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WP3 Developing of the ecosystem accounts

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Final methodological report

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Contents

1 Summary and project achievements

Work Package 3 (WP3), Developing Ecosystem Accounts, represented a pivotal step in aligning Estonia's statistical system with the amended EU Regulation 691/2011 and the System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA). The primary objective was to operationalize the ecosystem accounts module by producing initial and feasible set of data for the reference year 2024 and refining methodological approaches to ensure conceptual coherence, technical robustness, and policy relevance. This work responded to the increasing demand for integrated ecological and economic information to support the European Green Deal, biodiversity strategies, and climate adaptation policies.

The scope of WP3 was multifaceted. It encompassed the compilation of ecosystem extent accounts using harmonized spatial datasets and administrative sources, the development of supply-use tables for selected ecosystem services, and the testing of ecosystem condition indicators proposed under the revised legislative framework. These tasks were complemented by efforts to advance automation through Python and R scripts, enabling reproducibility and efficiency in data processing. Furthermore, WP3 addressed the semantic challenges inherent in ecosystem service valuation, aiming to test interpretative frameworks that prevent miscommunication and enhanced the usability of results for policy and stakeholders.

The methodological approaches applied in all activities are built on prior Eurostat grants and leveraged international best practices. Results are discussed for example in Eurostat Task Force or the UN London Group on Environmental Accounting. By integrating ecological and economic dimensions, WP3 sought to establish a transparent and partner-inclusive system for ecosystem accounting that could serve as a bases for future regular work.

1.1 Summary of fulfilment of the action

WP3 deliverables were successfully completed, meeting both technical and conceptual objectives:

D3.1 Final Methodological Report: This report consolidated the theoretical underpinnings and practical workflows for ecosystem accounts, detailing the alignment with EU Regulation 691/2011and additional Eurostat guidance and following SEEA EA principles. It addressed methodological approaches Estonia has taken to compile ecosystem accounts. The report touched upon challenges such as data availability, compatibility and alignment with NRR and other global policy initiatives, aligning dataflows between different institutions, monetary valuation approaches, integration of ecological indicators, and semantic structuring of monetary values.

D3.2 Python/R Scripts: Automation tools were developed to streamline the compilation of extent accounts and validate spatial datasets. These scripts reduced manual intervention, enhanced transparency, and ensured repeatability of processes, marking a significant advancement toward routine production. The calculations for local climate regulation ecosystem service were scripted in Python and fully automatic, data preparation excluded, Shell script was made.

D3.3–D3.5 Datasets: Comprehensive datasets with metadata for ecosystem extent, condition, and services supply-use tables were produced for 2024. These outputs adhered to Eurostat guidance notes and latest available reporting templates. The presented data includes ecosystem extent and conversion matrix, condition indicators (green urban areas, PM2.5 concentration, soil organic carbon, bird indices, tree cover density, dead wood and share of artificial area in coastal areas): and ecosystem services (crop provision, timber provision, pollination, air filtration, global and local climate regulation, nature-based tourism related services).

D3.6 Presentation: The presentation will give an overview of the work done under WP3 and achieved results. It will be communicated at Eurostat workshop(s).

Estonia's experience in compiling ecosystem accounts has been presented across multiple national and international forums, including the final methodological seminar, the Eurostat Task Force on Ecosystem Accounts, the Baltic States coordination meeting, and an exchange meeting between Statistics Estonia, representatives of the People's Republic of China, and the World Bank. At the ESP conference and the UN London Group meeting Statistics Estonia presented and contributed to the work on semantic structuring of monetary values related to ecosystem services. These forums have provided valuable feedback and helped validate the relevance and robustness of the approach. Statistics Netherlands, has been a partner and consultant for methodological development and capacity building.

1.2 Key achievements and impact

WP3 delivered methodological clarity and operational efficiency. The integration of ecological and economic perspectives in a coherent accounting framework enhanced the visibility of ecosystem contributions to human well-being and economic activity. Automation reduced resource intensity and supported scalability, while semantic structuring ensured that monetary values were interpreted correctly, avoiding the pitfalls of oversimplification. These advances positioned Estonia as a methodological frontrunner in ecosystem accounting and contributed to the broader European effort to embed ecological resilience into economic planning.

In the long term, WP3 established a foundation for regular ecosystem accounting, enabling evidence-based input to perspective needs for policy design and monitoring of sustainability targets. The outputs were analysed from the perspective of their potential relevance for national planning, climate adaptation strategies, biodiversity conservation, and international reporting related to ecosystem accounts.

1.2.1 Achievements by workstreams

The development work under Work Package 3 was organized into five major workstreams, each addressing a specific dimension of ecosystem accounting. Together, these streams contributed to the establishment of a more comprehensive and harmonized framework for ecosystem accounts in Estonia, fully aligned with the requirements of EU Regulation (EU) No 691/2011. All planned tasks were completed as foreseen, and the outcomes represent a significant advancement in both methodological rigor and operational capacity.

1.2.2 Ecosystem extent accounts

The first workstream focused on refining the methodology and producing the ecosystem extent account for the reference year 2024. The extent map was successfully compiled using spatial datasets and administrative sources. Definitions and classification rules were updated to ensure consistency with and Eurostat guidance.

A key achievement was the continuation and enhancement of automation tools initiated under the previous Eurostat grant (EGD 2022). Selected stages of the compilation process were automated using Python scripts, reducing manual effort and improving reproducibility. Integration of workflows between Statistics Estonia and the Estonian Environment Agency was strengthened, enabling a unified and streamlined process. Data were published at EU ecosystem typology levels I and II, while III, national-level, detail was retained internally for analytical purposes. These developments established a robust routine for future updates and laid the foundation for sustainable data production.

1.2.3 Ecosystem services accounts

The second workstream advanced the compilation of ecosystem service accounts and the refinement of basic monetary valuation methodologies. Supply and use tables were produced for ecosystem services, including crop and timber provision, pollination, air filtration, global and local climate regulation, and nature-related tourism. It was foreseen that not all input data for 2024 became available in 2025, so the actions were taken accordingly. Methodological work involved testing valuation approaches and assessing their policy relevance, consistency, and efficiency. The calculations for local climate regulation ecosystem service were scripted in Python and fully automatic, data preparation excluded, Shell script was made. For other selected ecosystem services calculation steps (e.g. for categorizing agricultural data) were automated in Excel environment. The feasibility of automated workflows for physical accounts was additionally tested by using IncaTool for crop and timber provision, local climate regulation as an alternative to currently applied methods that mostly require step-by step manual calculations.

Consultations with national data holders improved data quality and integration, while coordination with the Eurostat Task Force ensured alignment with latest guidance. These efforts resulted in a more comprehensive and operational framework for ecosystem service accounting.

1.2.4 Ecosystem condition accounts

The third workstream focused on ecosystem condition indicators, as specified in the EU Regulation 691/2011 and Eurostat Guidance Notes. Statistics Estonia compiled condition account for 2024 where data was available. and used placeholders (results for year 2022, where the same methodology was used) where necessary to maintain continuity. Indicators included green urban areas, PM2.5 concentrations, soil organic carbon, farmland and forest bird indices, dead wood, tree cover density, and share of artificial area in coastal zones. As several condition indicators are similar to indicators proposed in NRR, these linkages were examined and nationally aligned as much as possible.

The suitability of the proposed indicators was tested, and gaps for future integration were identified. This work provides a foundation for the regular production of ecosystem condition accounts.

1.2.5 Partner-inclusive system

The fourth workstream achieved the development of an integrated, partner-inclusive system for ecosystem accounts. Collaboration between Statistics Estonia and the Estonian Environment Agency resulted in clear definitions, harmonized workflows where applicable, and improved interoperability of datasets. This integration ensured that ecosystem extent, services and condition data can be shared and reused across statistical and spatial planning domains, supporting both national policy and EU reporting obligations.

1.2.6 Methodological development and communication

The fifth workstream extended beyond technical development to include conceptual clarification and communication strategies. Ecosystem accounts data were made accessible via Statistics Estonia's webpage, ensuring transparency and usability for a wide range of audiences. It also covered the publication of results through an online map interface.

Estonia's experience in compiling ecosystem accounts has been presented across multiple national and international forums, including the final methodological seminar, the Eurostat Task Force on Ecosystem Accounts, the Baltic States coordination meeting, and an exchange meeting between Statistics Estonia, representatives of the People's Republic of China, and the World Bank. At the ESP conference and the UN London Group meeting Statistics Estonia presented and contributed to the work on semantic structuring of monetary values related to ecosystem services. These forums have provided valuable feedback and helped validate the relevance and robustness of the approach.

International collaboration was strengthened through Statistics Estonia's participation in Eurostat Task Force on ecosystem accounting. Statistics Estonia contributed by providing feedback on guidance notes, participating in Task Force meetings, and engaging in additional discussions with JRC and Eurostat on the local climate regulation ecosystem service to address issues that emerged during the practical application of the guidance note. Statistics Estonia participated in another discussion involving Eurostat, JRC and other Member States that have assessed this service, with the shared aim of improving the guidance note. Statistics Estonia had previously incorporated marine areas into the ecosystem extent account under earlier grant work. This experience was shared with Eurostat, including a written crosswalk from HELCOM Underwater Biotopes (HELCOM HUB) present in Estonia to the EU ecosystem typology at level 3 for marine ecosystems.

In addition, experience gained on the compilation ecosystem accounting was exchanged at the high-level 'Closing data gaps on climate change' conference of the European Statistical Forum (ESF), at the exchange meeting between Statistics Estonia, representatives of the People's Republic of China, and the World Bank and also on a Baltic States coordination meeting. Estonia presented the results of the empirical study on the semantic approach as a case study for improving transparency in valuation first as work in progress at the 11th ESP World Conference and final version at UN London Group. Capacity building was supported by a study visit to Statistics Netherlands, which provided among other issues insights into semantic treatment of valuation methods. Statistics Estonia analysed the layered nature of ecosystem service values and distinguished between actual market transactions, hypothetical replacement costs, and risk-based estimates of loss. The approach followed principles discussed in the UN London Group 2024 and emphasized plural values and the continuum from ecological functions to societal benefits. Key advancements were based on the collaboration with researchers. Communication was enhanced through explanatory material, thematic article, and visual material designed to illustrate the multi-layered nature of ecosystem values based on Estonian and Dutch respective data.

These efforts intended on the design of the ecosystem accounting which is not only technically robust but also conceptually sound and publicly accessible. The was supposed to support informed decision-making and to reduce the risk of oversimplification.

1.3 Deliverables and milestones

All WP3 deliverables (D3.1–D3.6) were completed and submitted, including the final methodological report, Python/R scripts for automation, datasets for ecosystem extent, services, and condition accounts, and presentations for dissemination. All WP3 deliverables (D3.1–D3.6) are uploaded to the Funding & Tenders Portal together with this report. Evidence includes datasets, scripts, and presentations as required.

