2015). Available at: https://www.finlex.fi/fi/laki/kaannokset/2015/en20150609.pdf (Accessed 21 October 2021).

Committee on Climate Change (2019) Reducing emissions in Northern Ireland.

Copernicus Land Monitoring Service (2021) *Corine Land Cover (CLC) 2018, Version 2020_20u1.* Available at: https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=metadata (Accessed 15 April 2021).

Dahal K and Niemelä J (2017) Cities' Greenhouse Gas Accounting Methods: A Study of Helsinki, Stockholm, and Copenhagen. MDPI, 5(31).

DEFRA (2019) 2019 Government greenhouse gas conversion factors for company reporting. Methodology paper for emission factors. Final Report. London: Department for Business, Energy & Industrial Strategy.

DEFRA (2020) Conversion factors. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020 (Accessed 23. 10. 2021).

Department for Regional Development (2012) Regional Developoment Strategy RDS 2035. Building a Better Future, Belfast: Department for Regional Development.

Department for Regional Development (2015) Northern Area Plan 2016. Coleraine: Causeway Coast and Glens Borough Council.

Department of Environment, Climate and Communications (2021) Climate Action and Low Carbon Development Bill 2021. Available at: https://www.gov.ie/en/publication/984d2-climate-action-and-low-carbon-development-amendment-bill-2020/ (Accessed 23 October 2021).

Department of the Environment (NI) (2016) Northern Area Plan 2016. Available at: https://www.infrastructure-ni.gov.uk/topics/planning/northern-area-plan-2016 (Accessed 23 October 2021).

Doick et al (2017) Valuing Edinburgh's Urban Trees. An update to the 2011 i-Tree Eco survey – a report of Edinburgh City Council and Forestry Commission Scotland.

EEA (2013) TRACCS dataset. Available at: https://www.eea.europa.eu/data-and-maps/data/external/traccs (Accessed 23 October 2021).

EEA (2020) 2017 CO2 emission intensity of electricity generation.

EEA (2021) Annual European Union greenhouse gas inventory 1990-2019 and inventory report 2021. EEA/PUBL/2021/006.

Eggleston et al (2006) IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Japan: IGES.

Emisia (2021) COPERT 4. Available at: http://emisia.com/products/copert-4 (Accessed 23 October 2021).

EMRA (2019) Regional Spatial and Economic Strategy for the Eastern and Midland Region.Available at: https://emra.ie/final-rses/ (Accessed 23 October 2021).

Erickson and Morgenstern (2016) Fixing greenhouse gas accounting at the city scale. Carbon Management, 7(5–6), pp. 313–316.

ESPON EGTC (2020) Terms of Reference – "Quantitative Greenhouse Gas Impact Assessment Method for Spatial Planning Policy (QGasSP)", Technical and Administrative Terms and Conditions. ESPON EGTC.

ESPON (2020) Terms of Reference – "Quantitative Greenhouse Gas Impact Assessment Method for Spatial Planning Policy (QGasSP)", Technical and Administrative Terms and Conditions. ESPON EGTC.

European Commission (2001) SEA Directive.

European commission (2020) SEAP Guidebook part 2.

European Commission (2021) Household Budget Surveys. Available at: https://ec.europa.eu/eurostat/web/household-budget-surveys/database (Accessed 15 April 2021).

European Soil Data Centre (2013) European Soil Database Derived data. European Commission Joint Research Centre.

EXIOBASE Consortium (2021) EXIOBASE. Available at: https://www.exiobase.eu/ (Accessed 15 April 2021).

Fraunhofer, CE Delft, Ramboll (2020) Methodology for GHG Efficiency of Transport Modes, Karlsruhe: Fraunhofer-Institute for Systems and Innovation Research ISI.

GISPO (2018) Available at: https://github.com/GispoCoding/assessclimateimpact (Accessed 23 October 2021).

GOV.UK, 2021. Road transport energy consumption at regional and local authority level in 2019 (in tonnes of oil equivalent). Available at: https://www.gov.uk/government/statistics/road-transport-energy-consumption-at-regional-and-local-authority-level-2005-2019 (Accessed 23 October 2021).

Government, S., 2009. Climate Change (Scotland) Act 2009. *Explanatory notes.* Scottish Government.

Greenhouse Gas Protocol (2014) Global Protocol for Community-Scale Greenhouse Gas Emission Inventories: An Accounting and Reporting Standard for Cities.

Hastio P (2019) Tampereen ilmastovaikutusten arviointityökalu suunnittelun tukena.

