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MapEIre - National mapping of GHG and non-GHG emissions sources project

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EPA Research Report

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by

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Executive Summary

This reports documents the spatial emission model (MapEIre) created for Ireland under the project 'National mapping of GHG and non-GHG emissions sources' funded by the Irish EPA. The report describes the work carried out in the project, including the preliminary literature study, the technical specifications of the spatial and the temporal model as well as the spatial and temporal distribution keys (GeoKeys and TKeys, respectively) developed and used in the model. Model results are presented in spatial emission maps for Ireland. Extended technical documentation is available in the Technical documentation report available on the project webpage (www.mapeire.dk), and is intended to serve as guidance for experts installing and implementing the model as well as a thorough documentation of the GeoKeys used in the model. Further, a user manual has been prepared to guide users of the model through the basic functions in the model system (Plejdrup et al., 2019d).

The EPA is obligated to report on emissions of a wide range of pollutants that come under the scope of the CAFÉ Directive, the Convention on Long Range Transboundary Air Pollution (CLRTAP) and the UN Framework Convention on Climate Change (UNFCCC). The scope of the MapEIre project is to develop a model system to provide emissions for all activities and of all pollutants included in aforementioned legal agreements with respectively a temporal and a spatial resolution.

Reporting of spatial emissions is a requirement under CLRTAP, with priority have been given to the pollutants and the activities included in that Convention. Separate spatial distributions are created for each source category based on the best available digital spatial and statistical data, following the guidance under the relevant legal agreement. The spatial distribution is consistent with the European Monitoring and Evaluation Programme (EMEP) grid. Temporal variations have been decided for the source activities at an appropriate resolution, following the format of the EMEP standard temporal distributions

The MapEIre project has developed a high-resolution spatial and temporal mapping of the national Irish emission inventory. The work is state-of-the-art and combines a large amount of statistical data with detailed spatial information to allow for a complete spatial emission mapping on a 1 kilometre by 1 kilometre resolution for the Irish Exclusive Economic Zone. The results from the spatial model can be combined with sector-specific temporal profiles to generate a spatio-temporal emissions inventory with a temporal resolution of 1 hour. The temporal distribution is based on three levels of temporal profiles; hourly (24 hours), daily (7 days), and monthly (12 months).The MapEIre model is developed as an integrated database system focusing on performance optimisation.

The results from the spatial and temporal model can be used by all stakeholders to get an impression of where and when the highest emissions occur. This knowledge can be used as input for policy makers in decisions of implementation of environmental policies and measures, and data at this highly detailed level can be used to quantify pressures on vulnerable nature, e.g. Natura 2000 areas.

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1. Introduction

This report serves as the final report for the "National mapping of GHG and non-GHG emissions sources project" (MapEIre). The project is funded by the Irish EPA and is part of the Environmental Protection Agency Research Call 2015 on Climate - Air Science under the EPA Research Programme 2014-2020. The project duration was 24 months plus an extension of 12 months starting January 2016.

The project has been carried out by the Department of Environmental Science (ENVS) at Aarhus University (AU), Denmark, in cooperation with the Irish EPA; in particular with the Irish emission inventory team. The project team has also liaised with other organisations with relevant data.

The EPA is obligated to report on emissions of a wide range of pollutants that come under the scope of the CAFÉ Directive, the Convention on Long Range Transboundary Air Pollution (CLRTAP) and the UN Framework Convention on Climate Change (UNFCCC). The scope of the MapEIre project was to develop a model system to provide emissions for all activities and of all pollutants included in aforementioned legal agreements with respectively a temporal and a spatial resolution.

Reporting of spatial emissions is a requirement under CLRTAP with priority given to the pollutants and the activities included in that Convention. Separate spatial distributions were created for each source category based on the best available digital spatial and statistical data, following the guidance under the relevant legal agreement. The spatial distribution is consistent with the European Monitoring and Evaluation Programme (EMEP) grid. Temporal variations have been decided for the source activities at an appropriate resolution, following the format of the EMEP standard temporal distributions.

The spatial as well as the temporal model is based on input data from the current inventories to ensure consistency of the national total emissions in the national emission inventory, the spatial model, and the temporal model. Input and output data is in a format to facilitate input of emissions from the national inventory and further analysis of the outputs.

National stakeholders and inventory experts have been involved in the project in order to include knowledge on spatial properties for the activities concerned. Further, the national experts have been introduced to the final model system and trained in using it to make the model system useful to the national emission inventory system.

2. Objectives

The overall objective of the project was to develop models to enable a high spatial and temporal resolution of the Irish air emission inventories.

A main outcome is the preparation of the official Irish submission of spatial emissions to the UNECE due by 1 May 2017. Additionally, the project aimed to go beyond the official requirements, e.g. by using a finer sectoral disaggregation.

The project was divided into the following work packages to achieve the objectives of the project:

- WP1: Development of specifications for the spatial and temporal model
- WP2: Assessment and selection of geographical data for the spatial model
- WP3: Development of the model for spatial distribution of emissions
- WP4: Development of the model for temporal distribution of emissions
- WP5: Project management and communication

Additionally, two WPs were added as part of the project extension:

- WP6: Development of bottom-up inventory for Dublin
- WP7: Updating of the spatial model

In addition to fulfilling the official requirements for reporting under the UNECE, an important objective was to develop a model that could produce high quality input to air quality modelling. This meant a need for high spatial resolution, high temporal resolution and high sectoral disaggregation.

3. Project results

3.1 Identification of available spatial data

Through a survey of the Irish national emission inventory data and calculation system, the project team has identified the relevant sectors and sources and the methodology used in the previous spatial emission mapping. A list was elaborated including spatial data that could be used in the present mapping, both on a detailed and on a more aggregated level. In the first step, the main focus was to prepare a long list of spatial data that could be useful, without excluding any possibilities. Later the number of data sets decreased as data turned out to be non-existing or not available, the spatial data were of too poor quality, and/or more data processing were necessary than could be justified by the benefit of including the data. For example, it is not beneficial to apply very extensive methodologies for minor emission sources. The level of detail to be applied to the mapping methodology was decided after review of the obtained data.

The data survey was focusing on spatial data covering the entire country, with relevance for emission mapping. Both general data, like national borders (land and sea area), buildings, population density and land-use, and sector specific data, like road network including mileage, agricultural areas including animal numbers, and ferry routes, were covered. These data were all going to be used to map emissions from area sources, and the features in the layers were used as proxy data to determine the share of the national total emissions to be allocated to the individual cells in the 1 km x 1 km grid covering Ireland. The resulting tables holding shares of national emission by grid cell were referred to as GeoKeys. For some area sources, there were no closely related spatial data available to use as proxy for emission mapping, e.g. emissions from domestic solvent use have been allocated following the population density, as no data was available to indicate in more detail where the product use takes place. For other emission sources more close related spatial data were available, e.g. emissions from road transport have been allocated to the road network taking into account information on mileage, where available.