Milestones such as the kick-off and final seminars were held, with minutes and attendance documented. Minutes of the kick-off seminar and final methodological seminar are attached as Annexes 1 and 3.

1.4 Impact and sustainability

WP3 improved transparency and reproducibility through automation and open publication, strengthened harmonization with EU standards, and advanced semantic clarity for monetary values. Estonia's empirical study approach was presented at UN London Group meeting, supporting EU-level methodological development..

Sustainability measures include annual update cycles, maintenance of scripts and metadata, and continued collaboration with national partners. WP3 established a foundation for routine ecosystem accounting starting in 2026. Annual update cycle is defined for extent, condition, and services accounts. Partner-inclusive system is in the establishment phase with the Estonian Environment Agency for data exchange and joint governance.

1.5 Risk management

Identified risks—such as data gaps and inter-institutional coordination — were mitigated through placeholders, staged updates, and formalized workflows. Staffing risks were addressed through documentation and task scheduling.

Initial risks were addressed as follows:

Data gaps (e.g., PM2.5, ETS inputs): mitigated by placeholders and staged updates; aligned future cycles with data owners.

Institutional coordination: resolved through joint workflows and comparison studies with the Environment Agency; governance steps toward 2026 data exchange agreement.

Staffing dependency: reduced via automation scripts and documentation; cross-training supported by study visit and seminars.

Methodological uncertainty (local climate regulation): mitigated by prototyping per Eurostat guidance and documenting limitations for 2026 refinement.

Residual risks remained moderate and were managed through early data requests and continued partner engagement.

1.6 Summary

The achievements across these five workstreams collectively enhanced Estonia's capacity to produce ecosystem accounts that are methodologically sound, interoperable, and partially automated. The integration of ecological and economic data, combined with improved workflows and international collaboration might position Estonia as one of the frontrunners in ecosystem accounting within the European Statistical System. These outcomes provide a solid foundation for routine production and continuous improvement, supporting evidence-based environmental policy and contributing to the implementation of the European Green Deal.

2 Compilation of ecosystem extent account and application of EU ecosystem typology

2.1 Overview[1]

Ecosystem extent accounts are fundamental to ecosystem accounting, serving as the foundation for compiling both ecosystem services and ecosystem condition accounts. Ecosystem extent account was compiled for the year 2024. Compilation of ecosystem extent account was based both on experience and knowledge obtained from previous projects but also closely followed Eurostat guidance note on ecosystem extent accounts (version December 2024). Compilation of ecosystem extent account was further improved compared to previous year, mainly in sense of automatization of some new parts of the process and by applying EU ecosystem typology (level 1 and 2) to classify ecosystem assets consistently.

2.2 Compilation of extent account

Our methods for ecosystem extent account (extent map) compilation follows the proposed principal steps in iterative classification process as suggested by guidance note for ecosystem extent accounts. By defining priority orderings, it ensures that area once classified as such cannot become a something else later in the classification process, which ensures that classification will be mutually exclusive and exhaustive.

For ecosystem extent map, we used same approach as in previous project where the Estonian topographic database served as a basis for the creation ecosystem extent map. For the first step as part of compilation of ecosystem extent account, we first determined continuous and discontinuous settlement areas (EU typology level 2 classes) based on guidance note on ecosystem extent accounts. The continuous settlement area type is assigned when settlement structures and transport networks are dominating the surface area. At least 80% of the land surface in the ecosystem asset is covered by impermeable features such as buildings, roads and artificially surfaced areas. The discontinuous settlement area type is assigned when settlement structures and transport networks associated with vegetated areas and bare surfaces are present and occupy significant surfaces in a discontinuous spatial pattern. The impermeable features such as buildings, roads and artificially surfaced areas range from 30 to 80 % land coverage in the ecosystem asset. Therefore, whole Estonia was divided into 1 ha grid cells, and we determined the share/cover of impermeable features in every grid cell. As a part of the impermeable features, we regarded: residential or community buildings, buildings under construction, greenhouses, production buildings, other buildings, ruins, production yards, bus stations, pedestrian areas, the runways, traffic areas, parking lots, sport facilities, other roads, light traffic roads, side roads, other national roads, main roads, ramps and connecting roads, the streets and support roads. Data was obtained from the Estonian topographic database. Grid cells that met for the aforementioned criteria were assigned either as continuous or discontinuous settlement areas based on percentage of impermeable features cover and were not analysed any further.

For the rest of Estonia, we updated basis with additional data layers where more detailed data about ecosystem assets was available (actual ecosystem type). In areas where more detailed information was not available, the Estonian topographic database was only source of information which we could use. Concerning the more detailed data layers, these are both gathered/collected for different purposes and times, which creates inconsistencies in ecosystem boundaries (e.g., overlapping) but also making some records outdated. Therefore, it was questionable what the actual state of these older records is. Therefore, also in current grant we used a decision tree in order decide prioritization of the different data layers when overlaps did occur between two or more detailed data layers. As suggested in guidance note of ecosystem extent account, we preferred and therefore gave more weight to data layers which were most up to date (data from year 2024) and likely more precisely mapped due to local actual inventories. Different data sources reflect their status based on access date (ANNEX 5). Concerning the terrestrial land (including inland water bodies), main different detailed data layers were overlaid as follows (starting with highest priority):

[1] Some of text of this chapter copies the methodological descriptions given already in the following grant: Grant Agreement no NUMBER — 101022852 — 2020-EE-ENVACC, Development of environmental accounts; Activity "Developing and refining ecosystem accounts", D1.8 Description of the methodology for advancing ecosystem accounts" Authors of the text are the same. The reasons to copy also the basic descriptions are:
- These methodological descriptions were well-developed during the previous grant work,,
- Full methodological description is needed to provide the reader with comprehensive approach in single stand-alone document instead of references to other documents

1. Agricultural land and semi-natural habitats (support bases)

Data for agricultural land and semi-natural habitats (which are under support bases) was obtained from Estonian Agricultural Registers and Information Board. As this was generally most up to date dataset, we were able to use this dataset, and this got the highest priority. In this dataset only the lands which are under support bases are mapped, therefore it is quite certain that this data is both precisely mapped and to some extent verified. Nevertheless, some overlaps between agricultural land and semi-natural habitats still occurred (as owner of the land can receive support from multiple sources and purposes for the same land), in these cases we treated these overlapped areas as semi-natural habitats to avoid double counting.

2. Forest registry of Estonia

This was the largest and most detailed dataset that we were able to use. Data we used is within ten years' time frame. This dataset covers most of the forested areas in Estonia (around 80% are mapped). Nevertheless, there were some overlaps within the dataset which we dealt before merging it to other datasets. In case of overlaps we randomly merged overlapped areas to neighboring polygons within the dataset. For the remaining ca. 20% of forest, based on the soil type, the forest site type was determined or modeled using the national classification (Lõhmus, E. 1984). There are over 30 different forest site types and 71 forest soil types according to the national classification. In case when soil type corresponds to more than one forest site type the latter has been predicted based on the probability of its occurrence. This probability has been found by the model (based on the National Forest Inventory, sample size around 23 thousand plots from years 2005 to 2014). Thus, even if the type predicted for a particular area may not be always accurate, the result for a larger area (whole country) is mostly correct.

3. Wetlands

Data for wetlands was mainly obtained from Estonian Fund for Nature (ELF). This dataset uses Natura 2000 habitat types as classification units and often multiple classes were given for the same area (e.g. transition areas). In order to simplify the original classification, it was therefore decided to use information about the main class/type only. In case of overlaps which were also present, we randomly merged overlapped areas to neighboring polygons within the dataset.

4. Semi-natural habitats

This dataset consists of spatial information about Estonia's semi-natural habitats which are eligible to support, and it was obtained from Estonian Environment Agency. Similarly, to previous datasets, most of the data is within ten years' time frame and uses Natura 2000 habitat types as classification units. The reason we decided to use this dataset as a fourth layer was because of, although these are the areas which are designated as eligible to support, these do not actually receive support, meaning these areas are likely not being maintained. It is therefore questionable, what is the actual state of these older records. Therefore, we decided that if the area was registered in aforementioned datasets (agricultural land, forest or wetland) then the former information was used. In case of overlaps we randomly merged overlapped areas to neighboring polygons within the dataset.

5. Natura 2000 habitats

This dataset consists spatial information about Natura 2000 habitats in Estonia (around 10% of area is covered by Natura 2000 habitats in Estonia) and it was obtained from Estonian Environment Agency. Unfortunately, most of the data is older than ten years, although this dataset does receive constant updates and corrections yearly. Due to presence of these older records, we gave this dataset a lower priority in our decision tree. In case of overlaps we randomly merged overlapped areas to neighboring polygons within the dataset.

6. Meadows

This dataset consists spatial information mainly about Estonia meadows and was obtained from the Estonian Semi-natural Community Conservation Association. This dataset was the oldest we used as all the records are older than ten years. Hence, this dataset consists of inaccuracies and is probably outdated. Due to these reasons, we gave this dataset the lowest priority in our decision tree. In case of overlaps we randomly merged overlapped areas to neighboring polygons within the dataset.

For marine areas we used spatial data from HELCOM Underwater Biotopes (HELCOM HUB). This habitat classification is a system jointly developed by Baltic Sea countries, enabling the classification of all marine area habitats in both the water column and seabed. The HUB is a hierarchical classification system that covers the entire marine area. This classification system has six different levels, but all marine areas can be classified up to at least level 5 (based on communities). Underwater biotopes in Estonia were linked to EU ecosystem typology at level 3 of marine ecosystems.

To increase spatial accuracy of the ecosystem extent map it was decided that some classes: the roads, inland waters, peatlands, quarries, and private yards needed to separately overlay with combined dataset. In case of roads two different types of data was available: 1) polygon type of data (consisting of main roads in Estonia and 2) polyline type of data (consisting of smaller roads and trails). In case of polyline data, a 5-meter buffer was created around polylines to convert polyline to polygon type of data to match with other data sources. Additionally, we also delimited more linear features (artificial areas) which we converted to polygons: forest rides (2-meter buffers were created), ditches (average width per width class was used as buffers), power lines (rated power classes were used as buffers) and railroads. Forest rides and powerlines were distinguished only in forests based on the assumption that these areas in forests are treeless hence influencing ecosystem service flows in forests.

