# Calculating the greenhouse gas emissions of Finnish municipalities

The greenhouse gas emissions of Finnish municipalities have been calculated with a model called ALas. This document describes the ALas model's calculation principles.

## ALas model's calculation principles

The Finnish Environment Institute (SYKE) calculates the annual greenhouse gas emissions of Finnish municipalities by using the ALas model (Alueellinen Laskenta, regional calculation). ALas 1.2 – covers 309 municipalities and the years 2005–2019. The model is updated as necessary, and the most recent results are published annually. The carbon dioxide, methane and nitrous oxide emissions, as well as F-gases, are calculated and the results are presented as carbon dioxide equivalents. With regard to carbon dioxide, bio-based fuels have zero emissions in the calculations. The energy consumption of various operations is also calculated, in addition to the emissions.

The calculation method of the ALas model is usage-based. The region's production-based emissions act as the starting point, but some operations that generate emissions are calculated based on consumption, regardless of their geographical area of origin. In broad terms, the calculation is similar to the basic level of GHG Protocol's GPC standard, with agriculture, F-gases and grid losses included, but without the local air service included in the standard.

Table 1 presents the ALas 1.2 model's emission sectors and their calculation principles. Hinku calculation (of the Towards Carbon Neutral Municipalities project) is the default calculation approach for monitoring municipal emissions. The Hinku calculation rules imply that the following aspects are excluded from municipal emissions:

- fuel usage of industrial plants that are part of the EU Emissions Trading System (ETS),
- all industrial electricity consumption,
- emissions from industrial waste treatment,
- drive-through traffic of trucks, vans and buses.

Additionally, emission compensations are calculated for the municipality for any wind power produced in the region, based on the annual electricity emission factor.

In the ALas model, all results are also produced without the Hinku calculation rules. Furthermore, the emissions are allocated in the emission trading and effort sharing sectors.

Corrections with heating degree days are not used to even out the differences between different years or municipalities. The benefit allocation method is used to calculate the emissions of combined heat and power plants.

ALas 1.2 does not include the following sectors:

- Air traffic
- Foreign boat traffic
- Ice breakers
- Industrial processes
- LULUCF.

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*Table 1. ALas 1.2 model's emission sectors and calculation principles.*

| Emission sector | Calculation principle | Hinku calculation | Notes |
|---|---|---|---|
| District heating – ETS | Consumption | Yes | Municipal production + purchase - sales.<br>Subsectors: residential, services, industry, agriculture. |
| District heating – non-ETS | Consumption | Yes | |
| Oil heating | Territorial | Yes | Subsectors: residential, services, industry, agriculture. |
| Electric heating | Consumption | Yes | Finnish average electricity, monthly emission factor.<br>Subsectors: residential, services, industry, agriculture. |
| Ground source heat pumps | Consumption | Yes | |
| Wood heating | Territorial | Yes | Separate heating.<br>Subsectors: residential, services, industry, agriculture. |
| Other heating | Territorial | Yes | Gas, heavy fuel oil, peat, coal; separate heating.<br>Subsectors: residential, services, industry, agriculture. |
| Consumption electricity | Consumption | Yes | Finnish average electricity.<br>Subsectors: residential, services, industry, agriculture. |
| Consumption electricity – industry | Consumption | No | |
| Cars | Consumption | Yes | Annual mileage of vehicles registered in the municipality, regardless of municipal borders.<br>Subsectors: roads and streets. |
| Motorcycles and mopeds | Consumption | Yes | |
| Busses – drive-through | Territorial | No | Mileage of vehicles registered in other municipalities, in the area under study.<br>Subsectors: roads and streets. |
| Vans – drive-through | Territorial | No | |
| Trucks – drive-through | Territorial | No | |
| Busses | Territorial | Yes | Territorial emissions with drive-through traffic subtracted = "Own road traffic"<br>Subsectors: roads and streets. |
| Vans | Territorial | Yes | |
| Trucks | Territorial | Yes | |
| Rail traffic | Territorial | Yes | Metros, trams, commuter and passenger trains; electricity and diesel. Freight trains; electricity and diesel. |
| Water traffic | Territorial | Yes | Boats, passenger and cruise ships, cargo ships, fishing vessels, work boats and ferries. |
| Industry – ETS | Territorial | No | Industry fuel use. Electricity generation and district heat sold outside are excluded. |
| Industry – non-ETS | Territorial | Yes | |
| Machinery | Territorial | Yes | Construction, mining and industrial, road and street, agricultural and forestry and other machinery. |
| F-gases | Territorial | Yes | Commercial refrigeration, air-conditioning of buildings and vehicles, other sources |
| Agriculture | Territorial | Yes | Enteric fermentation, manure management and cultivation; inorganic and organic fertilizers, soil emissions, other. |
| Waste treatment | Consumption | Yes | Amount of waste generated in the municipality, regardless of the treatment site. Subsectors: Landfills, wastewater treatment, composting and anaerobic digestion; industrial and municipal waste. |
| Industrial waste | Consumption | No | |
| Compensations | Territorial | Yes | Wind power produced in the region; calculated by the annual emission factor for average Finnish electricity. |

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## ALas 1.5 updates

The calculation of emissions from site machinery for forestry, construction, mining and agriculture was updated in Alas 1-5 calculation.

Emissions from forest machinery in accordance with the TYKO model are allocated to municipalities based on the felling areas provided in forest use declarations. The different fuel coefficients of forest machines for final felling and thinning are taken into account in the calculations. The different fuel consumption of chopping machines and harvesters is also taken into consideration.

Emissions from construction machinery are allocated to municipalities on the basis of the surface area of buildings completed in the year of calculation.

Emissions from agricultural machinery are allocated to municipalities on the basis of the field area used by the municipality. The calculation takes into account the use of machinery required by each crops on the basis of the fuel consumption coefficient.

Emissions from mining machinery are allocated to municipalities on the basis of the extractive volumes reported by mines.

