eurac research

GHG Accounting: Emission Factors Related to Eurac Research Business Travel

Version 1 / September 2021-May 2022

Giulia Chersoni,
Roberto Vaccaro,
Andrea Nollo,
Wolfram Sparber

Content

Introduction

Eurac Research aims to include in the PIS system a CO_2 emissions calculator for business travel with the objective of making collaborators conscious of the environmental impact of their activities. The overall aim is to raise the environmental awareness of Eurac Research's collaborators and to collect data to be used to inform strategies to reduce the carbon footprint of Eurac Research activities. Within the Institute for Renewable Energy (RENENE), the Urban and Regional Group has already started working on a similar project gathering information and expertise. In light of this, it has been agreed that RENENE will conduct further research to identify the most relevant CO_2 accounting methods and to collect relevant data to perform the analysis. For this purpose, existing GHG accounting standard and methodologies have been reviewed, current datasets for calculating individual travel emissions compared, and a set of emission factors selected. The selected data have been chosen based on the transparency, consistency, comparability, completeness, and accuracy of the dataset.

The document is organized as follow: Chapter 2 sets the historical context and identifies the main existing methodologies. It then illustrates our approach and provides the first feedback on the existing PIS system. Chapter 3 contains a brief description of the tool and methods identified, while chapter 4 contains the reference to specific datasets. Finally, chapter 5 summarises the conclusion and reports the selected data to be used in the PIS system to calculate the CO_2 emissions of Eurac Research's business travels.

1 Research approach and methods

The objective of the analysis is to account for the emissions generated by business trips only. Emissions related to commuting to and from work are not considered. The mode of transport investigated are related to road transport, flights and train.

Methods to calculate travel emissions at individual level can be found in numerous carbon footprint calculators and tools operating also at corporate or institutional level. These tools can be considered as an evolution of the more general - national or regional - emissions inventories and from them they draw methodologies and approaches.

In consideration of the predominant common base on emissions inventories before introducing the followed research approach the main relevant methodological for such inventories are investigated.

1.1 Relevant general methodologies and standards

INTRODUCTION AND BRIEF HISTORICAL BACKGROUND

Emissions inventories are ways to systematically collect and organise pollutants emissions. Historically, the initial input for their development was the need to know and manage the emissions of the main pollutants with local and transnational impact, i.e., SOx and NOx, respectively, acid rain and urban smog. In 1979, 32 countries in the pan-European region signed the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP) within which the European Monitoring and Evaluation Programme (EMEP) was established[1,2].

In 1985, as part of the EMEP, the CORINAIR (CoORdination Information AIR) methodology was developed, one of the first tool for collecting and cataloguing data on pollutant emissions, which focus was on air pollutants with a local impact. Over the years, CORINAIR followed the evolution of air pollution studies, gradually including PM10, CO_2 ("global pollutant") and other pollutants.

Emission inventories are still used today for controlling local air quality. Yet, they also serve as tools for energy and climate analysis and planning, for the development of emission reduction measures and their evaluation, for awareness raising and as communication tools.

Particularly the last two points have, more recently (early 2000), led to the development of Carbon Footprints tools at various scales which embraces also wider environmental concerns.

1 EMEP https://www.emep.int/index.html
2 UNECE https://unece.org/convention-and-its-achievements

MAIN METHODS AND APPROACHES

1.1.1 EMEP/CORINAIR

As mentioned before, it is one of the first calculation methods. It is currently also one of the most widely used methodology for collecting emissions data in Italy[3], as it is the reference used by ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) for the compilation of regional and national emissions inventories.

Methodology

For the road transport the guidelines contain a complex methodology which is supported by COPERT (COmputer Programme to calculate Emissions from Road Traffic), a traffic emission calculation software whose development is coordinated by the European Environment Agency (EEA).

The software calculates emissions, disaggregated by vehicle type, based on: vehicle type (fuel type, year of manufacture, engine capacity for light vehicles or motorbikes and weight for goods vehicles), average speed, length of the stretch of road travelled, presence or absence of the preheating cycle, type of road travelled (urban, suburban, motorway), ambient temperature.

Flights are calculated based on Landing and Take-off cycle (LTO) referring only to local impacts and not considering the destination of the flight. Similarly, for train the methods consider only emissions generated on the territory.

Relevance for this study

Given the complexity of the approach for the road sector, its use is not suited for the purpose of this project. Flights and trains method are also not of relevance.

1.1.2 IPCC

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body to study global warming. It was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP).

In 1995, it published three volumes containing methods and data for calculating greenhouse gas emissions. The publication has been revised in the years 1996, 2006 and 2019.

These guidelines are the reference for the United Nations Framework Convention on Climate Change (UNFCCC) and for the creation of emission inventories developed within that frame.

Methodology

Distinction into tiers

The guidelines introduce the concept of Tier, which is used also by the EMEP guidelines[4]. A tier represents a level of methodological complexity. Tier 1 is the basic method; Tier 2 is intermediate, and Tier 3 is the most demanding in terms of complexity and data requirements.

---

3 The other widespread methodology is inspired by the SEAP/SECAP Covenant of Mayors which has been used in more than 2000 municipalities in Italy to develop Sustainable Energy Action Plans or, more recently Sustainable Energy and Climate Action Plans

4 It has not been further investigated whether that subdivision was originally to be found in the first IPCC document or in the initial EMEP Long-range Transboundary Air Pollution (LRTAP) guidelines.

The tier classification applies for the different types of transport activity. Of relevance for this study are road, air, and railways. In general tier 1 refer to the availability of an aggregate data e.g., total fuel consumed per type of fuel, while upper tiers might refer to finer disaggregation of those data accordingly to more detailed information (e.g., characteristics of the vehicle such as displacement, power etc.).

Calculation methods

IPCC guidelines contain a specific chapter on mobile combustion, which has not been updated in the 2019 version[5] and therefore the reference remains to the 2006 version.

In general, calculation methods require information on the extent to which a specific human activity (referred to as activity data or AD) takes place. For example, fuel consumption in the mobility sector or number of animals breeds (livestock) in agriculture.

This information is multiplied a by coefficients that quantify the emissions per unit of activity and are called emission factors (EFs).

The basic equation (Tier 1) is therefore: Emissions = AD x EF

IPCC methods are national methods and do consider only the emission directly emerging from a specific activity, not the upstream chain activities nor the indirect emission are considered (otherwise the sum of the different national account would lead to double counting). Indirect emission from electricity is not considered too.

In most of the cases the EFs refer to the type of fuel and is expressed in kg of Green House Gas (considered separately i.e., CO_2, N2O, CH4) per unit of fossil fuel consumed, expressed either in physical units (e.g., litres, m3, kg, thus kg/l) or in energy units (J, Wh, thus kg/kWh) as shown in Table 1 for CO_2.

5 The reason for that has not been investigated.

Table 1 Excerpt from IPCC. CO_2 Emission factors per type of fuel

TABLE 3.2.1
ROAD TRANSPORT DEFAULT CO_2 EMISSION FACTORS AND UNCERTAINTY RANGES [a]

Fuel Type	Default (kg/TJ)	Lower	Upper
Motor Gasoline	69 300	67 500	73 000
Gas/ Diesel Oil	74 100	72 600	74 800
Liquefied Petroleum Gases	63 100	61 600	65 600
Kerosene	71 900	70 800	73 700
Lubricants [b]	73 300	71 900	75 200
Compressed Natural Gas	56 100	54 300	58 300
Liquefied Natural Gas	56 100	54 300	58 300

Source: Table 1.4 in the Introduction chapter of the Energy Volume.

Notes:
[a] Values represent 100 percent oxidation of fuel carbon content.
[b] See Box 3.2.4 Lubricants in Mobile Combustion for guidance for uses of lubricants.

It is of interest to notice that while "CO_2 emission factors are based on the carbon content of the fuel and should represent 100 percent oxidation of the fuel carbon" […] "CH4 and N2O emission rates depend largely upon the combustion and emission control technology present in the vehicles" (IPCC, 2006)[6].

From the fuel emission factor (kg/TJ) related to the combustion process, as referred in the table above which are specific for each type of fuel and can be considered constant, it is possible to derive composite emission factors such as the emission per km (kg/km) travelled by the vehicle. This is done by multiplying the fuel emission factor by an average consumption per unit of distance travelled (e.g., TJ/km). These composite emission factors depend on the average performance of the vehicles under different conditions and might therefore vary from the considered context and therefore among different studies. In the IPCC guidelines reference to such emission factors from US EPA (U.S. Environmental Protection Agency) are found. Accordingly, activity data can be expressed either in fuel consumed, or in km travelled.

