National mapping of GHG and non-GHG emissions sources

Synthesis report for work package 1

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CONTENTS

MapEIre Work package 1

This report documents the work done in work package 1 of the project "National mapping of GHG and non-GHG emissions sources". The work consisted of a literature review on current state of the art for spatial and temporal distribution of emissions and development of the specifications for both the spatial and temporal model.

WP1.1 Literature review

Spatial distribution of emissions is a key element in assessing human exposure to air pollution through the use of dispersion modelling. The quality of the spatial and temporal distribution of emissions is crucial for the quality, applicability and reliability of the modelled air pollution levels, the estimated human exposure, incurred health effects and related costs; all issues that are very important information for policy makers in decisions of implementation of environmental policies and measures.

In addition to the importance of spatial and temporal resolution of emissions to air quality modelling there is also international requirements regarding the reporting of spatially distributed emissions. Under the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP) there is a requirement to report spatially distributed emissions every four years (ECE/EB.AIR/125). The reporting guidelines under CLRTAP specifies the coverage of pollutants, and emission sources and sectors to be covered as well as setting out requirements to the deadline for reporting. The pollutants to be included are SO_2, NO_x, NMVOC, NH_3, CO, paticulate matter, cadmium, lead, mercury, polycyclic aromatic hydrocarbons, dioxins and furans, polychlorinated biphenyls and hexachorobenzene. In addition to reporting of national total emissions, it is encouraged to provide a spatial distribution of the emissions in the geographical grid described in the reporting guidelines (gridded emissions). The sectoral requirements for the reporting of gridded emissions are the GNFR level, which encompasses main activity sectors. The GNFR list is included in Annex 1. According to the reporting guidelines, the gridded emissions should be prepared for the "EMEP grid", which refers to a 0.1°×0.1° latitude-longitude projection in the geographic coordinate system World Geodetic System (WGS) latest revision, WGS 84. The reporting deadline is 1 May for the gridded data.

The reporting by Parties is used in the European Monitoring and Evaluation Programme (EMEP) modelling. The EMEP model calculations have been supporting the decision making within CLRTAP for more than 30 years. Since the 1990s the EMEP models have been the reference tools for atmospheric dispersion calculations as input to the Integrated Assessment Modelling, which supports the development of air quality polices in the European Union.

Technical guidance for preparing spatial and to a lesser extent temporal distribution of emissions inventories are provided in the EMEP/EEA 2013 Guidebook (hereafter

referred to as the Guidebook). The Guidebook is mandatory to use as a minimum standard in preparing and reporting data under CLRTAP. T he Guidebook includes a tiered gridding method, and it is recommended to use the highest tier possible for each emission source. All emissions that can be allocated to a specific plant or location should be treated as point sources, and the emissions should be allocated to the exact geographical point (tier 3).

The remaining emissions are treated as area sources, which refer to emission categories that cover a large number of sources with similar characteristics, which are treated as a group in the emission calculation. As these emissions cannot be allocated to exact geographical points, spatial surrogate data must be used to make the spatial mapping. For some sources it is possible to use spatial surrogate data that is closely related to the emission source (tier 3), e.g. mileage by road segment and vehicle type. For other emission sources a less closely related spatial surrogate dataset must be used (tier 2), e.g. buildings per building type, employment statistics per sector, and areas of various land use categories. For emission sources where no closely related spatial surrogate data exists, it is necessary to use general surrogate data (tier 3), e.g. population density. It is required to strive for the highest tier method, especially for the emission sources that contribute most to national total emissions, and it is recommended to use at least tier 2 for key categories. The Guidebook contains guidance on the selection of spatial data sets, both related to possible nationally available data and internationally available datasets (such as CORINE or Eurostat data) that can be used if no national data are available, for the NFR categories at the three tier levels.

Another important issue, for which there are currently no international obligations, is the temporal distribution of emissions. While emission inventories have been subject to significant improvements over the last decades and efforts to both quantify and reduce the uncertainties of inventory datasets, both the sensitivity to and the processing of emission input data in currently applied atmospheric transport models has not been investigated in sufficient depth. This is in particular the case for the temporal resolution of emissions, which may have a significant impact on the match between modelled and measured air pollution levels, especially when applying atmospheric transport models with exceptionally high spatial resolution on a national or smaller scale (Reis et al., 2009). The temporal factor has a large impact on the dispersion, due to variations in climatic parameters like wind speed, wind direction, temperature, and precipitation, and thereby on the human exposure (Ramsdell and Rishel, 2006).

Regarding environmental policy decisions, information on temporal distribution can allow policy makers to adapt environmental initiatives both on a geographical and a temporal level to optimise the effect and minimise the costs.