Following guidance note of ecosystem extent account it was chosen 0.1 ha as minimum mapping unit (MMU). Therefore, assets smaller than 0.1 ha were merged with neighboring assets/polygons and not separated as individual ecosystem asset in extent map. Nevertheless, merging different data layers into one layer creates additional artifacts (sliver polygons, which are often also smaller than MMU) due to fact that different ecosystem assets borders do not coincide with each other perfectly. We separately dealt ecosystem assets which were relatively "narrow" and at the same time relatively long causing sometime remarkable polygon area (sliver polygons). Using polygon buffering tool, we decided to test most of the ecosystem assets based on formula: log (asset area+1) +5 as buffer size to capture change in area relative to ecosystem asset original area. If the change was more than 5% of the original ecosystem asset area the buffered boundaries were kept otherwise original boundaries were used. Captured narrow polygons were then subdivided into 20x20 meters grids and randomly merged to neighboring polygons within the dataset. For the last step we excluded some assets which by its nature do meet aforementioned criteria in some extent but should not be in principle merged with neighboring polygons. These were roads, inland waters, peatlands, quarries, private yards, forest rides, ditches, power lines and railroads. For terrestrial land (including inland water bodies), after merging and simplification of different data layers and overlying with Estonian topographic database, we were able to get more detailed information around 80% of ecosystem accounting area. For the remaining 20% of the area, Estonian Topographic Database was the only source of information we could use.

For the year 2024, final ecosystem extent map consisted of ca. 3.2 million polygons covering 130 different mapping units (ca. 200 with marine areas included) which were then aggregated into EU ecosystem typology level 2 and level 1 classes. Altogether, area of 70 453.6 km2 (terrestrial and marine areas combined - whole ecosystem accounting area) was mapped (Figure 1). Marine ecosystems covered most of the ecosystem accounting area (35.7%) followed by Forest and woodlands (33.89%), Cropland (11.73%) and Grassland (6.46%). All other ecosystem types covered less than 5% each from total ecosystem accounting area (Table 5).

Figure 1. Estonian ecosystem extent map for year 2024 (Eu ecosystem typology level 1 classes).

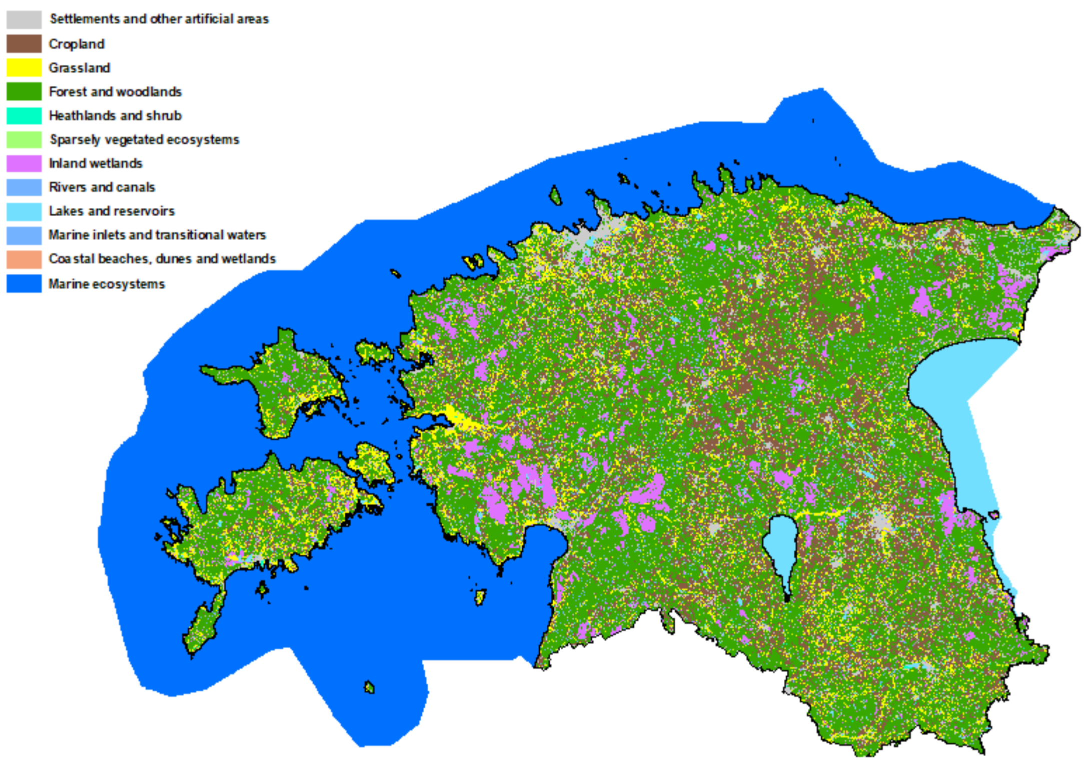


Table 1. Ecosystem type areas and shares based on EU ecosystem typology, level 1

Category	Name of ecosystem type	Total area (ha)	Share (%)
1.	Settlements and other artificial areas	299 550	4.25
2.	Cropland	826 081	11.73
3.	Grassland (pastures, semi-natural and natural grasslands)	455 266	6.46
4.	Forest and woodland	2 387 738	33.89
5.	Heathland and shrub	13 497	0.19
6.	Sparsely vegetated ecosystems	3 273	0.05
7.	Inland wetlands	274 625	3.9
8.	Rivers and canals	51 781	0.73
9.	Lakes and reservoirs	215 110	3.05
10.	Marine inlets and transitional waters	622	0.01
11.	Coastal beaches, dunes and wetlands	2 855	0.04
12.	Marine ecosystems (coastal waters, shelf and open ocean)	2 514 959	35.70
TOTAL		7 045 357	100

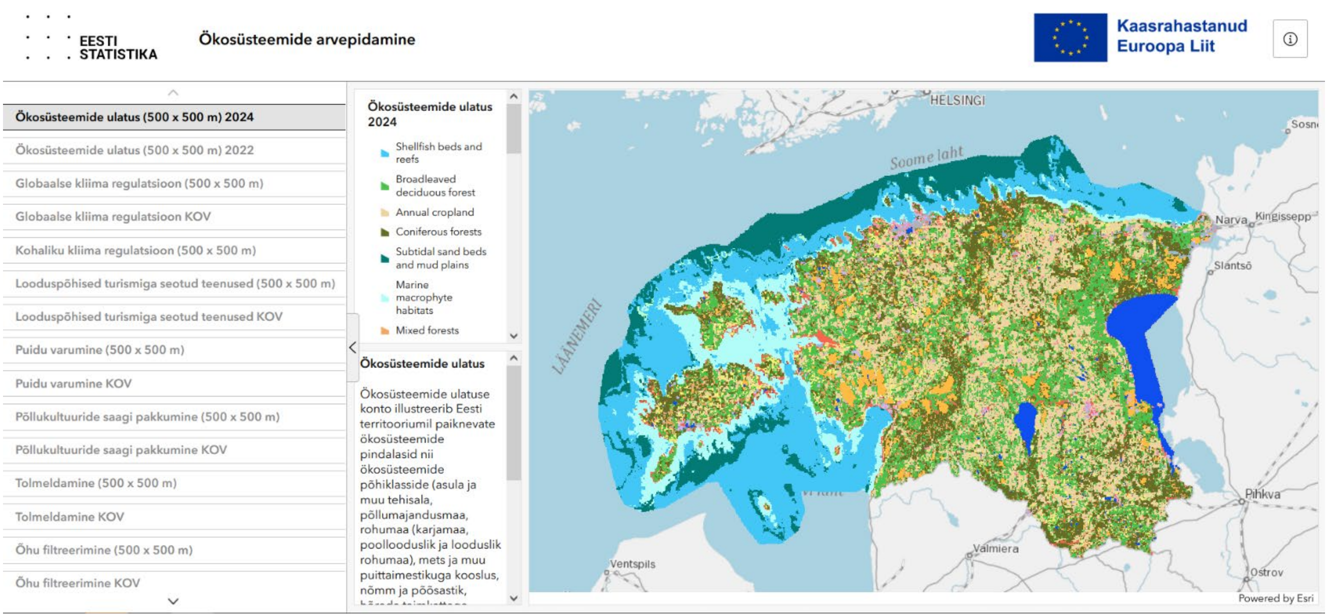
2.3 Communication of the results

The report with the results are made available on Statistics Estonia web platform.

Ecosystem extent maps are presented also in web interface. The data is visualized in the application of ArcGIS Experience which was developed in current and previous projects. The development and maintenance of the web application has been co-funded by the European Union.

Illustrative interactive maps were updated for year 2024 regarding ecosystem extent and data on extent by EU ecosystem typology level 2 types were added to previously published results on EU ecosystem typology level 1 data. The ecosystem extent is visualized by a 500x500m square grid covering the whole of Estonia.

Figure 2. Web interface (ArcGIS Experience) for ecosystem accounts in Estonia. Currently displayed is ecosystem extent on EU ecosystem typology level 1. The dashboard includes (from the left): list of map layers in ecosystem accounts, map legend and description of the displayed map layer, visualized map is the selected map layer.



The application includes also illustrative interactive maps for ecosystem services, which is discussed in more detail in chapter 4.8. Each of the ecosystem services, with the exception of one, is visualized both with local municipalities and 500x500m square grids spanning the whole country. The only exception is Local Climate Regulation ecosystem service, which is limited to the three biggest cities in Estonia – Tallinn, Tartu, and Narva. These cities are covered only with 500x500m square grids up to their administrative (LAU) limits.

As the interface is aimed mainly for experts of national audience, the user language is Estonian. An introductory prompt introduces the user to the application and explains the data and use cases behind the application. It also guides the user in using the application.

For each visual layer, a legend is shown, explaining the contents of the map. Texts further explaining the content of each service are also available. The whole application is in line with Statistics Estonia's Corporate Visual Identity (CVI) and adheres to the internal user experience guidelines. Analyses of the differences between the ecosystem maps developed in Estonia

Similarly to last year, analysis between the ecosystem extent map by Statistics Estonia and the ecosystem extent map by Estonian Environment Agency was done during the project. Both maps were analyzed in spatial resolution of 5 x 5 meters. Additionally, while ecosystem extent map by Statistics Estonia was based on year 2024 data (as data was available) then ecosystem extent map by Estonian Environment Agency was partially updated to year 2024 (mainly coastal areas and grasslands ecosystem types) as most of the data reflected still year 2022. The primary aim was to identify the main differences between two maps and potentially understand the underlying causes for these.

Comparisons were made on two different levels: 1) comparison in most detailed map level and 2) comparison on using EU ecosystem typology level 1. As this work is still ongoing, ~85% of total Estonia area was covered by these analyses at the moment concerning comparison in most detailed map level. Comparison on using EU ecosystem typology level 1 was done covering whole Estonia (excluding the marine areas).

In most detailed map level, it was found that 81.8% of the total area, both maps were similar and 3.3% of the area there were differences in sense of ecosystem type. 15% of Estonia area still needs to be analyzed although it could be expected that orders of magnitude will be similar to what was found.