## ALas 1.4 updates

The global warming potential (GWP) characterisation factor used to commensurate different greenhouse gases were updated in accordance with the practices of the national greenhouse gas inventory to comply with the fifth IPCC assessment report. This amendment had an impact on the emission results of waste treatment, agriculture and F-gases in particular.

Industrial emissions calculation was modified so that the emissions from all emissions trading industry were excluded from the Hinku calculation regardless of the type of gas. Previously, methane and nitrogen oxide emissions from the effort sharing sector caused by the emissions trading industry were included in the Hinku emissions, which significantly raised the amount of industrial emissions monitored in the Hinku calculation in a few municipalities.

In waste treatment emissions, the calculation of wastewater was specified by taking the source of wastewater and its treatment method into account in more detail. The new method distinguishes emissions from centralised and decentralised wastewater treatment, which are allocated to municipalities on the basis of population living in urban areas and sparsely populated areas.

In road traffic calculation, the emission factors related to road performance in the street and road network were specified, which also affected the total emissions of road traffic in municipalities.

## ALas 1.3 updates

The most significant amendment in ALas 1.3 is related to the reporting of industrial emissions. In previous calculation model versions, emissions from the separate heating of industrial buildings were reported under heating method-specific emissions. In the ALas 1.3 calculation, emissions from the separate heating of industrial buildings are reported under emissions caused by the Industry sector, which is why emissions per heating method are lower and industrial emissions correspondingly higher.

The change will have an impact on the emissions calculated using the Hinku calculation rules, as the emissions from the separate heating of buildings of industrial operators included in emissions trading were previously included in Hinku emissions, but in the future, they will be excluded from the calculation of Hinku emissions. The same calculation principle is also realised for industry in the effort sharing sector, but in this respect, the change will not affect Hinku emissions, as the emissions from industry in the effort sharing sector have been included in Hinku emissions in previous calculation versions as well.

Another amendment affecting the results was made to the grounds for allocating different greenhouse

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gas emissions to the effort sharing sector and emissions trading. In terms of electricity and district heating consumption and industrial fuel use, carbon dioxide emissions are allocated to emissions trading while methane and nitrogen oxide emissions belong to the effort sharing sector. The change affects the allocation of emissions from the aforementioned sectors into emissions trading and the effort sharing sector. The change will also have a minor impact on emissions from the use of electricity in rail transport.

## ALas 1.2 updates

The calculation of district heating emissions is changed so that the amount of residual emissions distributed across municipalities is lower. This affects especially the emissions in small municipalities.

The calculation principles of wind power compensation are changed. In ALas 1.2 municipal wind power outputs are calculated by multiplying annual wind power output in Finland by the share of municipality's wind power capacity of total capacity in Finland.

Corrections to heating degree days are made, that affect the emissions and energy usage of building-specific separate heating systems. Time series of agricultural emissions in 2005–2018 were corrected for five municipalities due to inaccuracies in the original datasets.

In Hinku calculation, territorial road traffic emissions are used for Åland due to missing data to calculate drive-through traffic.

## ALas 1.1 updates

The updates of the ALas 1.1 that have the most significant effect on the results compared to the previous calculation (ALas 1.0 / February 2020) were made for agriculture, industry and water transport. Agricultural emissions were recalculated for the whole reference period 2005–2018, whereas previously the results where combined from different sources.

The emission calculation for industry was adjusted in ALas 1.1 so that not all emissions from the separate heating of industrial buildings are deducted from the total emissions of the effort-sharing sector, but now also from the emissions trading sector. This gives a more realistic picture of the non-heating emissions of the industry, and for several municipalities, emissions from small-scale industries included in the Hinku calculation are now better reflected. Emissions from the industry under Emissions Trading System, on the other hand, are slightly lower than in ALas 1.0.

In the calculation of waterborne traffic, the municipal allocation of emissions from boats, ferries and cargo ships was fine-tuned. The initial data for boats registered in Åland were supplemented. The calculation of ferries was comprehensively renewed on the basis of better data sources. The basic data on emissions from connecting vessels and road ferries in mainland Finland are the fuel consumption of the operators by route, and in the case of Åland, fuel consumption is estimated on the basis of ferry activity data.

The calculation of emissions from cargo ships was refined so that the size of ships now also affects the municipal allocation of emissions, instead of the number of port calls alone. Emissions decreased, especially in municipalities with small-scale, albeit busy, freight traffic. Correspondingly, ALas 1.1 allocates more emissions to larger-scale freight traffic than before.

In addition to the more significant methodological updates, small changes were made to the emission calculation of the electricity consumption and electric heating, affecting the previous years' results. Also, the consumption of heating electricity in greenhouse-intensive municipalities was estimated lower than before. Emissions from district heating decreased somewhat between 2005 and 2015 due to a revision of the calculation of the residual emissions. In the case of individual municipalities, plant-specific data adjustments were made for both district heating and industry.

The sector-specific calculation principles are presented in more detail below.

More information:

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## District heating

The main data source of the district heat emission calculation is the annual district heat statistics published by Finnish Energy, which are supplemented with information from the Association of Finnish Municipalities' publication "Tietoa pienistä lämpölaitoksista" (Information on small-scale heat plants). After this, the possible residual emissions are allocated between the municipalities so that the total district heat emissions equal the district heat emissions presented in table 3.4.3 of the Statistics Finland's Energy -chart service.

The emission factors of carbon dioxide in Statistics Finland's fuel classification and methane and nitrous oxide in IPCC's Emission Factor Database (EFDB) are used for the calculation. The municipality-specific estimated district heat consumption, modelled on the basis of the region's building stock and heating demand, is also utilised for the calculations. The emissions from municipal waste incineration are allocated to the municipality where the heat that is produced from the waste is consumed. Hazardous waste is counted to have zero emissions.