Many studies have been published regarding spatial distribution of emissions. Several studies have endeavoured to make a spatial distribution for the whole of Europe. These include the EDGAR2 system developed by the European Commission Joint Research Centre and the system developed by TNO (Denier van der Gon et al., 2010). In general both of these projects used point source information where it was available. This information came from international databases such as EPER (European Pollutant Emission Register) and the World Electric Power Plants Database. For the area sources both studies used very crude spatial proxies to distribute emissions, such as population density, FAO data on distribution of livestock, and CORINE (Coordination of Information on the Environment) land cover. With thorough research at the country level, it is possible to significantly improve the spatial distribution compared to these models attempting to cover the entire European continent.

Most of the published studies have focussed on single pollutants (Bo et al., 2008; Sahu et al., 2011; Dalvi et al., 2006) or single sectors (Skjøth et al., 2011; Hellsten et al., 2008; Puliafito et al., 2015). In addition, many studies have not been at the national level but at a city or regional level (Sahu et al., 2011; Guttikunda & Calori, 2013; Tian et al., 2004). A few studies have focused on spatial distribution for a range of pollutants at the national level for all emission sectors (Plejdrup & Gyldenkærne, 2009; Tsilingiridis et al., 2010; Tsagatakis et al., 2013; Kannari et al., 2007).

A general approach in spatial emission distribution is to handle emissions from point sources e.g. large industrial plants and power plants separately, and allocate the emissions to the exact position of the plants (Kannari et al., 2007; Tsagatakis et al., 2015; Plejdrup & Gyldenkærne, 2009; Guttikunda & Calori, 2013).

Different approaches are used to make a spatial distribution of emissions from road transport depending on the availability of related data with a spatial component, e.g. road maps, traffic counts, and transport surveys. Tsagatakis et al. (2015) has used traffic counts combined with modelling to create a road map including mileage for all road segments. Guttikunda & Calori (2013) used population density, road density and commercial activity density for spatial distribution, combined with vehicle density surveys to split emissions between three road classes.

Residential combustion for cooking and heating is an important source in many countries to emissions of particulate matter, and persistent organic pollutants. Generally there is a lack of detailed data for this source both regarding fuel consumption, technology, and user behaviour, and following the emission estimates are associated with large uncertainties. Different approaches are used to make spatial distributions of residential emissions, and generally the distributions are also associated with large uncertainties due to lack of detailed spatial data. A rough approach is to use population density as a proxy for the spatial distribution, which is often the case when models are set up for large areas, e.g. Europe and large

countries (Denier van der Gon et al., 2010; Theloke et al., 2009; European Commission Joint Research Centre, 2009). Winijkul et al. (2016) improved the population density approach by including land use and nighttime light maps. When detailed spatial data is not available, it can be beneficially to combine different proxy data sets to improve the spatial distribution, e.g. population density can be combined with fuel statistics preferable including residential fuel consumption on a regional level to improve the distribution of residential emissions (Kannari et al,. 2007; Guttikunda & Calori (2013). For smaller areas (smaller country, county or city) more detailed data might be available like building registers, including geographical coordinates for buildings, and in some cases also information on building types, heating installation type and fuel type which can be used in spatial distribution of emissions (Tsagatakis et al., 2015; Plejdrup & Gyldenkærne, 2009). In cases where the fuel consumption is unknown, heating demand models can be used to estimate the residential fuel consumption on address or regional level (Tsagatakis et al., 2015), and degree-days or access to fuels (most important for wood) to differentiate the total fuel consumption between regions of different temperature and climate conditions and proximity to forests (Tian et al., 2004).

Methods for spatial distribution of emissions from agriculture also vary between different studies. In many cases the distribution methodology is based on agricultural statistics and related spatial information, and on land use maps (Tsagatakis et al., 2015; Plejdrup & Gyldenkærne, 2009). If agricultural statistics are not available on farm/field level, it can be beneficially to combine regional data with land use maps (Dragoosits et al., 1998; Kannari et al., 2007)

In Denmark, the SPREAD model has been developed for high resolution (1 km x 1 km) spatial distribution of all sources and all pollutants included in the national emission inventories (Plejdrup & Gyldenkærne, 2009). Spatial distribution is carried out on highly disaggregated emission source level, and resulting spatial emissions corresponds to the emissions in the national inventories. SPREAD is consistent with the national emissions in the official Danish emission inventories. Point source emissions from the inventories are allocated to the exact position of the plants, while the spatial distribution of emissions from area sources in SPREAD is based on detailed national spatial data, e.g. the Danish Building and Dwelling Register, the Civil Registration Register, the national GIS-based road and traffic data base, and the Central Husbandry Register. Spatial data are analysed in a Geographical Information System (GIS) and through geoprocessing converted to spatial distribution keys to be included in the integrated database system.