On EU ecosystem typology level 1, the biggest differences (in sense of area) were between Settlements and artificial area, Forest and Woodland area and inlands wetlands classes. For settlements and artificial area class, causes for differences are due to use of different methodology too determine these areas (continuous, discontinuous areas, infrastructure, urban green, other artificial areas). Area differences in forest and woodland class are multifaceted as in one hand it reflects the incompleteness of national datasets (Forest registry, topographic database) and in other hand the use of different definition of forest (what classifies as forest) between two maps and use of LIDAR data in compiling Environmental Agency ecosystem extent map. Causes of differences in inland wetlands class areas is currently in works, but likely the differences are not that big as initially found.

2.3.1 Feedback from Estonian Environment Agency to the Comparison of the extent maps of Estonian Environment Agency and Statistics Estonia 2024

Current chapter provides the Feedback from Estonian Environment Agency to the Comparison of the extent maps of Estonian Environment Agency and Statistics Estonia 2024, which was presented by Argo Ronk from Statistics Estonia On 3 December 2025.

Environment Agency (Estonian Environment Agency):

1) Both maps use 2024 as the reference year, with the note that the Estonian Environment Agency map was only partially updated from its 2022 version.
2) As this was the second year in which such a comparison was carried out, no major surprises were identified. The sources of the largest discrepancies between the two maps have been already identified earlier and remain unchanged.
3) For example, most differences arise from the varying methodological approaches to identifying settlement areas, the Estonian Environment Agency's use of a vegetation height model, and the Estonian Environment Agency's use of the soil map to distinguish between grassland and wetland types. The comparison is also significantly influenced by the Estonian Environment Agency's non-differentiation of several waterbody categories (marine ecosystems, rivers and canals, lakes and reservoirs), which are all separated in the Statistics Estonia map.
4) It is known that not all Estonian Environment Agency's ecosystem base-map classes can be directly assigned to Eurostat L2 categories. For example, the concept of urban areas differs between the two maps: Eurostat's definition of urban areas includes green spaces and distinguishes between "continuous settlement area" and "discontinuous settlement area", whereas

Estonian Environment Agency's map treats urban areas as built-up land, with intra-urban green areas classified separately as forests, grasslands, or other categories.

5) In addition, the forest classes in the Estonian Environment Agency's base map are not subdivided according to Eurostat L2 classes. The categories are incompatible because Estonian Environment Agency's forest types are based on Estonia's forest site-type classification (e.g. palumets, laanemets, salumets). Eurostat L2, however, classifies forests according to tree-species composition (e.g. coniferous forests, broad-leaved forests, mixed forests). Unfortunately, it is not possible to directly infer whether a given forest site type corresponds to a coniferous, broad-leaved, or mixed forest. For example, of Estonia's most widespread forest type, palumets, which typically occurs as pine forest, an estimated 20% of its area is actually broad-leaved forest (birch or aspen). Laanemets may be either coniferous or mixed forest, while salumets may be broad-leaved, mixed, or even coniferous forest.
6) There are even more mismatches in the smaller classes (for example, Estonian Environment Agency's "small islands" class—Natura 2000 habitat type 1620—may, depending on the specific location, correspond to Eurostat L2 categories such as "Rocky shores" or "Coastal dunes, beaches and sandy shores", but also to certain forest classes if the small island is forested). However, all such nuances need not be listed here. Due to their large extent, urban areas and forests remain the most significant points of divergence.

The Estonian Environment Agency concluded that while the Statistics Estonia extent map aligns with Eurostat's reporting guidelines, the Estonian Environment Agency's extent map is better suited for describing the ecological characteristics of Estonia's land cover.

2.4 Application of EU ecosystem typology

In 2024, the ecosystem extent account for Estonia reached general methodological completeness, including the application of the EU ecosystem typology. Consequently, no new tasks were planned for 2025 in relation to ecosystem typologies. However, Estonia continued to contribute to methodological development at the European level. As a member of the EU Task Force, Estonia participated in discussions during the second half of 2025 concerning heterogeneous ecosystems and refinements to marine ecosystem classes. Estonia compiles ecosystem extent using detailed national spatial data due to which intermixing of different ecosystems within a single ecosystem class does not occur. The only exception is continuous or discontinuous settlement areas, which, according to the EU typology, represent heterogeneous ecosystems created by aggregating clearly defined assets. The discussion on marine ecosystem classes remains ongoing, and the proposed refinements were not incorporated into the national extent account during the reporting period.

In preparation for national reporting, separate work was undertaken to translate the EU ecosystem typology as presented in the Technical Note on EU ecosystem typology by Eurostat (version: December 2024) into Estonian. This process was carried out in collaboration with the Estonian Environment Agency, the Ministry of Climate, and the University of Tartu Marine Institute. The translation of Level 1 ecosystem types was completed in 2024 as part of the official translation of Regulation (EU) No 691/2011, while the translation of Level 2 ecosystem types for national use was finalized in 2025. The initial translation relied on existing Estonian versions of EUNIS and Corine classifications, depending on the origin of each class. For marine ecosystem classes, terminology was reviewed and discussed with the University of Tartu Marine Institute to ensure scientific accuracy. Estonian Environment Agency provided suggestions on the existing use cases of applied terminology, ensuring that the translated terms were consistent with existing practices. The final version of the translation was revised by the Estonian Environment Agency and the Ministry of Climate. The translation of the typology is presented in ANNEX 7.

3 Compilation of ecosystem condition account

3.1 Overview

Compilation of ecosystem condition account for 2024 was based on previous experience. Under grant "Development of the environmental accounts" (101022852-2020-EE-ENVACC), feasibility of compiling ecosystem condition account was first tested where the average value per country area of proposed indicators in EU 691/2011 was calculated (green areas in cities, PM2.5 concentration in cities, soil organic carbon stock in topsoil in grasslands and croplands, farmland bird index, dead wood in forests, forest tree cover density, share of artificial impervious area cover in coastal areas).

Under grant "Development of the forestry, environmental subsidies and ecosystem accounts "(101113157-2022-EE-EDG), the work followed the guidelines set out in Eurostat guidance note on Ecosystem condition accounts (Fifth draft, November 2023)[2]. The average value per country area of proposed ecosystem indicators in EU 691/2011 were calculated and account for year 202 was compiled (green areas in cities, PM2.5 concentration in cities, soil organic carbon stock in topsoil in grasslands and croplands, farmland bird index, dead wood in forests, forest bird index, share of artificial impervious area cover in coastal areas). Methodologies for calculating indices such as butterfly index, forest connectivity and share of wetlands affected by drainage were developed.

In 2025 the main tasks regarding ecosystem condition account were to compile the account for year 2024 and proceed with methodological developments of those indicators where changes in methodology were introduced according to guidance notes by Eurostat. The work followed the latest available guidance notes for Ecosystem condition accounts (7th draft in June 2025[3] and 8th draft in October 2025[4]). These drafts introduced changes aimed at incorporating definitions from the Nature Restoration Regulation (NRR) to ensure the best possible alignment between NRR requirements and ecosystem accounting reporting. By adhering to these updated guidelines, the work sought to complement national efforts and maintain consistency with relevant regulations. However, as the monitoring and reporting system for NRR is still in development in Estonia, the focus was on mandatory condition indicators.

In 2025 the ecosystem condition indicators calculated in the ecosystem condition account for 2024 were: green areas in cities, soil organic carbon stock in topsoil in grasslands and croplands, farmland bird index, dead wood in forests, forest bird index, share of artificial impervious area cover in coastal areas. The input data for calculating PM2.5 concentration in cities will become available in 2026, therefore no calculations were done for the indicator. Green areas in cities, carbon stock and share of artificial impervious area cover in coastal areas were calculated in Statistics Estonia. The remaining indicators were obtained from existing databases from Estonian Environment Agency. Eurostat questionnaire and related metadata were filled in. The results are presented in

Table 2 and given in Annex "D3.5 Dataset on condition account" (MS EXCEL file) accompanied with metainfo.

Discussions with Estonian Environment and Ministry of Climate were held for updates on the development of the reporting and monitoring framework for NRR. Several indicators of NRR overlap or share similarities with ecosystem condition account, such as soil organic carbon, common bird indices, deadwood, and urban green space. However, the decision on the methodology and indicators for reporting under NRR has not yet been made in Estonia. The topic is discussed in ANNEX 3.

The approach and results were consulted with Statistics Netherlands during the study visit (ANNEX 2), in written form and during the final seminar (ANNEX 3). Notable issues covered included available input data and alignment with other global reporting systems.

Data availability and analysis for regular production of the mandatory condition indicators were conducted as part of the work. Input data and transmission is described in chapter 7 and ANNEX 4.

[2] Eurostat – Unit E2. Doc. ENV/EA/TF/2023_3/4. Ecosystem condition accounts – guidance note. Fifth draft. (November 2023) https://circabc.europa.eu/ui/group/922b4700-1c83-4099-b550-763badab3ec0/library/73788ea5-35fb-4e3e-be1c-c154b46dc285/details
[3] Eurostat – Unit E2. Doc. ENV/EA/TF/2025_2/4. Ecosystem condition accounts – guidance note. 7th draft https://circabc.europa.eu/ui/group/922b4700-1c83-4099-b550-763badab3ec0/library/18343118-dc61-46a1-868d-e78d0934fb06/details
[4] Eurostat – Unit E2. Doc. ENV/EA/TF/2025_3/3. Ecosystem condition accounts – guidance note. 8th draft https://circabc.europa.eu/ui/group/922b4700-1c83-4099-b550-763badab3ec0/library/cb9db3d6-a9f8-4394-9aa2-b9de4ac9a0e7/details

3.2 Compilation of ecosystem condition account

Ecosystem condition indicators for mandatory reporting in Regulation EU 691/2011 are:

1. For settlements and other artificial areas:
   a. green areas in cities and adjacent towns and suburbs should be reported in % of total area, calculated for the entire area of the cities and adjacent towns and suburbs, including all ecosystem types in that area.
   b. concentration of particulate matter, with a diameter up to 2.5 μm in cities, should be reported in μg/m^3 as a national average for the reporting period.
2. For cropland:
   c. soil organic carbon stock in topsoil should be reported in tonne/ha, as a national average for the reporting period.
3. For grassland:
   d. soil organic carbon stock in topsoil should be reported in tonne/ha, as a national average for the reporting period.
4. For cropland and grassland together:
   e. common farmland bird index should be reported as a national aggregate index for the reporting period.
5. For forest and woodland:
   f. dead wood should be reported in m^3/ha, as a national average for the reporting period;
   g. tree cover density should be reported in %, as a national average for the reporting period.
   h. common forest bird index; the forest bird indicator index describes trends in the abundance of common forest birds across their European ranges over time; it is a composite index created from observational data of bird species characteristic for forest habitats in Europe; the index is based on a specific list of species in each Member State.
6. For coastal beaches, dunes and wetlands:
   i. the share of artificial impervious area cover, present in coastal area that includes ecosystem type coastal beaches, dunes and wetlands should be reported in % as a national average for the reporting period.

