Ecosystem accounts in Sweden

Deliverable 2.1 of Eurostat grant project 2023-SE-EGD: Advanced data modelling for ecosystem accounts

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Advanced data modelling for ecosystem accounts

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Summary

This report aims to assess the current understanding of how to report statistics on ecosystem services in Sweden to the EU ecosystems accounts. The legislation has been decided and methods are being finalized, and so the calculations and interpretation of the outcome has been tested. There are seven ecosystem services that are obligatory to report and where the possibility to use a common tool is an option. For four of these, local climate, air filtration, wood provision and crop provision the report suggest a way forward for the reporting. For the other three obligatory ecosystem services: global climate regulation, nature-based tourism, and pollination, more analysis is needed.

For the international reporting, using the same data sources and aggregation as other EU countries could be beneficial for the comparison between EU countries and for summarising the EU contribution in a harmonised way. Still, it is also interesting to consider in what way the countries may differ.

Sweden, and to a certain extent the Nordic countries in general, have some characteristics that stand out among the EU countries. The domination of forests and water ecosystem types and the relatively small cities are such characteristics. Also, the electricity and heat are generated mostly without fossil fuels, so that the air pollution is to a large extent coming from the transport sector, and partly also by wind from other countries. The winters are long and often cold, but houses are generally well isolated, and typically not heated by fossil fuels. The summers are not very warm, and so air conditioning is not that common. For nature-based tourism, the tendency for people to have a second home in the countryside or to spend time outdoors, is competing with the more traditional tourism with over-night stay in hotels.

The major adaptation needed for the Swedish reporting is that the Local Administrative Unit (LAU) is not well adapted to show urban areas in Sweden, covering large areas that are not urban in their nature. A local adaptation to a more accurate urban area will be necessary.

Even if Swedish urban areas are relatively clean compared to urban areas further south, the ecosystem service of air filtration will still be important as a local ecosystem improvement. The air is generally better in the north of Sweden due to its large areas of forests, and the level of pollution in the south is affected by

pollution coming from other EU countries by wind The INCA use tables of this ecosystem service show that the service is only benefitting the households. This is a limitation with the tool. The opinion of Statistics Sweden is that the governmental sectors as well as businesses will benefit from cleaner air. This is further shown in the literature review for air filtration. Including businesses in the INCA results would be a large improvement. The INCA results were compared with national data for PM2,5 emissions and levels in order to gain an understanding of its implications. These data confirm that pollution levels are higher in the south of Sweden.

In case there is a need to assess the situation for a local scale, it is good to have knowledge about the possibilities for regional breakdown of the data and possibly data in a form that is more adaptable to local needs. In Sweden, the ecosystem service concept is being used for planning purposes at the municipal level since 2005. Many cities have mapped out their ecosystem services as part of the planning. A focus on green infrastructure for heat management, on water management and on habitats for sustaining biodiversity and support of culture and recreation is prominent in these plans.

For the marine ecosystems a planning tool has pooled together the data from the HELCOM and OSPAR measurements that together cover the marine areas of Sweden (and of some neighbouring countries).

For forest planning, Norway and Finland have made use of a model that assesses how to combine and plan for forest management with a view to take the many different ecosystems in the forest into account[1].

In assessing the communication of the provision indicators for wood and crops, the focus may also become slightly broader. For example, to consider how the management of land for forestry and agriculture can be linked to other ecosystem services. Forestry and agriculture are important in the context of the habitat conditions of ecosystems functioning for many endangered species.

Other identified statistical user needs are adding or guiding users to national indicators for other provision services. The provision of fish from marine areas, and the provision of game from hunting are such possible additions.

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[1] MultiOptForest: An interactive ... | Open Research Europe

1. Introduction and aim

The exact focus of the data and modelling for ecosystem accounts was to be determined at the start of the work package, since many factors were unknown at the time of writing of the application. The most important factors where the status of the revised regulation on the environmental accounts, the specific guidelines for producing indicators, the tools and data made available by Eurostat and the progress possible in Statistics Sweden’s earlier grant-funded project developing ecosystem accounts.

In light of what was known at the time of writing, the proposed work package would focus on the production of tables for ecosystem services, four out of the seven proposed in the legislation, namely pollination and local climate regulation, as well as nature-based tourism and air filtration.

In this report, two of the ecosystem services, local climate regulation and air filtration will be investigated thoroughly with new data. The evaluation will be performed by comparing the outcome from the advanced pilot tables with those produced according to “generic” methods with “generic” data.

For local climate regulation, such data could include national, high resolution data sources for land surface temperature, air temperature data, tree cover data and data on evapotranspiration. For ecosystem services where it is relevant, the possibility to investigate definitions of urban areas that track more closely actual urban areas (that the DEGURBA definition does) will be considered.

However, pollination will be saved for the new upcoming grant project in ecosystem accounts as it was too complex to handle at this stage. Nature based tourism has already been assessed with the INCA tool[2] in an earlier report. Also wood provision and crop provision will be reported with the help of the INCA tool in order to preserve the comparability with the EU reporting.

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[2] The INCA tool is a QGIS plugin to support the calculation of ecosystem services accounts and cover the following services: wood and crop provision, crop pollination, air filtration, global climate regulation, local climate regulation, flood control, soil retention and nature based tourism.

1.1. Background

In preparation for the obligatory data collection in 2025, this report aims to investigate if more detailed data than was provided in the INCA tool will improve the quality of the reporting for selected ecosystem service indicators. The indicators that have been investigated concern mainly urban areas where trees can contribute to local climate and air filtration.

In an earlier report (Roadmap), the results from using the INCA tool for Sweden were discussed. Besides the general objective of developing a roadmap for implementation of ecosystem accounts in the Swedish context, that report also aimed to build a national ecosystem extent accounts framework that can record areas and changes in areas in relevant ecosystem functional groups, identify complementary national available data source for characterising ecosystem condition accounts and ecosystem services accounts. Moreover, it aimed to identify data gaps and methodological issues in the current processes and suggest solutions for data compilation in a national context and methodological development more broadly.

1.2. Objectives

This work package address section 2.3 in the call - Produce estimates of ecosystem accounts according to the specifications in the Commission proposal COM/2022/329 final. This work package focusses on the call’s identified priority to pilot and produce new information and methodologies for the area of environmental statistics and accounts. By further developing ecosystem accounts for Sweden, it will contribute to expanding the scope of environmental accounts to meet the needs of the European Green Deal. It further aims to investigate the possibility of using data from providers not currently incorporated in the environmental accounts in Sweden.

The aim and general objectives of this work package is therefore to further develop ecosystem accounting in Sweden, with regard to the new technical specifications and certain indicators in particular. The results of the ongoing work with ecosystem accounts and the new technical specifications from the task force on ecosystem accounts will serve as important inputs and starting points.

The project has the following specific objectives:

1. Investigate potential advanced data sources and methods to improve pilot tables according to the requirements in the guidelines at the time of carrying out the project.
2. Produce pilot tables for relevant indicators using advanced data sources and methods where applicable.

2. Local climate regulation

2.1 Introduction

The development of advanced modelling for the Swedish ecosystem service account for local climate regulation was carried out in two interrelated areas.

Firstly, the urban ecosystem area definition (as used in the in force version of the Nature Restoration Law) was applied to assess urban areas relevant for the local climate regulation service in Sweden. This is to contrast the urban definition that is used in the current version of the revised regulation, 691/2011 that still refers to the Local Administrative Unit (LAU) when defining urban areas for the local climate regulation ecosystem service.

Secondly, a custom detailed temporal and spatial dataset was obtained from the Swedish Meteorological and Hydrological Institute for the purpose of applying the dataset to assess the duration of the summer season for which the local climate regulation service would be relevant.

The outcomes from these analyses were used as input for the subsequent calculation of the mandatory indicator for local climate regulation, namely the average cooling. The methods used in these development areas and for the final indicator calculation are described in more detail below.

2.2 Background

Urban ecosystem areas for calculating local climate regulation

Firstly, guidance in the area of local climate regulation notes the significance of identifying the service as it is made use of. For example –
“Cooling that occurs in situations without people present does not constitute an ecosystem service. This is accounted for by requiring measurement of the cooling by vegetation in cities only.” – p. 9 guidance note, local climate regulation.

However, this criterion is not really achieved according to the currently applied definition of cities. The recently published updated version of the European regulation on environmental accounts still applies the concept of local administrative unit when considering cities. The nature of local administrative units in Sweden (called “kommun” in Swedish) combined with the LAU definition of cities leads to large natural areas in Sweden being defined as belonging to built-up areas. This mismatch between Swedish administrative units and the local administrative unit definition has been raised in previous communications, for example reports submitted in previous ecosystem-related EU Grant financed work.

As these previous reports point out, the mismatch leads to the fact that data based on the LAU definition in Sweden is at best meaningless as a measure of ecosystem services in urban areas and potentially very misleading.
Since the completion of Sweden’s most recent EU Grant-financed project on ecosystem accounts, the Regulation on Nature Restoration has been published[3].

The definition of urban areas according to this does not strictly follow the LAU definition -
“4. Member States shall determine and map urban ecosystem areas as referred to in Article 8 for all their cities and towns and suburbs. The urban ecosystem area of a city or of a town and suburb shall include:
(a) the entire city or town and suburb; or
(b) parts of the city or of the town and suburb, including at least its urban centres, urban clusters and, if deemed appropriate by the Member State concerned, peri-urban areas. Member States may aggregate the urban ecosystem areas of two or more adjacent cities, or two or more adjacent towns and suburbs, or both, into one urban ecosystem area common to those cities, or towns and suburbs, respectively.”

Accordingly, in this work, the urban ecosystem areas for Sweden have been calculated according to option (b) above with the aim of better capturing areas in the Swedish Local Administrative Units that are actually built-up. The procedure for so doing is described in the following paragraphs.

Detailed spatial and temporal data to estimating the relevant cooling season in Sweden
The indicator according to the revised regulation on European Environmental Accounts is defined as “*the reduction of temperature in cities, due to the effect of urban vegetation, in degrees Celsius on days exceeding 25 degrees Celsius*” (see the guidance note on local climate regulation, p. 2). This identifies a need to assess the days on which the average temperature exceeds 25 ^{o}C.

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[3] Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869 (Text with EEA relevance)

The guidance note gives further information about how the threshold of 25 ^{o}C is to be interpreted:
"The threshold of 25 degrees Celsius relates to the maximum temperature that is measured during a day." p. 3.
"When applying the threshold, the spatial delineation of where the temperature is measured matters, for instance a city may include several forested hills and including or excluding them in the spatially averaged temperature calculation may make a large difference. To determine if the temperature in a city (defined through its city boundaries) exceeds 25 degrees, it is recommended to use either (i) the average of the maximum daily air temperatures of the local climate measurement stations per city ([4]); or (ii) the median of the LandSat land surface temperature (LST) data (see below). Air measurements (or air temperature models) should be considered first, because satellites provide the surface temperature, which is usually higher than air temperature. However, both approaches have limitations: air temperature is not spatially explicit, land surface temperature information represents a snapshot in time." p. 3.

Unfortunately, the current version of the INCA plug-in tool is not specifically able to calculate cooling effects only for those days where the temperature exceeds 25°C. However the INCA plug-in tool does allow for the user to select the months for which the cooling effect is calculated. In light of this, the guidance note recommends that the months selected for the analysis should be those where the maximum daily temperature exceeds the 25°C threshold for at least 10 days.

In addition to the mandatory indicator noted above, the guidance note identifies the number of days with a maximum temperature exceeding 25°C as a voluntary indicator. In light of these considerations, the aim of the work carried out here has been to apply highly disaggregated spatial and temporal data for the purpose of determining the length of the summer season according to definitions and interpretations relevant for the indicator for local climate regulation. In so doing it is intended to be able to produce data for the voluntary indicator noted above.

([4]) If there are insufficient measurement points per city, air temperature data from the Copernicus Programme: https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-cerra-single-levels?tab=overview) may also be used to pre-select the cities where maximum temperatures reached more than 25°C. Importantly, these data however are not suitable for the regression model.

2.3 Method

Urban ecosystem areas for calculating local climate regulation
The European degree of urbanisation classification[5] defines two different levels for urban areas depending on population density and total population:

- High-density clusters, or urban centres have a higher density and higher total population
- Urban clusters have a lower density and lower population than high-density clusters/urban centres

Notably both high-density clusters and urban clusters are distinct in DEGURBA from rural (non-urban) areas.
To implement these area definitions in this work, the 2021 High-density clusters and Urban clusters raster datasets were downloaded from Eurostat, see Figure 1.