For Ireland a study was published in 2001 on the modelling of the spatial distribution of SO2 and NOx emissions in Ireland (Kluizenaar et al., 2001). This study provides more detail than the first study reporting spatially distributed emissions in Ireland (McGettigan & O'Donnell, 1995). Kluizenaar et al. (2001) spatially distributed emissions of SO2 and NOx at a 1 km x 1 km resolution. The study relied on data from e.g. population census, land cover data from CORINE, road travel statistics,

and county based residential fuel consumption. The study lists several areas where the methodologies used could be improved. Since the study only focusses on SO2 and NOx, it does not include the agricultural sector and the land use sector. The agricultural sector is a main source of emissions of other pollutants, e.g. methane and ammonia, and will hence need to be given careful consideration.

Hynes et al. (2009) published a spatial micro-simulation analysis of methane emissions from Irish agriculture. This study used data from the National Farm Survey and the Census of Irish Agriculture, in particular data for the number of cattle and sheep at each farm spatially aggregated to Electoral Division level. The data from National Farm Survey and the Census of Irish Agriculture used by Hynes et al. (2009) could form the basis for a spatial distribution methodology for the agriculture sector.

A spatial emission inventory was prepared for Ireland in 2012 (Griffin 2012). The used methodologies follow the concepts included in the EMEP/EEA Guidebook, and outputs are in line with the reporting requirements for the LRTAP convention. Emissions handled as point sources in the national emission inventory are allocated to the location of the individual facilities. A comprehensive review of available spatial data sets were carried out, and the best spatial data for distribution of emissions from area sources are selected, considering coverage, updating, licensing expenses, and cost-benefit of preparing the spatial data sets for use in spatial emission distribution. Emissions from the national inventory at NFR category level are spatially distributed using the prepared normalised grids, which are based on relevant spatial data sets and statistics, and which includes the share of emissions to be allocated to each grid cell in the Irish domain. For many emission sources, the spatial distribution is based on a combination of more data sets, e.g. the distribution of emissions from road traffic is based the road network, traffic counts, vehicle statistics and population density. Employment statistics, sometimes combined with population density, are used to prepare normalised grids for distribution of area source emissions from more NFR categories, e.g. industrial combustion, small combustion (commercial/institutional and agricultural sector), industrial processes, and non-domestic solvent use. The spatial distribution of emissions from stationary combustion in the residential sector are based on end-use energy statistics. Data from agricultural census are used to distribute emissions from livestock, combined with land cover data, the latter also used as basis for the normalised grids for off-road vehicles/machinery and other agricultural sources. Emissions from navigation, aviation, waste disposal and waste incineration are mainly allocated to known sites weighted by available emissions or activities for the individual sites.

Table 1 Identified spatial proxies for GNFR categories

GNFR	Description	Most common spatial distribution methodology/proxy data (for further details see Annex 1)
A_PublicPower	Emissions from plants producing electricity and/or heat for the public grid	**Point sources:** Individual data for large point sources (e.g. IPPC, EU ETS, e-PRTR, local authority data, company data) **Area sources:** Employment statistics
B_Industry	Emissions from combustion and processes in industry	**Point sources:** Individual data for large point sources (e.g. IPPC, EU ETS, e-PRTR, local authority data, company data) **Area sources:** Employment statistics, production statistics, population statistics, land cover
C_OtherStationaryComb	Emissions from small combustion sectors, e.g. commercial, institutional, residential and agricultural	**Commercial/institutional sector:** Energy statistics, business register data, employment statistics , population density, landcover **Residential sector:** Energy statistics, address database, household statistics, population statistics, landcover **Industrial sector:** Energy statistics, employment statistics, business register data, landcover **Agriculture/forestry/Fishing:** Employment statistics, population statistics, land cover **Other:** Population statistics, land cover
D_Fugitive	Fugitive emissions associated with production, refining, transport and storage of fuels.	**Point sources:** Individual data for large point sources (e.g. IPPC, EU ETS, e-PRTR, local authority data, company data) **Area sources:** Employment statistics, production/capacity statistics, population statistics, site locations (e.g. production wells, service stations), transmission/distribution network
E_Solvents	Emissions from the use of solvents	**Point sources:** Individual data for large point sources (e.g. IPPC, EU ETS, e-PRTR, local authority data, company data) **Area sources:** Population statistics, business statistics, employment statistics, building statistics, land cover
F_RoadTransport	Emissions from road transport	Road network, traffic intensities, traffic counts, vehicle license statistics, passenger travel statistics, mean vehicle speed, population density
G_Shipping	Emissions from domestic navigation, i.e. navigation between two domestic ports. Fishing is included under "I_Offroad"	Port locations, goods statistics, land cover
H_Aviation	Emissions from landing and take-off (LTO) both for domestic and international flights	Airport locations, fuel statistics, land cover