Relevance for this study

The IPCC guidelines are one of the main references for calculating GHG emissions and as such cannot be disregarded. The scope (national emission inventories) diverges from that of this study (individual travel emissions) but the general approach and some main references, especially on emissions factors, are extremely relevant and set the basis for other tools and methods. Nevertheless, it can be anticipated that, in the development of the activities, the choices of reference tools fell on different approaches.

6 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2: Energy, Chapter 3 MOBILE COMBUSTION

1.1.3 GHG protocol (a Corporate Accounting and Reporting Standard)

The GHG protocol initiative was launched in 1998, by multi-stakeholder partnership of businesses, non-governmental organizations (NGOs), with the aim to "*develop internationally accepted greenhouse gas (GHG) accounting and reporting standards for business and to promote their broad adoption*"[7].

Methodology

Setting the boundaries

Unlike the previous two methods which refer to national inventories, the GHG Protocol applies to specific business units for which the boundaries of the analysis have initially to be identified. These are defined in terms of operations that the organization owns or controls and are divided in:

- **Scope 1: Direct GHG emissions** from sources owned or controlled by the organization such as boilers or vehicles.
- **Scope 2: Electricity indirect GHG emissions** from purchased electricity, consequence of an organisation's energy use that occur at sources the organisation does not own or control (self-produced electricity is obviously considered under Scope 1 if produced with fossil fuels).
- **Scope 3: Other indirect GHG emissions** consequence of the organization's actions that occur at sources an organisation does not own or control and are not classed as Scope 2 emissions (emissions that are 'embodied' in a product or service). Examples of Scope 3 emissions are business travel by means not owned or controlled by an organization and the emissions associated to the extraction, production, and transportation of, for example, purchased materials and fuels. Scope 3 therefore might include life cycle analysis of products.

Calculation methods

Three calculation methods are reported for business travels (GHG Protocol, 2013a):

- **Fuel-based method,** which involves determining the amount of fuel consumed during business travel and applying the appropriate emission factor for that fuel.
- **Distance-based method**, which involves determining the distance and mode of business trips, then applying the appropriate emission factor for the mode used.
- **Spend-based method**, which involves determining the amount of money spent on each mode of business travel transport and applying secondary (EEIO) emission factors.

Relevance for this study

Many of the tools and calculators considered (see Section 2.1) do refer to this methodology.

The methodological approach most relevant for this study is the distance-based approach that involves multiplying the activity data expressed in vehicle-kilometres or person-kilometres travelled by vehicle type, by the emission factors per km (kg/km). The distance-based approach is the most suitable to the PIS system as it retains information on the distance travelled by Eurac Research's collaborators during business travels.

7 https://ghgprotocol.org/

1.1.4 ISO standards

International Organization for Standardization (ISO) standards are a set of specifications and rules agreed by international expert "that describes the best way of doing something"[8]. *ISO "is the world's largest developer of voluntary international standards, and it facilitates world trade by providing common standards among nations"* [9].

Methodology

Methodologies have not been investigated in detail since they are complex and require access to specific databases.

Relevance for this study

Given their complexity they are not of direct relevance for the suggested calculation methods but have been briefly introduced and presented because some of the tools and calculators considered in this document do refer to these methodologies.

In particular, worth mentioning are the ISO standards referring to the ISO 14064 family (1,2,3) on "1) Greenhouse gases specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals; 2) Monitoring and reporting and 3) Verification and validation of greenhouse gas statements".

1.1.5 ICLEI methodologies

A further methodology is the one at the base of the Covenant of Mayors UE initiative, which refers to ICLEI (International Council for Local Environmental Initiatives) documentation and tools.

The Covenant of Mayors is one of the most relevant recent initiatives regarding quantification of emissions and raise of environmental awareness. Towards the end of 2019, out of the 7913 Italian municipalities surveyed by ISTAT, 4,608 are members of the "Covenant of Mayors" initiative and developed a Sustainable Energy and Action (and Climate in the new version) Plan.

1.2 Research approach adopted

An emissions accounting tool should generally meet the following requirements: transparency, consistency, comparability, completeness, and accuracy. Our primary goal has been to ensure that all five of these criteria are met, whenever possible. The initial emphasis has been placed on transparency, comparability, and completeness (**consistency**, to some extent, is ensured by always applying the same approach, so it can be seen as intrinsically given when a specific method is chosen). The research was therefore directed towards existing tools that provided information regarding the methodology and the reference data used (**transparency**), allowed to consider different types of transport modes (one aspect of **completeness**) and were widely used and adopted (**comparability**). In anticipating briefly the results, it emerges that, at the international level, there does not seem to be one tool that stands out and provides complete comparability among all the different tools. Considering the objective of the task - inclusion of GHG accounting for business travel in the PIS system - and the limitations of the information that can be acquired in the PIS filling-in process, it was accepted that the tool will present a not absolute level of **accuracy**, thus introducing some simplifying assumptions that will be discussed and illustrated in the results section.

8 https://www.iso.org/standards.html
9 https://en.wikipedia.org/wiki/International_Organization_for_Standardization

The research started by investigating the general methodologies describing how emission from different mode of transport could be calculated (section 1.1). While in most of the cases these methodologies could be applied directly to road transport emission calculations, their use for car, trains or flights - together the three main categories of relevance for this project - would be too cumbersome, requiring the access to datasets and the application of articulated calculations, both beyond the scope of this analysis. For this reason, the focus has been set on exploring existing simplified instrument and methods.

The research has identified various tools (section 2.1), some of them specific to a mode of transport only: road, train or aviation. For consistency reasons, i.e. internal coherence of emission factors and methodologies, our focus has been set on tools and datasets offering the whole spectrum of travels modality avoiding trying to create a patchwork of different single methods.

The most common method for calculating emissions multiplies activity data (AD) to the emission factors (EF) (IPCC). The activity data represents the quantity of units of fuel consumed or the estimated distance travelled. In the former case, EF refers to the quantity of GHG emission per unit of fuel considered as standards given. Indeed, there are established emission factors per unit of fuel (i.e., both physical (liter, kg or m^3) and energy content (Wh, J), e.g., CO_2 emissions in kg/kWh) based on laboratories analyses and calculations. In the latter case, composite EFs are derived: standard emission factors per unit of combustible (e.g., kg/litre) transformed considering the average fuel consumption per unit of distance (e.g., litre/km or kWh/km). The latter is subjected to numerous variables and factors (particularly for aviation and train activities) and is therefore subject to many changes in space and time and should be revised regularly. This variability resulted in the need in our research to identify tools with robust references.

Moreover, the initial fuel emission factors are differentiated according to the process taken into account:

- **Standard IPCC emission factors** refer to emissions generated during the combustion process only (as explained above in the paragraph on IPCC). IPCC guidelines reports emissions for the main GHGs such as CO_2, CH_4 and N_2O expressed in CO_2 equivalent EFs.
- **Life Cycle Assessment (LCA) emissions factors** consider also the emissions generated by the upstream production chain (cradle-to-gate) and are **calculated with LCA methods**.

In the transport sector, these two terms translate into Tank-to-Wheels (TTW) emissions, generated only in the combustion process, and into Well-to-Wheels (WTW) emissions. The latter, similar to LCA, takes into account both the combustion process and all the production processes in the upstream chain of a fuel or energy vector. The WTW analysis differs from the LCA since it only considers the emissions generated in the different processes (extraction, transport, refining, etc.) of an energy vector and it does not consider the emissions involved in building the facilities that support those processes. Since the focus is on energy vectors, the emissions related to the construction of the vehicles are also not considered[10].

The present study considers only the Tank to Wheels (TTW) GHG emissions, associated with the burning of the fuel in the vehicle while running and follows the GHG Protocol accounting methodology. This is consistent with the minimum standards set by the GHG Protocol technical guidance for calculating Scope 3 emissions (GHG Protocol, 2013a). We do not exoclude that in the future the analysis might also account for the production processes' emissions.

10 https://joint-research-centre.ec.europa.eu/welcome-jec-website/jec-activities/well-wheels-analyses_en

1.3 Feedback on PIS system

Parallel to the literature review, the activities in this study have also involved the analysis of the existing PIS system for the identification of relevant data and parameters to be investigated and the inclusion of the latter in the new system. This has been a continuous process with periodical meetings among RENENE, Health, Safety & Environment department and ICT representatives. Minutes and documentation emerged during this process are not included in this document.

2 Collection of carbon footprint calculators' examples

There is a wide range of emissions calculators available online today. In the following section we report the most relevant ones. Of importance for our analysis are those for companies and universities. For the purpose of comparison we also present information from general calculators for individuals and families. The reported calculators are divided in those which give access to the source of data and methodology and those which do not.

2.1 With data for calculation

2.1.1 ICAO Carbon Emissions Calculator

ICAO (Uniting Aviation UN specialized agency) has developed a methodology to calculate the CO_2emissions from air travel for use in offset programme. The ICAO Carbon Emissions Calculator[11] allows passengers to estimate the emissions attributed to their air travels.