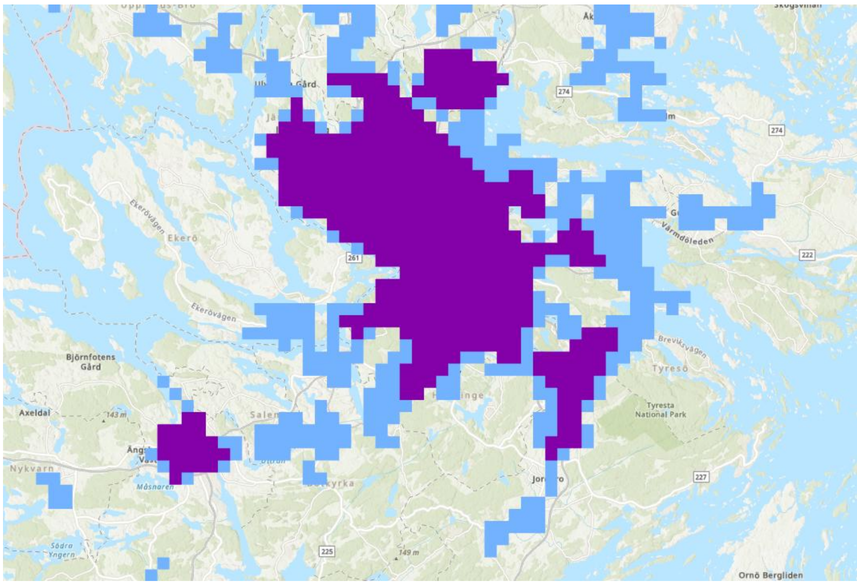

Figure 1: The original High-density and urban clusters from Eurostat.

The two raster data files were reclassified and merged into one single layer with pixels classified as High-density clusters, Urban clusters and non-urban. The raster file was then converted to vector format (polygons) with attributes for High-density clusters and Urban clusters, see also Figure 2.

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[5] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Degree_of_urbanisation_classification_-_2011_revision

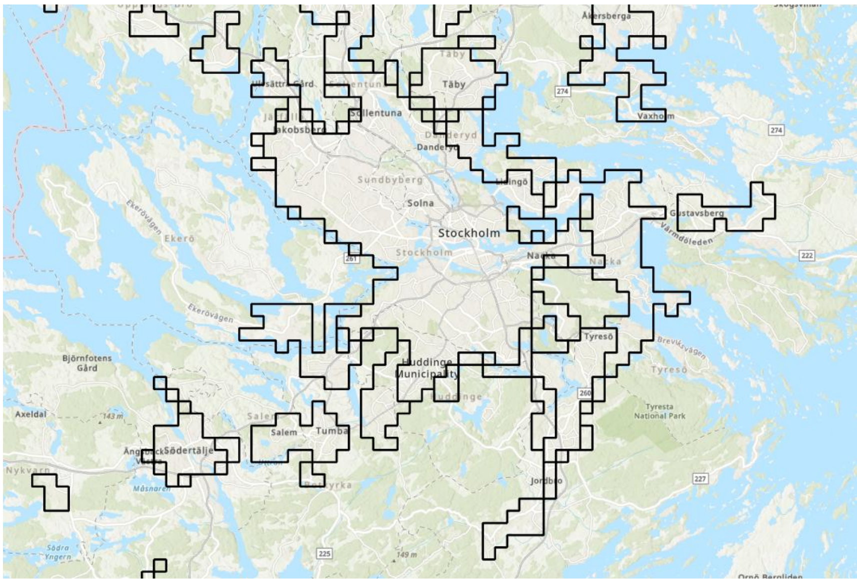

Figure 2: The vectorised High-density and Urban clusters.

The vector layer with High-density clusters and Urban clusters was buffered with 1 km. Minor gaps occurring inside buffered clusters were filled.

The DEGURBA code list was downloaded from Eurostat. The code list was joined onto the authoritative national LAU geography (municipalities with boundaries in reference scale 1:10 000).

The LAU geography was intersected with the vector layers containing the High-density clusters and Urban clusters (both the non-buffered and the buffered clusters, see Figure 3) to split urban polygons with municipality boundaries. Through the intersect, attributes from the DEGURBA code list were also transferred to the clusters.

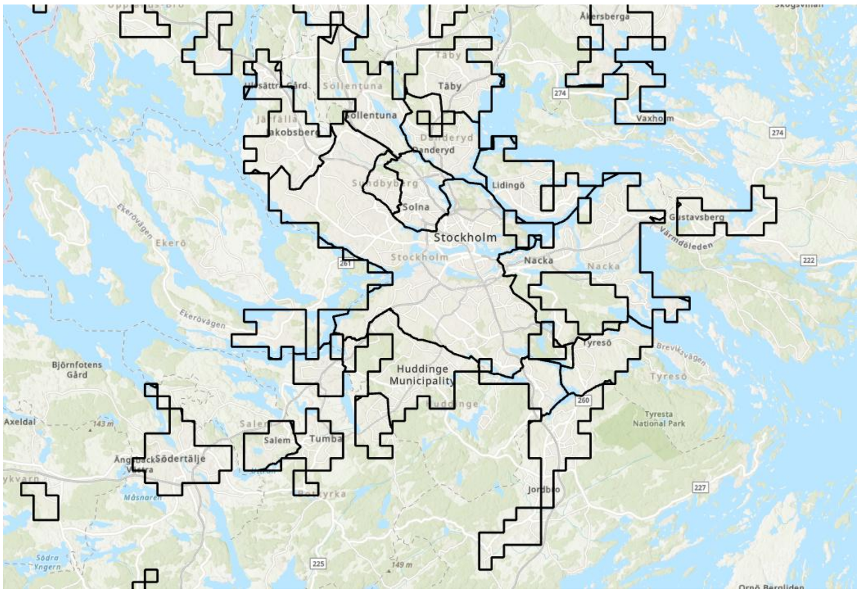

Figure 3: The non-buffered High-density and Urban clusters intersected with LAU geography.

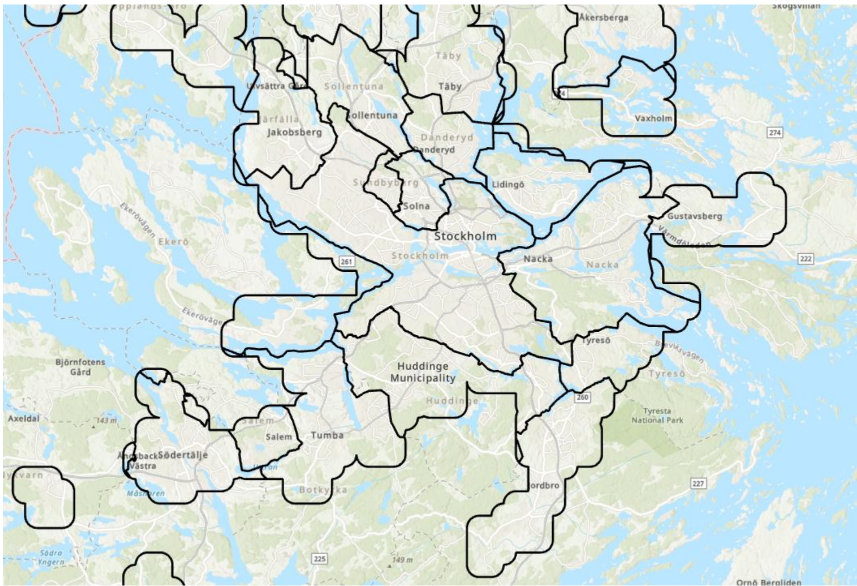

Figure 4: The buffered High-density and Urban clusters intersected with LAU geography.

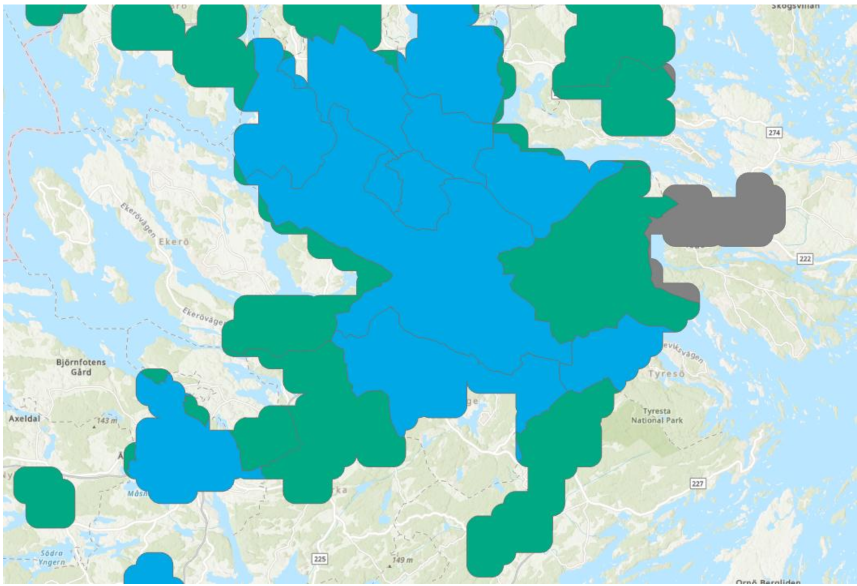

Figure 5: Buffered High-Density and Urban clusters classified according to DEGURBA. Blue=Cities, Green=Towns and Suburbs, Gray=Rural areas.

Once these urban ecosystem areas had been calculated, it was possible to calculate the tree cover density for each of the areas using QGIS.

The tree cover density was also calculated for the LAU definition of cities as it is applied in the INCA tool and recommended in the guideline for local climate regulation.

Detailed spatial and temporal data to estimating the relevant cooling season in Sweden

In a previous project financed by EU Grants, Statistics Sweden had identified the possibility of obtaining air temperature data for Sweden with a high degree of spatial temporal disaggregation from the Swedish Meteorological and Hydrological Institute (SMHI). In the project reported here this was followed up on and these data were obtained.

The temperature data obtained from SMHI are modelled data using the MESAN model[6]. It gives air temperature at 2 m height, with a spatial resolution of 2.5 km x 2.5 km. The following data were produced:

- Maximum daily temperature (24 hour period)
- Minimum daily temperature (24 hour period)
- Mean daily temperature (24 hour period, mean of hourly data)
- For years 2015 through 2024

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[6] See SMHI - https://www.smhi.se/en/research/research-units/meteorology/method-and-models

- All days for months April through September. Specified as all months where the maximum daily temperature can exceed the threshold of 25 °C
- The spatial disaggregation is according to degrees latitude and longitude

The data were provided by SMHI in NetCDF format (.nc files). In further data processing, the reference year 2018 was selected.

1. In the first data processing step, the files delivered from SMHI were processed in the following ways:
   a. Uploading of the .nc file in QGIS

   b. In QGIS data from the file were converted into a comma separated file with the help of a python script written with the help of Microsoft Copilot

   c. The following variables were prepared for all data in the file:

      i. Maximum daily temperature
      ii. Minimum daily temperature
      iii. Mean daily temperature
      iv. Spatial disaggregation (degrees long. and lat.)
      v. Day and month

2. In order to provide input for the voluntary variables for the number of days when local climate regulation is relevant, representative pixels in the file were selected for the three largest urban areas in Sweden (Greater Gothenburg, Greater Stockholm and Greater Malmö) and the northernmost city in Sweden (according to the relevant standard for the degree of urbanisation), Umeå. These pixels were chosen to represent the temperature in those cities on those days.

   For each of the cities, two specific area concepts were applied:

   - the city core - a rectangular area comprising only the central built-up areas in the city in question

   - the greater urban area – also a rectangular area, but comprising the central core as well as all suburbs, and of course non-built-up areas adjacent to built-up areas

   For Umeå, a further area was identified incorporating the greater urban area of the city as well as a large part of the relevant local administrative unit for the city, Umeå municipality (Umeå kommun in Swedish).

Clearly the use of rectangular areas is a somewhat approximate method. Having said that, the temperature data in and of itself is limited spatially from an urban perspective given the resolution of 2.5 km x 2.5 km. The application of these different area concepts also offers an opportunity to evaluate the effect that the degree of spatial resolution can have on identifying the period for which the local climate regulation service is relevant.

Table 1 shows the number of pixels and total geographic areas included according to the urban definitions applied above. It shows a wide variation in the total area included. This is of course dependent on the definitions chosen, but also on the size of the cities in question and the 2.5 km x 2.5 km resolution of the original data.

Table 1: The number of pixels and total area represented by the urban definitions as applied to determine the days when local climate regulation is relevant.

	Number of pixels	Area, km^2
Greater Stockholm	113	706
Stockholm Core	14	88
Greater Gothenburg	27	169
Gothenburg Core	2	13
Greater Malmö	30	188
Malmö Core	2	13
Greater Umeå	12	75
Umeå Core	1	6.3
Umeå kommun	163	1019

3. Based on these definitions, the average maximum daily temperature for each of the defined urban areas was calculated for all days in the months April to September. This made it possible to further calculate the number of days per month for which the temperature exceeded the 25 °C threshold.

4. The city areas chosen for the analysis were assumed to be representative of nearby cities (According to the DEGURBA definition) based on the table shown below

Calculating local climate regulation

Based on the output of the previously described methodological steps, the INCA tool was used to calculate local climate regulation for Sweden for the reference year 2018. The recommended default input data was used for the calculation. The length of the summer period chosen was based on the results of the analysis of SMHI data to determine the length of the cooling season in Sweden as described above.

The application in the INCA tool produced on the one hand the supply and use tables for the ecosystem services as required according to the revised European Regulation on Environmental Accounting (2011/691). The cooling according to this default method is calculated using the LAU definition of cities, for the entire area of the local administrative units. A further output from the INCA plug-in is a map in TIFF format containing data on the average cooling per pixel in the cities identified according to the LAU definition.