GNFR	Description	Most common spatial distribution methodology/proxy data (for further details see Annex 1)
I_Offroad	Emissions from machinery used in industry, households, agriculture as well as from railways and fishing vessels	**Railways:** Rail network, population density **Manufactuting industry and construction:** Employment statistics, population statistics, land cover **Commercial/institutional sector:** Employment statistics, land cover **Residential:** Household statistics, population, land cover **Agriculture/forestry:** Employment statistics, land cover **Other:** Population, land cover
J_Waste	Emissions associated with waste handling. Waste incineration with energy recovery is included under "A_PublicPower" or "B_Industry"	**Point sources:** Individual data for large point sources (e.g. IPPC, EU ETS, e-PRTR, local authority data, company data) **Area sources:** Site locations, activity/capacity statistics, population statistics, land cover
K_AgriLivestock	Emissions associated with animal husbandry and manure management	Agricultural census, land cover
L_AgriOther	All other agricultural emissions, e.g. from application of mineral or organic fertilizer, crops and field operations	Agricultural census, land cover
M_Other	Emissions from other anthropogenic sources	
N_Natural	Emissions from natural sources, e.g. volcanoes, forest fires, etc.	
O_AviCruise	Emissions from the cruise phase of both domestic and international flights	
P_IntShipping	Emissions from international navigation	Gridded sea shippping tracks, land cover
z_Memo	Emissions from multilateral operations	
Forest	Emissions from forests	Landcover

WP1.2 Specifications of the spatial model

The main purpose of creating a spatial model for the Irish emission inventories is for Ireland to be able to fulfil the requirements under the CLRTAP convention by reporting gridded emissions in the NFR reporting format. Therefore the spatial emission model for Ireland will be prepared in agreement with the methodologies in EMEP/EEA Guidebook (EEA, 2013), and the model will be designed to fulfil the new requirements for reporting in 2017 of gridded emissions for the year 2015 in agreement with the guidelines for reporting under CLRTAP (ECE, 2014). Further, spatial emissions can serve as valuable input to air quality models, but this requires

a rather high spatial resolution. Therefore the spatial emission model for Ireland will be prepared on a higher spatial resolution the required for reporting to the CLRTAP convention.

The spatial emission model is based on various Irish spatial data sets, and for the ease of use, the common Irish projection TM65 (EPSG 29902) is applied in the model instead of the geographic coordinate system (WGS84) used by EMEP. The CLRTAP requirement for reporting under the CLRTAP convention is a spatial resolution of 0.1 degree x 0.1 degree, which corresponds to approximately 7 km x 11 km. Though, it has been decided to prepare the model with a spatial resolution of 1 km x 1 km to increase the level of detail. The higher spatial resolution is agreed on as more spatial data sets are available on a higher resolution, and as the higher spatial resolution make the spatial emission inventory applicable as input to air quality modelling on national level. Further, it is convenient to have a grid with orthogonal cells of the same scale all over the grid, in this case 1 km both longitudinal and latitudinal, as emissions do not have to be normalised in order to generate easy understandable maps, as output from the spatial emission model will be emission per km^2. As both the projection and the spatial resolution of the grid differ from the CLRTAP reporting requirements, a module will be included in the spatial model to convert from the 1 km x 1 km Irish grid to the 0.1 degree x 0.1 degree EMEP grid.

Gridded emissions reported to CLRTAP are aggregated at a sectoral level defined by the GNFR sectors. The sectoral split in the spatial emission model for Ireland will, for the main part, be more disaggregated than the GNFR level. The details of the available spatial data will be the determining factor in selection of the sectoral disaggregation level. In a number of cases it might be appropriate to use the sectoral level defined by the NFR (Nomenclature For Reporting) categories, which are used for reporting of national emission to CLRTAP. For some sources it will be advantageous to disaggregate the emissions further to create the most accurate spatial distribution, again depending on the availability of detailed spatial data. This might be the case for residential heating where it might be beneficial to make a split on different fuels. The NFR format is prepared for reporting of emissions of air pollution. As the spatial emission model for Ireland covers both air pollution and greenhouse gases, not all sources are included in the NFR categories. This is the case for the sector Land use, land-use change and forestry (LULUCF), several categories within agriculture, i.e. enteric fermentation, liming and urea application, and categories related to emissions of fluorinated gases. These categories will be added to the spatial model to ensure the complete coverage of all anthropogenic emissions. As the sectoral level in the spatial model differs from the CLRTAP reporting requirements, a module will be included in the spatial model to aggregate the spatial emissions according to GNFR level.

Table 2 Comparison between the requirements under LRTAP and the planned Irish model

	Resolution	Projection	Sectoral level
CLRTAP	0.1 degree x 0.1 degree	Geographic coordinate system, WGS84, EPSG 4326	GNFR
Irish model	1 km x 1 km	Projected coordinate system, TM65 EPSG 29902	NFR e.g. with disaggregation for selected sectors

As ECE (2014) does not include guidance on the national sea territory, it has been decided to use the Exclusive Economic Zone (EEZ) as the outer border for the spatial emission model for Ireland. This decision will only influence the spatial distribution of emissions for navigation and international aviation.