The district heating statistics are used to calculate the district heat emissions for each heat producer, as well as the purchased and sold emissions, using the benefit allocation method. The net emissions are summed up for each municipality. Additionally, the emissions included in emissions trading are estimated by comparing the plants in the district heat statistics with the data from the emissions trading registry, and the production-based emissions are calculated separately.

The district heating statistics cover about 170 municipalities. The reports of small-scale heat plants by the Association of Finnish Municipalities add about 50 municipalities to the calculations. To prevent any overlap, only the municipalities in the report by the Association of Finnish Municipalities that are not included in the district heating statistics are included in the calculations. Any gaps of the time series are filled in with the previous year's results and the municipality's modelled consumption. The end results are the known emissions and energy consumption of district heating in around 220 municipalities.

According to building stock data, almost all Finnish municipalities have buildings with district heating. The combined emissions of the district heating statistics and small-scale heat plants are also smaller than the total Finnish district heat emissions calculated by Statistics Finland. The difference between emissions is divided between the municipalities where the known consumption is lower than the modelled consumption. The residual emissions are about 6–14 % of the total emissions of district heating, and the residual consumption is about 8 % of the total consumption.

Data sources:

- District heating statistics (Finnish Energy)
- Information on small-scale heat plants (The Association of Finnish Municipalities)
- Electronic service system of environmental protection control YLVA (Ministry of the Environment)
- Finnish air pollutant data system IPTJ (SYKE)
- Plant-specific verified emissions of emissions trading (Energy Authority)
- Energy 2020 chart service, table 4.1 (Statistics Finland)
- Energy 2020 chart service, table 3.4.3 (Statistics Finland)
- Fuel classification (Statistics Finland)
- Emission Factor Database EFDB (IPCC)
- Heating degree days (Finnish Meteorological Institute)
- Corrected building stock data (Statistics Finland)
- RHR – building and apartment data in the Population Information System (Digital and Population Data Services Agency)

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## Oil, wood and other separate heating

The principle of the municipality-specific oil heating calculation is to divide the amount of heating oil that is annually consumed in Finland between the municipalities based on certain allocation principles. Table 7.3 in the Statistics Finland's Energy 2020 chart service presents the light fuel oil consumption in single-family houses, linked and terraced houses, residential apartment buildings, recreational homes, service buildings, industrial buildings and agricultural buildings. These annual consumptions are distributed between the municipalities based on their oil-heated floor square meters, taking into account regional differences in heating demand. Heating demand has no effect on water heating. It is estimated that about 20 percent of heating energy is used for heating water.

With regard to residential buildings, gross floor area data corrected municipality-specifically by Statistics Finland's, are used for the calculations. The floor areas of other building types are calculated by using the building and apartment registry (RHR) in the Population Information System, adjusted with the average national correction factors calculated from the materials of Statistics Finland, excluding agricultural buildings, the floor areas of which are taken directly from the RHR.

The municipal allocation process of wood heating is equal to the allocation process of oil heating. Quantity information of small-scale wood usage presented in table 7.3 of Statistics Finland is used, divided between the wood-heated buildings in municipalities based on the corrected building data and heating demand.

Other separate heating include natural gas, heavy fuel oil, peat and coal, the consumption and emissions of which have been calculated for municipalities by applying the same method as with the oil and wood heating calculations. Agricultural diffuse consumption and emissions from the Finnish air pollutant data system IPTJ are added to other separate heating used in agriculture. These mainly cover the usage of grain dryers.

The greenhouse gas emissions of the oil, wood and other heating fuel consumption are calculated with the emission factors presented in the fuel classification of Statistics Finland and by IPCC. A zero-emission bio-share of 0–4 percent is calculated for heating oil in 2009–2015, and only the methane and nitrous oxide emissions are taken into account with regard to wood.

The calculation does not include buildings with an unknown purpose of use and buildings that have "other" or "unknown" as their heating fuel. However, their share of the total separate heating is very small.

Data sources:

- Energy 2020 chart service, table 7.3 (Statistics Finland)
- Corrected building stock data (Statistics Finland)
- RHR – building and apartment data in the Population Information System (Digital and Population Data Services Agency)
- Heating degree days (Finnish Meteorological Institute)
- Fuel classification (Statistics Finland)
- Emission Factor Database EFDB (IPCC)

## Electric heating and ground source heat pumps

The municipality-specific annual consumption of heating electricity and ground source heat pumps is calculated based on building type -specific typical heat consumption from POLIREM model, weighted with heating demand and the corrected building stock data. Consumption according to POLIREM is also estimated for other uses of electricity, i.e. consumption electricity. The model's typical consumption calculated for building volume is changed to correspond to the floor area-specific consumption with the help of the average room heights of different buildings.

The statistical electricity consumption of housing in a municipality is calculated for a residential building's heating electricity, ground source heat pumps' electricity demand (COP=3) and other electricity use in relation to the consumptions calculated with the help of POLIREM.

In the service and industrial sectors, the shares of electric heating, ground source heat pumps and other

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electricity of the sector's total electricity consumption are estimated in a similar manner to residential buildings. However, if the consumption of heating electricity is larger when using this method than when calculated directly with POLIREM's factors, the latter values are used. Then, other electricity consumption is the value that remains after heating electricity is deducted from the total statistical consumption. This ensures that the emissions of heating electricity will not become excessive, if the municipality has buildings that consume a great deal of electricity, but not a corresponding amount of floor area with electrical heating.

The POLIREM model does not have information on agricultural buildings. It is estimated that their typical heat consumption is 70–80 kWh/m2. The typical consumption is weighted with the heating demand of the municipalities, and the consumption of electric heating and ground source heat pumps are calculated based on the gross floor areas in the building and apartment registry (RHR).

The annual consumption of municipality-specific heating electricity is distributed over the months based on the monthly variation of local heating needs, and the emissions are calculated by using the monthly emissions factors of electricity. It is estimated that 20 percent of heating energy is used on heating household water, and the varying heating demand does not affect this.