Heinonen J, Ottelin J, Ala-Mantila S, Wiedmann T, Clarke J, Junnila S (2020) Spatial consumption-based carbon footprint assessments - A review of recent developments in the field. Journal of Cleaner Production, 256, 120335.

Heinonen et al (2020) Spatial consumption-based carbon footprint assessments - A review of recent developments in the field. Journal of Cleaner Production, 256(120335).

Heinonen J (2011) Dense downtown living more carbon intense due to higher consumption: A case study of Helsinki. Environmental Research Letters, 6(3).

Heinonen J, Ottelin J, Guddisardottir, A, Junnila S (2022) Spatial consumption-based carbon footprints: two definitions, two different outcomes, Environmental Research Communications, 4(2), 025006.

Hiraishi T (2014) 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Switzerland: IPCC.

Iarnród Éireann (2021) IE_FOI_516 Response Letter.

ICCT (2015) From laboratory to road. A 2015 update on official and "real-world" fuel consumption and CO2 values for passenger cars in Europe. White paper., Berlin: ICCT International Council on Clean Transportation in Europe.

IPCC (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge and New York, NY(United Kingdom and USA): Cambridge University Press.

IPCC (2014) Fifth Assessment Report (AR5).

IPCC (2019) Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

IPCC (2021) EFDB - emission factor database. Available at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php (Accessed 15 April 2021).

IRENA (2018) Biogas for road vehicles: Technology brief, International Renewable Energy Agency.

Ivanova D and Wood R (2020) The unequal distribution of household carbon footprints in Europe and its link to sustainability. Global Sustainability, Volume 3.

Johnston C and Radeloff V (2019) Global mitigation potential of carbon stored in harvested products. PNAS, 116(29) pp. 14526–14531.

Kenworthy JR (2018) Reducing Passenger Transport Energy Use in Cities: A Comparative Perspective on Private and Public Transport Energy use in American, Canadian, Australian, European and Asian Cities.

Kuikman et al (2011) Policy options for including LULUCF in the EU reduction commitment and policy instruments for increasing GHG mitigation efforts in the LULUCF and agriculture sectors. Synthesis report., UK: Alterra, Wageningen University & Research Centre, The Netherlands.

Kymenlaakson liitto (2020) Carbon Neutral Kymenlaakso Region 2040.

Kymenlaakson Liitto (2021) Kymenlaakson liitto, aluesuunnittelu ja liikenne. Available at: https://www.kymenlaakso.fi/aluesuunnittelu-ja-liikenne/liikenne/liikennejarjestelmasuunnittelu (Accessed 23 October 2021).

Mäkinen E (2019) Tampereen ilmastovaikutusten arviointityökalun tekninen toteutus. Miten lähtöaineistosta tuloksiksi.

McElrone M (2019) Development of a Sustainable Energy Strategy for Rathlin Island.

McLaughlin N (2019) Developing a Sustainable Transport Strategy for Rathlin Island. Final Project Report., Belfast: Queen's University Belfast, School of Mechanical and Aerospace Engineering.

Meath County Council (2019) Climate Action Strategy 2019–2024. Meath County Council.

NFP3 (2014) National Planning Framework 3. Available at: https://www.gov.scot/publications/national-planning-framework-3/#:~:text=This%2C%20Scotland%27s%20Third%20National%20Planning%20Framework%20-%20NPF,that%20support%20sustainable%20economic%20growth%20across%20the%20country (Accessed 23 October 2021).

Nielsen et al (2020) MapEire: National Mapping of Greenhouse Gas and Non-greenhouse Gas Emissions Sources Project.

NIR Ireland (2021) Ireland. 2021 National Inventory Report. United Nations Climate Change.

Nottingham City Council (2019) Scatter.

PAS (2013) Specification for the assessment of greenhouse gas emissions of a city – Direct plus supply chain and consumption-based methodologies, UK: BSI.

Pledjerup, Nielsen, Bruun (2018) Spatial high-resolution mapping of national emissions. WIT Transactions on Ecology and the Environment, Volume 230.

Pledjerup, Nielsen, Bruun (2019) MapEire - Technical documentation report.

Pledjerup, Nielsen, Bruun (2019) MapEire - User manual.

Ramboll; C40 Cities Climate Leadership Group (2020) Urban Climate Action Impacts Framework: A Framework for Describing and Measuring the WIder Impacts of Urban Climate Action.

Scottish Government (2014) Scotland's Third National Planning Framework: Ambition - Opportunity - Place, Scottland: Scottish Government.

Scottish Parliament (2009) Climate Change Act, Scotland. Available at: https://www.legislation.gov.uk/asp/2009/12 (Accessed 23 October 2021).