Choice of data for EEZ, coastline, national border

Outer borders for the land area and sea area included in the spatial model has to be defined, and appropriate spatial data sets have to be chosen for use in creating spatial distribution keys. The included land area is defined by the coastline and the national border between Republic of Ireland and Northern Ireland (UK), both available in more versions and from different data providers. The coastline chosen is provided by EPA in the spatial data set "ADMIN_CoastPolyline". The border to Northern Ireland included in the spatial model is based on the 2011 census by CSO on constituency level included in the spatial data set "Census2011_Constituencies_2013.shp", following advice from EPA as small discrepancies are detected between spatial census data sets on different levels, e.g. small areas, garda districts, and constituencies. International guidelines on emission inventories and gridded emissions do not include guidance on definitions of the national sea area, why this must be decided individually by the countries. The exclusive economic zone (EEZ) is chosen as outer border for the spatial model, and the version provided by the Department of Communications, Energy and Natural Resources (DCENR) is applied. This version deviates from the version available from MarineRegions.org.

A 1 km x 1 km grid is developed for the spatial emission model, using the standard tool "Create Fishnet" in ArcMap, using the projection TM65 (EPSG 29902). The fishnet is created so that the corners of the grid cells follow the 1 000 meter x-axis and y-axis. The extent and resolution of the fishnet are defined by the parameters included in table 3.

Table 3 Fishnet parameters

Extent	Bottom: -345 000 Top: 630 000 Left: -360 000 Right: 385 000
Resolution	Width: 1 000 m Height: 1 000 m
Size	Number of rows: 975 Number of columns: 745

Using the calculate geometry tool in ArcMAP, each grid cell is applied X and Y coordinates for the centerpoint (Xc and Yc). The grid cells are named according to the location of the lower left corner and the grid resolution: IE_1km_±Y_±X, where ±Y and ±X are the Y and X coordinates rounded down to nearest full kilometre (eg. the point (-296 713.384 , 158 922.683) will be given the grid ID 1km_158_-297). By using a name convention based on the X and Y coordinates, it is easy to apply grid cell name to point sources, which are defined by their exact location (X,Y), and following to summarise emissions from point sources and area sources per grid cell, without using GIS.

It is very important that the models developed within this project is easily compatible with the data systems currently used by the emission inventory team at the EPA. Currently, the calculation of emissions are based on a series of MS Excel spreadsheets covering different pollutants, sectors or both. In addition, the final reporting formats are available, i.e. NFR and CRF tables.

As the reporting formats are believed to be stable for years to come and hence it is benficial to base the input to the spatial model on the reporting formats to the extent possible. Therefore, the aim is to base the input on the official reporting formats and to take any spatial variations within the reporting categories in the development of the spatial distribution keys.

WP1.3 Specifications of the temporal model

Currently, temporal distribution in the EMEP model is done at a very coarse level, e.g. considering all non-road transport and mobile machinery as one source with the same temporal profile. This is deemed to be insufficient and therefore temporal profiles will be defined at the emission reporting level, e.g. separately for railways, aviation, navigation and machinery in different sectors.

Temporal profiles will be developed at three levels identical to the current setup in the EMEP model, i.e. monthly, weekly and daily variations. This means that for each emission reporting sector and for each pollutant the following three tables will be completed.

Table 4 Template for monthly variations

January	February	March	April	May	June	July	August	September	October	November	December
1.070	1.078	0.944	1.045	1.027	0.932	1.026	0.962	0.874	1.021	1.053	0.973

Table 5 Template for weekly variations

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1.030	1.057	1.079	1.076	1.058	0.892	0.808

Table 6 Template for diurnal variations

	1	2	3	4	5	6	7	8	9	10	11	12
Monday-Friday	0.79	0.72	0.72	0.71	0.74	0.80	0.92	1.08	1.19	1.22	1.21	1.21
Saturday-Sunday	0.69	0.62	0.62	0.61	0.64	0.70	1.02	1.18	1.29	1.32	1.31	1.31
	13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Monday-Friday	1.17	1.15	1.14	1.13	1.10	1.07	1.04	1.02	1.02	1.01	0.96	0.88
Saturday-Sunday	1.27	1.25	1.24	1.23	1.20	1.17	0.94	0.92	0.92	0.91	0.86	0.78

The temporal keys will be based on the available data, which in some cases means that the temporal variations will be based on expert judgement.