The mask developed to apply the urban ecosystem area definitions for Swedish cities was then applied to the INCA-output map with high resolution data on cooling per pixel. This was done with the zonal statistics function in QGIS to produce a table giving the average cooling for each city in Sweden according to the urban ecosystem area definitions of cities. This was done on the one hand for the urban ecosystem areas considering only the central urban cluster. It was also done for the urban ecosystem area concept including the central urban cluster and the periurban area. The average cooling arising based on the different area definitions was then compared.

2.4 Results

Detailed spatial and temporal data to estimating the relevant cooling season in Sweden

Table 2 and Figure 6 both show the number of days per month where the spatially averaged maximum temperature exceeds the 25 ^{o}C in the Swedish cities selected.

The data here show that the indicator measured (number of days exceeding 25 ^{o}C) is not very sensitive to which pixels or how many pixels are chosen to represent a given city. For example, Table 2 shows that the spatially averaged temperature in Greater Gothenburg exceeded 25 ^{o}C for a total of 42 days. The equivalent number of days for Gothenburg Core is 44, barely 5 percent higher. The same analysis applies to the other cities.

It can be noted from Table 2 that the criterion for the summer season that at least 10 days in a given month have an average temperature exceeding 25 ºC is met for at least one of the cities considered for all months May through August. Having said that, the table also shows that there is some variation between the cities according to this measure. For Gothenburg, the criterion is met for example May through July. For Malmö and Stockholm the criterion is met for July and August. For Umeå the criterion is met in July only. A further observation is that in Gothenburg the criterion is met in June only for the Gothenburg Core, but falls short by one day based on the Greater Gothenburg area.

Table 2 can be used to fulfil the requirements for voluntary reporting noted in the Guidance Note for local climate regulation. A similar method to that used to produce Table 2 can be used to produce further voluntary indicators noted in the guidance note, for example number of days with maximum temperature exceeding 30 and 35 °C respectively.

Although the method applied here applied area definitions without a high level of detail, the analysis showed that there was no great effect on the quantitative result, the area definitions applied provide very similar time series.

Table 2: The number of days in 2018 with spatially-averaged maximum temperature above 25 ºC per month, and per Swedish City, according to different are concepts (see method section)

Month	APR	MAY	JUN	JUL	AUG	SEP
Greater Gothenburg	0	12	9	18	3	0
Gothenburg core	0	13	10	18	3	0
Greater Malmö	0	6	9	19	10	0
Malmö core	0	6	8	19	10	1
Stockholm core	0	8	7	23	10	0
Greater Stockholm	0	8	7	23	10	0
Umeå core	0	2	1	21	5	0
Umeå LAU	0	2	1	22	5	0
Greater Umeå	0	2	1	21	5	0

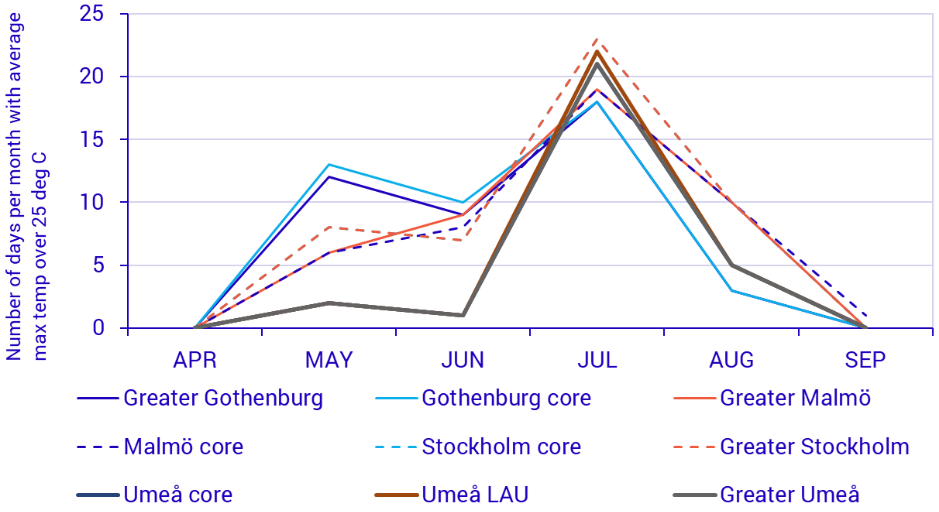


Figure 6: The number of days in 2018 with spatially-averaged maximum temperature above 25 °C per month, and per Swedish City, according to different are concepts (see method section). Note the lines for “Stockholm Core” and “Greater Stockholm” have exactly the same values.

Calculating local climate regulation for the cooling season in Sweden using INCA

Fel! Hittar inte referenskälla. and Table 4 show the supply table and use table for the local climate regulation service calculated using INCA. These data and the underlying maps were used in further analysis to calculate cooling using alternative area measures as described in the subsection below.

Table 3: Average cooling between May and August (inclusive) 2018 in Sweden due to urban green space in degrees C. Supply table for the ecosystem service for local climate regulation for all of Sweden in 2018. Calculated using the INCA tool.

Ecosystem type	Average cooling
Settlements and other artificial areas	0.047
Cropland	0.181
Grassland	0.013
Forest and woodland	0.804
Heathland and shrub	0.000
Sparsely vegetated ecosystems	0.001
Inland wetlands	0.013
Rivers and canals	0.001
Lakes and reservoirs	0.017
Marine inlets and transitional waters	0.000
Coastal beaches, dunes and wetlands	0.000
Marine ecosystems	0.000
Total	**1.077**

Table 4: Average cooling between May and August (inclusive) 2018 in Sweden due to urban green space in degrees C. Use table for the ecosystem service for local climate regulation for all of Sweden in 2018. Calculated using the INCA tool.

Sector	Average cooling
Intermediate consumption by industries	
Government final consumption	
Households final consumption	1.08
Gross capital formation	
Exports	
Total	**1.08**

Calculating tree cover density and local climate regulation according to urban ecosystem area and LAU

Figure 7, Figure 8 and Figure 9 show the comparison of tree cover density for Swedish cities (by DEGURBA definition) as calculated according to the different area definitions applied in the work, namely the entire local administrative unit (LAU – the area concept intended to be applied in the European ecosystem

accounts according to regulation 2011/691), the high-density cluster and the high-density cluster plus a buffer of periurban area. The latter two concepts are applied according to the definition in the Nature Restoration regulation.
A few general points can be made. For a large number of cities shown, the tree cover densities are higher for the LAU area definition than the alternative area definitions. Västerås, Uppsala, Linköping, Norrköping and Umeå are relevant cases of this. All of these examples are cases where the total area included in the LAU is significantly greater than the areas included in the alternative area definitions. In addition, much of this extra area is covered in forest land (a very common ecosystem type in Sweden).

There are nevertheless examples where the opposite is the case (e.g. Solna, Helsingborg), or where the tree cover density is actually higher than that for the LAU-defined are in one of the alternative definitions but lower in the other (e.g. Nacka, Sollentuna, Täby, Danderyd).

These cases can be subdivided into two further categories. In the first instances these cases arrive in cities that belong to the Stockholm urban conurbation. That the differences are smaller in these cases is due to the fact that the total area of the city when the LAU concept is applied is actually very similar to the actual area calculated for the alternative due to the alternative area definitions. This in turn is due to the fact that a very large proportion of the total area of the LAUs in question is subject to urban development.

The second subset of these cases arises for Malmö and Helsingborg, both in the Skåne region in southern Sweden. The smaller differences in these cases arise because the non-urbanized areas surrounding the urban cores in these cities is to a great extent made up of open arable land largely denuded of trees.

It can further be noted that the difference in tree cover density between the LAU defined areas and the alternative definition is generally greater for the area definition for the high-density cluster only, than for the urban high-density cluster plus the periurban area. This is of course due to the fact that the periurban area includes many areas that are not explicity subject to urban development but rather are covered with other ecosystem types, which in large parts of Sweden is predominantly forest.

Finally, it can be noted that the differences in tree cover density between the different area definitions is in some cases quite large (see Figure 9). More specifically this difference can be up to and even exceed 50 percent (see for example Linköping and Uppsala in the figure) for the comparison between the LAU definition and specifically the cluster.

The percentage differences between the LAU definition and the high-density cluster plus the urban periphery are in general smaller, but in certain cases can exceed 40 percent (Linköping and Uppsala for example). These differences are large enough to suggest that the LAU definition is unsatisfactory as a basis for the calculation of the local climate regulation service.

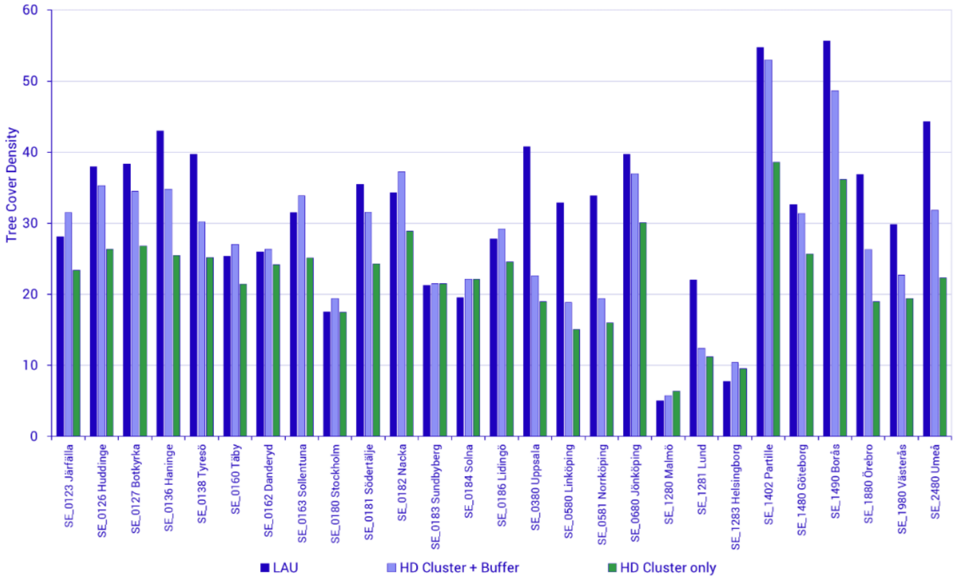


Figure 7: Tree Cover Density (in percent) in Swedish cities (based on the DEGURBA definition) for different interpretations of the urban area – Entire area of the local administrative unit (LAU), only the high-density cluster and the high-density cluster plus the periurban buffer (high-density Cluster + buffer)

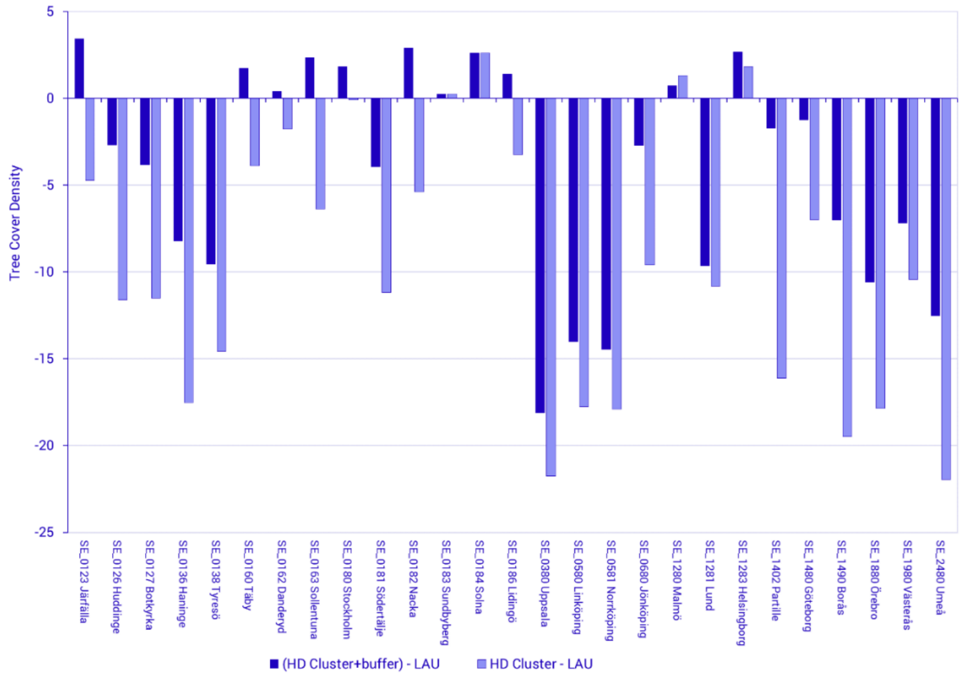


Figure 8: Difference in tree cover density in Swedish cities (based on the DEGURBA definition) for (high density (HD) cluster + buffer) and high-density cluster, compared with the entire local administrative unit. HD Cluster – only the urban cluster, HD Cluster + buffer - the urban area plus the periurban buffer. Negative values show that the calculated tree cover density is higher for LAU than for the alternative area concepts.