The most accurate emission mapping can be made for sources that are handled as point sources in the national emission inventory. This was the case for e.g. power plants and large industrial plants, for which annual emissions are available for the individual plants based on ETS reporting or other plant specific data. In those cases, emissions have been allocated to the exact position (XY coordinates) of the plants. For other point sources, emissions are not calculated annually on an individual level, but instead based on plant specific data for one or few years or as a sum for all the sources based on aggregated activity data. This was the case for emissions from wastewater treatment plants and solid waste disposal sites, among others.

The first step of identification of spatial data set was a search for online geo-data. The project team had been looking into relevant institutions' websites to identify which institutions have public available spatial data and to what extend the data could be downloaded from the web. Among the Irish institutions that had been surveyed are Ordnance Survey Ireland (OSi), the GeoDirectory, the Geoportal, Transport Infrastructure Ireland and IRLOGI. In addition, census data provided by e.g. the Central Statistics Office, the National Road Authority, and Transport Infrastructure Ireland were explored.

The second step was to contact institutions that presented relevant data where these were not public available. This included a lot of input from meetings in the Steering Committee as well as input received during the stakeholder workshop. In all cases, the institutions have been very positive and cooperative, and in most cases, it was possible to obtain the relevant data and explanations, in some cases in an aggregated form to comply with confidentiality conditions. See Nielsen & Plejdrup (2017) for more information.

3.1.1 Review and selection of the spatial data sets

Based on the analysis of the available spatial datasets, a selection of the best dataset for each category was made. Many factors were considered when selecting the best spatial dataset, e.g. whether the coverage was sufficient, if the spatial uncertainty was acceptable, and if the data format was suitable.

An extended description of the selected geodata and the GeoKey(s) for each of the source/sink categories currently included in the national Irish emission inventories is available in the technical documentation report (Plejdrup et al., 2019a) available on the project webpage (www.MapEIre.dk). The report include tables listing the source categories in the sector with a short description when relevant, and the geodata and methodology used to generate GeoKeys. Further, it is listed if the categories cover point sources (P), area sources (A), or both point and area sources (P/A). In some cases, the GeoKey have been defined for a group of pollutants where the pollutants have a similar distribution e.g. across fuels. This has been done, as it was not practicable to have more than 25 different GeoKeys for a sector with only minor differences between most of the GeoKeys.

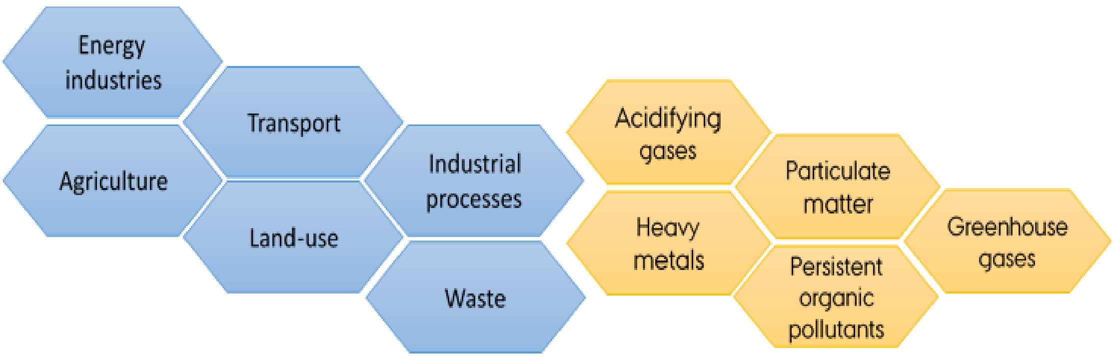
The categories that were reported as not estimated in the Irish inventory had been included in the discussion work to ensure completeness. Where possible, a suggested source of geodata had been provided and GeoKeys have been developed to the extent that resources allowed it.

3.2 Model description

The MapEIre project has developed a high-resolution spatial and temporal mapping of the national Irish emission inventory. The work is state-of-the-art and combines a large amount of statistical data with detailed spatial information to allow for a complete spatial emission mapping on a 1 kilometre by 1 kilometre resolution for the Irish Exclusive Economic Zone. The results from the spatial model can be combined with sector-specific temporal profiles to generate a spatio-temporal emissions inventory with a temporal resolution of 1 hour. The MapEIre model has been developed as an integrated database system focusing on performance optimisation.

The MapEIre model includes all sectors (138) and pollutants (32) in the national inventories of GHG and non-GHG emissions, see Figure 1. The MapEIre model enables spatial emission mapping on three sectoral levels; censuses of population (NFR) gridded nomenclature for reporting (GNFR), and national total for all sectors, and on two spatial resolution levels; 1 km x 1 km and 0.1 degree x 0.1 degree.

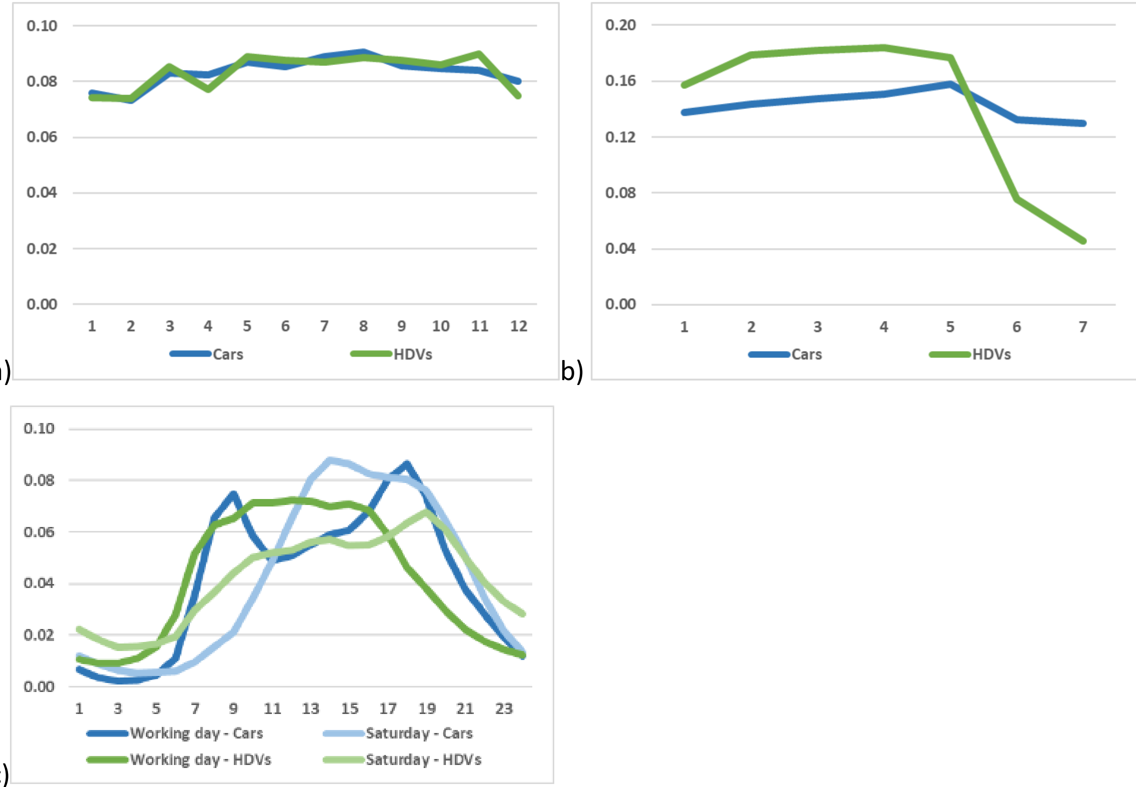
Figure 1 Main sectors and pollutant groups included in the MapEIre model



Further, the MapEIre model includes a module that adds a temporal component and calculates spatio-temporal emissions on a spatial resolution of 1 km x 1 km and a temporal resolution of 1 hour. The temporal distribution is based on three levels of temporal profiles; hourly (24 hours), daily (7 days), and monthly (12 months), see

Figure 2.