The condition account was compiled for the year 2024 where possible.

Table 2 gives an overview of ecosystem condition indicators and their values which represent the national average. Table 3 shows how the results are presented in the Eurostat questionnaire.

Table 2. Mandatory ecosystem condition indicators in ecosystem condition account. Values represent the national average. Reference year shows the year indicator was calculated for.

Ecosystem	Indicator	Reference year	Unit	Value
Settlements and other artificial areas	Green areas in city LAUs and adjacent towns and suburbs (mandatory) of which: Green areas in ecosystem type 1 ‘Settlements and other artificial areas’ (voluntary)	2024	%	75.1 22.9
Settlements and other artificial areas	Concentration of Particulate Matter (PM) with a diameter up to 2.5 µm	2022*	µg/m^3	6.63
Cropland	Soil organic carbon stock in topsoil	2024	tonne/ha	670.0
Grassland	Soil organic carbon stock in topsoil	2024	tonne/ha	857.0
Cropland & Grassland	Common farmland birds index	2024	index	67.82
Forest and woodland	Deadwood Standing (voluntary) Lying (voluntary)	2024	m^3/ha	15.8 6.3 9.0
Forest and woodland	Tree cover density	2024	%	67.45
Forest and woodland	Common forest bird index	2024	index	76.76
Coastal beaches, dunes and wetlands	Share of artificial impervious area cover	2024	%	6.7

*Results were calculated in project 101113157 — 2022-EE-EGD.

Table 3. Ecosystem condition account questionnaire

Table 1 - Ecosystem condition indicators

Country: EE

Reference year: 2024

Condition indicator	Unit	TOTAL: Total (respective accounting area for the measurement of the indicator)	1: Settlements and other artificial areas	2: Cropland	3: Grassland	2+3: Farmland (Crop + Grassland)	4: Forest and woodland	5: Heathlands and shrub	6: Sparsely vegetated ecosystems	7: Inland wetlands	8: Rivers and canals	9: Lakes and reservoirs	10: Marine inlets and transition al waters	11: Coastal beaches, dunes and wetlands
Green areas in city LAUs and adjacent towns and suburbs	%	75.1												
Green areas in ecosystem type 1 'Settlements and other artificial areas'	%		22.9											
Green areas in urban areas as designated by the Article 14(4) of the NRR option a) or option b)	%	n/a												
Green areas in urban areas as designated by the Article 14(4) of the NRR option a) or option b) limited to the extent of ecosystem type 1 'Settlements and other artificial areas'	%	n/a												
Total national area of urban green space	km²	n/a												
Concentration of particulate matter (PM2.5) in city LAUs	µg/m³		6.63	n/a	n/a		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Concentration of particulate matter (PM2.5) in city LAUs	µg/m³	n/a												
Soil organic carbon stock in topsoil (30 cm; all soils)	tonne/ha			670	857									
Soil organic carbon in topsoil - mineral soils (30 cm; mineral)	tonne/ha			n/a	n/a									
Soil organic carbon in topsoil - organic soils (30 cm; organic)	tonne/ha			n/a	n/a									
Soil organic carbon in organic soils (100 cm)	tonne/ha			n/a	n/a									
Soil organic carbon in organic soils (whole depth)	tonne/ha			670	857									
Common farmland bird index	index					67.82								
Common forest bird index	index						76.76							
Deadwood (total)	m³/ha						15.8							
of which deadwood - standing	m³/ha						6.3							
of which deadwood - lying	m³/ha						9							
Tree cover density	%						67.45							
Share of artificial impervious area cover in coastal zone (1 km)	%	6.7	n/a	n/a	n/a		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

mandatory
voluntary
not relevant / not in scope
n/a - not available

Green areas in cities and adjacent towns and suburbs

In the Guidance Note on ecosystem condition accounts by Eurostat, there are several approaches described for the calculation of green areas in cities: 1) delineation of urban areas based on LAU, 2) delineation based on the ecosystem type 'Settlement and other artificial areas' 3) delineation as is designated by the Nature Restoration Regulation (all cities, towns and suburbs) and 4) delineation as is designated by the Nature Restoration Regulation in ecosystem type 'Settlements and other artificial areas'.

Calculations were done using options 1 and 2. Relevant LAUs in Estonia are Tallinn with adjacent town and suburbs (Viimsi, Saue LAUs), Tartu linn (Kambja, Luunja), Narva. The administrative borders of the aforementioned LAUs were used for the calculations. Classes that can be considered as urban green were identified from ecosystem extent map (level 3 ecosystem types) and then their share from each LAU or ecosystem type 'Settlement and other artificial areas' was calculated, which was then averaged over national territory. More details on the methodology and alternative approaches are described in respective subchapter.

Concentration of PM2.5 in cities

Concentration of PM2.5 in cities is calculated based on the map of average annual PM2.5 concentrations, which is calculated based on national emissions and meteorological data in Airviro modelling system, by Estonian Environmental Research Centre (EKUK), which is also used as an input for the air filtration, and ecosystem extent map, where the ecosystem type 'Settlements and other artificial areas' in LAUs considered as cities (Tallinn, Tartu, Narva) are delineated to calculate the average. The input data is foreseen to be obtained as part of the work on air filtration service which is made by Environmental Research Centre (EKUK) per contract. The input data of PM2.5 concentrations is available T-15, where T is reference year.

Soil organic carbon stock in topsoil in croplands and grasslands

Soil organic carbon stock was calculated using the soil carbon map created during ELME2[5] project based on national soil map and literature with the assumption that in croplands and grasslands the whole stock describes the stock in topsoil because of its natural depth which rarely falls under 30 cm. For the delineation of cropland and grasslands, the map of ecosystem extent was used. More relevant data is foreseen to become available in 2026/2027 in connection with the project "Land and Soil Use Management System for Effective and Sustainable Use of Soil

[5] Estonian MAES project, Countrywide Socioeconomic Assessment of Ecosystem Services https://loodusveeb.ee/en/countrywide-MAES-EE-socioeconomic-terrestrial

Services, Biodiversity Protection, and Climate Impact Reduction"[6] which is led by the Ministry of Climate (completion by 2027).

Common farmland bird index

Farmland Bird Index (FBI) is a composite index that measures the rate of change in the relative abundance of common farmland bird species at selected sites. It is reported yearly to OECD and the Statistical Office of the European Commission (Eurostat). The input data is collected and the index is calculated yearly in Estonian Environment Agency. Calculated indices become available T-2 via Estonian Environment Agency.

Deadwood in forests

The estimates of deadwood volume are based on data measured in the process of the National Forest Inventory (NFI) conducted by Estonian Environment Agency. All NFI basic estimates are compiled from the measurements of the 5 most recent years and attributed to the latest year of measurement. The distinction between lying and standing deadwood can be made based on data. Data is available T-6 – T-10 via Estonian Environment Agency.

Forest tree cover density

Forest tree cover density spatial data was obtained from Estonian Environment Agency. ALS measurements (carried out yearly by the Estonian Land Board, the whole country is covered over 4-year cycle) made in summertime were used for canopy cover estimation. For the delineation of forests, the map of ecosystem extent was used.

Common forest bird index

Forest Bird Index (FoBI) is a composite index that measures the rate of change in the relative abundance of common forest bird species at selected sites. It is reported yearly to OECD and the Statistical Office of the European Commission (Eurostat). The input data is collected and the index is calculated yearly in Estonian Environment Agency. Calculated indices become available T-2 via Estonian Environment Agency.

The share of artificial impervious area covering coastal areas

After the delineation of the coastal area (1 km from coastline) and defining the classes that can be considered as artificial in ecosystem extent map, the total share of the artificial area was calculated. More details on the methodology are described in respective subchapter.

3.3 Green areas in cities and adjacent towns and suburbs

In the Guidance Note on ecosystem condition accounts by Eurostat, there are several approaches described for the calculation of green areas in cities: 1) delineation of urban areas based on LAU, 2) delineation based on the ecosystem type 'Settlement and other artificial areas' 3) delineation as is designated by the Nature Restoration Regulation (all cities, towns and suburbs) and 4) delineation as is designated by the Nature Restoration Regulation in ecosystem type 'Settlements and other artificial areas'.

Calculations were done using options 1 and 2. Local Administrative Units (DEGURBA class 1) and adjacent towns and suburbs (DEGURBA class 2) based on the map of Administrative and Settlement Division from Estonian Land and Spatial Development Board (https://geoportaal.maaamet.ee/eng/spatial-data/administrative-and-settlement-division-p312.html) were used to delineate relevant LAUs. The relevant LAUs in Estonia are Tallinn with adjacent town and suburbs (Viimsi, Saue LAUs), Tartu linn (Kambja, Luunja), Narva. The administrative borders of the aforementioned LAUs were used for the calculations. Options 3 and 4 were not included in the present work. The coherence of the indicator with those used in the NRR was discussed (ANNEX 3), however, the development of the NRR in Estonia is still ongoing, and no definitive guidance could be derived.

Classes that can be considered as urban green were identified from ecosystem extent map (level 3 ecosystem types, national use). Green areas include all natural ecosystems, including inland waterbodies, and urban green (green space, cemetery, sport complex). Marine areas were excluded. No additional datasets were used in the current work, but the use of additional datasets, such as tree cover density maps, can be considered to help determine whether—and to what extent—selected ecosystem classes are green, particularly in cases such as private yards or roadside areas with tall vegetation. The use of satellite imagery is being considered for the development of NRR indicators. In the future, this experience could be incorporated for defining green areas better.

The area of green ecosystem types and consequently the share of green areas from LAU area was calculated in relevant LAUs. For finding the national average, the results per LAUs were averaged. Delineation of ecosystem class 1 'Settlement and other artificial areas' was done based on Estonian ecosystem extent map.

[6] https://kliimaministeerium.ee/uudised/kliimaministeeriumi-eestvottel-valmib-kaasaegne-mullastikukaart

The results for the share of green areas in ecosystem type 'Settlement and other artificial areas" in relevant LAUs was calculated the same way after delineating settlement and other artificial areas in relevant LAUs.

The approaches gave significantly different results (Table 4). The average share of all green areas in the relevant LAUs was 75.1%, whereas within the ecosystem class "Settlements and other artificial areas" in the same LAUs it was 22.9%; the corresponding shares of urban green areas were 4% and 8.8%, respectively. This contrast highlights the influence of spatial scale and land-use composition on the results. LAUs in Estonia are generally large and encompass extensive areas of natural ecosystems (weighted average 82.7%), which substantially inflates the proportion of green areas when calculated across entire administrative units.