The electricity consumption of heat pumps other than the ground source heat pumps is included in other electricity usage (Consumption electricity).

Data sources:

- POLIREM – Policy scenario model for building sector energy consumption and greenhouse gas emissions (TTY/SYKE)
- Municipality-specific electricity use (Finnish Energy)
- Corrected building stock data (Statistics Finland)
- RHR – building and apartment data in the Population Information System (Digital and Population Data Services Agency)
- Heating degree days (Finnish Meteorological Institute)

## Consumption electricity

Consumption electricity includes the use of all electricity except electric heating, the electricity consumption of the ground source heat pumps and rail transport. In addition to the electricity consumption of machines, equipment, air conditioning and lighting, consumption electricity also includes the electricity consumption of charging electric cars and other heat pumps.

The share of consumption electricity of the total energy consumption of housing is estimated based on the typical consumption values for residential houses presented in the POLIREM model. The municipality-specific usage of consumption electricity in agriculture and industry is calculated by deducting heating electricity and the electricity used by ground source heat pumps from the sector-specific total electricity consumption. Additionally, the electricity used by rail transit (passenger and local traffic) is deducted from the service sector's other electricity usage.

Housing and agriculture have been counted together in the statistic of municipality-specific electricity consumption by Finnish Energy. First, the agricultural electricity consumption is separated from this value on a national level. Natural Resources Institute Finland (Luke)'s data on agricultural electricity consumption in 2010, 2013 and 2016 are supplemented with data on the development of agricultural buildings' floor area in the missing years.

The national annual total electricity consumption of agriculture is divided between the municipalities based on the municipality-specific total floor areas of agricultural buildings and, with a lower weighted value, based on the share of agricultural buildings with electric heating as well as local heating demand. The electricity consumption of greenhouses is taken into account separately in few municipalities.

The emissions of consumption electricity are calculated by using the national annual emission factors of electricity, taking into account the higher emissions of heating electricity compared to other electricity usage.

Data sources:

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- Municipality-specific electricity use (Finnish Energy)
- POLIREM – Policy scenario model for building sector energy consumption and greenhouse gas emissions (TTY/SYKE)
- Energy source-specific agricultural and horticultural energy consumption (Luke)
- Corrected building stock data (Statistics Finland)
- RHR – building and apartment register in the Population Information System (Digital and Population Data Services Agency)
- Heating degree days (Finnish Meteorological Institute)

## Wind power

In accordance with the Hinku calculation rules, emission compensations are calculated for a municipality for wind power generated in its region. These compensations are calculated as their own emission category as negative greenhouse gas emissions. They can be considered to primarily compensate the municipality's emissions of electricity usage and, if they are compensated in full, other emissions. Utilising wind power compensation means that the national emission factor of electricity is increased correspondingly, when wind power's effect of decreasing the emissions of grid electricity has already been allocated to certain municipalities as emission compensations.

The project listing of Finnish Wind Power Association has the data on municipal capacity. The wind power production is calculated by multiplying annual wind power output in Finland by the share of municipality's wind power capacity of total capacity in Finland. The annual grid loss calculated by the Finnish average, presented in table 3.2 of the Statistics Finland's Energy chart service, is then deducted from this value. This results in an estimate of the wind electricity produced in the municipality that has ended up for consumption, which is then multiplied by the national electricity emission factor.

The amount of compensation is dependent on the installed capacity and windiness, but also, notably, on the emissions of electricity generation in Finland. When the annual emission factor of national electricity generation decreases (when calculated without wind power), the emission compensations received by the municipality for generating wind power will also decrease.

Data sources:

- Wind power plants built in Finland 1991–2019, project listing (Finnish Wind Power Association)
- Capacity factors of wind power production in Finland (VTT)
- Energy 2020 chart service, table 3.2 (Statistics Finland)

## Industry

The greenhouse gas emissions of industry include the emissions generated due to the fuel use of industrial plants. They do not include electricity and district heat production and the heating of industrial buildings. The emissions are divided into emissions trading and effort sharing sectors.

Industrial emission data (carbon dioxide, methane, nitrous oxide) have been gathered from the Finnish air pollutant data system (IPTJ) where they are divided between industry and energy production by using a classification method used in international reporting of air pollutant emissions (NFR).

With regard to the emissions trading sector (ETS), electricity production's emissions, as separately estimated with the benefit allocation method, as well as municipality-specific, production-based emissions of district heating and separate heating, are deducted from the IPTJ-based total emissions of the sites included in both industrial and energy production, based on their NFR classification. The result of this is an estimate of the ETS emissions of industrial heating and steam production, which is then further scaled so that the total emissions of the energy sector are equal to the Finnish greenhouse gas inventory. Industrial emissions that are part of emissions trading are not included in Hinku calculation.

With regard to plants involved in emissions trading, the IPTJ data has been corrected so that the emissions

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of plants, which have belonged to the ETS only in part of 2005–2019, are calculated as ETS emissions during the whole period of 2005–2019. This prevents any unmerited benefits or detriments to the municipality caused by changes in the emissions trading register.

Industrial emissions excluded from emissions trading system include the heat and steam emissions of industrial plants belonging in the effort sharing sector, as calculated based on the IPTJ, as well as industrial diffuse emissions. The estimated emissions from separate heating of non-ETS industrial buildings is then deducted from this.

The diffuse emissions in IPTJ are based on the difference between the national fuel balance and the consumption of known locations. The emissions have been divided among the municipalities in relation to the surface areas of their industrial buildings that do not use district heat.

The lack of emissions of industry in the effort-sharing sector in some years does not (necessarily) mean that the municipality has no industry and industrial emissions, but instead this can be due to the calculations' technical factors or it could be related to the adequacy of initial data. As such, it can be assumed that the industrial emissions are included in the emissions of industrial buildings' oil heating and other separate heating.

The best possible data sources have been used for industrial municipal calculations, but, simultaneously, the calculations include many assumptions that compromise their accuracy. All emission and energy consumption estimates are computational, both in the emissions trading and effort sharing sectors, and cannot be directly linked to any individual company.