Methodology

The ICAO Carbon Emission Methodology (2018)[12] applies the best publicly available industry data to account for various factors such as aircraft types, route specific data, passenger load factors and cargo carried.

The CO_2 emissions per passenger take into consideration the load factor and are based only on passenger operations (i.e. fuel burn associated with belly freight is not considered). Steps for the estimation of CO_2 emissions per passenger:

- Step 1: Estimation of the aircraft fuel burn
- Step 2: Calculation of the passengers' fuel burn based on a passenger/freight factor which is derived from RTK data
- Step 3: Calculation of seats occupied (assumption: all aircraft are entirely configured with economic seats). Seat occupied = Total seats * Load Factor
- Step 4: CO_2 emissions per passenger = (Passengers' fuel burn * 3.16) / Seat occupied

11 https://www.icao.int/environmental-protection/Carbonoffset/Pages/default.aspx
12 https://www.icao.int/environmental-protection/CarbonOffset/Documents/Methodology%20ICAO%20Carbon%20Calculator_v11-2018.pdf

Note: for flights above 3000 km, CO_2 emissions per passenger in premium cabin = 2 x CO_2 emissions per passenger in economy.

ICAO has been conducting studies on regional differences in international airline operating economics to estimate and compare airline operating cost and revenues in different regions of the world, using a unique database which includes fuel consumption. The fuel consumption in that database is estimated for each airline, on each sector of a scheduled flight, based on information reported by airlines for their scheduled operations. The fuel consumption by aircraft type is estimated using ICAO developed equation updated based on publicly available information. Most of the data come from the US Department of Transportation (DOT), which requires most American airlines to report financial and operating information. The methodology presents the average fuel consumption by stage length based on the ICAO fuel consumption formula.

2.1.2 UK Greenhouse Gas Reporting: Conversion Factors (2021) - DEFRA

The Department for Business, Energy & Industrial Strategy each year relies on the updated version of the "UK Government Greenhouse Gas Conversion factors for Company Reporting" that represent the official version of UK Government conversion factors[13]. The UK GHG conversion factors are developed as part of the NAEI (National Atmospheric Emissions Inventory) contract, managed by Ricardo Energy & Environment, which includes:

- UK Air Quality Pollutant Inventory (AQPI)
- UK Greenhouse Gas Inventory (GHGI):

    Values for the non-carbon dioxide (CO_2) GHGs, such as methane (CH_4) and nitrous oxide (N_2O), are presented as CO_2equivalents (CO_2e), using Global Warming Potential (GWP) factors from the Intergovernmental Panel on Climate Change (IPCC)'s **fourth assessment report** (RA4) (GWP for CH_4= 25, GWP for N_2O = 298). This is consistent with reporting under the United Nations Framework Convention on Climate Change (UNFCCC).

The 2021 GHG Conversion Factors are for use with activity data that falls entirely or mostly within 2021. The factors will continue to be improved and updated on an annual basis with the next publication in June 2022.

Methodology

The methodology (Government, 2021) follows the categorization of the GHG Protocol, listing each company activity as Scope 1 (direct), Scope 2 (energy indirect), or Scope 3 (other indirect). This is consistent with the GHG Inventory from UK National Inventory Report 2021 (UNFCC), upon which the 2021 UK GHG conversion factors are based. It collects the conversion factors to calculate GHG emissions from a range of activities, including energy use, water consumption, waste disposal and recycling, and transport activities.

The GHG emission can be calculated following two different GHG Protocol (2013b) methodologies:

Fuel-based methodology:

Emissions = Total energy consumption (fuel, electricity) * Emission Factors (fuel, electricity)

Distance-based methodology:

13 https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting

Emissions = Total activity for vehicle category (in km) * Emission Factors

2.1.3 Planet and People University League (UK)

People and Planet[14] is the largest student network in the UK working for social and environmental justice. The People and Planet University League[15] is a comprehensive and independent league of UK Universities ranked based on their environmental and ethical performance. It rewards universities based on their environmental policies, associated strategies (specific and time-bound targets) or performance indicators (covering all major aspects of environmental management).

Methodology

The carbon management approach follows the GHG protocol for Corporate Accounting and Reporting Standard. Travel emission factors are categories under the Scope 3 (other indirect) category, accounting for both business travel and staff and student commuting. Business travel account for the air travel, road vehicle travel, rail travel, taxi travel, bus and coach travel, and ferry travel. Each university, based on their data availability, can calculate its travel associated emissions based on the following methodology:

- Amount of fuel consumed
- Distance travelled
- Amount of money spent
- Average emissions estimated from commuting patterns

The emission factors data might be collected from:

- Transport emission sourced from suppliers based on the amount of fuel consumed or distance travelled
- Government published carbon conversion factors
- Environmentally extended input-output database to estimate the carbon emissions based on the amount of money spent

Among the suggested tool to calculate the emission factors, the DEFRA 'Greenhouse Gas Reporting: Conversion Factors (2017)"[16] was suggested as the most updated and comprehensive set of emission factors when the document was written.

2.1.4 Bilan Carbone© Clim'Foot tool

Clim'Foot[17] is a European project aiming at implementing public policies to calculate and reduce an organisations' carbon footprint. The project consortium includes the scientific institution of five European countries: Italy, France, Croatia, Greece, Hungary. The project outcome consists of 5 national databases containing at least 300 emission factors, including 150 emission factors specific for each country.

14 https://peopleandplanet.org/
15 https://peopleandplanet.org/university-league
16 https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2017
17 https://www.climfoot-project.eu/

Methodology

The Italian emission factors database has been developed following the IPCC guidelines, the GHG Protocol, and the ISO standards methodology as described in Section 1. It also refers to the LCA standards (ISO 14040/14044: 2006) and the European Commission recommendations (2013/179/EU) on common methods to measure and communicate the life cycle environmental performance of product and organizations[18]. The project output is the Bilan Carbone© Clim'Foot tool[19], an excel file with several spreadsheets containing fixed data and cases to fill in according to the sectors and the organization's activities (energy, transport, etc). One spreadsheet contains the emission factors used for the calculation and a final spreadsheet displays the results. The results might be extracted following GHG Protocol reporting, ISO 14069 reporting, and in CO_2 equivalent.

2.1.5 GHG Protocol - The GHG Emissions Calculation Tool

The GHG Protocol tools is a list of tools developed by GHG Protocol to enable companies to develop comprehensive and reliable inventories of their GHG emission[20]. The GHG Protocol tools include:

- Cross-sectors tools: applicable to many industries and business regardless of the sector
- Country-specific tools: customized for developing countries
- Sector-specific tools: applicable to specific industries such as aluminium, cement, iron and steel

The *Cross-sector tools* is the one more appropriate to use for companies to estimate their GHG emissions, which is based on the *GHG Emissions Calculation Tool*.

Methodology

The *GHG Emissions Calculation Tool* is a free excel-based tool from Greenhouse Gas Protocol and World Resource Institute (WRI) that helps companies estimate their GHG emissions based on the GHG Protocol[21]. The tool offers users a step-by-step process to estimate company emissions for specific cross-sectoral emissions sources, but it does not cover all potential GHG emissions sources within a company's inventory boundary. The tool is in its beta version and uses default emission factors, which vary country by country.

2.1.6 UNFCC - Greenhouse Gas Emissions Calculator

The UNFCC secretariat developed the GHG emissions calculators[22] to provide the general public a free up-to-date methodology for estimating GHG emissions. The UNFCC GHG Emissions Calculator aims to support organizations to estimate their GHG emissions to raise awareness and to promote climate actions. The data and information on the spreadsheet are for reference purpose only and the emission factors are publicly available on third parties' websites. The emission factors used to calculate business travels rated emissions retrieve the data from UK Greenhouse Gas Reporting: Conversion Factors (2021). The spreadsheet should not be used for certification purposes and does not replace a formal, tailored GHG inventory development process nor third-party verified GHG inventories.

18 LIFE CLIM'FOOT Deliverable A2.2: Methodology for constituting the National Databases
19 https://www.climfoot-project.eu/en/overview-0
20 https://ghgprotocol.org/calculation-tools
21 https://ghgprotocol.org/ghg-emissions-calculation-tool
22 https://unfccc.int/documents/271269

Methodology

The tool is a bottom-up spreadsheet that enable companies to calculate their CO_2 equivalent emission related to the organization activities. It is based on the GHG Protocol standard dividing the emission per Scopes. It permits to calculate the GHG emissions also for home office and food.