Only one LAU—Tallinn—has an artificial area exceeding half of its total area (55.9% artificial area, 71.1% artificial and urban green area). In all other administrative units, the share of artificial land is remarkably low, limiting the suitability of LAU-level calculations for assessing green space within built-up environments. Consequently, the high share of green areas at the LAU level largely reflects the dominance of natural ecosystems rather than the availability of green spaces in settlements.

Therefore, calculating the share of green areas specifically within the ecosystem class "Settlements and other artificial areas" provides a more realistic and relevant estimate, as it excludes large natural areas and better captures the distribution of green and urban green spaces within urban areas.

Table 4. Urban green – % of the area of the local administrative unit and in class 1 "Settlements and other artificial area" in cities and adjacent towns and suburbs.

	Local administrative unit				Class "Settlements and other artificial area"			
		Green area				Green area		
	Artificial area	Total green area	Urban green	Natural ecosystems, including waterbodies	Artificial area	Total green area	Urban green	Natural ecosystems, including waterbodies
Narva linn	44.2	55.9	6.4	49.4	84.5	15.5	12.3	3.0
Tallinn	55.9	41.9	15.2	26.7	74.8	25.2	20.4	4.8
Saue vald	8.1	92.4	0.3	92.2	79.1	20.9	2.5	18.1
Viimsi vald	24.6	73.2	0.5	72.7	80.7	19.3	1.7	17.5
Tartu linn	18.6	77.5	4.7	72.8	72.3	27.7	18.4	9.1
Kambja vald	11.1	90.9	0.2	90.6	78.1	21.9	1.7	19.4
Luunja vald	6.9	93.6	0.5	93.1	70.4	29.6	4.8	24.4
Total (weighted average)	17.2	82.7	2.6	80.0	78.1	21.9	10.3	11.3
AVERAGE per LAUs	**24.2**	**75.1**	**4.0**	**71.1**	**77.1**	**22.9**	**8.8**	**13.7**

3.4 Share of artificial impervious area cover in coastal areas

For coastal areas, the share of artificial impervious area cover (% as a national average) is reported as an indicator describing the condition of coastal ecosystems.

According to the latest guidance note coastal areas are defined by a buffer of 1 km inland from the mean high tide mark. As an alternative, another (national) coastline may be used, e.g. as used for the Water Framework Directive or in the Marine Strategy Framework Directive, provided that this coastline is aligned with the coastline used in the ecosystem extent accounts.

In present work, national data for defining coastline was used for the spatial delineation of the reference area. The coastline was defined based on Estonian Topographic database[7], which is one of the input layers for ecosystem extent map, therefore on ecosystem extent map, the same coastline is used.

For the calculation of the impervious era, using High Resolution imperviousness product by the Copernicus Land Monitoring Service[8] is the recommended approach. HRL Imperviousness includes two main products that approach impervious surfaces from a land cover-based, Earth observation approach:

- Imperviousness Density (IMD) which maps artificial sealing (incl. larger areas of open solar parks, permanent greenhouses and construction sites with perceivable progress during the reference year) in % per pixel;
- Impervious Built-Up (IBU) that gives the presence/absence of built-up areas (i.e. larger buildings and other permanent above-ground constructions) per pixel.

Imperviousness Density (IMD) contains the approximate percentage of artificially sealing per pixel (0-100%) as retrieved from satellite image time series of the reference year. The data are available in 10 m pixel size (from 2018 onwards), with 3-yearly update cycle. According to the Copernicus Land Monitoring Service (CLMS), the next update of the High Resolution Layer (HRL) Imperviousness for the reference year 2024 is currently in production and is **planned for release in spring 2026.[9]

In previous grant work[10], the calculation of the index was tested using Corine Land Cover (CLC; 2018[11], Estonian Topographic Database (ETD; 2023[12]), and Copernicus imperviousness layer (2019, based on 2018 data[13]). The comparison showed that high-resolution imperviousness data and ETD provide very similar and more realistic estimates (share of artificial area was 9 % in LAUs bordering coastline in both cases), while CLC (share of artificial area was 16 %), systematically overestimates artificial areas due to its generalized classification.

As IMD is not available for 2024 and it was found not to be the most accurate, an attempt was made to calculate the share of impervious area in coastal areas by using ecosystem extent map (10x10 m resolution). Impervious ecosystem types were identified on the level 3 ecosystem extent map (private yard, flight path, landfill, railroad, port, road, industrial yard, building). These ecosystem types were treated as 100% impervious. By building a link with ecosystem extent map and Copernicus HRL Imperviousness (IMD) product, data could be derived for years when IMD is not produced. The comparison of the results is foreseen when IMD for 2024 becomes available.

After the delineation of the coastal area (1 km from the coastline) and defining the classes that can be considered as artificial in ecosystem extent map (level 3), the total share of the artificial area (national average) was calculated. National average share of artificial areas on the coastal area (1 km from coastline) was found to be 6.7%.

In addition to applying Copernicus imperviousness layer for 2024, it might be useful to test the NDVI-based indices. Copernicus imperviousness layer is also NDVI-based, but the input data outdated and newer information would be useful.

[7] https://geoportaal.maaamet.ee/eng/spatial-data/estonian-topographic-database-p305.html
[8] https://land.copernicus.eu/en/products/high-resolution-layer-imperviousness
[9] https://land.copernicus.eu/en/news/product-update-high-resolution-layer-imperviousness-2021
[10] Statistics Estonia, 2023. D1.8 Description of the methodology for advancing ecosystem accounts, methodology "Development of the environmental accounts" (Eurostat Grant Agreement no NUMBER — 101022852-2020-EE-ENVACC) https://www.stat.ee/sites/default/files/2023-09/D1_8_%20Description%20of%20the%20methodology%20for%20advancing%20ecosystem%20accounts%2C%20methodology%20_101022852_2020-EE-ENVACC_k%C3%BClj.pdf
[11] https://land.copernicus.eu/pan-european/corine-land-cover/clc2018
[12] https://geoportaal.maaamet.ee/eng/Spatial-Data/Estonian-Topographic-Database-p305.html
[13] Imperviousness Density 2018 — Copernicus Land Monitoring Service (https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/status-maps/imperviousness-density-2018?tab=metadata)

4 Compilation of ecosystem services account

4.1 Overview[14]

The main objective of the work was to compile ecosystem services account for year 2024 where data was available according to the EU regulation 691/2011 using the approaches described in latest available guidance notes by Eurostat.

According to the Regulation (EU) 691/2011 the ecosystem services account includes the following services for which the supply and use tables should be reported in the following physical units.

- Crop provision, is defined as the ecosystem contribution to plant growth as approximated by the amount of harvested crops for different uses. This includes food and fibre production, fodder and energy, and grazed biomass, as set out under in Annex III, Table A, Sections 1.1 and Section 1.2.
- Pollination is, defined as the ecosystem contribution by wild pollinators to the production of the crops referred to in the first indent above. The contributions should be reported in tonnes of pollinator-dependent crops that can be attributed to wild pollinators, by type of crop for the main types of pollinator-dependent crops comprising fruit trees, berries, tomatoes, oilseeds and "'other'".
- Wood provision, is defined as the ecosystem contribution to the growth of trees and other woody biomass, and should be reported as net increment as defined in Annex VII in over-bark, in thousand m3.
- Air filtration is defined as the ecosystem contribution to filtering air-borne pollutants through the deposition, uptake, fixing and storage of pollutants by ecosystem components (particularly trees). This mitigates the harmful effects of the pollutants. The contributions should be reported in tonnes of particulate matter abdsorbed.
- Global climate regulation is defined as the ecosystem contribution to reducing concentrations of greenhouse gases in the atmosphere through the removal (net sequestration) of carbon from the atmosphere and the retention (storage) of carbon in ecosystems. The contributions should be reported in terms of tonnes of net sequestration of carbon and tonnes of organic carbon stored in terrestrial ecosystems, including above ground and below ground stock.
- Local climate regulation is defined as the ecosystem contribution to regulating ambient atmospheric conditions in urban areas through vegetation that improves the living conditions of people and supports economic production. It should be expressed and reported as the reduction of temperature in cities, due to the effect of urban vegetation, in degrees Celsius on days exceeding 25 degrees Celsius.
- Nature-based tourism-related services are defined as the ecosystem contribution, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in- situ, physical and experiential interactions with the environment. Those contributions should be reported in number of overnight stays in hotels, hostels, camping grounds, etc. that can be attributed to visits to ecosystems.

In 2025 the ecosystem services assessed were: crop provision, wood provision, pollination, local climate regulation, nature-based tourism-related services. Global climate regulation and air filtration were excluded from the workflow as the input data for the calculations becomes available in 2026. The methodologies and results for air filtration and global climate regulation are presented in ANNEX 9 as they were calculated for year 2022 in previous grant work [15] because the numbers are used as placeholders in supply and use tables of ecosystem services account for year 2024.

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[14] Some of text of this chapter copies the methodological descriptions given already in the following grants: Grant Agreement no NUMBER — 101022852 — 2020-EE-ENVACC, Development of environmental accounts; Activity "Developing and refining ecosystem accounts", D1.8 Description of the methodology for advancing ecosystem accounts", Statistics Estonia, 2024. D1.9 Description of the methodology and problematic issues for ecosystem accounts (Eurostat Grant Agreement no NUMBER — 101113157 — 2022-EE-EGD) https://stat.ee/sites/default/files/2025-01/D1.9%20Description%20of%20the%20methodology%20and%20problematic%20issues%20for%20ecosystem%20accounts_0.pdf Authors of the text are the same. The reasons to copy also the basic descriptions are:
- These methodological descriptions were well-developed during the previous grant work,,
- Full methodological description is needed to provide the reader with comprehensive approach in single stand-alone document instead of references to other documents

[15] Statistics Estonia, 2024. D1.9 Description of the methodology and problematic issues for ecosystem accounts (Eurostat Grant Agreement no NUMBER — 101113157 — 2022-EE-EGD) https://stat.ee/sites/default/files/2025-01/D1.9%20Description%20of%20the%20methodology%20and%20problematic%20issues%20for%20ecosystem%20accounts_0.pdf

Monetary valuation of the ecosystem services was carried out based on the new and previous experience. Following chapters provide the results for the services. An in-depth analysis of alternative monetary valuation approaches, including their methodological foundations, and implications for the results, is discussed in chapter 5. Supply and use tables in monetary units are presented in chapter 4.7.