Data sources:

- Finnish air pollutant data system IPTJ (SYKE)
- Electronic service system of environmental protection control YLVA (Ministry of the Environment)
- Energy 2020 chart service, table 3.4.3 (Statistics Finland)
- Corrected building stock data (Statistics Finland)
- RHR – building and apartment data in the Population Information System (Digital and Population Data Services Agency)

## Machinery

Emissions of work machinery are calculated by dividing the national results of the TYKO model between the municipalities by using different allocation principles that depend on the machinery class. TYKO is a Finnish emission calculation model of machinery developed at VTT Technical Research Centre of Finland. It is used to produce the official annual emission quantities for the statistics of EU, UN and Finland. The allocation principles are taken from the Finnish Regional Emission Scenario model FRES by SYKE.

TYKO features a total of 51 machinery types, including off-road vehicles. In FRES, machinery types are divided into 13 main types: cranes, forklift trucks and industrial tractors, road graders, wheel loaders and dumper trucks, excavators, agricultural machinery, other maintenance machinery, forestry machinery, snow mobiles and ATVs, gardening machinery, diesel generators, diesel compressors and chain saws. Various allocation models, i.e. "proxies", are used to divide the emission results of these main categories between municipalities.

In total, nine different proxies have been developed to describe the conditions associated with the use of machinery in the municipalities. These are based on land use (industrial areas, fields, forests, residential areas, mines, green areas), road and street sections and their traffic numbers, as well as population data. Depending on the machinery category, one proxy or a combination of several can be used to allocate the emissions to municipalities. For example, all forestry machinery are allocated in accordance with the Forestry proxy, which means that the emissions are divided between municipalities in accordance with the categories Clc3111–3133 of CORINE Land Cover (forests, excluding national parks, and nature conservation areas), but, in comparison, 25% of excavators' emissions are allocated to industry, 25% to roads and 50% to building (population data).

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The results of the 13 main types will then be further combined municipality-specifically into nine different categories; agricultural machinery, forestry machinery, construction machinery, landscaping machinery, industrial machinery, mining machinery, machinery of residential homes, road machinery, roads and road machinery, and streets. This is the most detailed level on which producing results is possible. When reporting municipal emissions, the number of categories has been cut to five: construction machinery, mining and industrial machinery, road machinery, agriculture and forestry machinery and other machinery.

Data sources:

- Emissions calculation model of machinery in Finland TYKO (VTT)
- Finnish Regional Emission Scenario model FRES (SYKE)
- Mining industry statistics (TUKES)
- Total extractive statistics (2001–2010) (TEM)
- Suomen kaivosteollisuus ja mineraalisten raaka-aineiden tuotanto vuosina 1530-2001, historiallinen katsaus erityisesti tuotantolukujen valossa. 578 pp. (Puustinen 2003)
- Forest use declarations (Forest Centre)
- Measuring and Modelling of Fuel Consumption in Forest Machines (Kääriäinen 2020)
- Utilised agricultural area (Luke)

## F-gases

The basis for municipality-specific emissions of fluorinated greenhouse gases in 2005–2019 are the emissions of the Finnish greenhouse gas inventory reported to the EU and UNFCCC in spring 2020. For the municipality-specific calculations, the emissions of the entire country have been divided using sector-specific, applicable data or, if there is none, population figures.

In municipality-specific calculations, F-gas emissions have been divided into four different sectors – commercial refrigeration, buildings' ventilation devices (including heat pumps), the air conditioning devices of vehicles and other sources of F-gases. The emission calculations of the GHG inventory are made on the level of more than 20 different sectors, and the emissions are reported by using the classification defined in IPCC's guidelines (Common Reporting Format, CRF). Other sources of F-gases contain other refrigeration units and air conditioning devices (household and industrial refrigeration units and refrigerated transport), cellular plastics, aerosols, electricity distribution equipment, semiconductor industry, fire extinguishing equipment and a group of other, smaller emission sources.

Dividing the F-gas emissions of commercial refrigeration between different municipalities is based on the number of various grocery stores and professional kitchens in the municipality. The emissions of building's air conditioning devices have been allocated municipality-specifically based on population. With regard to air conditioning devices in vehicles, the municipal traffic emission calculations based on the ALas model have been utilised. It is assumed that the F-gas emissions of road traffic are distributed to the municipalities in accordance with their road traffic mileage. The F-gas emissions of rail transit have been allocated municipality-specifically, based on the electricity consumption of passenger and local traffic. The F-gas emissions of machinery have been allocated to municipalities the same way as their carbon dioxide emissions. The emissions of underground railway and trams have been allocated to municipalities where these transport forms are available. The emissions from other sources of F-gases, excluding the semiconductor industry, have been allocated to municipalities based on their population numbers. The emissions of semiconductor industry have been allocated to municipalities based on the production plants' locations.

Data sources:

- Finnish greenhouse gas inventory (Statistics Finland/SYKE)
- Municipal numbers of grocery stores, listed by store types (Liiteri/SYKE)
- The numbers of professional kitchens in regions (Horeca register/Taloustutkimus)
- Population information (Statistics Finland)
- Rail transit performances in 2019, station locations of the metro line (Helsinki City Transport HKL)
- Finnish Regional Emission Scenario model FRES (SYKE)

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## Road traffic

VTT Technical Research Centre of Finland maintains LIISA, the calculation system of exhaust gases and energy consumption of Finnish road traffic. The LIISA model is part of the LIPASTO calculation system for all modes of transport. It is used to calculate the Finnish official annual emissions for the statistics of EU and UN.