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Annex 1

GNFR	Description	Spatial distribution methodology/proxy data
A_PublicPower	Emissions from plants producing electricity and/or heat for the public grid	**EMEP/EEA 2013 Guidelines** Tier 1: Individual data for LPS Tier 2: Employment statistics Tier 3: Land cover **Large point sources (LPS):** Individual data for LPS (e.g. IPPC, EU ETS, e-PRTR, local authority data) (Ireland: Griffin, 2012; Kluzinaar et al., 2001 ;UK: Tsagatakis et al., 2015; Denmark: Plejdrup & Gyldenkærne, 2011; Cyprus: Tsilingiridis et al., 2010; Grece: Sidiropoulos & Tsilingiridis, 2006; Delhi, India: Guttikunda & Calori, 2013) **Area sources:** Employment statistics (UK: Tsagatakis et al., 2015)
B_Industry	Emissions from combustion and processes in industry	**EMEP/EEA 2013 Guidelines** Tier 1: Plant spacific data Tier 2: Employment statistics, land cover Tier 3: Population, Land cover **Large point sources:** Individual data for LPS (Ireland: Griffin, 2012; Denmark: Plejdrup & Gyldenkærne, 2011; Thessaloniki, Greece: Tsilingiridis et al., 2002; Delhi, India: Guttikunda & Calori, 2013) **General methodology/area sources:** Employment statistics (Ireland: Griffin, 2012) Population density (Japan: Kannari et al, 2007) Production statistics (Delhi, India: Guttikunda & Calori, 2013) Land cover (Denmark: Plejdrup & Gyldenkærne, 2011) **Manufacturing industries:** Individual data on LPS , employment statistics, landcover (Ireland: Kluzinaar et al., 2001) **Quarrying and mining:** Location of mines, production statistics (UK: Tsagatakis et al., 2015)

C_OtherStationaryComb	Emissions from small combustion sectors, e.g. commercial, institutional, residential and agricultural	**General methodology:** Population statistics, employment statistics, landcover (CORINE) (Ireland: Kluzinaar et al., 2001) **Commercial/institutional sector:** **EMEP/EEA 2013 Guidelines** Tier 1: Plant specific data Tier 2: employment statistics Tier 3: Land cover Employment statistics , energy statistics (Ireland: Griffin, 2012) Building statistics (Denmark: Plejdrup & Gyldenkærne, 2011) Employment statistics (Europe: Theloke et al, 2009) Population density, employment statistics ((Japan: Kannari et al, 2007) Energy consumption statistics, employment statistics, business register data (UK: Tsagatakis et al., 2015) **Residential sector:** **EMEP/EEA 2013 Guidelines** Tier 1: fuel delivery statistics, household statistics, population Tier 2: Household statistics, population, smoke control areas Tier 3: Land cover Energy end-use statistics (Ireland: Griffin, 2012) Household statistics, population census, landcover (CORINE) (Ireland: Kluzinaar et al., 2001) Energy statistics, address database, building census, energy consumption modelling, gas connections (UK: Tsagatakis et al., 2015)) Building statistics (Denmark: Plejdrup & Gyldenkærne, 2011) Population density, energy consumption statistics, nightlight data and landcover (Global: Winijkul et al, 2016) Population density, landcover (Europe: Theloke et al, 2009) Population density, energy consumption statistics (Japan: Kannari et al, 2007) Household census, population density, (Delhi, India: Guttikunda & Calori, 2013) Elevation model, landuse, temperature, climatic conditions, population-, road- and building density, (State of California: Tian et al, 2004) **Space heating:** Landuse, population/household density, building characteristics, space heating technology (Thessaloniki, Greece: Tsilingiridis et al., 2002) **Industrial sector:** Energy consumption statistics, employment statistics, business register data (UK: Tsagatakis et al., 2015) **Agriculture/forestry/Fishing:** **EMEP/EEA 2013 Guidelines** Tier 1: Fuel delivery statistics, employment statistics Tier 2: Employment statistics Tier 3: Land cover **Agricultural sector:** Employment statistics, population density (Ireland: Griffin, 2012) Land cover (UK: Tsagatakis et al., 2015; Denmark: Plejdrup & Gyldenkærne, 2011) **Other:** **EMEP/EEA 2013 Guidelines**

D_Fugitive	Fugitive emissions associated with production, refining, transport and storage of fuels.	**Large point sources:** Individual data for LPS (Ireland: Griffin, 2012; Denmark: Plejdrup & Gyldenkærne, 2011) **General methodolog:** Population density (Japan: Kannari et al, 2007) **Solid fuels:** **EMEP/EEA 2013 Guidelines** Tier 1: Plant specific data Tier 2: Plant specific data, industry specific employment statistics Tier 3: Employment statistics **Coal production:** Location of mines, production statistics (UK: Tsagatakis et al., 2015) **Oil and gas:** **EMEP/EEA 2013 Guidelines** Tier 1: Site specific data, distribution network, leakage rates Tier 2: Employment statistics, capacity statistics Tier 3: Location of large point sources, employment statistics, population **Oil and gas production:** Site specific emissions, activity/production statistics, well locations (UK: Tsagatakis et al., 2015; Denmark: Plejdrup & Gyldenkærne, 2011) **Gasoline storage and distribution:** Central depots of oil companies, service stations (Thessaloniki, Greece: Tsilingiridis et al., 2002) **Gasoline distribution:** Population density (Ireland: Griffin, 2012) Service stations (Denmark: Plejdrup & Gyldenkærne, 2011) **Gas transmission:** M/R station locations (Denmark: Plejdrup & Gyldenkærne, 2011) Pipeline map (INOGATE) (Europe: Denier van der Gon,2013) **Gas distribution:** Building statistics, distribution network (Denmark: Plejdrup & Gyldenkærne, 2011) Population density (Europe: Denier van der Gon,2013)