2.1.7 Mobilize Your City

The Mobilise Your City[23] is a partnership, launched at the COP21 in Paris in 2015, of nearly 100 partners for Sustainable Urban Mobility Plans (SUMPs) and National Urban Mobility Programs (NUMPs). The Mobilize Your City Emissions Calculator[24] supports cities and countries to project the GHG impact of their SUMPs and NUMPs. The tool has been developed by the Institute for German Energy and Environmental Research in cooperation with the German and French development agencies.

Methodology

The tool is a bottom-up spreadsheet model for greenhouse gas emission (GHG) calculations in the transport sector at the national and local level. It enables calculating GHG inventories of cities and countries as well as BAU "business as usual" scenarios and climate scenarios. The tool enables governments to calculate potential effects of national and urban transport policies on total GHG emissions, e.g. extension of public transport, subsidies for electric vehicles. The scope of the analysis is based on a territorial principle (all traffic within the city/country must be considered within the defined territory).

The emissions factor has been selected from a number of sources ranging from IPCC guidelines 2006, IEA statistics, and EMEP/EEA air pollutant inventories 2016.

2.1.8 Casa Clima CO_2 Calculator

The Casa Clima CO_2 calculator[25] calculates households CO_2 emissions associated to energy consumption, mobility habits, nutrition and other consumption habits in Germany and Italy. The tool uses different datasets for the German and Italian versions.

Methodology

The German version methodological source is "The CO_2 balance of the citizen research for an internet-based tool for creation personal CO_2 balances (2007)"[26] developed by the Heidelberg Institute for Energy and Environmental Research, while to the best of the authors understanding a methodological source for the Italian version is not available. The Italian data comes from the Italian UNFCC GHG inventory, and other dataset such as TREMOVE, WIOD, EUROSTAT end other calculations elaborated by KlimAktiv. It is based on the "territorial principle", while the German version in based on the "consumption principle". The territorial-based accounting includes the GHGs emissions and removals taking place within national territory, irrespectively of where the the goods consumed are produced. In the consumption-based approach, a source balance contains all emissions that arise due to the consumption of resources in the country: each sector is therefore responsible for the emissions that occur directly in the production process or in the provision of electricity and heat generated along he supply chain. A consumption balance also includes foreign trade to account for those emissions that result from outside the country's borders, which are changing in the course of globalization increasingly moving abroad.

23 https://www.mobiliseyourcity.net/
24 https://www.mobiliseyourcity.net/mobiliseyourcity-emissions-calculator
25 https://casaclima.co2-rechner.de/de_IT
26 https://www.klimaktiv.de/media/docs/Studien/20642110_uba_die_co2-bilanz_des_buergers.pdf

2.2 Without data for calculation

2.2.1 Planetly

Planetly[27] is an online software used for carbon management systems. Planetary software is a one-stop-shop for corporate carbon footprint that calculates the company carbon footprint under Scope 1, 2 and 3. It also offers reduction and offset services.

2.2.2 The 2030 Calculator

The 2030 Calculator[28] is a digital tool to calculate a products carbon footprint. The Calculator uses unique emissions factors for each of the product parts, material, packaging, transportation, as well as the energy consumed in the manufacturing process to determine its calculations. All calculations are cradle-to-gate (LCA) and self-declared. It is linked to UN Carbon Footprint Calculator for offsetting.

2.2.3 AG-TS Energy

AG-TS Energy offers consulting services for energy efficiency and saving, including an online calculator[29] to estimate the company CO_2 emissions.

2.2.4 UN Caron Footprint Calculator

The UN Carbon Footprint Calculator[30] calculates the CO_2 emissions associated to three main categories: household, transport (car, train, flight), and lifestyle. The UN calculator estimates households' emissions based on the latest country specific data available. The data are obtained from external and reliable sources such as EDGAR, EPA, Climate Watch, ICAO, and other organizations. The greenhouse gas emissions associated with different activities are recalculated in CO_2 equivalent to produce a uniform result. The calculator applies country-specific reference values for public services and for activities for which the user does not know its footprint.

27 https://www.planetly.com/
28 https://www.2030calculator.com/
29 https://www.ag-ts.energy/calcolo-impronta-carbonio-aziende/
30 https://offset.climateneutralnow.org/footprintcalc

3 Collection of datasets

The following section presents the datasets coming from the main tools identified in section 2.1 and other sources not associated with online or off-line tools for GHG emission accounting. All the datasets contain publicly available information on the emission factors to be used for business travel CO_2 accounting. For a meaningful comparison, the emission factors related to business travel are reported in Appendix A.

3.1 ICAO

The ICAO methodology estimates the amount of CO_2 emissions generated **by a passenger in a flight**. The dataset collects information on fuel consumption data for different flight fleets. To convert the fuel consumption in CO_2 equivalent emission it applies a conversion factor of 3.16 and weights the related passenger emission on seat occupied:

CO_2 emissions per passenger = (Passengers' fuel burn * 3.16) / Seat occupied

However, the dataset does not report the emissions factors for flight type or category. Therefore, the use of the dataset is subject to individual assumption about the fleet type to be used in the calculation. For this reason, the dataset is not reported in Appendix A, and it is not included among the suitable datasets for the project aims.

3.2 UK DEFRA - Greenhouse Gas Reporting: Conversion Factors (2021)

The 2021 GHG Conversion factors are reported in a separate spreadsheet that collects the emission factors for company related activities, updated on an annual basis. The business travel emission factors are reported under Scope 3 (indirect emissions), following the GHG Protocol Calculation Guidelines. Only the emission factors for vehicles under the company premises are reported under Scope 1 (direct emissions). The emission factors for business travel under Scope 3 do not account for the indirect/WTT (Well-To-Tank) emissions from fuels[31], according to GHG Protocol Scope 3 Calculation Guidelines.

Here below a brief description of the assumptions used to define the emission factors based on the distance-based method. The GHG emission are reported in units of CO_2 equivalent, using the IPCC AR4 GWP data.

Business travel-land: Car

The car emission factors are based upon data from Society of Motor Manufacturers and Traders (SMMT) for regulatory testing average carbon dioxide per kilometre (CO_2/km) and corresponding registrations in the UK by vehicle size (or market segment) and fuel type. The regulatory test procedures are currently under transition from the previous NEDC (New European Driving Cycle) to the new WLTP (Worldwide Harmonised Light Vehicle Test Procedure) which apply to new vehicle registrations with CO_2 emissions data based on tests. Vehicles registered in the EU from 2020 have WLTP-based regulatory CO_2 emissions

31 The indirect/WTT are the emissions 'upstream' from the point of use of the fuel that results from the extraction, transportation, refining, purification, or conversion of primary fuels to fuels for direct use by end-users.

values and these are used in the calculation of conversion factors where possible. However, most vehicles are registered before 2020 and so continue to use NEDC-based values.

NEDC does not account for "real-world" effects that can have a significant impact on fuel consumption. Therefore, an uplift factor is applied to convert the mean CO_2/km data to account for the real-world impacts[32]. WLTP based g CO_2/km factors used from 2020 onwards require a different uplift to account for the "real-world" effects.

The calculation of UK fleet average conversion factors for electric vehicles is based upon data obtained from the EEA CO_2 monitoring databases for cars and vans, which are publicly available (EEA, 2020a; EEA, 2020b). Reported electricity consumption for Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) up to the end of 2019 has still been based on the previous NEDC testing regime.

The approach used for the calculation of conversion factors for conventionally fuelled passenger cars is applied also to hybrid and electric vehicle.

CO_2 equivalent emissions: CO_2eq (kg/km) = Emission Factor * Number Km

Business travel-land: Taxi
The conversion factors for black cabs are based on data provided by Transport for London (TfL) on the testing of emissions from black cabs using real-world London Taxi cycles, and an average passenger occupancy of 1.5. This methodology accounts for the significantly different operational cycle of black cabs/taxis in the real world when compared to the NEDC (official vehicle type-approval) values, which significantly increases the emission factor by ~40% compared to NEDC.

The conversion factors (per passenger km) for regular taxis were estimated based on the average type-approval CO_2 factors for medium and large cars, uplifted by ~40%, based on TfL data, based on the different driving conditions compared to average car use, plus an assumed average passenger occupancy of 1.4.

Conversion factors for CH_4 and N_2O have been updated for all taxis based on the conversion factors for diesel cars from the latest UK GHG Inventory (Ricardo Energy & Environment, 2021). It should be noted that the current conversion factors for taxis still do not account for emissions spent from "cruising" for fares. Currently, robust data sources do not exist that could inform such an "empty running" factor.

Business travel-land: Bus
The 2015 and earlier updates used data from DfT from the Bus Service Operators Grant (BSOG) in combination with DfT bus activity statistics (vehicle km, passenger km, average passenger occupancy) to estimate conversion factors for local buses.