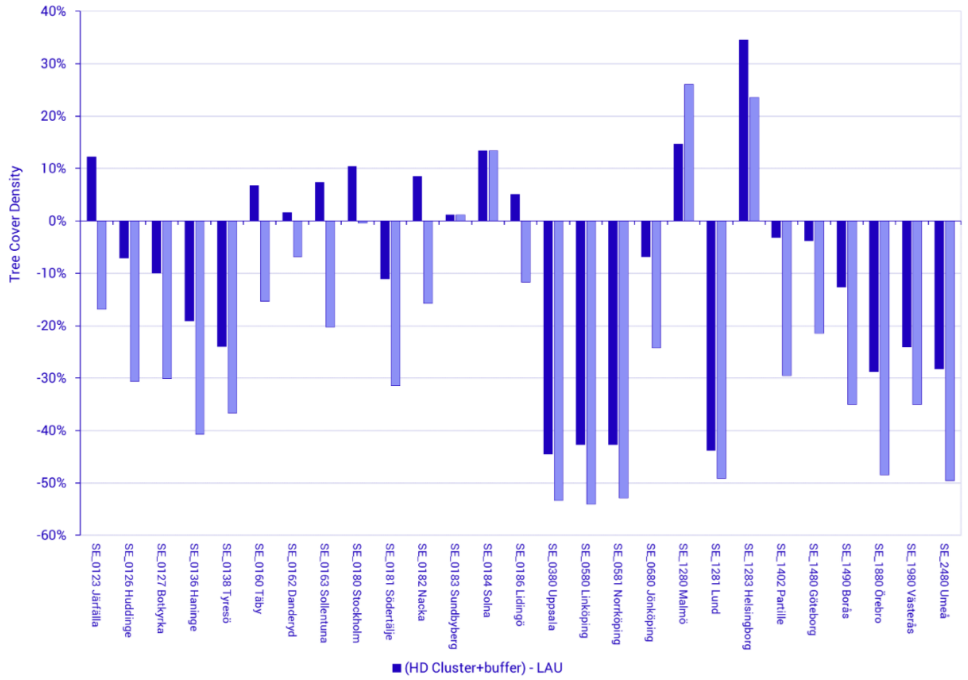


Figure 9: Percentage difference in tree cover density in Swedish cities (based on the DEGURBA definition) for (cluster + buffer) and cluster, compared with the entire local administrative unit. HD Cluster – only high-density cluster as defined by DEGURBA, HD sluster + buffer - the urban area plus the periurban buffer. Negative values show that the calculated tree cover density is higher for LAU than for the alternative area concepts.

Figure 10, Figure 11 and Figure 12 show and compare the calculated average cooling during summer months (May through August) in Swedish cities in 2018 based on the results of the INCA tool using the different city area definitions considered in the work.

The results here follow a very similar pattern to that demonstrated for the variation in tree cover density due to different area definitions (see Figure 7, Figure 8 and Figure 9). Firstly that the calculated cooling effect is predominantly greater when applying the LAU definition than either of the alternative definitions for many of the cities shown.

The differences are large in particular for cities where the LAU definition yields significantly larger total areas than the alternative definitions, for example, Uppsala, Linköping, Örebro and Västerås.

The differences are smaller for other cities, notably those that comprise the Greater Stockholm conurbation – Täby, Danderyd, the City of Stockholm itself (a subset of Greater Stockholm), Sollentuna, Sundbyberg. Again, the small differences noted for Helsingborg and Malmö arise because much of the area outside of the built-up areas included in the LAU for these cities is occupied by open arable land largely denuded of trees.

The differences between the assessed cooling for LAU and the other definitions are larger for the definition comprising only the built-up urban core (called “high-density cluster”) than for the definition comprising the periurban area as well (called “high-density cluster plus buffer”) in the figures.

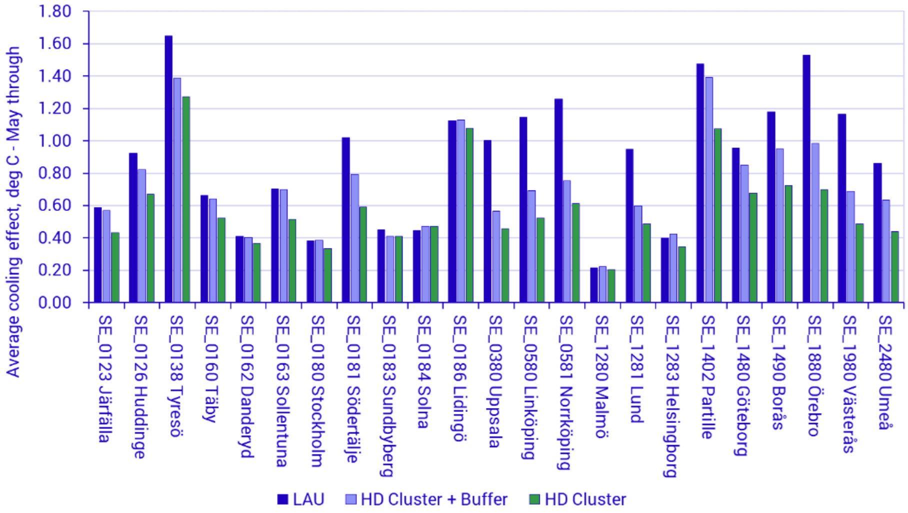


Figure 10: Average cooling during summer months for cities in Sweden due to tree cover for 2018. Based on results from the INCA tool. Three different area definitions for cities – Entire local administrative unit (LAU, according to specifications in updated regulation on environmental accounts 2011/691), high-density cluster and high-density cluster plus buffer (including periurban areas). Last 2 definitions according to specifications in the nature restoration law.

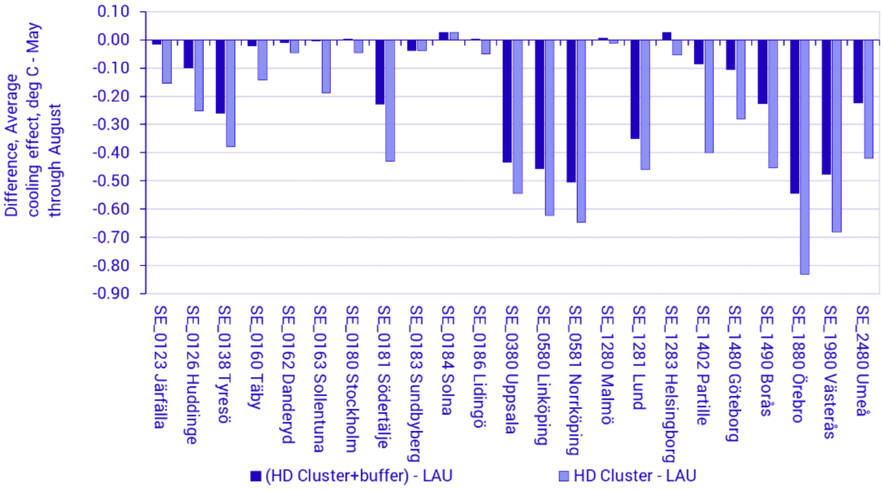


Figure 11: Difference in average cooling during summer months for cities in Sweden due to tree cover for 2018 depending on the area definition applied. Bars represent the difference between cooling based on local administrative unit definition and the high-density urban cluster on the one hand and the local administrative unit and the high-density urban cluster including periurban areas on the other. Negative values indicate that the LAU definition overestimates compared to other definitions to which it is compared and vice versa.

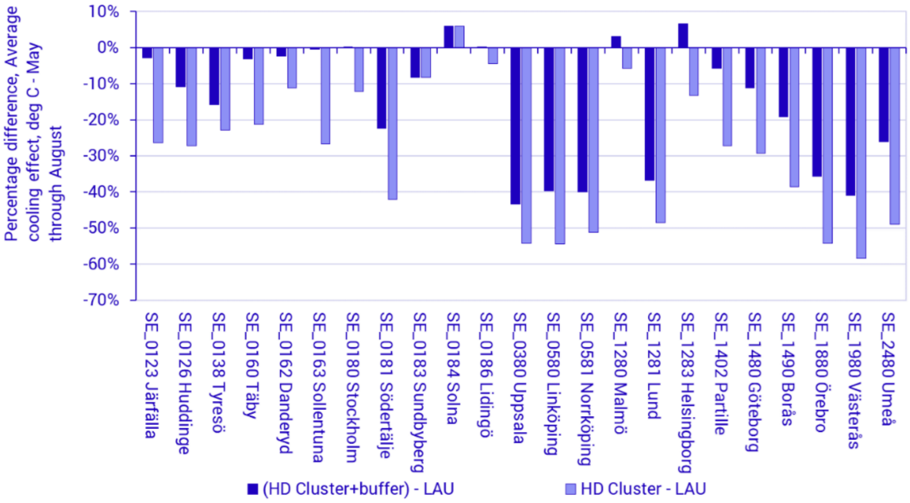


Figure 12: Difference in average cooling during summer months for cities in Sweden due to tree cover for 2018 depending on the area definition applied. Bars represent the difference between cooling based on local administrative unit definition and the high density cluster on the one hand and the local administrative unit and the high-density cluster including periurban areas on the other. Negative values indicate that the LAU definition overestimates compared to other definitions to which it is compared and vice versa.

2.5 Concluding discussion

The comparison of the average cooling indicator based on LAU and urban ecosystem areas showed that for many urban areas in Sweden significant differences in the calculated average cooling arise when changing the area definition for cities.

Going forward, it is recommended that in national reporting and communication with national users (for example the Swedish Environmental Protection Agency, the Swedish Board of Housing, Building and Planning, local authorities) that urban ecosystem areas are used exclusively. In reporting condition indicators required according to the Nature Restoration Regulation, the urban ecosystem areas will also be used. It is also strongly recommended that urban ecosystem areas are used for reporting local climate regulation to Eurostat in conjunction with the revised regulation on European Environmental accounts.

The analysis in this work also showed that the temperature datasets are a valuable source to be able to determine the time period for which the ecosystem service local climate regulation is relevant. The analysis showed that it is possible to apply for each identified urban area in Sweden. The data and analysis have produced tables that can be used for the voluntary reporting of the length of the cooling season for each city in Sweden.

Going forward it is recommended that the same method be applied for all urban areas in Sweden, and it can be applied for all years for which we have data (2015 through 2024). It is also possible to develop analysis to be able to report further voluntary indicators noted in the current guidance, namely the number of days that average maximum temperatures in a city exceed 30 and 35 degrees C respectively. These data also make it possible in the future to calculate the mandatory average cooling indicator for different time periods for different cities, given that other analysis in this work has shown that local climate regulation is relevant for different parts of the year in different parts of Sweden.

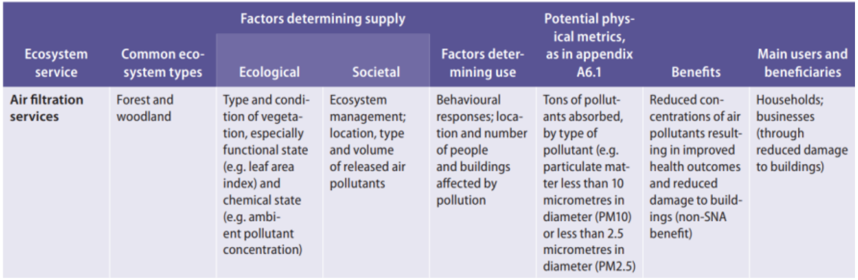
3. Air filtration

3.1 Introduction

The air filtration ecosystem services are ecosystem contributions to the filtering of airborne pollutants through the deposition, uptake, fixing and storage of pollutants by ecosystem components, particularly plants, that mitigate the harmful effects of those pollutants. The air filtration ecosystem service contributes to both households and the economy, and the contributions extend beyond marketed goods.

The boundary between the air filtration ecosystem service and its benefits can be illustrated by a logic chain which reflects a sequence where the ecosystem asset supplies an ecosystem service to an economic unit that uses this service as an input to production or a consumption activity. The logic chain is illustrated in table 5 where it can be seen that the benefits of this ecosystem service is valuable for both households and businesses. Air filtration has positive effects on multiple types of pollutants, but this report will focus on particulate matter 2,5 (PM2.5).

Table 5: Logic chain for the air filtration ecosystem service. Source: SEEA EA, (2024).



Ecosystem service	Common ecosystem types	Factors determining supply		Factors determining use	Potential physical metrics, as in appendix A6.1	Benefits	Main users and beneficiaries
		Ecological	Societal				
Air filtration services	Forest and woodland	Type and condition of vegetation, especially functional state (e.g. leaf area index) and chemical state (e.g. ambient pollutant concentration)	Ecosystem management; location, type and volume of released air pollutants	Behavioural responses; location and number of people and buildings affected by pollution	Tons of pollutants absorbed, by type of pollutant (e.g. particulate matter less than 10 micrometres in diameter (PM10) or less than 2.5 micrometres in diameter (PM2.5)	Reduced concentrations of air pollutants resulting in improved health outcomes and reduced damage to buildings (non-SNA benefit)	Households; businesses (through reduced damage to buildings)

3.2 Literature review

Studies have analyzed benefits from air filtration in different contexts, in particular health consequences of PM2.5 exposure and negative impacts on businesses. Kriit et al (2024) studies the relationship between short term fine particulate matter exposure and number of sick days. Data of PM2.5 was measured by collecting average daily concentration of this pollutant from a monitoring station in the city center of Stockholm, and data of sick leave was collected from Statistics Sweden. The levels of air pollution and data of temperature was obtained from the Swedish Meteorological and Hydrological Institute. The study applied a case-crossover method to measure the potential association between PM2.5 and sick days, as well as a conditional logistic regression method with adjustments for temperature, pollen and season. A human capital method was then used to analyze potential productivity loss. The results from this study were that there was a positive association between PM2.5 and sick leave days where the odds of sick leave increased by approximately 8.5 percent per 10 µg/m3 average exposure 2–4 days before. In total, PM2.5 exposure was the reason behind 4 percent of sick leave episodes, which caused an estimation of 17 million euro in productivity loss per year (Kriit et al., 2024).