Figure 2   Temporal profiles for road transport with cars and heavy duty vehicles (HDVs) showing a) monthly, b) daily, and c) hourly variation.



a) b) c)

The MapElre model is based on the most detailed data available regarding both emissions, and spatial and temporal conditions.

3.2.1 Specifications of the spatial model

The main purpose of creating a spatial model for the Irish emission inventories was for Ireland to be able to fulfil the requirements under the CLRTAP by reporting gridded emissions in the NFR reporting format. Therefore the spatial emission model for Ireland has been prepared in agreement with the methodologies in EMEP/EEA Guidebook (EEA, 2016), and the model has been 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 (UNECE, 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 has been prepared on a higher spatial resolution than 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) has been applied in the model instead of the geographic coordinate system (WGS84) used by EMEP. The CLRTAP requirement is a spatial resolution of 0.1 degree x 0.1 degree, which corresponds to approximately 7 km x 11 km. Though, it had 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 was agreed as more spatial data sets were 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 was 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 has been 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, see Table 1.

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 has, for the main part, been more disaggregated than the GNFR level. The details of the available spatial data have been the determining factor in selection of the sectoral disaggregation level. In a number of cases it was 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 has been advantageous to disaggregate the emissions further to create the most accurate spatial distribution, again depending on the availability of detailed spatial data. This was the case for residential heating where it was found to 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 has been 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 has been included in the spatial model to aggregate the spatial emissions according to GNFR level.

Table 1   Comparison between the requirements under LRTAP and the spatial 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 UNECE (2014) do 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. For more information, please see Nielsen & Plejdrup (2016).

3.2.1.1 Choice of data for EEZ, coastline, national border

Outer borders for the land area and sea area included in the spatial model had to be defined, and appropriate spatial data sets had 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 was 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, so this must be decided individually by the countries. The exclusive economic zone (EEZ) has been chosen as the outer border for the spatial model, and the version provided by the Department of Communications, Energy and Natural Resources (DCENR) has been applied. This version deviates from the version available from MarineRegions.org.

A 1 km x 1 km grid was developed for the spatial emission model, using the standard tool "Create Fishnet" in ArcMap, using the projection TM65 (EPSG 29902). The fishnet was 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 2.

Table 2 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 was applied X and Y coordinates for the centerpoint (Xc and Yc). The grid cells were 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 (e.g. the point (-296 713.384 , 158 922.683) had been 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 was very important that the models developed within this project were easily compatible with the data systems used by the emission inventory team at the EPA. Currently, the calculation of emissions is 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 was beneficial to base the input to the spatial model on the reporting formats to the extent possible. Therefore, the aim was 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. For more information, please see Nielsen & Plejdrup (2016).

3.2.2 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 have been defined at the emission reporting level, e.g. separately for railways, aviation, navigation and machinery in different sectors. Temporal profiles have been developed at three levels identical to the current setup in the EMEP model, i.e. monthly, weekly and daily variations. For more information, please see Nielsen & Plejdrup (2016).

3.2.3 GeoKeys

The spatial distribution of emissions has been based on a large number of spatial distribution keys (GeoKeys), which are tables including information on the part of a national emission that should be allocated to the individual grid cells. The GeoKeys are normalised tables where emissions shares sum up to 1. GeoKeys have been prepared either from statistical data in spreadsheets or in a geographical information system (GIS) based on digital spatial data. Among the data used in the MapEIre model are official statistics, such as the Irish emission inventory, censuses of population, housing and agriculture. Spatial datasets as diverse as land cover, road network, building use and heat demand have been used to prepare the GeoKeys.

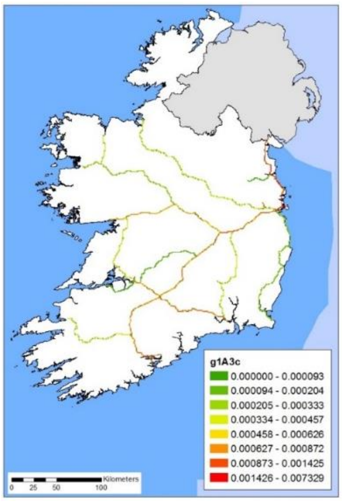
3.2.3.1 Data integration

Integration of spatial data sets can improve the spatial distribution and have been used to wide degree in creating the MapEIre model (Plejdrup et al., 2018). Using data integration makes it possible to include detailed data covering only part of an emission sector, to prepare combined GeoKeys e.g. for sectors with both point and area sources, and to combine information from different data like regional statistics and spatial maps in GeoKey, e.g. mileage data for a part of the

road network has been integrated with a simple road network covering the entire domain to generate GeoKeys for road transport. Another example is identification of cultivated organic soils via integration of the Land Parcel Identification System (LPIS) and a soil map including organic soils.
GeoKeys were prepared from the most detailed, complete and accurate data available, the best being data on source level. Pollutant and/or year specific GeoKeys were prepared for sectors if detailed emissions or activity data were available, e.g. data from PRTR reporting or information provided by individual plants, facilities or companies. If less detailed data were available, the sectoral GeoKeys were used for all pollutants and/or for all years, causing similar spatial emission patterns for the sector for all pollutants and/or all years included in the model. This is most likely not the case, but a necessary assumption in the spatial emission model due to data limitations.
A number of GeoKeys are a combination of two or more sub-sector keys. When a NFR sector covers both point sources and area sources, e.g. non-ferrous metals (NFR category 1A2b) where 85 % of the emissions were covered by point sources, a spatial distribution key was prepared from the point source data. The remaining emissions from the sector have been allocated using a spatially distribution based on more general data, e.g. heat demand for industrial buildings. The sectoral GeoKey has been calculated as an average of the two spatial distributions, weighted by the share of emissions from point sources and area sources, respectively (Plejdrup et al., 2018).
If source specific data were not available, spatial proxy data were used to prepare the GeoKeys, preferably on sector level, but in cases where no spatial sector specific data exists, or none was available, the GeoKeys were based on general spatial data, e.g. buildings, heat demand or population. Even if general GeoKeys were prepared from detailed, complete and accurate spatial data, the appropriateness as proxy for a given emission sector might be poor, which is often the case when population density is used as proxy.
In other cases, the GeoKey was based on spatial data that served as a good proxy, but that was poor regarding accuracy, spatial resolution or that was out-of-data, an example being the use of catching statistics by ICES areas as a proxy for emissions from fishing, due to the low spatial resolution of the spatial data. Another example is the use of CORINE land cover (CLC) maps to prepare GeoKeys for the LULUCF sector. This satellite based pan-European map has considerable uncertainties when applied on a national scale regarding geographical demarcation of features and assigned land use category.
All GeoKeys are documented in the technical documentation report (Plejdrup et al., 2019a). An example of the documentation of the GeoKeys is provided for railways in Table 3.