Combined figures based on data from DfT are used for non-local buses and coaches. In particular, the conversion factors for coach services were estimated based on figures from National Express, who provide most scheduled coach services in the UK. Actual occupancy for coaches alone is likely to be significantly higher.

Business travel-land: Train
The international rail factor is based on a passenger-km weighted average of the conversion factors of different Eurostar routes. The conversion factors were provided by Eurostar for the 2021 update, together with information based on the electricity figures used in their calculation. Conversion factors for electricity (in kg CO_2 per kWh) for the UK are based on the UK grid average electricity and the

32 These include use of accessories (air conditioning, lights, heaters etc.), vehicle payload (only driver +25kg is considered in tests, no passengers or further luggage), poor maintenance (tire under inflation, maladjusted tracking, etc.), gradients (tests effectively assume a level road), weather, more aggressive driving style, etc.

France/Belgium grid averages from the last freely available version of the IEA CO_2 Emissions from Fuel Combustion highlights dataset (from 2013). CH_4 and N_2O conversion factors have been estimated from the corresponding conversion factors for electricity generation, proportional to the CO_2 emission factors.

The national rail factor refers to an average emission per passenger kilometre for **diesel and electric trains** in 2019-2020. The factor is sourced from information from the Office of the Rail Regulator's National rail trends for 2019-2020 (ORR, 2020).

The emission factors report the CO_2 equivalent emission per person and kilometre in kg. Passenger/km factors are used when single passengers are travelling by means of mass transport (such as by train and airplane) and the aim is to report emissions on a single-person basis, not account for the whole vehicle[33].

CO_2equivalent emissions: CO_2eq (kg / PERSON) = Emission Factor * Number Km

Business travel-air: Flight
Conversion factors for flights calculated using the EUROCONTROL small emitter's tool. The tool is based on a methodology designed to estimate the fuel burnt for an entire flight, it is updated on a regular basis to improve accuracy whenever possible and has been validated using actual fuel consumption data from airlines operating in Europe. The tool is approved for use for flights falling under the EU ETS via the Commission Regulation (EU) No. 606/2010.

Average seating capacities, load factors and proportions of passenger km by the different aircraft types (subsequently aggregated to overall averages for domestic, short- and long-haul flights) have all been calculated from detailed UK Civil Aviation Authority (CAA, 2021) statistics for UK registered airlines for the year 2018. **Domestic** flights are defined as those flying within the country, **short-haul** within Europe, **long-haul** outside of Europe, and **international** flights between non-UK country destinations. The current definition, assume that all flights between the UK and Europe (excluding Moldova and Ukraine, but including the Channel Islands, Gibraltar, Greenland and Turkey) and between the UK and North Africa (Algeria, Egypt, Libya, Morocco and Tunisia) are short-haul. Flights between the UK and other destinations (North and South America, Asia including Russia, but excluding Turkey, most of Africa, Australasia, Moldova, and Ukraine) should be counted as long-haul. In earlier versions of the UK DEFRA conversion factors, it was suggested a "crude level" to assign all flights <3700km to short-haul and all >3,700km to long-haul, which definition was based on the maximum range of a Boeing 737.

The UK methodology consider also the seating class factors, i.e. economy, business and first class. The seating class factors are calculated based on the area of the plane each passenger takes up. Indeed, the efficiency of aviation per passenger km is influenced not only by the technical performance of the aircraft fleet, but also by the occupancy factor of the flight. Premium priced seating, i.e. first and business class, takes up considerably more room in the aircraft than economy seating and therefore reduces the total number of passengers that can be carried. This in turn raises the average CO_2 emissions per passenger km, which influence the observation that in the UK DEFRA (2021) dataset the emission factors for an average passenger are not decreasing with increased flight distance.

Freight transported on passenger services has also been accounted for. The UK Civil Aviation Authority (2021) data show that almost all freight carried by passenger aircraft is done on scheduled long-haul flights, making a significant difference in long-haul emissions factors. This also helps to explain why we do not observe a decrease in the emissions with increasing flight distances for average passengers' emissions factors.

33 Note the difference compared to vehicle km conversion factors that applies to a whole vehicle (such as a car) being used for business purposes.

The emission Factors reports the CO_2 equivalent emission per passenger km in kg. All the factors include the distance uplift of 8% to compensate for planes not flying using the most direct route (such as flying around international airspace and stacking). The emission factors refer to direct (non-stop) flights only.

CO_2 equivalent emissions: C CO_2eq (kg / PERSON) = Emission Factor * Number Km

3.3 IPCC - Emission Factor Database (EFDB)

The EFDB[34] have been developed by the IPCC project on the "Establishment of a database on GHG Emission Factors". EFDB is meant to be a recognised library, where users can find emission factors and other parameters with background documentation or technical references that can be used for estimating greenhouse gas emissions and removals. The overall objective of the EFDB is to be an always up-to-date companion for the IPCC Guidelines for National Greenhouse Gas Inventory that is seen as a worldwide resource for greenhouse gas inventory developers.

EFDB at present contains the IPCC default data (Revised 1996 IPCC Guidelines, IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry, 2006 IPCC Guidelines for National Greenhouse Gas Inventories and 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands), and data from peer-reviewed journals and other publications including National Inventory Reports (NIRs).

It exists an off-line version of the dataset[35]. The dataset is organized following the IPCC 2006 categories. The transport related emission factors are reported in the Energy category. The emission factors are divided by fuel and gases type and reported in the most appropriate unit. A CO_2equivalent aggregation is not provided. Therefore, in other to obtain CO_2 equivalent emission factors applicable to calculate business travel related emissions, an analysis should be performed. Moreover, it exists an elevated level of uncertainty and subjectivity to select the gases and fuel type emission factors best associated to the project needs, which is outside the project scopes.

3.4 EPA - GHG Emission Factors Hub

The Environmental Protection Agency (EPA) Center for Corporate Climate Leadership has developed an easy-to-use set of default emission factors for organizational greenhouse gas reporting[36]. The dataset includes updated emission factors collated from both EPA's Greenhouse Gas Reporting Program and the Center's technical guidance. The most recent version of the Emission Factors Hub (April 2021) includes updates to emission factors for upstream and downstream transportation, business travel, product transport and employee commuting, waste, and purchased electricity from EPA's Emissions & Generation Resource Integrated Database (eGRID).

GHG emission are not reported in units of CO_2 equivalent. To transform the data, it is mentioned to use the IPCC AR4 GWP data. Business travel related emission factors are reported under Scope 3 following the GHG Protocol Calculation Guidance. The conversion factors are intended for use in a distance base method as define in the Scope 3 Calculation Guidelines[37]. Following a brief description of the Business Travel emission factors assumption and data source divided by mode of transport.

34 https://www.ipcc-nggip.iges.or.jp/EFDB/main.php
35 https://www.ipcc-nggip.iges.or.jp/EFDB/downloads.php
36 https://www.epa.gov/climateleadership/ghg-emission-factors-hub
37 if fuel data are available the fuel related emission factors should be used following the fuel-based method.

- *Passenger Car*: Passenger car includes passenger car, minivans, SUVs and small pickup trucks. The CO_2, CH4 and N2O factors are reported in vehicle-mile. The emission data comes from the EPA (2020) Inventory of US GHG Emission and Sinks.
- *Rail*: Intercity rail emission factors for national average are reported in passenger-mile.
- *Air Travel*: The air travel emission factors are divided into short-haul, medium-haul and short-haul distance and are reported in passenger-mile. The data come from DEFRA 2020 version.

3.5 GHG Protocol – GHG Emission Calculation Tool

The dataset uses default, free to use and publicly available emission factors, which vary by country. In the current beta version, a separate sets of emission factors are available for the UK and US. The data are reported in CO_2 equivalent following a distance-based approach. The CO_2 equivalent emission are calculated based on the GWP data using both IPCC AR4 and AR5 data.

The emission factors related to business travel are derived from EPA GHG Emission Factors Hub (2018) and UK DEFRA (2019) datasets. In particular, the emission factors derived from the fuel consumption of the vehicle owned by the company is reported under Scope 1 and uses the EPA (2018) dataset by default. The emissions factors for Air Travel, Rail, Taxi and Car, reported under Scope 3, includes both the EPA (2018) and UK DEFRA (2019) conversion factors.

3.6 UNFCC - Greenhouse Gas Emissions Calculator

The UNFCC secretariat makes no representation to the accuracy, completeness, suitability or validity of any information in the dataset. The emissions factors used are publicly available data from third party websites.

The emission factors sources relative to business travels come from UK DEFRA (2020) and ICAO. Specifically, the DEFRA dataset is used to account for business travel on land and sea (Scope 3), Well-to-Tank fuels (WTT), and owned vehicles (Scope 1), while it uses ICAO Calculator for calculating GHG associated to flights. In case the organization has many flights related emission to calculate, it is possible to ask to the UNFCC support that applies a Radiating Forcing Index (RFI) equals to 1 in the calculation.