Studies of health effects caused by PM2.5 exposure have also been focusing on the potentially increased risk of dementia. Andersson et al (2023) studies this relationship in a Swedish context where data was collected from the Betula project which is a Swedish study of memory, dementia and aging, and annual mean levels of PM2.5 was received by SMHI. The level of PM2.5 was used in a dispersion model that could be matched with participants´ residential addresses. All participants went through a health test and a cognitive test and were tested twice with five years between the tests. The study showed that 348 of 1846 participants developed dementia within the studied time period, and the risk of getting dementia increase with PM2.5 exposure.

Studies have also been analyzing the combination of both health effects and economic consequences of PM2.5 exposure. Kriit et al (2024) concludes that the increase in sick days of four percent led to a productivity loss of approximately 17 million euro. Leroutier and Olliver (2022) made a study within this area in a French context where the aim was to study the relationship between PM2.5 exposure and number of sick leave days, as well as measuring the potential productivity loss caused by this relationship. Data of 400 000 workers, monthly sales data from their employers, data of air pollution and weather conditions were collected based on postal codes. PM2.5 is collected from the French national institute for industrial environment and risks, meteorological data is collected from the Copernicus Climate Change Service, and lastly, the firms´ sales are collected from the French firms´ monthly VAT records.

The study applies a conceptual framework where the effects of pollution chocks are measured for workers and firms and presents three alternative ways where pollution might affect these sectors: decrease in labor supply, decrease productivity of non-absent workers, and decrease in demand. The main results of this study showed that productivity decreased and a ten percent increase in monthly PM2.5 exposure increased the number of sick days by 2.7

days per 1000 workers. This caused a decrease in sales for a few industries, one ug cubic meter increase in pollution exposure resulted in decreased sales by 0.24 percent for manufacturing industries and 0.44 percent in the construction industry.

The economic consequences of PM2.5 exposure has also been studied in a Chinese context where the connection between the pollutant and economic growth, measured as total factor productivity, is analyzed. Zhao and Yuan (2020) applied a two-stage least square framework and performed a regression model with total factor productivity, that represents the output, and PM2.5 together with other key variables: foreign direct investments, industrial structure, technical innovation, and population density.

The study by Zhao and Yuan (2020) also applied an instrumental variable to solve the endogeneity issue with pollution. That issue occur since pollution can decrease economic development due to for example labor supply loss, but economic growth can in itself cause effect on pollution due to for example scale and technology. The instrumental variable was decided to be rainfall since pollution tend to decrease with rainfall and the variable is determined by complex meteorological systems, not economic factors. Zhao and Yuan (2020) concluded that PM2.5 has degraded economic development in China by causing labor supply loss, counter urbanization, and human capital disruption.

These studies of health effects as well as economic consequences of PM2.5 exposure levels clearly show that PM2.5 is important to measure and analyze.

3.3 Method

The air filtration ecosystem service has been calculated using the INCA tool in QGIS by applying INCA default data sets from Eurostat[7] of leaf area index rasters, PM2.5 rasters, wind rasters, deposition of PM, wind tables and aquatic ecosystems, as well as Corinne land cover map and ecosystem translation at level two. The applied data was provided for year 2006, 2012, 2018 and 2021, and the INCA calculations was performed using monthly, seasonal and annual data for leaf area index rasters, PM2.5 rasters and wind rasters. The default data for deposition of PM, wind tables and aquatic ecosystems were the same for both monthly, seasonal and annual calculations. The reporting areas have been NUTS-0, and the selected region is Sweden.

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[7] The INCA default data was downloaded from the INCA platform: INCA Tool | INCA Platform

National data of PM2.5 levels was also provided to Statistics Sweden by SMHI in NetCDF format (.nc files) that was processed in several steps. Firstly, the NetCDF format of the data was uploaded in QGIS by adding a raster layer and the QGIS data was then saved as a CSV file by applying R code. This file was processed in SAS in order to convert the CSV file to an Excel file with separate columns. The number of pixels were over 21 million, so the process was very time consuming.

The ambition was to include the data sets of PM2.5 levels from SMHI in the INCA tool in order to compare those results with the ones resulting from the calculation based on the default data set of PM2,5 rasters. The process of doing so could however not be performed because of the different structure of these data sets. The data from SMHI was still valuable for the analysis even if it not could be included in the INCA calculations since these gave an indicator of where the largest levels of PM2,5 occur in Sweden.

3.4 Results

The calculations in INCA are presented as supply and use tables for each year. The calculations on a monthly, seasonal and annual basis, are all presented below.

Table 6 presents the supply tables of air filtration on a yearly basis, where it can be seen which ecosystem types that accounts for the most air filtration of PM2.5. The forest and woodlands are responsible for the largest part of air filtration, as expected, and accounts for between 73 and 76 percent of total air filtration. Cropland is the second largest ecosystem type in the air filtration ecosystem service with between 13 and 16 percent. Marine ecosystems, rivers and canals, lakes and reservoirs, marine inlets and transitional waters, and coastal beaches, dunes and wetlands, have no air filtration according to the INCA output.

Table 6: Supply table of air filtration calculated applying yearly data. Source: INCA tool

Ecosystem type	2006	2012	2018	2021
Settlements and other artificial areas	2,3	2,2	1,2	1,8
Cropland	18,4	17,3	9,6	14,4
Grassland	1,4	1,3	0,8	1,2
Forest and woodland	104,1	88,8	56,0	66,8
Heathland and shrub	4,1	2,9	1,7	3,0
Sparsely vegetated ecosystems	0,6	0,5	0,3	0,5
Inland wetlands	6,7	5,2	2,8	3,8
Rivers and canals	0,0	0,0	0,0	0,0
Lakes and reservoirs	0,0	0,0	0,0	0,0
Marine inlets and transitional waters	0,0	0,0	0,0	0,0
Coastal beaches, dunes and wetlands	0,0	0,0	0,0	0,0
Marine ecosystems	0,0	0,0	0,0	0,0
Total[8]	**137,7**	**118,1**	**72,5**	**91,5**

The INCA default data sets do not only contain data on a yearly basis, but it also contains data on a monthly basis which is presented in table 7. The data that differs between these methods are those for Leaf Area Index, PM2,5 rasters and wind rasters. Total air filtration divided by ecosystem types are very similar between the methods, forest and woodland is still the largest ecosystem type, followed by cropland and inland wetlands.

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[8] INCA

Table 7: Supply table of air filtration calculated applying monthly data. Source: INCA tool

Ecosystem type	2006	2012	2018	2021
Settlements and other artificial areas	2,4	2,3	0,9	1,3
Cropland	18,8	18,8	7,8	10,3
Grassland	1,5	1,4	0,7	0,8
Forest and woodland	112,2	96,0	41,1	43,4
Heathland and shrub	4,5	3,1	1,2	1,2
Sparsely vegetated ecosystems	0,7	0,5	0,2	0,2
Inland wetlands	7,8	5,9	1,9	2,1
Rivers and canals	0,0	0,0	0,0	0,0
Lakes and reservoirs	0,0	0,0	0,0	0,0
Marine inlets and transitional waters	0,0	0,0	0,0	0,0
Coastal beaches, dunes and wetlands	0,0	0,0	0,0	0,0
Marine ecosystems	0,0	0,0	0,0	0,0
Total[9]	**147,8**	**128,0**	**53,8**	**59,2**

The third and final method for calculating air filtration using the INCA tool is air filtration based on seasonal data and is presented in table 8. The distribution of air filtration amongst the ecosystem types follows the same pattern as the two previously mentioned methods.

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[9] INCA

Table 8: Supply table of air filtration calculated applying seasonal data. Source: INCA tool

Ecosystem type	2006	2012	2018	2021
Settlements and other artificial areas	2,5	2,4	1,2	1,5
Cropland	19,7	19,4	10,6	11,7
Grassland	1,5	1,4	0,9	0,9
Forest and woodland	113,9	97,8	52,1	52,0
Heathland and shrub	4,5	3,0	1,5	1,6
Sparsely vegetated ecosystems	0,7	0,5	0,3	0,3
Inland wetlands	7,7	5,9	2,3	2,6
Rivers and canals	0,0	0,0	0,0	0,0
Lakes and reservoirs	0,0	0,0	0,0	0,0
Marine inlets and transitional waters	0,0	0,0	0,0	0,0
Coastal beaches, dunes and wetlands	0,0	0,0	0,0	0,0
Marine ecosystems	0,0	0,0	0,0	0,0
Total[10]	**150,6**	**130,5**	**69,0**	**70,6**

There are small differences in values when comparing the air filtration divided by ecosystem types, but the differences are clearer when comparing the total amount of air filtration from the three different methods. The total air filtration increases when moving from yearly data to monthly and seasonal data for 2006 and 2012, and the differences between the models are between 1,9 and 10,5 percent. The same pattern is not true for 2018 and 2021 where the differences are between 4,9 and 35,3 percent, and the total amount of air filtration decreases from the yearly model to the monthly model, and then increase from the monthly to the seasonal model. It is difficult to interpret which of these models that should be preferred. It is not clear if the data accuracy increases by applying seasonal or monthly data compared to a yearly average. More detailed data should although imply improved accuracy, in which case the monthly data would be preferred. The comparison is illustrated in table 9.

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[10] INCA

Table 9: Comparison between total air filtration by applying yearly, monthly and seasonal data. Source: INCA-tool.

Air filtration	**2006**	**2012**	**2018**	**2021**
Total applying yearly data	137,7	118,1	72,5	91,5
Total applying monthly data	147,8	128,0	53,8	59,2
Total applying seasonal data	150,6	130,5	69,0	70,6
Monthly vs yearly data	7,4%	8,4%	-25,8%	-35,3%
Seasonally vs yearly data	9,4%	10,5%	-4,9%	-22,9%
Seasonally vs monthly data	1,9%	1,9%	28,2%	19,2%

The INCA output also consist of use tables and these results are presented on a yearly basis in table 10. The table show the use of the air filtration services divided by economic actors. However, the only actor that has any use values are households' final consumption. This means that the INCA output states that households are the only beneficiaries of air filtration, and not industries, the government, export, or gross capital formation. This output is unexpected since there should be other beneficiaries of air filtration than just households. The use tables for monthly and seasonal data are not presented in the report but they can be found in the Excel file containing pilot data tables for this grant project.

Table 10: Use tables of air filtration ecosystem service. Source: INCA-tool.

Actor	**2006**	**2012**	**2018**	**2021**
Intermediate consumption by industries	0,0	0,0	0,0	0,0
Government final consumption	0,0	0,0	0,0	0,0
Households final consumption	137,6	118,0	95,0	91,4
Gross capital formation	0,0	0,0	0,0	0,0
Exports	0,0	0,0	0,0	0,0
Total	**137,6**	**118,0**	**95,0**	**91,4**

A key principle underpinning the SUT structure is that the supply of ecosystem services must equal the use of those services during an accounting period. This is an application of the supply and use identity (SEEA Central Framework, para. 3.35). Thus, both the supply and the use of air filtration services, for example, should be recorded using the same measurement unit (e.g., tons of PM2.5 absorbed by vegetation).

A weakness to the supply and use tables that are created using the INCA-tool is that the results are difficult to interpret. One can question if households are the only beneficiaries of air filtration when industries and governments should benefit from healthier residents. Studies presented under the section *background* show that exposure to PM2.5 can have a negative impact on health and thereby also affect industries, and so the use tables of the ecosystem service air filtration should be more logical if they included industries and governments, as well as households.

The supply tables are also difficult to interpret since it is unclear what the values presented really implies. High values of air filtration might be positive since more tonnes of pollutants are cleaned from the air, but it is not necessarily positive if air filtration has increased due to increased emissions of PM2.5. These questions remains to be tackled in communicating the results.

3.4 PM2.5 emissions and levels

The cause of PM2.5 emissions in is presented in table 11. It shows that the main reasons behind PM2.5 emissions are heating of homes and premises, the industrial sector and domestic transportation. Table 11 also shows that the total of PM2.5 emissions are less than the total amount of air filtrated PM2.5 for all reference years. This was first assessed as being a mistake in either the INCA calculations or the PM2.5 emission data, however, the Swedish Environmental Protection Agency (2024) confirmed that it is reasonable to get these results. This occurs since the applied methodology for calculation of PM2.5 emissions differ from the calculation made in the INCA tool for air filtration. PM2.5 emissions are calculated from an anthropogenic perspective, meaning emissions caused by human activities, and include emissions from industrial processes, agriculture, and waste. Emissions from natural sources, such as sea salt or particles from the forest, are excluded, and the same is true for emissions from international shipping, flights above 3000 feet and emissions from other countries (The Swedish Environmental Protection Agency, 2024).