E_Solvents	Emissions from the use of solvents	**EMEP/EEA 2013 Guidelines** Tier 1: Plant specific data Tier 2: Employment statistics, population Tier 3: Land cover **Domestic:** Population density (Ireland: Griffin, 2012; Denmark: Plejdrup & Gyldenkærne, 2011) Landuse, population density (Thessaloniki, Greece: Tsilingiridis et al., 2002) **Non-domestic:** Employment statistics (Ireland: Griffin, 2012) Building map, building statistics, land cover (Denmark: Plejdrup & Gyldenkærne, 2011) **Adhesives and sealants:** Business data, employment statistics, population census, land cover data (Dai & Rocke, 2000)
F_RoadTransport	Emissions from road transport	**EMEP/EEA 2013 Guidelines** Tier 1: Traffic flow data Tier 2: Road network, population Tier 3: Population, land cover **General methodolog:** Road network, traffic counts, population density, regional vehicle category data (Ireland: Griffin, 2012) Vehicle license statistics, road travel statistics (Ireland: Kluzinaar et al., 2001) Road network, traffic census for count points, population density (UK: Tsagatakis et al., 2015) Road network, traffic intensities (Denmark: Plejdrup & Gyldenkærne, 2011; Europe: Denier van der Gon,2013) Road network, mean vehicle speed, traffic data (Thessaloniki, Greece: Tsilingiridis et al., 2002; Grece: Sidiropoulos & Tsilingiridis, 2006) Road network, traffic counts, road geometry (altitude, gradient) (Styria, Austria: Rebolj & Sturm, 1999) Passenger travel survey, vehicle density figures (Delhi, India: Guttikunda & Calori, 2013) **Cold starts:** Car ownership census, employment statistics (UK: Tsagatakis et al., 2015)

G_Shipping	Emissions from domestic navigation, i.e. navigation between two domestic ports. Fishing is included under "I_Offroad"	**EMEP/EEA 2013 Guidelines** Tier 1: route-specific ship emissions Tier 2: Port arrival and destination statistics Tier 3: Land cover **Inland waterways:** Main inland waterways (the rivers Shannon and Erne) (Ireland: Kluzinaar et al., 2001) National sea area (Denmark: Plejdrup & Gyldenkærne, 2011) **National navigation:** Port location (Ireland: Griffin, 2012; Denmark: Plejdrup & Gyldenkærne, 2011) **National fishing:** **EMEP/EEA 2013 Guidelines** Tier 1: Fish landing statistics for ports, fishing grounds Tier 2: Fish landing statistics for ports Tier 3: Land cover (ports) Port location, goods statistics (Ireland: Griffin, 2012) National sea area (Denmark: Plejdrup & Gyldenkærne, 2011)
H_Aviation	Emissions from landing and take-off (LTO) both for domestic and international flights	**EMEP/EEA 2013 Guidelines** Tier 1: LTO emissions per airport Tier 2: Airports location Tier 3: Land cover **General methodolog:** (Main) airport locations, fuel statistics (Ireland: Griffin, 2012; Denmark: Plejdrup & Gyldenkærne, 2011) Main airports (Dublin, Shannon and Cork) (Ireland: Kluzinaar et al., 2001) Airports footprint (UK: Tsagatakis et al., 2015)

I_Offroad	Emissions from machinery used in industry, households, agriculture as well as from railways and fishing vessels	**Railways:** **EMEP/EEA 2013 Guidelines** Tier 1: Traffic flow data Tier 2: Road network, population Tier 3: Population, land cover Rail network, population density (Ireland: Griffin, 2012) Rail network, rail emission model (REM) (UK: Tsagatakis et al., 2015) Rail network (Ireland: Kluzinaar et al., 2001; Denmark: Plejdrup & Gyldenkærne, 2011; Thessaloniki, Greece: Tsilingiridis et al., 2002; Europe: Denier van der Gon,2013) **Manufactuting industry and construction:** **EMEP/EEA 2013 Guidelines** Tier 1: Individual data for LPS Tier 2: Employment statistics Tier 3: Population, Land cover Employment statistics (UK: Tsagatakis et al., 2015; Japan: Kannari et al, 2007) Land cover (Denmark: Plejdrup & Gyldenkærne, 2011) **Commercial/institutional sector:** **EMEP/EEA 2013 Guidelines** Tier 1: Plant specific data Tier 2: employment statistics Tier 3: Land cover Employment statistics (Japan: Kannari et al, 2007) Land cover (Denmark: Plejdrup & Gyldenkærne, 2011) **Residential:** **EMEP/EEA 2013 Guidelines** Tier 1: fuel delivery statistics, household statistics, population Tier 2: Household statistics, population, smoke control areas Tier 3: Land cover Land cover (Denmark: Plejdrup & Gyldenkærne, 2011) **Agriculture/forestry:** **EMEP/EEA 2013 Guidelines** Tier 1: fuel delivery statistics, employment statistics Tier 2: employment statistics Tier 3: Land cover Land cover (Denmark: Plejdrup & Gyldenkærne, 2011) **Agricultural:** Vehicle license statistics, landcover (Ireland: Kluzinaar et al., 2001) Land cover (Ireland: Griffin, 2012; Thessaloniki, Greece: Tsilingiridis et al., 2002; Japan: Kannari et al, 2007) **Other:** **EMEP/EEA 2013 Guidelines** Tier 1, 2 and 3: Population, land cover