Following the specific assumptions for the business travel related emission factors:

- *Owned vehicle* (Scope 1): the emission factors are divided by fuel used and car size. Data are collected from UK DEFRA (2020). For Hybrid Plug-in and Hybrid Electric cars the portion of emissions correspondent to fuel is considered under Scope 1, while the portion of emissions correspondent to electricity is considered in Scope 2.
- *Business travel land and sea* (Scope 3): full set of factors for kg CO_2e coming from the UK DEFRA (2020).
- *Flights*: ICAO aviation carbon emission calculator recommended but possible to ask a UNFCC support if the organization has many flights to calculate (RFI = 1 applied).

3.7 BILAN CARBONE - LIFE Clim'Foot Project

The Bilan Carbone tool relies on different dataset.

The main source for developing the emission factors database for Italy are the following (Deliverable A2.2):

- The Italian National Inventory Report 2017 (NIR, 2016), for fuel, waste, direct emission from agriculture, product and process
- National database on transport, elaborated by ISPRA (2016)
- Leap Database (FAO, 2015)
- The Global Database of GHG emissions related to feed crops (FAO) for the agricultural product (FAO, 2015)

The Italian national database includes 180 country-specific emission factors and 120 European emission factors developed by the project partners[38]. The emission factors are converted in CO_2 equivalent using the GPW data from the IPCC AR5.

Analysing the national (Italian) database, the transport related emission factors come mainly from two sources: ISPRA (2014), valid for the year 2020, and UK DEFRA (2016), valid for 2017. The ISPRA (2014) database of average emission factors related to road transport is based on the estimates made for the national inventory of air emissions, annually elaborated by ISPRA as verification tool of the commitments made at international level on air protection.

- *Passenger cars*: ISPRA (2014) is the source for the emission factors related to passenger cars, divided by fuel type (i.e. gasoline, diesel and hybrid gasoline) for mix route.
- *Buses*: The Italian database collects also the mission factors for buses (only diesel) on any route, or for urban and rural for fuel mix.
- *Flights*: The UK DEFRA (2016) was the source for flights related emission factors (i.e. domestic, short-haul, long-haul).
- *Trains*: The Italian database does not report specific emission factors for business travel on rail. Those were recovered from the Bilan Carbone tool spreadsheet, which does not report the source of the data, but reports the conversion factors associated with different countries, including Italy.

3.8 Casa Clima CO_2 Calculator

The CasaClima calculators uses different data sources for the Italian and German version. For the Italian version the mean emissions per citizen are based on data coming from the Italian UNFCC GHG inventory, TREMOVE, WIOD, EUROSTAT, and other calculations elaborated by KlimAktiv, for which it is not possible to retrieve more detailed information on the emission factors used.

Contrarily, the methodology and specific data used for the German version are available in "The CO_2 balance of the citizen research for an internet-based tool for creation personal CO_2 balances (2007)"[39]. For the entire transport sector, it first determines the energy consumption in GJ and converts this into CO_2 emissions using suitable factors. It is important to note that the values calculated following the reported methodology do not exactly match with the results of the current online calculator. Only the

38 The data source for the EF collected by the Italian partners was the ELCD - European Life Cycle Database (JRC – EU).

39 https://www.klimaktiv.de/media/docs/Studien/20642110_uba_die_co2-bilanz_des_buergers.pdf

calculation for local transport mirror those reported in the methodology. The emission factors of the calculation tool refer to the year 2005 and will be updated in the coming years.

- *Passenger cars*: For cars the calculator is based on emission factors associated to the mid-size car. To compute the CO_2 emission for small cars and luxury cars, the consumption of the small car is reduce by a factor of 0.9 while a 30 percent is add for the luxury class (factor 1.3). The calculator assumes an average occupancy of 1.4 people. The emissions are differentiated by the vehicle-specific energy efficiency (kg CO_2/liter of fuel), which ranges from 3 to more than 13 l/100km, with the associated fuel factors to convert the fuel-based emission factors in distance-based emission factors. The emission factors for electric vehicle are not reported assuming that their share in the country vehicle fleet is absolutely marginal.
- *Buses*: For local transport the emission factor associated to long-distance buses is equal to 0.087 CO_2 equivalent (kg/km)
- *Flights*: The user states how many air trips he takes per year and how often he takes off (hence intermediate landings are also counted) and the distance covered. A certain amount of emissions is added for each start. The calculator distinguishes for the further emissions per kilometer not differentiating between intra-European and intercontinental flights. The starting point is the energy consumption at the start and during the flight, which is then converted into CO_2 emissions. The energy consumption is calculated as follows: Eflight = 0.7 GJ x takeoff(number) + 0.0022 GJ x flight-km. This results in emissions: CO_2 flight = Eflight x 0.065 kg/GJ

3.9 Ecoinvent database

For the sake of completeness in Appendix A we also reported the data from the ecoinvent database, a Life Cycle Inventory (LCI) database[40]. The repository covers a diverse range of sectors on global and regional level. It currently contains more than 18'000 life cycle inventory datasets, covering a range of sectors modelling human activities or processes. Each dataset in the ecoinvent database is attributed to a specific geographic location, e.g. country level, European level, Global level. For each dataset in the ecoinvent database, Life Cycle Impact Assessment (LCIA) scores for several impact assessment methods (such as "IPCC 2013", "EF v3.0", or "ReCiPe") and corresponding impact categories (such as "climate change", "human toxicity", "water use", or "land use") are available.

For a meaningful comparison we only report the emission factors associated with the carbon footprint for the "climate change" impact category following the IPCC 2013 method. Those can be assessed with different indicators, e.g. "global warming potential 20 years (GWP20)", "global warming potential 100 years (GWP100)", or "global temperature change potential (GTP100)". We used the GWP 100 years indicator to be consistent with the other datasets in order to ensure a meaningful comparison.

It is important to note that the carbon footprint emission factors under the ecoinvent database are not available for free. We have retrieved the data thanks to Eurac Research access to the database and its expertise on the LCA assessment methods. In Appendix A we report the emission factors associated with the TTW GHG emissions (IPCC 2013 methos, GWP 100 years). Those have been gathered using the LCA SimaPro software that has enabled us to decompose the life cycle emission factors in its different components, therefore deriving only the emission factors associated with the burning of fuel for each km travelled (TTW). The data are reported for Italy or European geographic location when available, otherwise the emission factors are at the global level.

40 https://ecoinvent.org/the-ecoinvent-database/

- *Passenger cars*: the emission factors for passenger cars are divided by fuel, car size, and Euro emission standards. We have retrieved the data for EURO 4 emission[41] based on the available information from ACI (Automobile Club Italia) that states that more than 56% of cars in Italy are more then 10 year hold. For diesel and petrol cars the data are retrieve from European emission factors, while for electric cars the emission factors reported are at the global level.
- *Buses*: we reported the data form coach fueled by diesel, the only available in the ecoinvent database. The emission factors are retrieve from Switzerland.
- *Flights*: following the ecoinvent database long haul flights correspond to flights greater than 4000 km, medium haul between 1500 and 4000 km, and short haul between 800 and 1500 km. The emission factors are retrieve from global dataset.
- *Train*: we select the emission factors for electric trains, to have a meaningful comparison with the other dataset. In this case the data are reported specifically for Italy.

41 Euro 4 emissions: all new cars from January 2005 and all newly registered cars from January 2006.

4 Results of the analysis and suggested methods and data

The aim of the project is to identify a single tool offering the whole spectrum of travel mode emission factors, to maintain a methodological and data coherence. Based on the analysis conducted, the present project suggests using the UK DEFREA (2021) "2021 Government Greenhouse Gas Conversion Factors for Company Reporting" as the basis to define the emission factors for the new PIS system.

The choice has been motivated by the completeness of the dataset, its frequent (yearly) update under the responsibility of the UK Department for Business, Energy and Industrial Strategy, its public and governmental sponsorship. Another important reason lies in its wide use by other organizations: it is the major source of all the other datasets found during the analysis (see Appendix A). Just as importantly, the datasets report the emission conversion factors based on the distance-based method, which is the most appropriate for the new PIS system construction, which collects information of the distance travelled by Eurac Research collaborators. It should be noted that for vehicles where an organization has data in litres of fuel or kWh of electricity consumed, the 'fuels' or 'electricity' conversion factors should be applied. The current version of the project does not account for fuel or electricity consumption data as those are not available for third parties' own vehicles.

The UK DEFRA (2021) follows the GHG Protocol (2013b) for corporate accounting and standards. Therefore, business travels are categorized under Scope 3 emissions (GHG Protocol, 2013a), which refers to the emissions of business travels by means not owned or controlled by an organization. Only the emissions of cars owned by Eurac Research fall under Scope 1 (see Section 4.1).