Table 11: Total PM2.5 emissions. Source: The Swedish Environmental Protection Agency (2024a).

Sectors	2006	2012	2018	2021
Machinery	1,4	1,3	1,0	0,9
Waste	0,9	0,9	0,9	0,9
Heating of homes and premises	8,6	8,4	5,9	5,6
Electricity and district heating	1,8	1,3	0,8	0,8
Industrial sector	12,0	8,8	5,2	3,9
Domestic transportation	6,5	5,1	4,6	4,1
Agriculture	0,6	0,6	0,6	0,6
Product use (incl. solvent)	0,3	0,2	0,2	0,1
Total PM2.5 emissions	**32,1**	**26,5**	**19,1**	**16,9**

The Swedish Environmental Protection Agency (2024b) concluded that a large portion of PM2.5 emissions comes from other countries. The amount of PM2.5 emissions that are caused by these countries are difficult to estimate since these are affected by many factors. Estimations for these emissions have however been made by different actors and one of these estimations are made by the European Commission (2021). The study focuses on air quality in European cities and the results are presented in the Urban PM2.5 Atlas.

The Urban PM2.5 Atlas by the European Commission (2021) analyze the effect other countries have on national levels of PM2.5. It applies a Java/Python tool named SHERPA (Screening for High Emission Reduction Potential on Air quality) which is developed to explore air quality improvements resulting from reduction measures made nationally, regionally or locally. It is based on a CTM (chemistry transport model) but with simplified assumptions, and applies EU-wide data on emissions, as well as source-receptor models.

The model applies anthropogenic emissions, just like the emission data from The Environmental Protection Agency (2024a), which are based on CAMS V4.2 emissions per country-pollutant-sector for 2015 and covers emissions for UNECE-Europe for the main air pollutants and greenhouse gases (Kuenen et al., 2014, Granier, et al., 2019). Meteorological input data are also applied, and these are based on 2015 forecasts from the Integrated Forecast System (IFS) which is a global operational forecasting model from the European Centre for Medium-Range Weather Forecasts (ECMWF).

Figure 12, 13 and 14illustrate estimates of total mass of PM2.5 allocated by spatial and sectoral factors. Total PM2.5 comes from transportation (T), industry (I), agricultural (A), residential (R), shipping (S), other (O), natural (N) and external (E) factors. The transboundary part of PM2.5 represents particulate matter that comes from other countries. These figures shows that Malmö, in the south of Sweden, has the highest part of transboundary emissions of approximately 65 percent, whilst Stockholm, in the middle of Sweden, only has 25 percent. Gothenburg has approximately 30 percent of transboundary emissions, and these results goes in line with the data presented by The Swedish Environmental Protection Agency (2024b) in figure 15.

The figures 12, 13 and 14, also shows that shipping results in a significant part of total PM2.5 emissions. This can also be part of the explanation to why PM2.5 emissions are less than the amount of PM2.5 reduced by the air filtration ecosystem service, since PM2.5 emission calculations in Sweden excludes shipping.

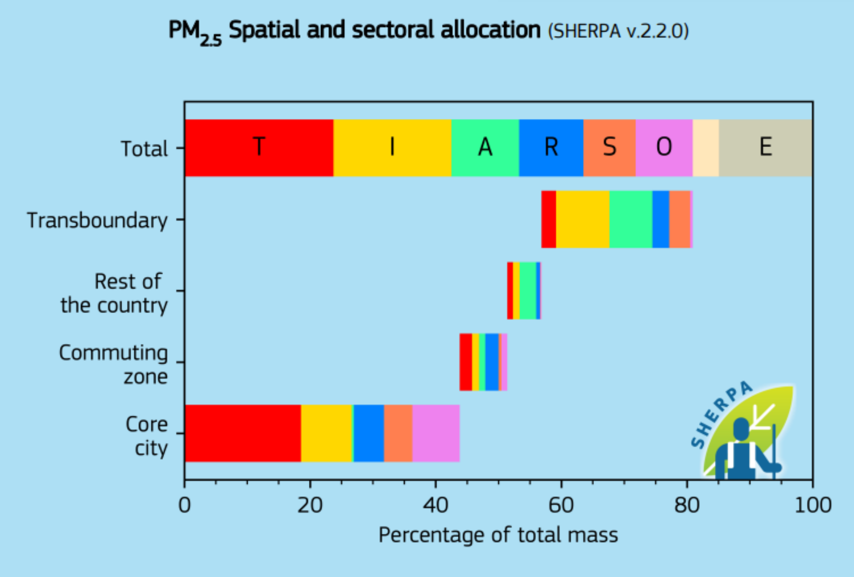

Figure 12: PM2.5 spatial and sectoral allocation, Stockholm. Source: (Kuenen et al., 2014, Granier, et al., 2019).

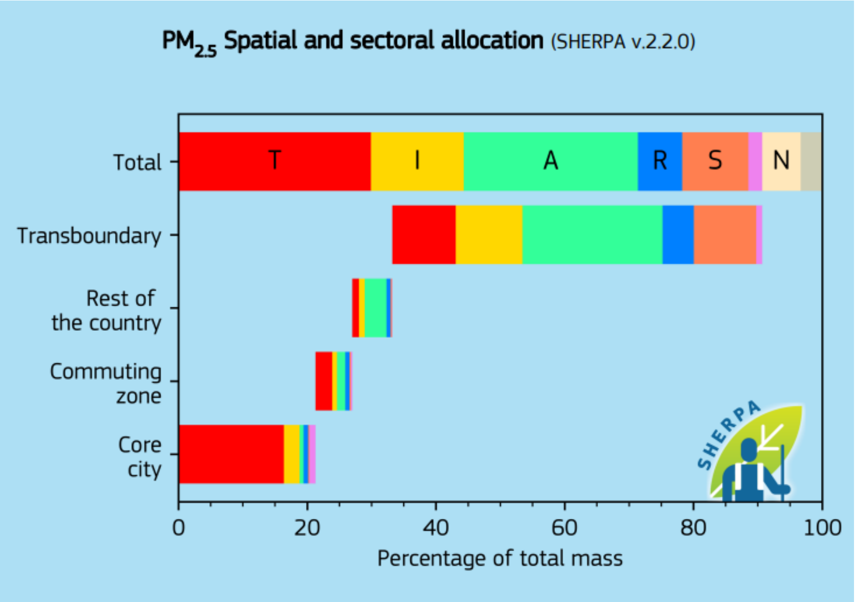

Figure 13: PM2.5 spatial and sectoral allocation, Malmö. Source: (Kuenen et al., 2014, Granier, et al., 2019).

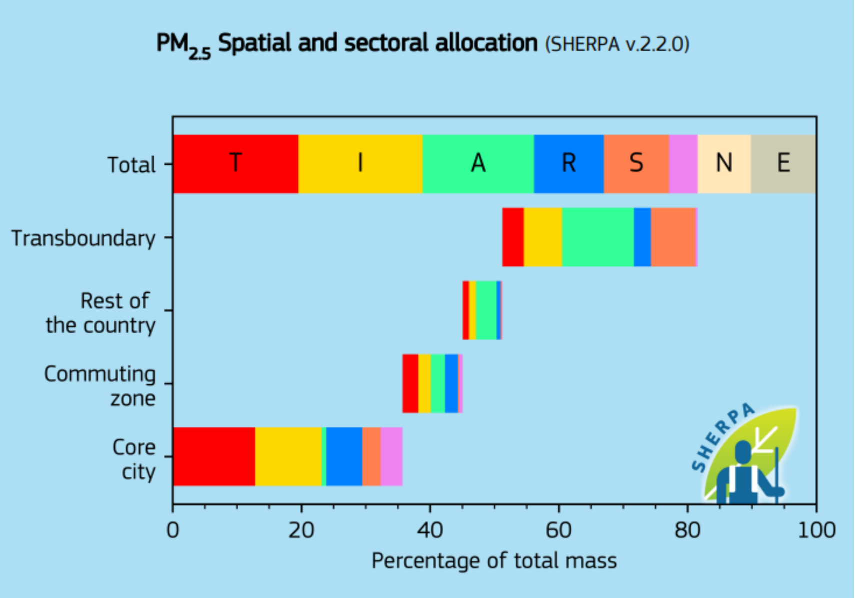

Figure 14: PM2.5 spatial and sectoral allocation, Gothenburg. Source: (Kuenen et al., 2014, Granier, et al., 2019).

The extent of emissions that come from other countries have also been analyzed by The Swedish Environmental Protection Agency (2024b) where PM2.5 levels from three large cities in Sweden was chosen and compared. The study showed that the emission exposure is much lower for the northern part of Sweden when compared with the middle and south of Sweden. The most southern part of Sweden is more exposed to emissions from other European countries than the north of Sweden is, and this can be one of the reasons to why PM2.5 levels are higher in this area. The results are illustrated in figure 15. It is however difficult to measure the exact portion of total PM2.5 levels that are caused by other countries.

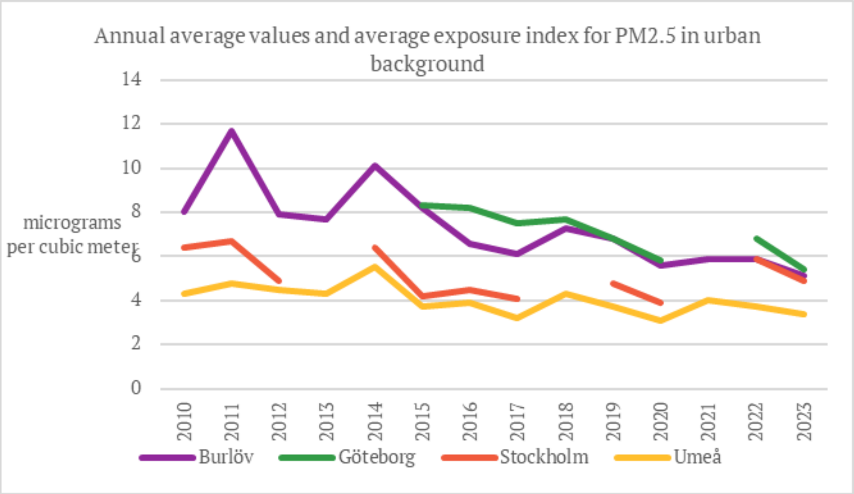

Figure 15: Annual average values and average exposure index in Sweden for PM2.5 in urban background. Source: The Swedish Environmental Protection Agency (2024b)

The different levels of PM2.5 have further been analyzed by the Swedish Meteorological and Hydrological Institute (2019) and is illustrated in figure 16. The result shows a similar pattern to the previously mentioned studies. The north of Sweden has the lowest levels of PM2.5 and the levels are increasing when moving to the south of Sweden which supports the theory that European emissions is a larger problem in the south.

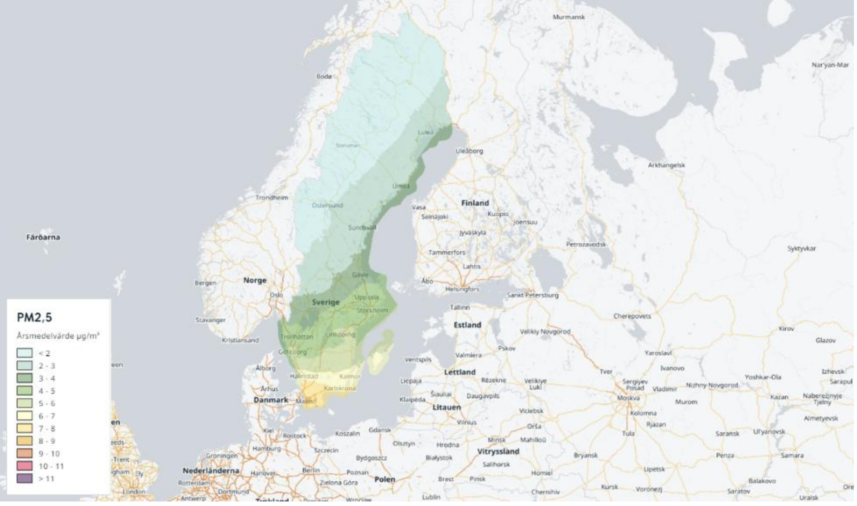

Figure 16: Level of PM2.5 emissions in Sweden. Source: Swedish Meteorological and Hydrological Institute (2019).

Data containing detailed levels of PM2.5 emissions was also directly delivered to Statistics Sweden by SMHI. It is presented in the attached Pilot data tables for this grant project. The data show that the maximum level of PM2.5 was 8.21 and the minimum level was 1.14. The lowest level of PM2,5 was measured in the north of Sweden, and the level increases to the highest level in the south of Sweden. This confirms the previously mentioned discussion regarding the impact of other countries PM2,5 emissions on Sweden. The data was run through QGIS and the result is shown in figure 17.

Figure 17: Level of PM2.5 emissions in Sweden based on detailed data received from SMHI. The color white represents the lowest level of PM2.5 and black represents the highest level of PM2.5.