For the estimation of the ecosystem services; Estonian experts' experience was used in the calculation of services and consultations on methodological approaches. Collaboration with Statistics Netherlands was useful for determining of the methodology and validation of the results. Both national and international experts were consulted in order to integrate the knowledge generated in the area.

Supply and use tables were compiled, these are presented in chapter 4.7. Eurostat questionnaire and related metadata (2024 data collection)[16] were filled in and presented in Annex "D3.3 Dataset on ecosystem service supply-use.xlsx" (MS EXCEL file).

Attempt to automate some of the service calculations was made to decrease the future workflow. Services included were crop, pollination, local climate regulation, nature-based tourism services. The work was done using Python, Excel solutions or incorporating INCATool according to what fit the approach taken to assess the respective service. The calculations for local climate regulation ecosystem service were scripted in Python and fully automatic, data preparation excluded, Shell script was made. It is described in ANNEX 10 and presented in Deliverable "D3.2 Python/R Scripts". For other selected ecosystem services calculation steps (e.g. for categorizing agricultural data) were automated in Excel environment. The feasibility of automated workflows for physical accounts was additionally tested by using INCA Tool version 2.2.1[17] for crop and timber provision, local climate regulation as an alternative to currently applied methods that mostly require step-by step manual calculations.

The report with the results is made available on Statistics Estonia web platform. The supply of services is presented also in web interface.

4.2 Crop provision

According to the Regulation (EU) 691/2011, the ecosystem service crop provision is defined as the ecosystem contribution to plant growth as approximated by the amount of harvested crops for different uses. This includes food and fibre production, fodder and energy, and grazed biomass, as set out under Annex III, Table A, Section 1.1 and Section 1.2.

For physical valuation, data from MFA (material flow accounts) were used to compile the supply. Data available from agriculture statistics and national geo-spatial data on crop production areas and/or data from national registries of agricultural parcels were used for more detailed analysis. Latest guidance by Eurostat was followed (Ecosystem Accounts Handbook, June 2025)[18].

For monetary valuation, the service was valued with rent price method.

4.2.1 Physical account - crop provision

The supply of crop is found by using the amount of harvested crops in the MFA (material flow accounts) breakdown, sections 1.1 and 1.2. In MFA, the amount of harvested crops is recorded under characteristics 'Domestic extraction'. It is suggested in the guidance note for crop provision that when compiling the supply side of crop provision, 'Domestic extraction' of all reporting items of MFA sections 'Crops' (1.1), 'Crop residues' (1.2.1) and 'Fodder crops including biomass harvest from grassland' (1.2.2.1) is to be recorded as a supply from ecosystem type 'Cropland'. 'Domestic extraction' of MFA item 'Grazed biomass' (1.2.2.2) is to be reported as a supply from 'Grassland'. The results are presented in Table 5.

The use of the crop provision ecosystem service is to be attributed to intermediate consumption by industries (agriculture activity). The results are presented in Table 6.

[16] https://ec.europa.eu/eurostat/web/environment/methodology#Ecosystem%20accounts
[17] https://ecosystem-accounts.jrc.ec.europa.eu/inca-tool
[18] https://circabc.europa.eu/ui/group/922b4700-1c83-4099-b550-763badab3ec0/library/3200bb0e-4173-49b1-8ae4-30b9c47de056/details

Table 5. Supply of crop production, thousand tons, 2024

	Cropland	Grassland	Total supply
MF.1.1 Crops (excluding fodder crops)	1665	281	1664
MF.1.1.1 Cereals	1304	0	1304
MF.1.1.2 Roots, tubers	75	0	75
MF.1.1.3 Sugar crops	0	0	0
MF.1.1.4 Pulses	149	0	149
MF.1.1.5 Nuts	0	0	0
MF.1.1.6 Oil-bearing crops	96	0	96
MF.1.1.7 Vegetables	35	0	35
MF.1.1.8 Fruits	6	0	6
MF.1.1.9 Fibres	0	0	0
MF.1.1.A Other crops (excluding fodder crops) n.e.c.	0	0	0
MF.1.2 Crop residues (used), fodder crops and grazed biomass	1753	0	2034
MF.1.2.1 Crop residues (used)	1263	281	1263
MF.1.2.1.1 Straw	1135	0	1135
MF.1.2.1.2 Other crop residues (sugar and fodder beet leaves, etc.)	128	0	128
MF.1.2.2 Fodder crops and grazed biomass	490	0	771
MF.1.2.2.1 Fodder crops (including biomass harvest from grassland)	490	281	490
MF.1.2.2.2 Grazed biomass	0	0	281
TOTAL	1665	281	3698

Table 6. Use of crop production, thousand tons, 2024

	Intermediate consumption by industries	Government final consumption	Households final consumption	Gross capital formation	Exports	Total use
MF.1.1 Crops (excluding fodder crops)	1664					1664
MF.1.1.1 Cereals	1304					1304
MF.1.1.2 Roots, tubers	75					75
MF.1.1.3 Sugar crops	0					0
MF.1.1.4 Pulses	149					149
MF.1.1.5 Nuts	0					0
MF.1.1.6 Oil-bearing crops	96					96
MF.1.1.7 Vegetables	35					35
MF.1.1.8 Fruits	6					6
MF.1.1.9 Fibres	0					0
MF.1.1.A Other crops (excluding fodder crops) n.e.c.	0					0
MF.1.2 Crop residues (used), fodder crops and grazed biomass	2034					2034
MF.1.2.1 Crop residues (used)	1263					1263
MF.1.2.1.1 Straw	1135					1135
MF.1.2.1.2 Other crop residues (sugar and fodder beet leaves, etc.)	128					128
MF.1.2.2 Fodder crops and grazed biomass	771					771
MF.1.2.2.1 Fodder crops (including biomass harvest from grassland)	490					490
MF.1.2.2.2 Grazed biomass	281					281
Total	3698					3698

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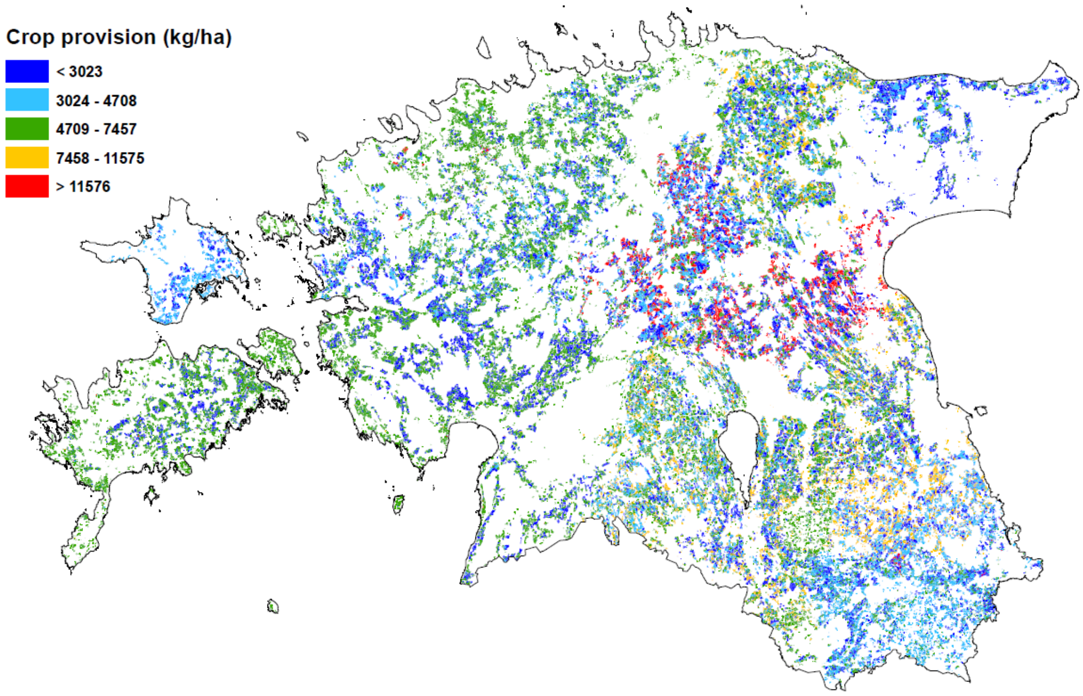
Spatial distribution was made using agricultural statistics, which includes data on area under cultivation (ha), production area(ha), production (tons) and yield (kg(ha) divided by counties. Considering the possibilities of data from Agricultural Registers and Information Board which includes agricultural fields and crops grown in the field, the additional data on crop residues and crazed biomass that is included in MFA was not included to the data from agriculture statistics. In order to distribute crop provision on map, crop yields from agriculture statistics were combined with geospatial field data from Agricultural Registers and Information Board and additional grassland and field units from extent map. Only crops were mapped (Figure 3).

Figure 3. The ecosystem service provisioning areas (croplands and grasslands) and values of crop provision (excluding crop residues). The areas coloured from blue to red represent service provisioning areas according to the physical unit value kg/ha). Areas coloured white represent areas that do not supply the ecosystem service.



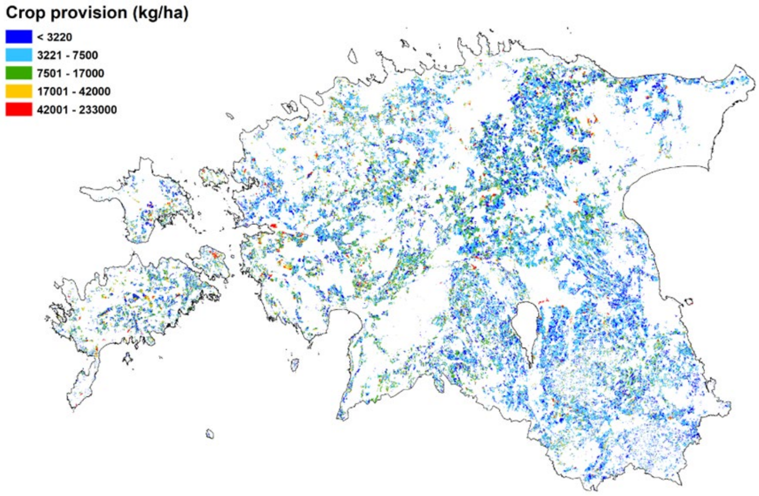
Calculating the service was tested in INCATool using both MFA and agriculture statistics data for years 2022 and 2023. and national ecosystem map and CLC map. As the calculations are straightforward and depend on the input crop yield data, the results in supply and use tables were the same. The computed maps in Incatool show a similar pattern on service provision as obtained with the original method. However, the intensity of the supply differed (Figure 5).

Some observations were made regarding output tables.