The UK DEFRA (2021) dataset is based on Global Warming Potential (GWP) values from the Fourth IPCC Report (AR4), while the use of the latest GWP values is recommended by the "GHG Protocol accounting note on the use of alternative factor sets" (GHG Protocol, 2013). Therefore, the present project proposes to use the UK DEFRA (2021) dataset updated with the GWP of the lates IPCC Report (AR5) (IPCC, 2014).

4.1 Selection of data and assumptions

This section reports the suggested emission factors and assumption for each mode of transport, reported at the end of the section in Table 6 and Table 7. All the emission factors have been updated with the AR5 GWP data (IPCC, 2014).

Business Travel – land: Cars

The emission factors are defined in CO_2 eq (kg/km), which express the emissions in kilograms of CO_2 equivalent per km travelled. Therefore, if more than one collaborator uses the same car for a business travel, the associated emission should be divided by the total number of passengers to avoid double counting.

Plug-in Hybrid Electric Vehicle (PHEV) and Battery **Electric Vehicle** (EV) emission factors are set to zero for the part concerning electricity use, as in the present study we only account for the emission related to the electricity used during the travel (TTW emission factors). Therefore, we retrieve the data for PHEV and EV emission factors as reported under Scope 1, which does not include the parts of emission relate to electricity consumption. Indeed, following the GHG Protocol (2013b), the proportion of electricity used to charge Plug-in Hybrid Electric Vehicle and Battery Electric Vehicles should be reported under

Scope 2 (indirect energy emissions derived from purchased or acquired electricity), which is behind the scope of the present analysis.

Eurac Research owns two diesel cars, a Toyota Hilux (4x4) and a Skoda, and different hydrogen cars. Therefore the **Hydrogen** vehicle category has been added into the dataset to account for Eurac Research's fleet vehicles. As for EV and PIEV cars, the emission per km travelled with an hydrogen car is set to zero, as we account only for the TTW emission factors.

Business Travel – land: Taxi

Among the reported taxi category by UK DEFRA (2021) datasets, the project selects the emission factors related to "regular" taxi as the "black can" category is UK specific. Two different options for the unit to use are available: emission associated per passenger km, calculated assuming an average passenger occupancy of 1.4 (Hill et al. 2021), and emissions associated to the number of km travelled. The projects select the km unit (as in the case of cars), therefore the total associated emissions should be divided by the number of persons travelling within the same taxi to obtain the correct information.

Business Travel – land: Bus

Within the classification of buses proposed by UK DEFREA (2021) the Coach category corresponds to long-distance bus, which is the one chosen in the present study. Local and average local bus emission factors are calculated for buses operating at the local level (within UK cities), while the present project looks only at travels between cities, as the emissions related to the commuting activities during a business travel are not accounted for. The average passenger occupancy is equal to 17.5, which is likely to be considerably higher in real cases. It should also be noted that fuel consumption and conversion factors for individual operators and services will vary significantly depending on the local conditions, the specific vehicles used and on the typical occupancy achieved. Therefore, the emission factors for coach cannot be associated with a specific fuel type, as done for passengers cars emission factors.

Business Travel – land: Train

In the UK DEFREA (2021) datasets the emission factors related to train are reported for national (diesel and electric) and international rail (electric). The project selects only the emission factors associated with international rails as they represent most business travels. Moreover, in Italy exists only few trains fuelled by diesel, which are included in the national rail category based on UK specific statistics not applicable to other countries.

Business Travel – air: Flight

The UK DEFRA (2021) distinguishes between different **flight categories** relying on a differentiation of flights based on the destination, assuming the UK as starting point. This project applies the "crude level" assignment used in the previous UK DEFRA versions (i.e. short haul < 3,700 km; long haul > 3,700 km) as it is more consistent for flights departing mainly from Italy. The international flight emissions factors (see Appendix A) are an average of short and long-haul flights, therefore excluded from the selected data. Domestic flight category also has not been considered as the emission factors are reported only for average passengers.

The UK DEFRA (2021) dataset considers also the **seating class factors** (economy, business and first class), the occupancy factors that influence the efficiency of aviation per passengers km. First and business class, takes up considerably more room in the aircraft than economy seating that raises the average CO_2 emissions per passenger km. In the present study the emission factors associated with the economy class are taken as the basis for the PIS system. This choice is justified by Eurac Research policy, which does not allow to book first and business class flights.

An important point of discussion regards the facts that the emissions from aviation have both direct (CO_2, CH_4 and N_2O) and indirect (**non- CO_2 emissions** e.g. water vapour, contrails, NO_x) climate change effects. The non- CO_2 impacts result in changes in the chemical composition of the global atmosphere and cloudiness, perturbating the heart-atmosphere radiation budget. The net impact of aviation non-CO_2 emissions is a **positive** radiative forcing (warming)[42]. However, there are significant scientific uncertainty in quantifying aviation's non- CO_2 impacts on climate[43] (Lee et al. 2020). The main issue is the aviation emissions equivalencies for short-lived climate forcers (e.g. non- CO_2 impacts) with the long-lived greenhouse gas (e.g. CO_2).

Different metrics exist to measure the non- CO_2 impact of aviation on climate change. The Radiative Forcing Index (RFI) - the ratio of total radiative forcing to that from CO_2 emissions alone - is a measure of the importance of aircraft-induced climate change other than that from the release of fossil carbon alone[44]. The IPCC (1999) established the RFI of aviation in 1992 to be in the range of 2-4, while other estimations report a range between 1.9 and 5 (Jungbluth et al 2019), but, so far, there is no clear recommendation by the IPCC on a specific RFI factor to be used as customary practice. More recently, the scientific community has adopted the 'Effective Radiative Forcing' (ERF) as a better metric of the absolute impact when compared to RFI (Lee et al. 2020). Another simple approach to account for the climate effects of non- CO_2emissions would be to formulate a single CO_2 equivalent emissions 'multiplier' averaged across the aircraft fleet and all atmospheric conditions. However, adopting a single multiplier may not be appropriate because the magnitude of the multiplier depends on the metric chosen, and mostly, the time horizon considered (Lee et al. 2020).

The UK DEFRA (2021) uses and **emission multiplier** for all aviation effects of 1.9[45] times the effects of CO_2 alone. However, the report notes that the multiplier is not a straightforward instrument as it implies that other emissions and effects are directly linked to the production of CO_2, which does not reflect accurately the different relative contribution of emissions to climate change over time or the potential trade-offs between the warming and cooling effects of different emissions. On the other hand, consideration of the non- CO_2 climate change effects of aviation leads surely to an underestimate of the impact of flights on the environment.

After careful consideration of all the available scientific background, it has been decided to take into consideration the radiative forcing of the flight emissions by using the multiplier of **1.9** presented in the UK DEFRA (2021).

Data

Table 6 and Table 7 report the emissions factors selected for Eurac Research business travel CO_2 accounting. Followingn the Eurostat glossary CO_2 equivalent is abbreviated in CO_2 -eq[46] and the emissions factors measured for passenger-kilometer is abbreviated as pkm[47].

42 The sum of non- CO_2 impacts yields a net positive (warming) that accounts for more than half (66%) of the aviation net forcing in 2018 (Lee et al. 2020).

43 The uncertainty distributions (5%, 95%) show that non- CO_2 forcing terms contribute about 8 times more than CO_2 to the overall uncertainty in the aviation net forcing in 2018 (Lee et al. 2020).

44 https://archive.ipcc.ch/ipccreports/sres/aviation/index.php?idp=64

45 A multiplier of 1.9 is recommended as a central estimate, based on the best available scientific evidence (Sausen et al. 2005; Lee et al. 2009; CCC, 2009).

46 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Carbon_dioxide_equivalent

47 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Passenger-kilometre

Table 6. Selection of Emission Factors for Business travel – Land

			CO2-eq (kg / unit)						
Activity	Unit	Type	Disel	Petrol	Hybrid	PHEV	EV	Hydrogen	Unknown
Passenger Car	km	Average car	0.16823	0.17431	0.11942	0.07068	0.00000	0.00000	0.171379
Taxis	km	Regular							0.208056
Bus	pkm	Coach							0.026781
Rail	pkm	International rail							0.004459

Note: pkm (passenger-kilometre) is the unit of measurement representing the transport of one passenger by a defined mode of transport (road, rail, air, sea, inland waterways etc.) over one kilometre[48].