QGIS was also used to create a histogram of this data to see the frequency of the different levels of PM2.5. The histogram shows that low levels of PM2.5 are more frequent than high levels. This is reasonable since the north of Sweden represents a larger are of Sweden than the far south of Sweden, and the levels of PM2.5 in the north of Sweden is, as stated before, lower than the south. The histogram is illustrated in figure 18.

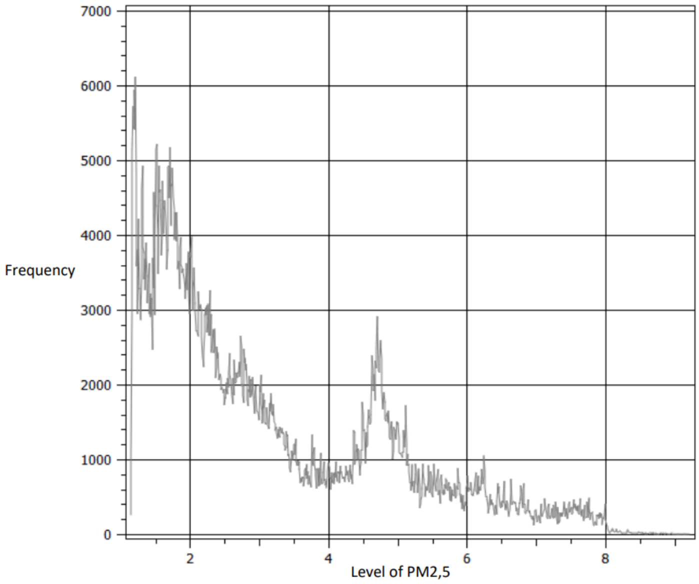

Figure 18: Level of PM2.5 emissions in Sweden based on detailed data received from SMHI.

3.5 Concluding discussion

Air filtration is calculated for the whole country, and not on a more detailed level. It is of interest to know where the air filtration levels are high and low in order to analyze the possible explanations behind it, but it would be an even more interesting outcome if the air filtration could be calculated on a finer level. It is reasonable that air filtration is higher in the north of Sweden since those areas mainly consist of forests and woodland, which stands for the majority of air filtration, but trees in cities could be even more interesting to analyze.

The INCA results showed that air filtration not only occur in forests and woodland, but also in settlements and other artificial areas as well. This can be explained by the function trees have in these ecosystem type areas. The trees do not only filter the air, but they also provide with social and cultural benefits as well as other ecosystem services. They play a vital role regarding creating habitats and thereby also improving biological diversity and pollination, to mention a few. These benefits are illustrated in figure 19. To calculate air filtration using the INCA tool would thereby be improved if deeper analysis could be made.

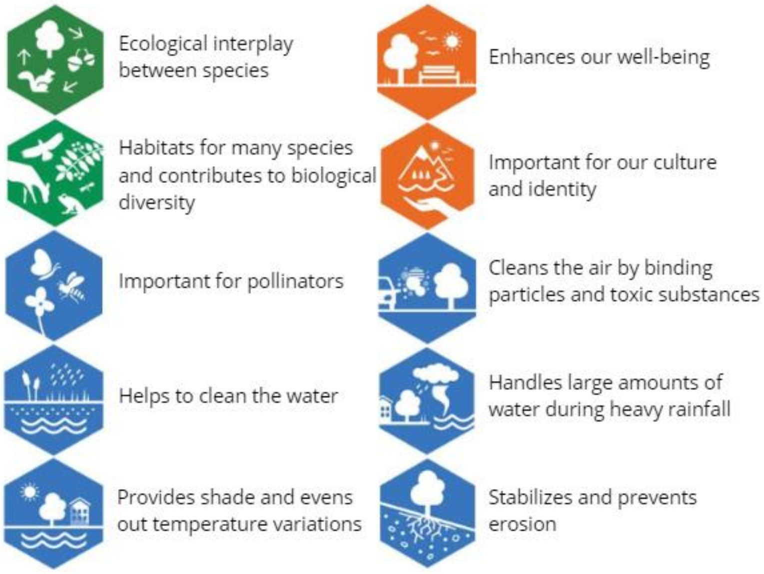

Figure 19: Trees´ ecosystem services in cities. Source: The Swedish National Board of Housing, building and planning (2023).

4. Provision of wood and crops

In preparation for the obligatory data collection of the provision of wood and crops to Eurostat in 2026, this chapter reflects on how the information from the INCA tool can be interpreted and what additional information or indicators will improve the quality of the communication about provision indicators.

In an earlier report (Brown et al, 2024. Deliverable 3.1 of project 2022-SE-EGD), the results from using the INCA tool for Sweden were discussed for provision of wood and crops. The wood provision is defined as the ecosystem contribution to the growth of trees and other woody biomass, measured as net annual increment in thousands m3 over mark. Annual growth stands at around 125 million cubic metres.

For wood provision, the results of INCA tool were calculated, for 2000, 2006, 2012, 2018 and 2021, giving the supply and use tables for one out of three categories: the category “Forest and woodland”. The results are presented in table 12. Since Sweden are just finalising the methods for reporting the categories “other wooded land” and “forest not available for wood supply” to Eurostat yet, those categories cannot be reproduced yet. The forest accounts are currently being designed in a separate project, so that a proper reporting to Eurostat with all categories can be done in September 2025. Once this reporting has been set up, the INCA tool should be able to be used to provide the final wood provision numbers, well in time for the obligatory reporting in 2026.

Table 12: Supply table of wood provision. 1000 m3. Source: INCA tool

Ecosystem type	2000	2006	2012	2018	2021
Settlements and other artificial areas	0,0	0,0	0,0	0,0	0,0
Cropland	0,0	0,0	0,0	0,0	0,0
Grassland	0,0	0,0	0,0	0,0	0,0
Forest and woodland	126415,4	127428,3	132437,0	126253,8	124036,1
Heathland and shrub	0,0	0,0	0,0	0,0	0,0
Sparsely vegetated ecosystems	0,0	0,0	0,0	0,0	0,0
Inland wetlands	0,0	0,0	0,0	0,0	0,0
Rivers and canals	0,0	0,0	0,0	0,0	0,0
Lakes and reservoirs	0,0	0,0	0,0	0,0	0,0
Marine inlets and transitional waters	0,0	0,0	0,0	0,0	0,0
Coastal beaches, dunes and wetlands	0,0	0,0	0,0	0,0	0,0
Marine ecosystems	0,0	0,0	0,0	0,0	0,0
Total	**126415**	**127428**	**132437**	**126254**	**124036**

The use table for wood provision is presented in table 13 which shows that intermediate consumption by industries is the only beneficiary. The removals of wood from the other two forest land categories (Forest not available for wood supply and Other wooded land) are assumed to be minor quantities and to become an economic output of the logging industry. It represents a voluntary reporting item in the Ecosystem accounts.

Table 13: Use table of wood provision, Vol (1000 m3). Source: INCA tool

Ecosystem type	**2000**	**2006**	**2012**	**2018**	**2021**
Intermediate consumption by industries	126415,4	127428,3	132437,0	126253,8	124036,1
Government final consumption	0,0	0,0	0,0	0,0	0,0
Households final consumption	0,0	0,0	0,0	0,0	0,0
Gross capital formation	0,0	0,0	0,0	0,0	0,0
Exports	0,0	0,0	0,0	0,0	0,0
Total	**126415**	**127428**	**132437**	**126254**	**124036**

The crop provision ecosystem service is defined as the amount of harvested crops for different uses. This includes food and fibre production, fodder and energy, and grazed biomass. In Figure 20 the map of crop provision use for the EU is shown from the INCA website.

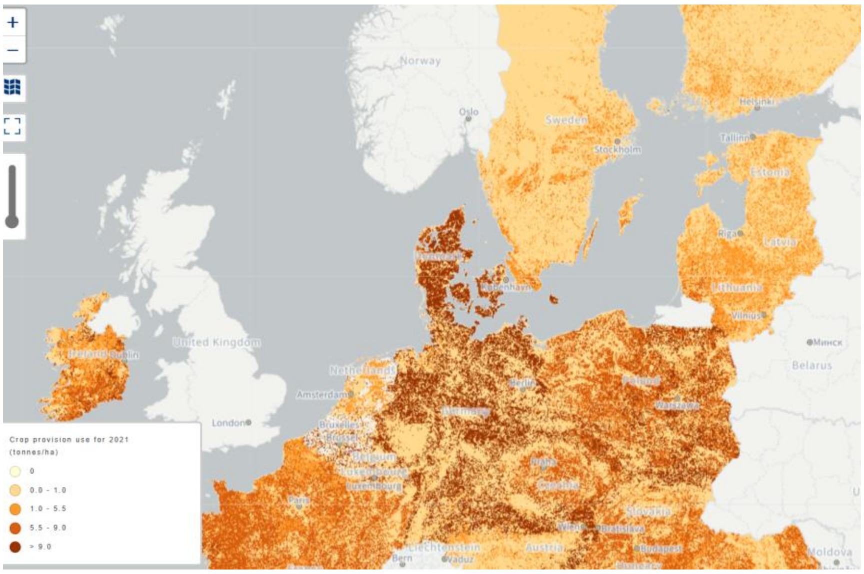

Figure 20. Crop provision in the EU 2021. Tonnes/hectare. (The map does not show the whole Sweden, Finland nor the South of the EU).[11]

Crop provision can be calculated in INCA using two different data sets. The first option is to apply material flow data, and this is presented in table 14. This is the method that Sweden plans to report with.

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[11] Map | INCA Platform

The second option is to apply agricultural statistics which is presented in table 15. Both tables show only the ecosystem types that have values greater than zero, which is settlements and other artificial areas, cropland and grassland. The complete tables with all ecosystem types are presented in the sheets for crop provision in the Excel file “Pilot data tables”.

Table 14: Supply table for 2018 of crop provision calculated using material flow data, the preferred method for the Swedish reporting. The ecosystem types have been selected to only showing settlements and other artificial areas, cropland and grassland since the remaining ecosystem types have zero values. Thousand tonnes in EU standard humidity. Source: INCA tool

Crop types	Total	Settlements and other artificial areas	Cropland	Grassland
MF1.1.1 cereals	3256	0	3256	0
MF1.1.2 roots and tubers	723	0	723	0
MF1.1.3 sugar crops	1698	0	1698	0
MF1.1.4 pulses	84	0	84	0
MF1.1.5 nuts	0	0	0	0
MF1.1.6 oil-bearing crops	222	0	222	0
MF1.1.7 vegetables	315	0	315	0
MF1.1.8 fruits	50	0	50	0
MF1.1.9 fibres	1	0	1	0
MF1.1.A other crops (excluding fodder crops) n.e.c.	80	0	80	0
MF1.2.1.1 Straw	1610	0	1610	0
MF1.2.1.2 Other crop residues (sugar and fodder beet leaves and other)	233	0	233	0
MF1.2.2.1 Fodder crops (including biomass harvest from grassland)	4328	0	4328	0
MF1.2.2.2 Grazed biomass	537	0	0	537
All regions	**13135**	**0**	**12598**	**537**

Crop provision was also calculated using agricultural statistics for 2018 and the results are presented in table 15.

Table 15: Supply table for 2018 of crop provision calculated using agricultural statistics. Shown as comparison to the material flow calculation. The ecosystem types have been selected to only showing settlements and other artificial areas, cropland and grassland since the remaining ecosystem types have zero values. Source: INCA tool

Crop types	Total	Settlements and other artificial areas	Cropland	Grassland
MF1.1.1 cereals	3260	0	3260	0
MF1.1.2 roots and tubers	723	0	723	0
MF1.1.3 sugar crops	1698	0	1698	0
MF1.1.4 pulses	83	0	83	0
MF1.1.5 nuts	0	0	0	0
MF1.1.6 oil-bearing crops	222	0	222	0
MF1.1.7 vegetables	306	49	257	0
MF1.1.8 fruits	49	1	48	0
MF1.1.9 fibres	0	0	0	0
MF1.1.A other crops (excluding fodder crops) n.e.c.	66	0	66	0
MF1.2.1.1 Straw	412	0	412	0
MF1.2.1.2 Other crop residues (sugar and fodder beet leaves and other)	160	0	160	0
MF1.2.2.1 Fodder crops (including biomass harvest from grassland)	4872	0	4872	0
MF1.2.2.2 Grazed biomass	1197	0	0	1197
All regions	**13049**	**51**	**11802**	**1197**

The results from these two methods differ for some of the crop types. The largest differences are seen for straw, fodder crops and grazed biomass. All differences are presented in table 16. The total 1000 tonnes of crop provision is larger for settlements and other artificial areas, and grassland, when applying the agricultural statistics, and larger for grassland when applying the material flow data. The material flow data results in a slightly larger total for crop provision than agricultural statistics provides.