Table 3 Documentation of the GeoKey for railways

Source data	IR Network and 2016 Traffic (2016 05 24)(RevA).pdf) IR_Rail_Network_LineNames_20161219
Data provider	Irish Rail
File location	\\MapEIre\DataLibrary\Rail\IR Network and 2016 Traffic (2016 05 24)(RevA).pdf \\MapEIre\DataLibrary\Rail\Rail.mdb
Projection	ING-75 (Authority: Custom) (corresponds to TM75_Irish_Grid, EPSG: 29903)
Data description	Annual train passes on different sections of the network for 2011 and 2016 Centre lines for the Irish Rail track network
Workflow	The rail network layer is modified by deleting the coastline segments, and adding length of rail network by route. Annual train passages in 2016 [ATP_2016] are added to the routes in the rail network layer. Only one ATP is applied for each route, and for routes where more ATP values are available, the selection of ATP will be based on expert judgement, but in general, the highest ATP value will be applied. Annual train kilometres are calculated by route ([ATP_2016]*[Length]), and the share of total train kilometres are calculated by route ([ShrATP16xL]) Add field “ATPxLen16” and calculate value as [ATP_2016]*[Length] Add field “ShrATP16xL” and calculate values as [ATPxLen16]/SumOf[ATPxLen16], the latter from the statistics tool. The share of the total rail network length is calculated by grid cell ([LenPrRoute]) The GeoKey shares are calculated as [ShrATP16xL]*[LenPrRoute]
GeoKey	1A3c
NFR/CRF sector	1A3c - Railways



3.2.4 TKeys

The temporal distribution of emissions is based on a large number of temporal distribution keys (TKeys), which are tables including information on the part of a national emission that should be allocated to the individual time intervals. The TKeys are normalised tables where emissions shares sum up to 1.

Temporal variations in emissions occur on monthly, daily and hourly basis based on e.g. production, use and transport patterns. The time factors are highly variable from emission source to emission source, and variability is expected between pollutants.

The temporal model includes temporal distribution profiles on monthly, daily and hourly level. The emission source aggregation level in the temporal model depend on the availability of statistical data with a temporal component. A number of statistics were available on monthly basis, but temporal data on daily and hourly level were generally scarce, so it has been necessary to use data for smaller areas, from other countries using proxy data, or base the temporal profiles on expert judgement, in order to prepare TKeys for all sectors.

Three temporal profiles have been prepared for each emission source category in the spatial model describing the monthly, the daily and the hourly distributions. For selected emission sources, separate hourly TKeys were prepared for different days of the week, where weekday 1 refer to Monday. An example is road transport, where separate hourly TKeys were prepared for Monday (weekday 1), Tuesday-Thursday (weekday 2-4), Friday (weekday 5), Saturday (weekday 6) and Sunday (weekday 7), respectively (Plejdrup et al., 2019c). In other cases, separate TKeys were prepared for different pollutants for an emission source category, as the emissions were related to different activities or processes. This was e.g. the case for domestic wastewater handling, where two separate TKeys were prepared for N_2O and for remaining pollutants, respectively.

TKeys were developed to reflect the distribution of emissions from a source on a given temporal level (months, days, or hours). The temporal distribution has been based on different kinds of temporal data and information, e.g. monthly electricity output, hourly traffic counts, and assumptions such as shut down or reduced activity levels in weekends for specific industries. Some of the temporal input data were closely related to the emission, e.g. electricity output, as the fuel consumption, and to a certain degree also emissions, were well correlated with the electricity production. Others are poorer proxies, e.g. number of trains by route from timetables, as the trains might be of different types. Further, neither activities at service and shunting areas nor freight trains were covered in the timetables, but contribute significantly to the emissions.

To improve the quality of the temporal distribution, TKeys should be prepared on a disaggregated sectoral level, as this would leave the possibility to reflect the sectoral properties as detailed as possible. E.g. separate TKeys should be prepared for different animal types in the agricultural sectors and for different vehicle types for road transport. In some cases, it could be of benefit to prepare separate TKeys for different pollutants for a sector, as pollutants might occur from different activities or processes. This is, e.g. the case for domestic wastewater handling, where N_2O show a seasonal variation with the water temperature, while the same correlation is not found for CH_4.

The temporal model uses the TKeys for the entire Irish domain, and following it is not possible to reflect regional differences using the temporal emission distribution. Including a spatial parameter in the temporal model would increase the data amounts significantly, and for many sectors, it would be of no or little relevance, as the TKeys are based on proxies for national characteristics. Few sources could benefit from including a spatial parameter in the temporal model, e.g. agricultural soils, where different practices occur in different parts of the country, and road transport, where the temporal pattern is different in large cities, along commuting routes and in rural areas.

More documentation on the development of TKeys are provided in Plejdrup et al. (2019a). An example for public electricity production is provided in Table 4.

Table 4 Documentation of the TKey for public electricity production

GNFR	A		
NFR/CRF	1A1a		
Pollutant	All		
Temporal resolution	Monthly	Daily	Hourly
Weekday			Monday-Saturday Sunday
Input data	MSM01: Electricity Output by State, Month and Statistic Net Electricity Output (Gigawatt Hours)	Electricity generation excluding wind. Hourly actual electricity generation (MW)	Electricity generation excluding wind. Hourly actual electricity generation (MW)
Data provider	CSO	EirGrid	EirGrid
Data source	https://www.cso.ie/px/pxeirestat/Statire/SelectVarVal/Define.asp?maintable=MSM01&PLanguage=0	http://smartgriddashboard.eirgrid.com/#	http://smartgriddashboard.eirgrid.com/#
Description	Average monthly net electricity output for the years 2010-2017	Average electricity generation ex. wind by weekday	Average electricity generation ex. wind by hour for Monday-Saturday and for Sunday

3.2.5 Dublin

As part of the extension of the MapEIre project, a detailed case study was made for Dublin. The spatial model has been extended with a module for Dublin, where the spatial resolution has been increased to 100 m x 100 m. The Dublin model covers the pollutants NO_x, NMVOC, SO_2 and PM_{10}. The higher spatial resolution improves the applicability of the spatial emissions as basis for air quality modelling. Further, Dublin data gives a better opportunity for comparison with measurements of air quality for verification of the model.