VTT produces territorial road traffic emission data. In this calculation method, all driving mileage within the municipalities' borders, and the corresponding emissions, are allocated to that municipality. Road traffic emissions are calculated separately for cars, vans, buses and trucks, as well as for motorcycles, mopeds and moped cars. Car, van, bus and truck emissions are separated into street and road emissions. Due to the territorial-based allocation in LIISA, the emissions of road traffic are high in municipalities that have a great deal of traffic from vehicles registered to other areas (drive-through traffic). The territorial allocation principle of emissions has been found to be problematic, which is why two alternative ways of municipal allocation of road traffic emissions have been developed: usage-based calculation and calculation that takes drive-through traffic into account.

In Hinku calculation, the emissions of cars, motorcycles, mopeds and moped cars are calculated based on their usage. Region-based emissions are calculated for vans, buses and trucks, but drive-through traffic is excluded ("region's own road transportation").

In the usage-based calculation method, all emissions caused by the driving mileage of vehicle stock registered in a certain municipality are allocated to it, regardless of where the driving actually takes place. The calculation is based on Traficom's vehicle register information about the vehicle's first registration date and the odometer reading registered during the vehicle's latest inspection. An average annual driving mileage of each vehicle has been calculated based on this information and, based on this, the average annual, municipality-based driving mileage of each vehicle registered in the municipality is calculated. When calculating the average driving mileage, vehicles that do not have an odometer reading are excluded. These include new cars that have not yet gone through an annual inspection and old cars that do not have a reading for some other reason.

Annual, municipality-specific total driving mileage is calculated by multiplying the municipality-specific average driving mileage with the number of vehicles registered in the municipality (including vehicles that do not have an odometer reading). The total driving mileage is allocated to municipalities' streets and roads based on LIISAs road and street driving shares. The computational street and road driving mileage are transformed into emissions utilising the vehicle-specific emission factors in Traficom's vehicle register. Based on this information, the average gCO2/km emission factor of the vehicle stock is calculated for each municipality. The lacking gCO2/km data have been imputed from vehicle information saved in the vehicle register, categorised by the vehicle's year of initial registration, engine displacement and driving power.

The vehicle register does not include emission factor data for buses, trucks, motorcycles, mopeds or moped cars. Buses have been divided into five classes: small and large diesel engine buses, large buses that use natural gas, large buses that use bio-fuel and large buses that run on electricity. The usual average emission factors typical to vehicles from a certain year, as determined in LIPASTO unit emissions database, have been used for these vehicles. Similarly, annual average emission factors have been used for vans, motorcycles, mopeds and moped cars. Municipality-specific emissions are calculated by multiplying the municipal driving mileage with a municipality-specific emission factor. Finally, the levels of municipal emissions are adjusted municipality-specifically so that the computational emissions of vehicle classes in the entire country are equal to the emissions in LIPASTO calculated as Finland's carbon dioxide equivalents.

A calculation that takes drive-through traffic into account means the allocation aims to estimate the amount of emissions caused by vehicles registered in other municipalities. In other words, drive-through traffic includes the driving which may end in the inspected region, start there or pass over the borders of the inspected municipality. Both the region- and usage-based calculation methods are utilised for drive-through traffic calculations. If the region-based driving mileage is larger than the computational annual driving mileage of the municipality's registered vehicle stock (surplus), the vehicles registered to other municipalities must drive in the region of the inspected municipality as much as the difference indicates. Equally, if the region-based driving mileage is smaller than the computational annual driving mileage of the municipality's registered vehicle stock (deficit), the vehicles of the inspected municipality must drive in other municipalities as much as the difference indicates. The deficit sum is deducted from the surplus sum of driving mileage, so

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that the total driving mileage is equal to LIPASTO's Finnish total driving mileage. The remaining drive-through mileage is allocated to municipalities based on their street and road driving mileage. The emissions caused by the driving allocated to the municipality (region's own road traffic) are calculated based on the average emission factor of the vehicles in the inspected vehicle class that are registered in the municipality in question. The emissions of drive-through traffic are calculated by applying the whole country's average emission factor.

Territorial emissions are used for Åland's municipalities in Hinku calculation.

Data sources:

- LIISA, road traffic exhaust emissions calculation model (VTT Technical Research Centre of Finland)
- LIPASTO, the calculation system of exhaust gases and energy consumption of Finnish traffic (VTT Technical Research Centre of Finland)
- Vehicle register (Traficom)

## Rail traffic

The emissions of rail transit are calculated separately for electricity and diesel used for passenger traffic and freight transport, as well as for electricity used for local traffic (including metros and trams). The national energy consumption data of rail transit that is allocated to municipalities are taken from VTT's LIPASTO calculation system, the Finnish greenhouse gas inventory and, with regard to metros and trams, from Helsinki City Transport (HKL). The emissions are calculated by applying the national annual electricity emission factor. The diesel emission factor (tCO2e / GWh), on the other hand, is calculated based on data from LIPASTO and the Finnish greenhouse gas emission inventory.

When allocating the emissions of passenger traffic to municipalities, passenger kilometers need to be calculated for different railway sections (= number of trips x length of the section). The proportion of passenger kilometers in the rail section to the similarly calculated performance of the whole country is further weighted with the population numbers along the track (municipalities with a train station/stop in 2019). The result is a municipality-specific "passenger kilometer share" of the railway section, weighted with population numbers, which is calculated in total, and also separately for electrified and unelectrified railway sections.

The annual electricity consumption of passenger traffic in Finland is allocated to the municipalities based on electrified railway sections' passenger kilometre shares, and the consumption of diesel based on the unelectrified sections. The diesel consumption of shunting and depot operations is allocated to municipalities in relation to the passenger kilometres of municipalities that have depots.

The rail sections' net tonne-kilometres (= transported freight x length of the section) are calculated for freight transport, and these are then divided evenly between the section's departure and arrival municipalities. The municipal net tonne-kilometres are calculated from the whole country's net tonne-kilometres as a whole and separately for electrified and unelectrified rail sections. The specific net tonne-kilometres of railway sections have been compiled from three years (2005, 2012, 2017), and the gap years have been interpolated linearly. The railway sections of freight transport that are no longer in use have been taken into account.