Table 16: Differences between of applying agricultural statistics and material flow data for crop provision in 2018. The ecosystem types have been selected to only showing settlements and other artificial areas, cropland and grassland since the remaining ecosystem types have zero values. Source: INCA tool

Crops	Total	Settlements and other artificial areas	Cropland	Grassland
MF1.1.1 cereals	5	0	5	0
MF1.1.2 roots and tubers	0	0	0	0
MF1.1.3 sugar crops	0	0	0	0
MF1.1.4 pulses	0	0	0	0
MF1.1.5 nuts	0	0	0	0
MF1.1.6 oil-bearing crops	0	0	0	0
MF1.1.7 vegetables	-9	49	-59	0
MF1.1.8 fruits	0	1	-2	0
MF1.1.9 fibres	-1	0	-1	0
MF1.1.A other crops (excluding fodder crops) n.e.c.	-14	0	-14	0
MF1.2.1.1 Straw	-1198	0	-1198	0
MF1.2.1.2 Other crop residues (sugar and fodder beet leaves and other)	-72	0	-72	0
MF1.2.2.1 Fodder crops (including biomass harvest from grassland)	544	0	544	0
MF1.2.2.2 Grazed biomass	660	0	0	660
All regions	**-86**	**51**	**-797**	**660**

Table 14-16 focuses on 2018, while calculations were made for the years 2000, 2006 and 2012 as well. This time series is illustrated using the agricultural statistics, in figure 21.

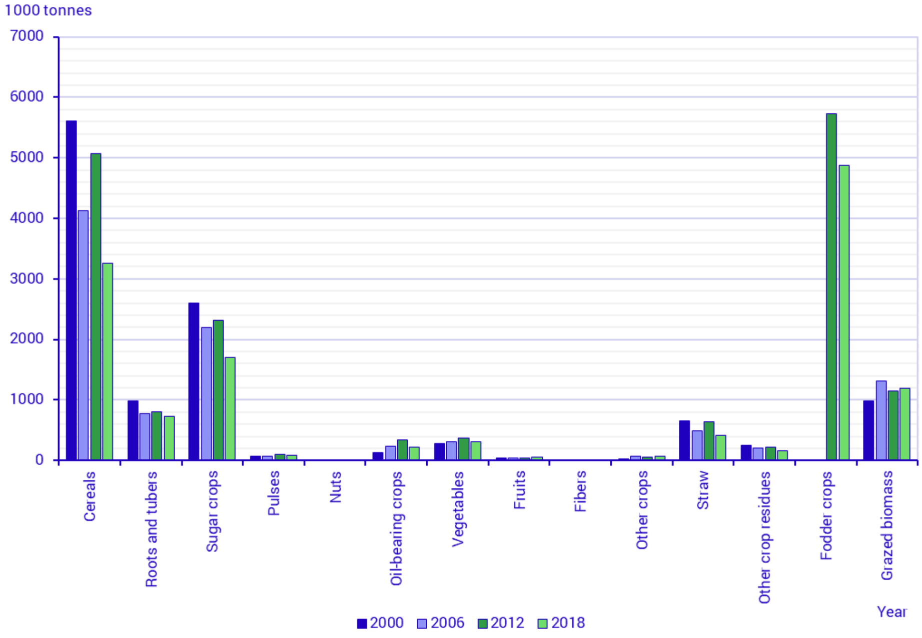

Figure 21: Crop provision 2000, 2006, 2012 and 2018, by applying agricultural statistics. Source: INCA tool.

This time series is also illustrated when applying the second method, in figure 22.

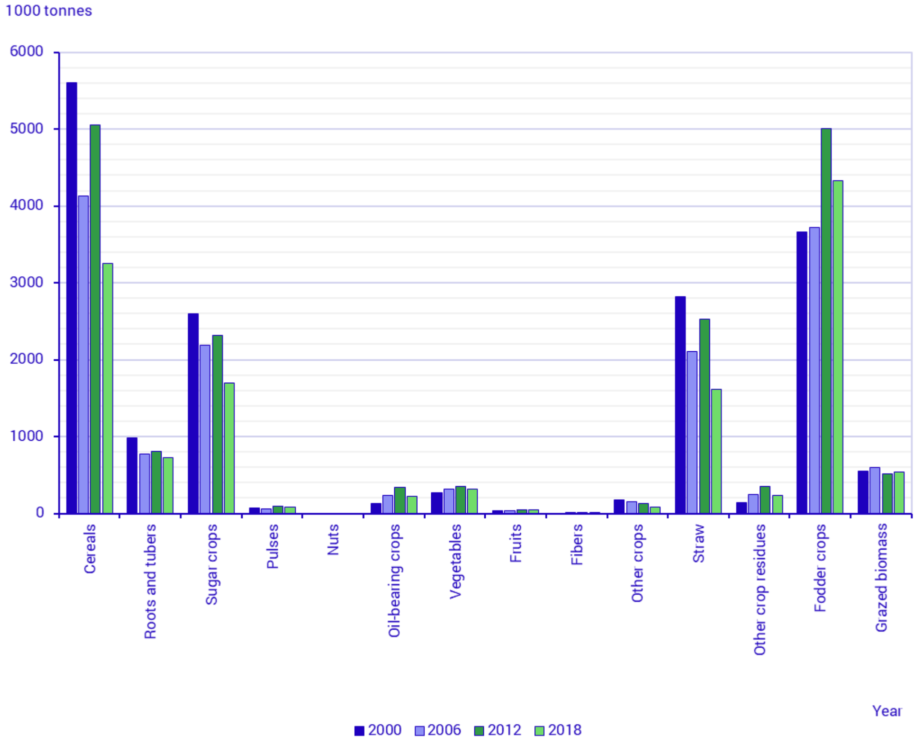

Figure 22: Crop provision 2000, 2006, 2012 and 2018, by applying material flow data. Source: INCA tool.

Additional data of crop provision was gathered from Swedish data already reported to Eurostat, to estimate the proportion of crop provision arising in permanent green houses, adding up to a total of 19539 Ktonnes for the year 2020. The extra calculation added only 227 Ktonnes of potatoes and vegetables (about 1 percent of the total) and does not seem to be worth assessing for the yearly reporting. For the international reporting, using the same data source as other EU countries could be beneficial for the comparison between EU countries and for summarising the EU contribution in a harmonised way.

Still, for communication purposes or in case there is a need to assess the situation nationally, it is good to have knowledge about the possibilities for regional breakdown of the data. The supply and use tables are not very helpful for communication purposes. Time series and maps are more appealing. In assessing the local needs for provision indicators, the focus may also become slightly broader.

A perspective that allows the connection to the other information in the environmental accounts modules is through ownership of land. Since the accounts have environmental and economic data by industry, the knowledge of what forest land is owned by forest industry, by large organisations like the Swedish church, by households and by the state, can give rise to new insights. The Swedish church is an important owner of forests and has recently made a report on how it could manage the forest in order to maintain ecosystem values, through using less intensive felling methods. Also, the Swedish Environmental Objectives contain indicators and goals for reaching a sustainable forest.

For national users, it may also be of interest to consider how the various uses of land for forestry and agriculture are linked to other ecosystem services that depend on the habitat conditions of ecosystems functioning for endangered species.

Analysis of the needs also open up for adding indicators for other provision services. The provision of fish from marine areas, and the provision of game from hunting are such possible additions. If we would show hunting and the fishing as part of ecosystem services in a national context, how would that be related to the boundaries of the national accounts? Sweden has around 300 000 active hunters, and 50 000 elks were shot 2023, decreasing the amount of elks to 200 000.

For marine ecosystems, the data from the two international Marine Conventions that cover Swedish Marine areas, the HELCOM and the OSPAR conventions, have been used in a planning instrument that is available in a map format on the web of the Swedish Agency for Marine and Water Management, and is shown in figure 23.

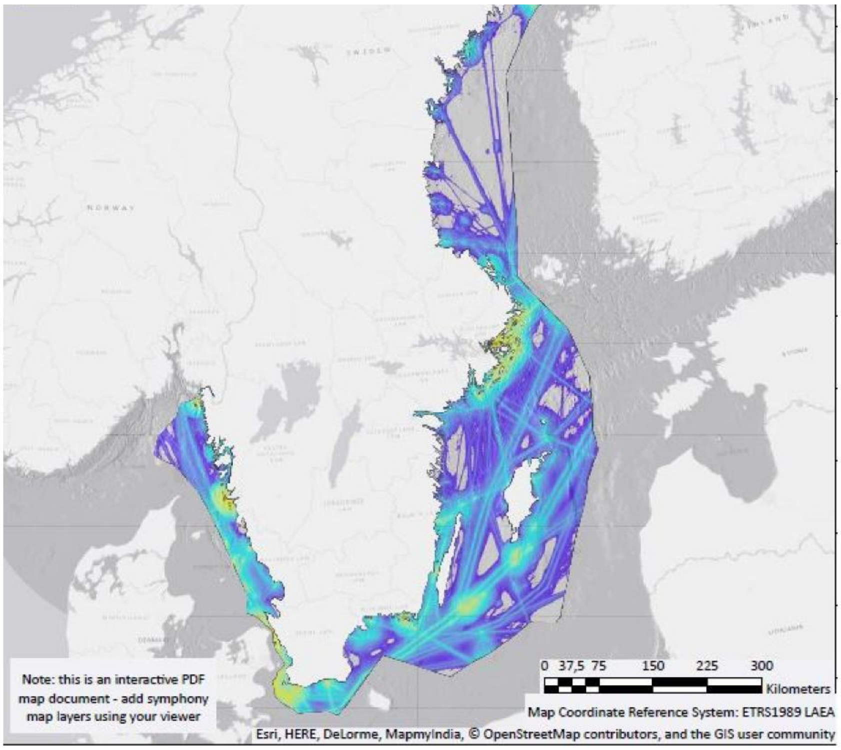

Figure 23: Symphony, a tool for marine spatial planning, using HELCOM and OSPAR data for the marine areas outside of Sweden. [12]

Norway is leading the way for marine ecosystem services, and have recently started a project to work on Lofoten area and distinguish two marine ecosystem services, fishing of wild fish and CO2 storage. As for the categories of marine areas they also mention that it could be of interest to define areas that are heavily impacted by humans (as the agriculture and urban areas are defined in the terrestrial accounts. GIS tools for marine spatial planning and management and a European marine spatial planning platform that looks at species, habitats and geophysical zonation. It also connects socio-economic pressures as shoreline exploitation, communication infrastructure, marine noise disturbance, effects of recreational fishing on sensitive species, erosion and other factors.

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[12] Symphony: a tool for ecosystem-based marine spatial planning | The European Maritime Spatial Planning Platform

5. Concluding discussion

The comparison of the average cooling indicator based on LAU and urban ecosystem areas showed that for many urban areas in Sweden significant differences in the calculated average cooling arise when changing the area definition for cities.

Going forward, it is recommended that in national reporting and communication with national users (for example the Swedish Environmental Protection Agency, the Swedish Board of Housing, Building and Planning, local authorities) that urban ecosystem areas are used exclusively. In reporting condition indicators required according to the Nature Restoration Regulation, the urban ecosystem areas will also be used. It is also strongly recommended that urban ecosystem areas are used for reporting local climate regulation to Eurostat in conjunction with the revised regulation on European Environmental accounts.

The analysis in this work also showed that the temperature datasets are a valuable source to be able to determine the time period for which the ecosystem service local climate regulation is relevant. The analysis showed that it is possible to apply for each identified urban area in Sweden. The data and analysis have produced tables that can be used for the voluntary reporting of the length of the cooling season for each city in Sweden.

Going forward it is recommended that the same method be applied for all urban areas in Sweden, and it can be applied for all years for which we have data (2015 through 2024). It is also possible to develop analysis to be able to report further voluntary indicators noted in the current guidance, namely the number of days that average maximum temperatures in a city exceed 30 and 35 degrees C respectively. These data also make it possible in the future to calculate the mandatory average cooling indicator for different time periods for different cities, given that other analysis in this work has shown that local climate regulation is relevant for different parts of the year in different parts of Sweden.

The INCA results for the air filtration ecosystem service show that forests and woodland is the ecosystem type where the majority of air filtration is performed, followed by cropland and inland wetlands. The results also show that the amount of air filtrated in Sweden is higher than the actual PM2.5 emissions. This is partially explained by the fact that pollution is spread to Sweden from other EU countries, and partly explained by that data of

PM2.5 emissions in Sweden exclude emissions caused by natural sources, and from international shipping and flights above 3000 feet. The analysis of the air filtration ecosystem service can be further developed by investigating the service at a more detailed level than the once presented in the INCA tool. The service focuses on air filtration at a national level, but air filtrated in cities would be particularly interesting to dive deeper into, since trees in cities that filter the air, also provide a number of other benefits for humans, animals and plants.

The reporting on provision of crop and wood is already based on Swedish statistics reported to Eurostat and does not need to be replaced with other national data. For the provision of crops Sweden plans to use the method that is based on material flow analysis data in the INCA tool. For the provision of wood, the improved forest accounts that will be reported to Eurostat in September 2025 will populate the INCA tool with an improved national data set. Other provision indicator themes may be added with time, provided there is demand for that. For the marine ecosystem services there is already a working model with data and connected to marine planning. The planning of green infrastructure is also ongoing, and these developments will need further analysis in the future when, and if, more data becomes available.

The next step for Statistics Sweden is to analyze and develop data for crop pollination. This is a very complex area, which is why the next grant funded project will focus on just that. Statistics Sweden are optimistic with the possibilities to develop the ecosystem services accounts even further after that project.

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