Table 7. Selection of Emission Factors for Business travel – Air

		CO2-eq (kg / unit)
Haul	Unit	Including indirect effect
Short-haul (Economy class)	pkm	0.15094
Long-haul (Economy class)	pkm	0.19298

Note: multiplier used to calculate indirect emissions (non-CO2 effects) is equal to 1.9

48 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Passenger-kilometre

5 References

- Hill, Nikolas, et al. "2021 Government greenhouse gas conversion factors for company reporting: Methodology paper for conversion factors." Final Report 2 (2021).
- EEA. (2020a), from https://www.eea.europa.eu/data-and-maps/data/co2-cars-emission-18
- EEA. (2020b). Monitoring of CO2 emissions from vans – Regulation 510/2011. Retrieved March 19, 2021, from https://www.eea.europa.eu/data-and-maps/data/vans-14
- ORR. (2020). Official Statistics. Retrieved April 10, 2019, from: http://dataportal.orr.gov.uk/browsereports/9
- IPCC (2006) "2006 IPCC guidelines for national greenhouse gas inventories", from: https://www.ipcc-nggip.iges.or.jp/public/2006gl/
- IPCC (2014). "Anthropogenic and Natural Radiative Forcing", from: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf
- Jungbluth, N., Meili, C. Recommendations for calculation of the global warming potential of aviation including the radiative forcing index. Int J Life Cycle Assess 24, 404–411 (2019). https://doi.org/10.1007/s11367-018-1556-3
- Lee, D., Arrowsmith, S., Skowron, A., Owen, B., Sausen, R., Boucher, O., ... & van Wijngaarden, L. (2020). Updated analysis of the non-CO2 climate impacts of aviation and potential policy measures pursuant to EU Emissions Trading System Directive Article 30 (4).
- LIFE CLIM'FOOT DELIVERABLE A2.2: METHODOLOGY FOR CONSTITUTING THE NATIONAL DATABASE, ITALY
- GHG Protocol. "Technical Guidance for Calculating Scope 3 Emissions Supplement to the Corporate Value Chain (Scope 3) Accounting & Reporting Standard." WBCSD and WRI, Geneva (2013a).
- GHG Protocol. "Required greenhouse gases in inventories: Accounting and Reporting Standard Amendment." WBCSD and WRI, Geneva (2013b).
- Ricardo Energy & Environment. (2021). UK Greenhouse Gas Inventory, 1990 to 2019: Annual Report for Submission under the Framework Convention on Climate Change. Ricardo Energy & Environment. Brown P, Broomfield M, Cardenas L, Choudrie S, Karagianni E, Mullen P, Passant N, Thistlethwaite G, Thomson A,Turtle L, Wakeling D. Retrieved from https://naei.beis.gov.uk/reports/reports?report_id=998

6 Appendix A. Summary of datasets

Table 1. Business-travel emission factors: Passenger cars

					CO2-eq (kg / unit)					
Dataset	Source	GPW source	Unit	Type	Disel	Petrol	Hybrid	PHEV	EV	Unknown
UK DEFRA (2021)		AR4	km	Average car	0.16843	0.17431	0.11952	0.09694	0.05477	0.17148
			km	Small car	0.13758	0.14946	0.10494	0.05568	0.04565	0.14549
			km	Medium car	0.16496	0.18785	0.10957	0.09097	0.05254	0.17562
			km	Large car	0.20721	0.27909	0.15151	0.10492	0.06066	0.22597
ClimFoot_IT_DB (2019)	ISPRA (2014)		km	Average car	0.15352	0.17943	0.10643			
EPA (2021)		AR4	km	Average car						0.21351
GHG Protocol	EPA (2018)	AR5	km							0.21527
	UK DEFRA (2019)	AR5	km	Average car	0.17201	0.18025	0.11376	0.11467	0.05982	0.17613
UNFCC	UK DEFRA (2020)	AR4	km	Average car	0.17000	0.17000	0.12000	0.10000	0.05000	0.17000
			km	Small car	0.14000	0.15000	0.10000	0.06000	0.05000	0.15000
			km	Medium car	0.16000	0.19000	0.11000	0.09000	0.05000	0.18000
			km	Large car	0.21000	0.28000	0.15000	0.10000	0.06000	0.23000
CasaClima			km	Average car						0.096 - 0.343
Ecoinvent_v3	IPCC2013	AR5	km	Average car					0.00000	
			km	Small car	0.13706	0.17260				
			km	Medium car	0.18121	0.21063				
			km	Large car	0.22567	0.24863				

Table 2. Business-travel emission factors: Taxi

Dataset	Source	GPW source	Unit	Type	CO2-eq (kg / unit)
UK DEFRA (2021)		AR4	pkm	Regular	0.14876
			km		0.20826
			pkm	Black cab	0.20416
			km		0.30624
GHG Protocol	UK DEFRA (2019)	AR5	pkm	Regular	0.14921
UNFCC	UK DEFRA (2020)	AR4	pkm	Regular	0.15000
			km		0.21000
			pkm	Black cab	0.20000
			km		0.31000

Table 3. Business-travel emission factors: Bus

Dataset	Source	GPW source	Unit	Type	CO2-eq (kg / unit)
UK DEFRA (2021)		AR4	pkm	Local Bus	0.11774
			pkm	Average local bus	0.10227
			pkm	Coach	0.02684
ClimFoot_IT_DB (2019)	ISPRA (2014)		km	Bus (diesel)	0.69274
EPA (2021)		AR4	pkm	Bus	0.03404
GHG Protocol	UK DEFRA (2019)	AR5	pkm	Local Bus	0.10411
UNFCC	UK DEFRA (2020)	AR4	pkm	Local Bus	0.12000
			pkm	Average local bus	0.10000
			pkm	Coach	0.03000
CasaClima			km	Coach	0.08700
Ecoinvent_v3	IPCC 2013	AR5	pkm	Coach (diesel)	0.03822

Table 4. Business-travel emission factors: Rail

Dataset	Source	GPW source	Unit	Type	CO2-eq (kg / unit)
UK DEFRA (2021)		AR4	pkm	National rail (diesel and electric)	0.03549
			pkm	International rail (electric)	0.00446
ClimFoot_BC_BD		AR5	pkm	Italy	0.03170
EPA (2021)		AR4	pkm	National Average	0.07084
GHG Protocol	UK DEFRA (2019)	AR5	pkm	National rail	0.04085
			pkm	International rail	0.00593
UNFCC	UK DEFRA (2020)	AR4	pkm	National rail	0.04000
			pkm	International rail	0.00000
Ecoinvent_v3	IPCC 2013	AR5	pkm	Train (electric)	0.0000878

Table 5. Business-travel emission factors: Flights

						Direct effects only	Including indirect effect
Dataset	Source	GPW source	Unit	Haul	Class	CO2-eq (kg / unit)	CO2-eq (kg / unit)
UK DEFRA (2021)		AR4	pkm	Domestic	Average passenger	0.13003	0.24587
			pkm	Short-haul	Average passenger	0.08117	0.15353

			pkm		Economy class	0.07984	0.15102
			pkm		Business class	0.11976	0.22652
			pkm	Long-haul	Average passenger	0.10208	0.19309
			pkm		Economy class	0.07818	0.14787
			pkm		Premium economy class	0.12508	0.23659
			pkm		Business class	0.22671	0.42882
			pkm		First class	0.3127	0.59147
			pkm	International	Average passenger	0.09708	0.18362
			pkm		Economy class	0.074345	0.140625
			pkm		Premium economy class	0.11895	0.225
			pkm		Business class	0.2156	0.40781
			pkm		First class	0.29739	0.56251
ClimFoot_IT_DB (2019)	UK DEFRA (2016)	AR4	pkm	Domestic		0.64502	
			pkm	Short haul		0.38785	
			pkm	Long haul		0.44271	
			pkm		Tourist class	0.31679	
			pkm		First class	1.26712	
EPA (2021)	UK DEFRA (2020)	AR4	pkm	Short Haul (< 483 km)		0.129316315	
			pkm	Medium Haul (483-3700 km)		0.08218663	
			pkm	Long Haul (>= 3700 km)		0.100994411	
GHG Protocol	UK DEFRA (2019)	AR5	pkm	Domestic	Average passenger	0.13378726	
			pkm	Short-haul	Average passenger	0.08311698	
			pkm		Economy class	0.08175433	
			pkm		Business class	0.12263768	
			pkm	Long-haul	Average passenger	0.10269733	
			pkm		Economy class	0.07864638	
			pkm		Premium economy class	0.12584563	
			pkm		Business class	0.22809031	
			pkm		First class	0.31460761	
			pkm	International	Average passenger	0.09490878	
			pkm		Economy class	0.07268299	
			pkm		Premium economy class	0.11629178	
			pkm		Business class	0.21077791	
			pkm		First class	0.29072666	
CasaClima			km			0.700143	
Ecoinvent_v3	IPCC 2013	AR5	pkm	short-haul		0.09586562	
			pkm	medium-haul		0.082365621	
			pkm	long-haul		0.083267634	