The Dublin case model was designed in a similar format as the national model, and the model setup allows for an easy extension of the model to include gridding of all pollutants in the Irish emission inventories. All GeoKeys have been recalculated, based on the original spatial data sets used in the national model, to ensure the highest level of spatial details possible. The best available spatial data have been used in the national model, e.g. detailed point source data for large point sources, and therefore the Dublin case model is based on the same spatial data as the national model.

3.3 Main outputs

Detailed spatial emission inventories on a resolution of 1 km x 1 km have been developed for all major pollutants. The detailed sectorial breakdown in the model setup enables implementation of detailed GeoKeys, and following a good estimate of the emissions pattern, leaving the possibility to identify emission hotspots and peak hours.

3.3.1 Spatial

The output from the spatial model was aggregated to the national total emissions as well as to main sectoral emissions following the EMEP classification. The output is available on the project website both as images and as data files for further processing in GIS; http://projects.au.dk/mapeire/spatial-results/download/. Maps showing national total emissions of selected pollutants are shown in Figure 3.

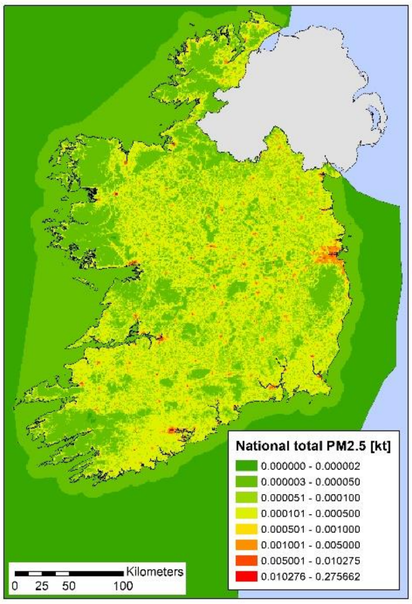
The largest sources to emissions of $PM_{2.5}$ are residential plants, agriculture, and road transport, and following the large urban areas are clearly visible on the map, and to a less degree also the major roads.

The largest sources to emissions of CO_2 are power plants, road transport and residential combustion, and hence the map is dominated by point sources, the road network and urban areas. Both CO_2 emissions and removals are included in the national total. The major part of the removals occur in forest areas, which are also visible on the map.

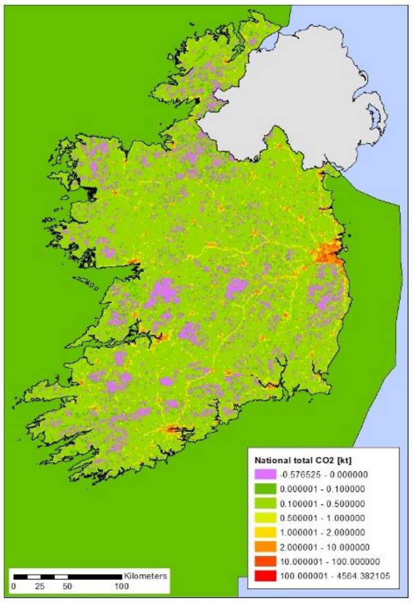
National total NO_x emissions are dominated by road transport, power plants, industry and shipping, which is reflected in the emission map with large emissions on the major roads and in densely populated areas. The largest sources to emissions of NO_x are road transport, power and cement plants, shipping, and residential plants, and the map is dominated urban areas. Further, the major roads are visible on the map. Emissions from power plants are allocated to point source locations and, due to the high spatial resolution of the emissions model, not clearly visible on the map.

Emissions of NH_3 mainly come from the agricultural sector. The largest sources are cattle, manure applied to soils, grazing animals, and mineral fertiliser. The pattern on the map basically reflects animal density and the agricultural area. No NH_3 emissions occur from water-based sources.

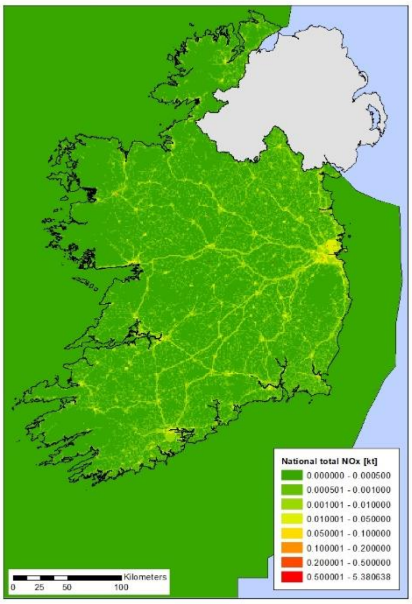
Figure 3 Spatial emissions maps for national total emissions of a) $PM_{2.5}$, b) CO_2, c) NO_x, and d) NH_3



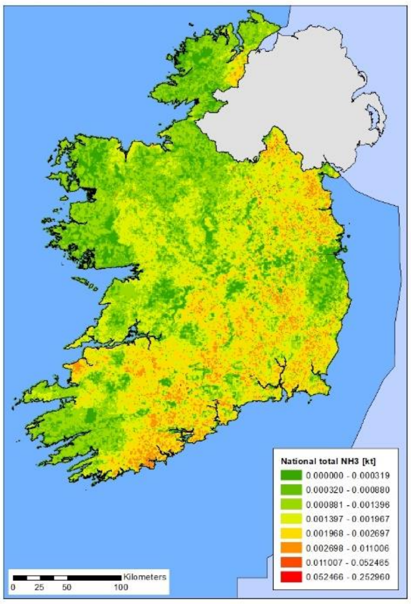
a)



b)



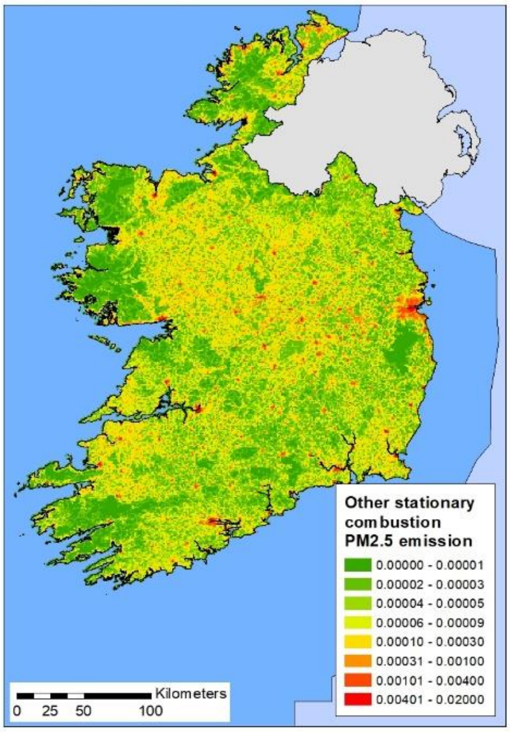
c)