The annual electricity consumption of freight transport in Finland is allocated to municipalities by multiplying the electricity consumption with each municipality's annual net tonne-kilometre share of its electrified rail sections.

The consumption of diesel is divided between the unelectrified railway network (49%) and the electrified railway network (51%) based on its net tonne-kilometre shares, diesel's total consumption and the average typical consumption of diesel locomotives. The consumption shares of diesel are distributed to municipalities based on the net tonne-kilometres of their electrified and unelectrified railway network. The diesel consumption of shunting and depot operations is allocated to municipalities in relation to the net tonne-kilometres of municipalities that have depots.

The energy consumption and emissions of electrical and diesel locomotive operations are allocated to municipalities based on their freight transport. With regard to electrical locomotives, the allocation principles of freight transport's electricity consumption are applied. The consumption of diesel locomotives is allocated

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based on the municipality-specific net tonne-kilometres of the entire rail network.

The electricity consumption of local traffic is divided between the municipalities with local rail network according to their population figures. The metro and tram power consumption data of Helsinki and Espoo are based on a report by HKL.

Data sources:

- LIPASTO/RAILI emission etc. data (VTT)
- Greenhouse gas inventory (Statistics Finland)
- Passenger and freight transport on railways (data and annual reports by Finnish Transport Infrastructure Agency)
- Railway network data (Finnish Transport Infrastructure Agency)
- Maps and schedules of long-haul and local transport (VR)
- Power consumption of metro and tram transport (HKL)
- Municipal population data (Statistics Finland)

## Water traffic

In the water traffic calculations, the domestic water traffic emissions in the greenhouse gas inventory of Finland are allocated to municipalities. Allocation principles based on available materials have been developed for seven different categories of water traffic – recreational boats, passenger ships, cargo ships, cruise ships, fishing vessels, work boats, and ferries. The emissions of ice breakers are not included in municipal water traffic emission calculations. The fairly low emissions of cruise ships have been combined with passenger ships in the reports.

The emissions of recreational boats are allocated based on Traficom's and Åland's vessel registers. The category of recreational boats includes outboard motorboats, sterndrive motor boats, inboard motor boats, inflatable boats, hydrocopters, jet skis, motor sailboats and sail boats. The allocation basis is the municipality's total amount of recreational boats and for Åland's vessel register, the municipalities' population data.

With regard to passenger ships, the source material used are port calls (Portnet/MEERI) and the annual reports of domestic water traffic's passenger transport. The water body -specific share of each year's passenger traffic is calculated based on the passenger kilometres of domestic passenger traffic. The water body shares are allocated to municipalities with ports that were visited by vessels.

The allocation basis for cargo ships is the statistics data of port calls of domestic cargo transport and the tonne-mileages in inland and coastal areas.

The emissions of cruise ships are allocated to municipalities that have business locations of companies involved in coastal and/or inland passenger water traffic. This information is taken from Statistics Finland's regional business statistics. Coastal water passenger traffic has been weighted with the annual total revenue.

When allocating the emissions of fishing vessels (note, vessels of sea fishing), the regional business statistics are also utilised. The share of municipality-specific business locations of sea fishing are weighted with the combined total engine powers of fishing boats, as determined in the statistics maintained by the regional Centres for Economic Development, Transport and the Environment (ELY centres).

Ferries are distributed to municipalities on the basis of fuel consumption on connecting ferry and road ferry routes. Consumption data for mainland Finland have been obtained from the ELY Centre for Southwest Finland and consumption data for Åland have been estimated on the basis of road ferry activity and fleet data.

The work boats' emissions are allocated to municipalities based on their water surface areas and population figures.

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Data sources:

- Finnish greenhouse gas inventory, water traffic emissions (Statistics Finland)
- Vessel register (Traficom)
- Port visits (MEERI calculation system; VTT)
- Domestic water traffic statistic (Finnish Transport Agency)
- Domestic water traffic statistics (Traficom/Statistics Finland)
- Regional business statistics (Statistics Finland)
- Registered fishing vessels in the sea area (LUKE)
- Municipal surface area data (National Land Survey)
- Population data (Statistics Finland)
- Åland Road Ferry Statistics (ÅSUB Statistics and Research Åland)
- Consumption data for connecting vessels and road ferries (Southwest Finland ELY Centre)

## Agriculture

The greenhouse gas emissions of agriculture include the methane and nitrous oxide emissions of livestock, manure and cultivation of agricultural lands as well as the carbon dioxide emissions of liming and urea fertilization. The carbon dioxide emissions generated by the decomposition of peatlands are allocated to land use, land use change and forestry sector (LULUCF) and they are not included in the Alas calculation.

The calculation principles are the same as in the greenhouse gas inventory of Finland. The emissions of animals' enteric fermentation and manure management are based on municipality-specific animal numbers. The calculations include cattle, horses, sheep, goats, swine, poultry, reindeer and fur animals.

The emissions from cultivation are generated by the application of inorganic fertilizers, manure, urea and sewage sludge, nitrogen released from organic soil, plant residue decomposing on the fields, manure and urine from grazing, field burning of plant residues, liming and nitrogen leaching.

The emissions from cultivation are calculated based on the municipal, crop-specific cultivated surface areas, municipal soil data, regional yield data (by ELY centre) as well as the national data on the use of lime, mineral nitrogen fertilizers and sewage sludge.