J_Waste	Emissions associated with waste handling. Waste incineration with energy recovery is included under "A_PublicPower" or "B_Industry"	**EMEP/EEA 2013 Guidelines** Tier 1: Site specific emissions/data, Tier 2: Landfill sites location, capacity data, population, employment statistics Tier 3: Land cover (arable land) **General methodolog:** Population density (Ireland: Kluzinaar et al., 2001) **SWDL:** **EMEP/EEA 2013 Guidelines** Tier 1: Site specific emissions/data, Tier 2: Landfill sites location Tier 3: Population, land cover (urban area) Landfill location, site specific CH_4 emissions (Ireland: Griffin, 2012) Landfill sites (UK: Tsagatakis et al., 2015; Denmark: Plejdrup & Gyldenkærne, 2011) Landfill sites, population density (Delhi, India: Guttikunda & Calori, 2013) **Waste incineration:** **EMEP/EEA 2013 Guidelines** Tier 1: Site specific emissions/data, Tier 2: Site locations, capacity data, population Tier 3: Employment statistics, population/farm statistics Facility location, site specific dioxin emissions (Ireland: Griffin, 2012) Facility location, activity data (Denmark: Plejdrup & Gyldenkærne, 2011,) **Accidential fires:** Land cover, population census (UK: Tsagatakis et al., 2015; Denmark: Plejdrup & Gyldenkærne, 2011) **Other waste:** Rural population density (Ireland: Griffin, 2012) Population staistics, land cover (Denmark: Plejdrup & Gyldenkærne, 2011) **Waste water:** **EMEP/EEA 2013 Guidelines** Tier 1: Site specific emissions/data, Tier 2: Site locations, employment statistics, capacity data, population Tier 3: Population Facility locations, activity data (Denmark: Plejdrup & Gyldenkærne, 2011)

K_AgriLivestock	Emissions associated with animal husbandry and manure management	**EMEP/EEA 2013 Guidelines** Tier 1: Farm specific data, livestock survey Tier 2: Employment statistics, production statistics, land cover Tier 3: Land cover (arable land) **General methodolog:** National farm survey, census of irish agricultural census (Ireland: Hynes et al., 2009) Agricultural census, landuse (Ireland: Griffin, 2012) Animal census (UK: Tsagatakis et al., 2015; Dragosits et al, 1998) Agricultural statistics, animal register (Denmark: Plejdrup & Gyldenkærne, 2011) Livestock quantities (FAO) (Europe: Denier van der Gon,2013) Land cover (Thessaloniki, Greece: Tsilingiridis et al., 2002; Japan: Kannari et al, 2007: Japan: Kannari et al, 2007)
L_AgriOther	All other agricultural emissions, e.g. from application of mineral or organic fertilizer, crops and field operations	**EMEP/EEA 2013 Guidelines** Tier 1: Farm specific data, livestock survey Tier 2: Employment statistics, production statistics, land cover Tier 3: Land cover (arable land) **General methodolog:** Fertiliser accounts, land parcel information system, agricultural census (Denmark: Plejdrup & Gyldenkærne, 2011) Land cover (LANDSAT thematic mapper; CORINE) (Ireland: Griffin, 2012; UK: Tsagatakis et al., 2015; UK: Dragosits et al, 1998; Thessaloniki, Greece: Tsilingiridis et al., 2002; Japan: Kannari et al, 2007; Europe: Denier van der Gon,2013)
P_IntShipping	Emissions from international navigation	**General methodolog:** Gridded sea shippping tracks (EMEP) (Europe: Denier van der Gon,2013) National sea area (Denmark: Plejdrup & Gyldenkærne, 2011)
Forest	Emissions/removals from forests	**General methodolog:** Land cover (forest species) (Thessaloniki, Greece: Tsilingiridis et al., 2002) Land cover (Denmark: Plejdrup & Gyldenkærne, 2011)