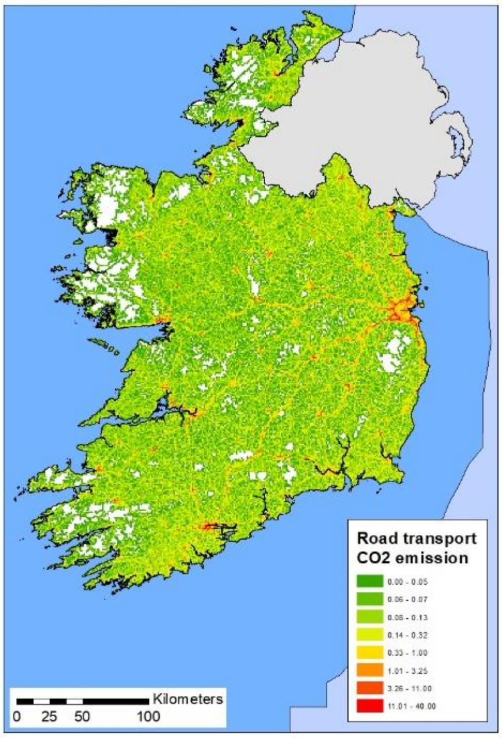
d)

The map of emissions from road transport reflect the road network with the highest levels on the major roads. The railway network is visible on the map of NO_x from off-road mobile sources, as this source make a significant contribution to the sectoral emission, and as the emission levels are high due to the allocation to a relatively small area. NH_3 from agricultural livestock mainly come from manure management for cattle, and the spatial distribution is based on animal numbers by electoral districts and the areas with agricultural fields.

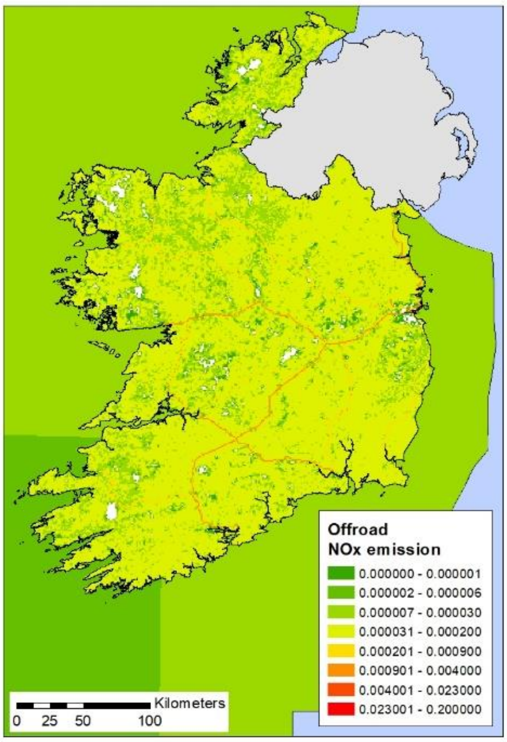
Figure 4 Spatial emissions maps for a) $PM_{2.5}$ from residential combustion, b) CO_2 from road transport, c) NO_x from off-road mobile sources, and d) NH_3 from agricultural livestock



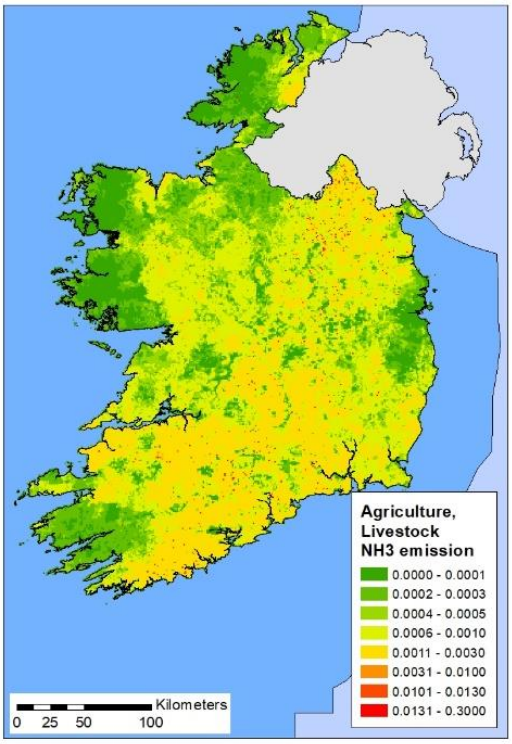
a)



b)



c)



d)

Previously published projects on spatial distribution in Ireland have been done at a resolution of 10 × 10 km (de Kluizenaar et al., 2001; AEA, 2012), and the official submissions have been done at a resolution of 50 × 50 km. The MapEIre project increased the resolution to 1 × 1 km to improve the usability for air quality modelling and to allow for a more detailed regulation implementing measures targeting areas where the emissions are highest allowing for more cost-effective initiatives. Development of a national spatial emission model covering the entire country allows for assessment of effects of measures on local, regional and national scale. The MapEIre project has made comparisons between the previous Irish spatial emissions and the new higher resolution emissions to illustrate the increased accuracy that can be gained by changing to a higher resolution. Using data at a more disaggregated level and a higher spatial resolution results in a more detailed spatial emission mapping with higher accuracy, when based on appropriate background data. The improvements from the coarse 50 × 50 km resolution spatial inventory to both the 10 × 10 km and the 1 × 1 km spatial inventories are significant, especially for NO_x, SO_2 and $PM_{2.5}$. See Plejdrup et al. (2019b) for further information.

3.3.2 Temporal

For each of the sectors and pollutants covered by the spatial model, temporal profiles have been developed. The temporal profiles have been made at three levels: monthly, daily and hourly. To reflect as many details as possible, the temporal profiles were prepared on sector level and when relevant, separate profiles were prepared for different pollutants or weekdays, e.g. for waste water and for road transport, respectively.

The temporal profiles (TKeys) are available for download on the project webpage; http://projects.au.dk/mapeire/temporal-results/temporal-profiles/

Calculation of the entire Irish emissions inventory on high spatial and temporal resolution would result in very large data amounts, which are difficult to handle by the common user. To solve this issue and to ensure good model performance, the temporal model was set up to run the calculation for user defined time period, emissions sector and pollutant, e.g. $PM_{2.5}$ from residential combustion in March 2016.

An appropriate way to visualise the temporal emissions is by using videos. The temporal model was setup to generate output in a format that can be used in a GIS (ArcMAP) to make hourly emissions maps, which can be processed into a video. Examples on videos are available for download on the project webpage; http://projects.au.dk/mapeire/temporal-results/

3.3.3 Dublin

The Dublin case study is methodologically very similar to the national model, but due to the improved spatial resolution, the emission maps show a different pattern. Further, the sectoral contribution to the total emission are different for Dublin and for Ireland, as shown in Figure 5. The contribution to NO_x emissions from road transport and other stationary combustion (mainly residential combustion) are larger in Dublin than in Ireland, while navigation and agriculture are smaller. Industry and road transport make up larger contributions to the total PM_{10} emissions in Dublin than in Ireland. Shipping, that makes up a significant share of the national PM_{10} emissions, do not occur in the Dublin model, as the coverage is the land area. Solvent use is the dominating sector in Dublin to NMVOC emissions, while livestock dominates the national total NMVOC emissions. In both the national model and the Dublin model, emissions from Industry contribute significantly, and part of the emissions are allocated to specific point source locations, here among six industrial plants in Dublin. Other stationary combustion (mainly residential) is a large source of SO_2 emissions on both national level and in Dublin. On national level, power plants and fugitive emissions also make up large sources, which are not the case in Dublin.