Data sources:

- Municipal, crop-specific cultivated surface areas (Natural Resources Institute Finland; Luke)
- Regional yield data for different crops (Luke)
- Forage grass areas by region (Luke)
- Agricultural use of municipal sewage sludge (Luke)
- Soil class information database (Luke)
- Finnish normative manure system (Luke and Finnish Environment Institute SYKE)
- Municipal data on the number of animals by Luke, Finnish Fur Breeders' Association (FIFUR) and Reindeer Herders' Association
- Finnish greenhouse gas inventory report (Statistics Finland)

## Waste management

The landfill emissions include the methane emissions of municipal waste, construction and demolition waste, municipal sludge, and industrial waste and sludge taken to a landfill. These emissions are generated when the biodegradable parts of waste decompose in oxygen-free conditions into methane over years. The FOD method (First Order Decay), in accordance with the IPCC's calculation guidelines, is used in the calculations. This method assumes that the amount of generated methane depends on the amount of coal left in the waste, if conditions remain stable. The recovered quantity of landfill gas is deducted from the emissions and, additionally, the oxidising share of the landfill's surface layers is taken into account.

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The quantity of landfill emissions is also dependent on the annual amounts of waste deposited in the landfill, the composition of waste and their decomposition properties and the recovery of landfill gas. The default values in the greenhouse gas inventory of Finland are applied as the calculation parameters. The waste quantity and gas recovery data are municipality- and landfill-specific.

Municipal waste landfill utilization rates are based on cooperation areas of regional and municipal waste management companies and other reviewed cooperation. The landfill waste quantities within these cooperation areas are distributed to the municipalities in relation to their population. In history data, the waste quantities of the years preceding the cooperation (for which landfill-specific data are not available) are also allocated based on the municipal population figures. Otherwise, history data, of which landfill-specific information is not available, are scaled by applying the same waste quantity ratios as in the national inventory. Other waste fractions (sludge, construction waste and industrial waste) are either allocated based on the cooperation areas and population figures of municipalities or estimated as local.

In a few cases, a different method of allocation is applied; for example, forest industries' landfills are often located in other municipalities than where the actual plant is. In such cases, the waste emissions are allocated to the municipality where the waste has been generated, in accordance with the principles of usage-based calculations. Industrial waste emissions are not included in the Hinku calculation.

The HSY data of the Ämmänsuo landfill emissions have been used with regard to Helsinki, Espoo, Vantaa, Kauniainen and Kirkkonummi. All landfill emissions in the Helsinki Metropolitan Area are allocated to municipal waste.

The greenhouse gas emissions from wastewater treatment, composting and anaerobic digestion are calculated by distributing the emission data of the national greenhouse gas inventory to municipalities. The allocation basis is population data for community waste and the floor surface area of industrial buildings for industrial waste.

Data sources:

- Finnish greenhouse gas inventory (Statistics Finland/SYKE)
- Landfill-specific waste quantity data, methane recovery (YLVA, SYKE's inventory surveys)
- IPCC 2006 Guidelines for National Greenhouse Gas Inventories
- Municipality-specific landfill usage (Suomen Kiertovoima Ry KIVO/other reviews)
- Population information (Statistics Finland)
- RHR – building and apartment data in the Population Information System (Digital and Population Data Services Agency)
- Helsinki Region Environmental Services Authority HSY

## Electricity emission factors

When calculating the greenhouse gas emissions of municipalities, an average emission factor of electricity consumption in Finland is applied to all municipalities. This factor is calculated by dividing the emissions of Finnish electricity production, calculated with the benefit allocation method, by the total consumption of electricity.

The emission factor of consumption is different than the electricity production's factor, as the amount of electricity consumed in Finland every year is different from the annually generated amount of electricity. The difference is due to distribution losses and net import. Because consumption in Finland exceeds the production, the emission factor of total consumption is smaller than the emission factor of production. Imported electricity is assumed emissions-free.

The emission factors are calculated both on annual and monthly levels, the latter of which is applied to calculating the emissions of heating electricity. The emission factor is, on average, larger during the heating season than during other times, which means that heating electricity has larger specific emissions than other use of electricity.

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The monthly factor is calculated by allocating the annual GHG emissions of Finnish electricity production to different months in accordance with different production methods, and by dividing the monthly emission result with the electricity consumption of each month. The monthly data are taken from the statistics of Finnish Energy.

The emission factor other electricity use than heating (consumption electricity) is calculated by deducting the emissions of heating electricity, calculated with the monthly factors, from the total emissions of electricity and, similarly, the consumption of heating electricity from the total electricity consumption.

The monthly and annual factors are also calculated without wind power production. These higher factors, in which wind power's effect of decreasing the electricity emissions has been neutralised, are used in the Hinku calculation, in connection to the wind power compensation.

Data sources:

- Energy 2020 chart service, tables 3.1, 3.2 and 3.4.3 (Statistics Finland)
- Monthly statistic of electricity (Finnish Energy)
- Fuel classification (Statistics Finland)
- Emission Factor Database EFDB (IPCC)

## Emission factors of fuels

The CO2 emission factors of fuels are taken from the annually updated Fuel Classification maintained by Statistics Finland. Bio-based fuels have zero carbon dioxide emissions. The factors of methane and nitrous oxide are obtained from IPCC's Emission Factor Database.

Until 2013, fuel classifications are available as Excel files. Before this, the same factors as in 2013 were applied, excluding light fuel, for which zero-emission bio-shares were calculated in 2009–2012. The factors of earlier years than 2013 of engine petrol and diesel have also been calculated based on the figures of 2013, while taking into account the change of the bio-composition share. For traffic, however, the emission factors of VTT's LIPASTO system are used in the emission calculation of the ALas model.

The methane and nitrous oxide emission factors of fuels are taken from IPCC's Emission Factor Database. They are separate for energy industries, manufacturing industries and other sectors, which includes housing and services. The 2006 IPCC Default is the selected emission factor option.

The carbon dioxide equivalence factors are calculated by using IPCC's Global Warming Potential (GWP) values of 2007, which are also used for national greenhouse gas inventory calculation. In a hundred-year period, the heating effect of methane is 25 times that of carbon dioxide (GWP100 = 25), and for nitrous oxide it is 298 times as large (GWP100 = 298). The GWP values of F-gases vary between 124–22,800, depending on the compound.

Data sources:

- Fuel classification (Statistics Finland)
- Emission Factor Database EFDB (IPCC)

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