Scottish Parliament (2019) Planning (Scotland) Act. (Accessed 23. 10. 2021).

Sharma et al (2011) Life cycle assessment of buildings: A review. Renewable and Sustainable Energy Reviews, 15(1).

Stadler et al (2018) EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables. Journal of Industrial Ecology, 22(3), pp. 502–515.

UBIGO (2019) Available at: https://github.com/ubigu/emission (Accessed 23 October 2021).

UK Climate Change Act (2008) legislation.gov.uk. Available at: https://www.legislation.gov.uk/ukpga/2008/27 (Accessed 23 October 2021).

UK Department for Business, Energy & Industrial Strategy (2021) Sub-national consumption statistics. Methodology and guidance booklet.

UK Department for Business, Energy & Industrial Strategy (2021) UK Greenhouse Gas Inventory 1990 to 2019: Annual Report for Submission under the Framework Convention on Climate Change, Harwell: UK Department for Business, Energy & Industrial Strategy.

Vayla (2021) Transport system planning.Available at: https://vayla.fi/en/transport-network/transport-system/transport-system-planning (Accessed 23 October 2021).

VTT (2021) LIPASTO. Available at: lipasto.vtt.fi (Accessed 23 October 2021).

Wende et al (2012) Climate change mitigation and adaptation in strategic environmental assessment. Environmentla Impact Assessment Review, Volume 32, pp. 88–93.

World Resources Institute; C40 Cities Climate Leadership Group; ICLEI - Local Governments for Sustainability (2014) Global Protocol for Community Scale Greenhouse Gas Emission Inventories, USA: World Resources Institute.

Annex

A1 The ESPON GGIA tool Methodology

A2 Final case study report: County of Meath, Ireland

A3 Final case study report: Rathlin Island, Northern Ireland

A4 Final case study report: City of Edinburgh, Scotland

A5 Final case study report: Kymenlaakso Region, Finland

A6 The ESPON GGIA tool. User manual

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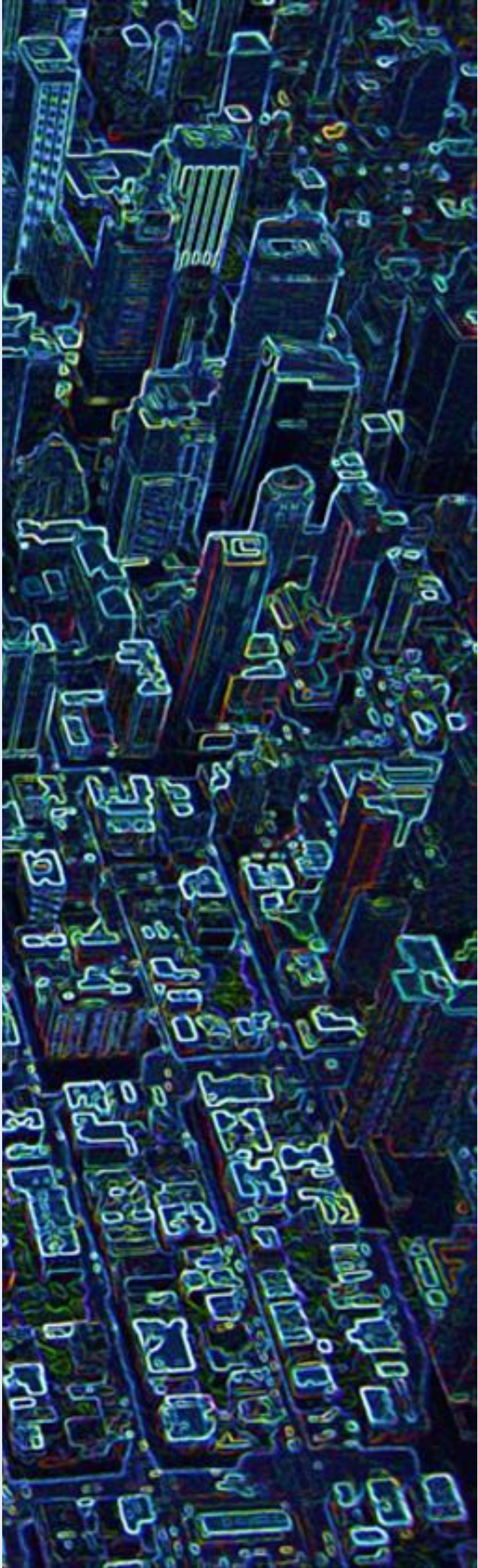

ESPON 2020

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