Figure 5 Sectoral contribution to the total emission for Dublin and for Ireland and for the pollutants NO_x, PM_{10}, NMVOC and SO_2

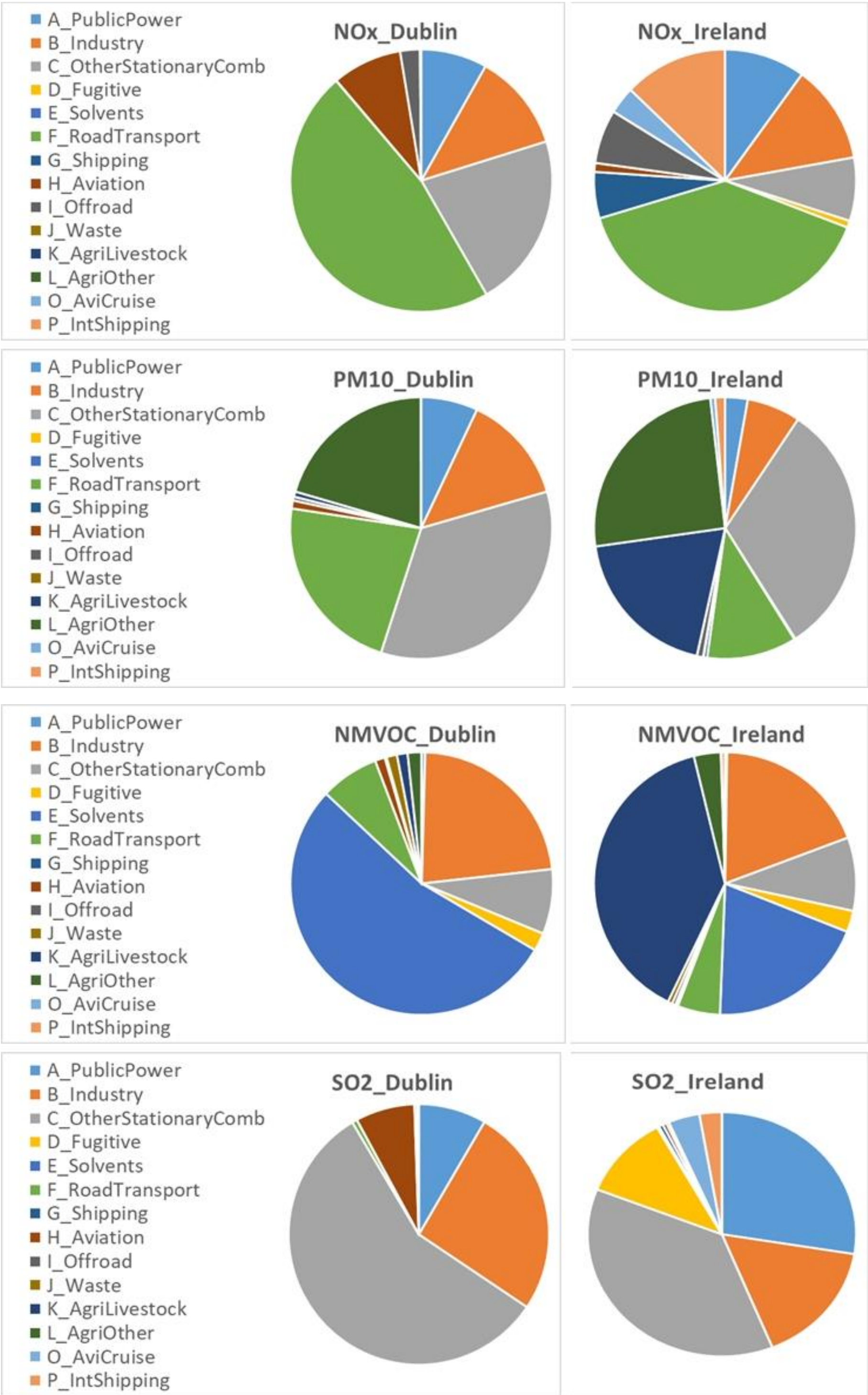
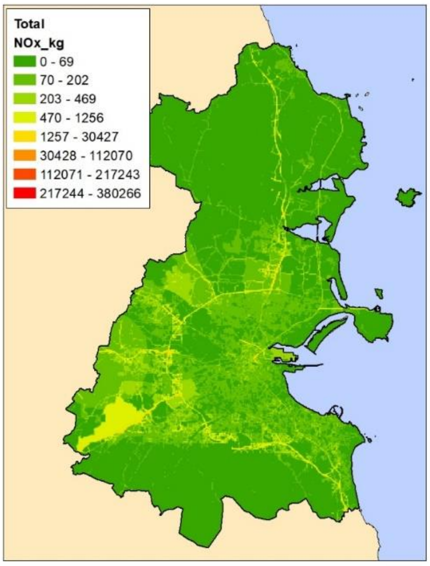
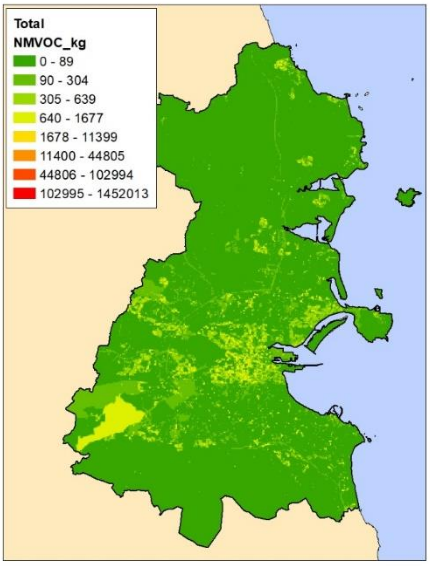


Figure 6 show maps of total emissions in Dublin for selected pollutants. The road network is identifiable on the NOx map, as road transport is a dominant sector. The NMVOC map show that emissions are largest in densely populated areas and in industrial areas.

Figure 6 Spatial emissions maps for Dublin for a) NO_x and b) NMVOC



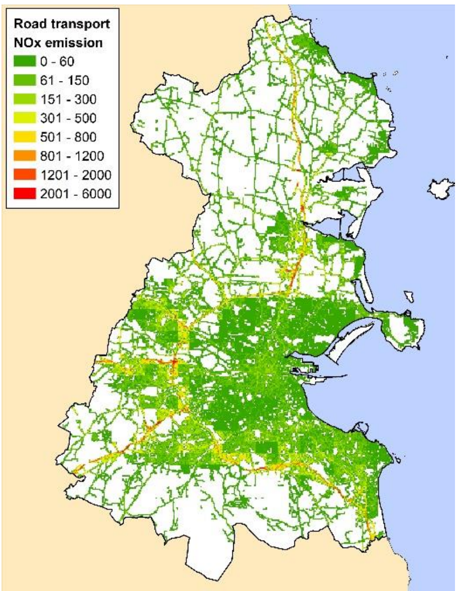
a)



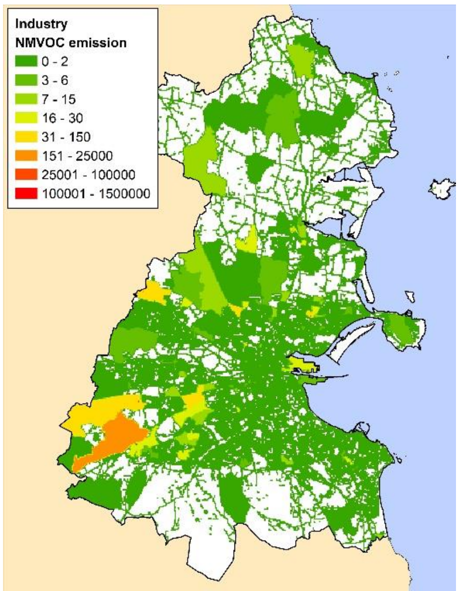
b)

Using the 100 m x 100 m grid in the Dublin model left many grid cells without emissions, as these areas have no emission activity for a given sector. This was apparent on both maps showing sectoral emissions results from the Dublin model, see Figure 7, where large areas are visible with no emissions from road transport and industry, respectively.

Figure 7 Spatial emissions maps for Dublin for a) NO_x from road transport and b) NMVOC from industry



a)



b)

4. Communication activities

The MapEIre project activities and results have been documented in a number of papers, reports and presentations. The main communications are listed in the following and are available for download at the project webpage; http://projects.au.dk/mapeire/publications/.

Papers

Spatial high-resolution mapping of national emissions. Plejdrup, M.S., Nielsen, O.-K. & Bruun, H.G. WIT Transactions on Ecology and the Environment: Air Pollution XXVI. Vol. 230 WIT Press, 2018. pp. 399-408.

Influence of improved methodology and increased spatial resolution on gridded emissions. Plejdrup, M.S., Nielsen, O.-K. & Bruun, H.G, International Journal of Environmental Impacts, Vol. 2, No. 2 (2019) 161–173.

Temporal variations in road transport emissions as input to air quality modelling. Plejdrup, M.S., Nielsen, O.-K., Bruun, H.G. & Christensen, J.H. Atmospheric Environment. Submitted.

Abstract

Abstract presented at the EFGS Conference in Dublin, 2.-3. November 2018.

Reports

Two-page summary report

Technical documentation report

User manual

WP1 Synthesis Report.

WP2 Synthesis Report.

Presentations

10th EFGS Conference, 2017, Dublin, Ireland

11th FAIRMODE Plenary Meeting, 2018, Baveno, Italy

Air Pollution 2018, Naples, Italy

1st stakeholder workshop, Dublin 2016

2nd stakeholder workshop, Dublin 2018. Presentation of the project

2nd stakeholder workshop, Dublin 2018. The spatial model

2nd stakeholder workshop, Dublin 2018. The temporal model

2nd stakeholder workshop, Dublin 2018. Data availability and future applications

Other publications

Pamphlet (November 2017)

5. Recommendations

The MapEIre model is state-of-the-art, and the model leaves room for improvements by application of new spatial and temporal data, and by further development and refinement of the model setup. Both the spatial and temporal model can be improved by developing more detailed distribution keys. The spatial model can be improved by including time-series for more GeoKeys, while the temporal model can be improved by use of more detailed profiles for the sectors where the present TKeys are based on expert assumptions. If data availability allows, it could be relevant to evaluate if pollutant specific TKeys should be made for more sectors, and if more sectors should have different hourly profiles for different days of the week.

In future work, the emphasis should be on refining methodologies as a further increase in the resolution is unlikely to improve the accuracy of the spatial inventory, as very few datasets are available to support a resolution of e.g. 100 × 100 m.

The results from the spatial and temporal model can be used by all stakeholders to get an impression of where and when the highest emissions occur. This knowledge can be used as input for policy makers in decisions of implementation of environmental policies and measures, and data at this highly detailed level can be used to quantify pressures on vulnerable nature, e.g. Natura 2000 areas.

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EEA, 2016: EMEP/EEA air emission inventory guidebook, prepared by the UNECE/EMEP Task Force on Emission Inventories and Projections, 2016 update. https://www.eea.europa.eu/publications/emep-eea-guidebook-2016

Nielsen, O.-K. & Plejdrup, M.S. 2016. National mapping of GHG and non-GHG emissions sources - Synthesis report for work package 1. Aarhus University - Department of Environmental Science. 24 p.

Nielsen, O.-K. & Plejdrup, M.S. 2017. National mapping of GHG and non-GHG emissions sources - Synthesis report for work package 2. Aarhus University - Department of Environmental Science. 21 p.

Plejdrup, M.S., Nielsen, O.-K. & Bruun, H.G. 2018. Spatial high-resolution mapping of national emissions. WIT Transactions on Ecology and the Environment: Air Pollution XXVI. Vol. 230 WIT Press, 2018. pp. 399-408. ISBN 978-1-78466-269-1.

Plejdrup, M.S., Bruun, H.G., Nielsen, O.-K., Gyldenkærne, S. 2019a. National mapping of GHG and non-GHG emissions sources - Documentation of the spatial and temporal emission model for Ireland. Technical documentation report. Aarhus University - Department of Environmental Science. 159 p.

Plejdrup, M.S., Nielsen, O.-K. & Bruun, H.G. 2019b. Influence of improved methodology and increased spatial resolution on gridded emissions. Int. J. Environ. Impacts, Vol. 2, No. 2 (2019) 161–173.

Plejdrup, M.S., Nielsen, O.-K., Bruun, H.G. & Christensen, J.H. 2019c. Temporal variations in emission from road transport. In Preparation.

Plejdrup, M.S.; Bruun, H.G. & Nielsen, O.-K. 2019d. User manual for the MapEIre model system. Aarhus University - Department of Environmental Science. 96 p.

UNECE. 2014. Guidelines for Reporting Emissions and Projections Data under the Convention on Long-range Transboundary Air Pollution. ECE/EB.AIR/125. United Nations Publication.

Acronyms and Annotations

CLRTAP	Convention on Long-Range Transboundary Air Pollution
CRF	UNFCCC Common Reporting Format
EEZ	Exclusive economic zone
EMEP	European Monitoring and Evaluation Programme
ENVS	Department of Environmental Science, Aarhus University
ETS	EU Emissions Trading System
GeoKey	Spatial distribution key
GNFR	UNECE Nomenclature For Reporting of Gridded emission data
LULUCF	Land Use, Land-Use Change and Forestry
MapEIre	The project National mapping of GHG and non-GHG emissions sources (MapEIre), funded by the Irish EPA
NFR	UNECE Nomenclature For Reporting of emission data
PRTR	Pollutant Release and Transfer Register
TKey	Temporal distribution key
UNECE	United Nations Economic Commission for Europe
UNFCCC	The United Nations Framework Convention on Climate Change