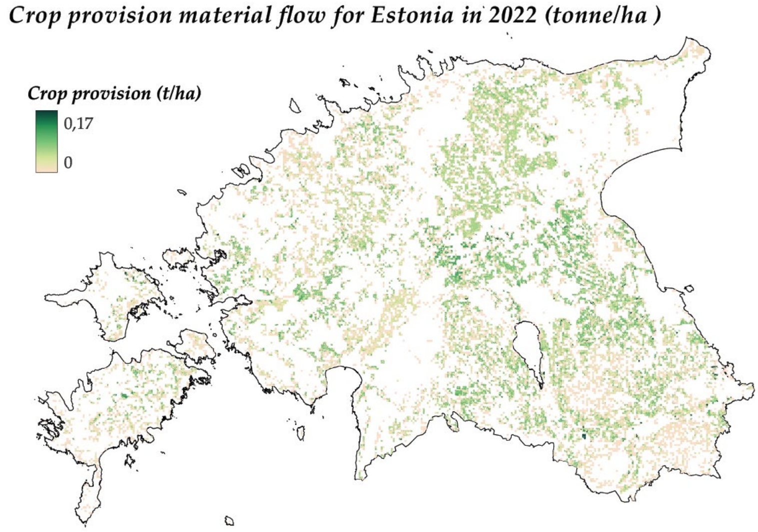
1. Missing Aggregate rows: According to the Eurostat Guidance Note, crop provision tables should include aggregate rows like: MF.1.1 Crops (excluding fodder crops); MF.1.2 Crop residues (used), fodder crops and grazed biomass; MF.1.2.1 Crop residues (used); MF.1.2.2 Fodder crops and grazed biomass. However, INCA does not calculate or include these aggregate rows automatically. Instead, it provides only the subcategories. Therefore, users must calculate these rows manually by summing relevant subcategory values.

2. Inconsistent rounding between tables: When comparing values between the Use and Supply tables generated by the INCA tool, some small inconsistencies appear due to how numbers are rounded. The Use table displays exact values with decimals, (e.g. 7.80), while the Supply table only shows integers, and it is not always clear how rounding is applied. One might expect that all values are rounded normally (e.g. 0,5 and higher get rounded up), but that is not always the case. For example, sometimes rounding works as expected: 11.65 is shown as 12 in the totals. Other times, it doesn't round up even when the decimal is high: A total of 3158.94 from the Use table should become 3159, but the INCA generated output still shows it as 3158. This likely reflects small inconsistencies between how INCA sums subcategories or applies rounding internally.

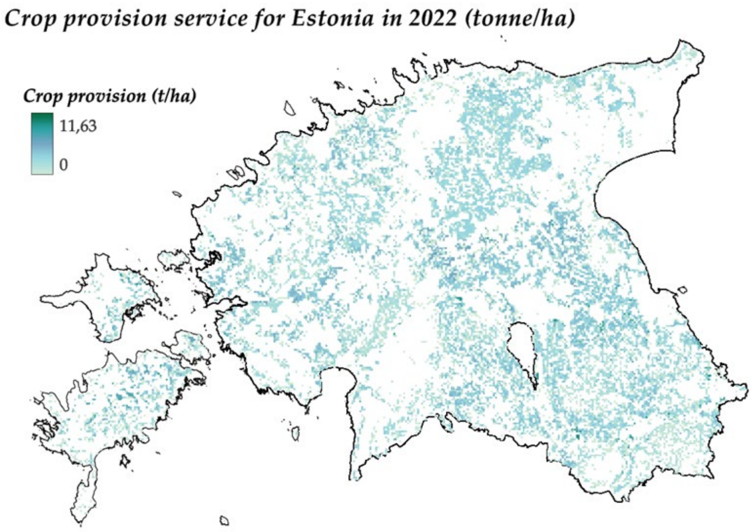
Figure 7. The ecosystem service provisioning areas and values of crop provision. 1)Original method, using MFA and Estonian extent map, 2022, as inputs, 2) Incatool using MFA and Estonian extent map, 2022 as inputs. 3) Incatool using MFA and CORINE Land Cover map, 2018 as inputs



1)



2)



3)

4.2.2 Crop provision – monetary valuation

Rent price was used for monetary valuation of crop production. However there are ongoing discussions which method is the most suitable (Chapter 5).

Rent is an expenditure user pays to the owner to use the resource. Rent payments can be related to the crop provision supplied by ecosystem as the renter is willing to pay the rent to use the service.

Data for rent price method are rent payments and area under cultivation. Rent price data were available from agricultural statistics but no distinction on land type or county is made. The average rent price of agricultural land in 2024 was 115 EUR/ha (agriculture statistics, PM59). In a separate analysis it was found that semi-natural and natural areas, whereas under agricultural land, contribute little to crop production. These areas are rented by State Forest Management Centre for the purpose of maintenance. The average rent price for semi-natural and natural grasslands, represented here by the area of ecosystem type “Grazing outside of agricultural land”, was 115 EUR/ha in 2024. The total value of crop production ecosystem service calculated based on rent price of agricultural land was 113 million EUR. (Table 7). The use of the crop provision ecosystem service is attributed to intermediate consumption by industries (agriculture sector).

Table 7. Monetary value of crop provision by ecosystem type, 2024, million EUR

	Area under cultivation, ha	Rent price, EUR/ha	Value of rent price, mln EUR
Utilised Agricultural Area	982 440	115	112.98
Arable land	705 400	115	81.12
Permanent grassland	272 987	115	31.39
Permanent crops	4 554	115	0.52
Natural and semi-natural grasslands	2 577	13.3	0.03

4.3 Wood provision

According to the Regulation (EU) 691/2011, the ecosystem service wood provision is defined as the ecosystem contribution to the growth of trees and other woody biomass, should be reported as net increment as defined in Annex VII in over-bark, in thousand m3. Annex VII references to the forest accounts in the same proposal for the amendment of Regulation (EU) 691/2011 where it defines net increment as follows: “Net annual increment of timber is defined as the average annual volume growth of live trees, calculated from the stock of live trees (growing stock) available at the start of the year less the average annual mortality“. It is noted that wood provision data in ecosystem accounts and forest accounts should be coherent, and the latter could be the input for the previous.

The calculations were made with increment data for year 2024, however data for removals for 2024 were not available on FAWS.

For monetary valuation, the service was valued with stumpage prices calculated over increment using data from 2023, because data for 2024 was not yet available from SNA.

4.3.1 Wood provision – physical account

Data on increment and removals was obtained from Estonian Environment Agency as part of the work on development of forest account, which is also ongoing parallel process. Similarly to forest accounts, a distinction is made between forest available for wood supply (FAWS) and forest not available for wood supply (FNAWS). Data on increment or removals from other land available for wood supply (AWS) or other land not available for wood supply (NAWS) was not available during the development of forest accounts (Table 8). In ecosystem accounts forests available for wood supply (FAWS) are assumed to represent cultivated forests for wood and forests not available for wood supply (FNAWS) are assumed to represent non-cultivated forests (in the sense ‘not cultivated for wood’).

To obtain the spatial distribution of increment data, which was approximated by forest stock change, data from the Forest Registry (as of January 2025) was used as primary data source. The increment was found for each forest stand compartment based on a simplified methodology using age, height, normal stand density and site quality class according to the formulas given in Annex 12 "Calculation of the increment of growing stock " in the Regulation of the Minister of the Environment "Forest Survey Guidelines" (RT I, 31.08.2018, 8). In case of forest land, for which data were not available in the register, an average annual increment of growing stock was assigned using the weighted averages of the majority tree species and site type allocations according to the available data in the forest register. Thus, nearly 400 tree species / forest site type groups were formed, the averages of which were generalized to forest areas with incomplete data on the basis of forest site type and main tree species. The output was then combined with ecosystem extent map and increment data over all land as it was not possible to distinguish between FAWS and FNAWS spatially. The result is shown in Figure 4.

All use of wood provision from FAWS is attributed to 'Intermediate consumption by industries' (forestry activity). The results of the supply and use of wood provision service is presented respectively in Table 9 and Table 10.

Figure 4. Wood provisioning (based on net increment) areas and values. The areas coloured from blue to red represent service provisioning areas according to the physical unit value m3/ha). Areas coloured white represent areas that do not supply the ecosystem service.

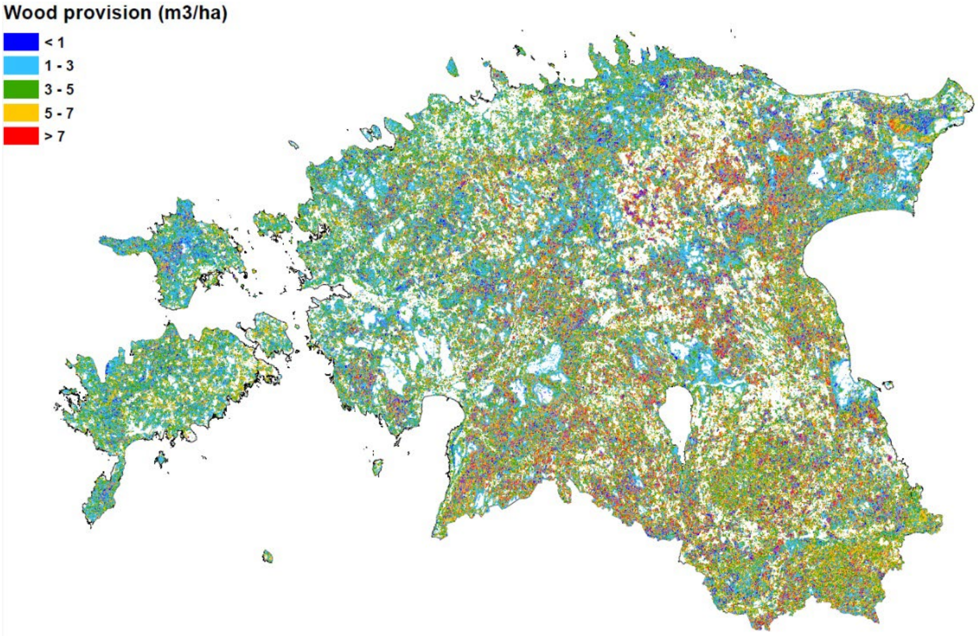


Table 8. Wood increment and removals (harvested wood) in land available for wood supply (AWS, FAWS- forest available for wood supply) and land not available for wood supply (NAWS, FNAWS- forest not available for wood supply), 1000 m3 overbark, 2024. The data on removals for 2024 is not yet available.

	Total supply
Wood provision - increment	9 300
Wood provision - increment in FAWS (cultivated forest)	8 300
Wood provision - increment in FNAWS (non-cultivated forest)	1 000
Wood provision – increment in other land AWS	n.a
Removals from FAWS (cultivated forest)	n.a
Removals from FNAWS (non-cultivated forest)	0

Table 9. Wood provision – supply table (1000 m3 overbark), 2024

	Settlements and other artificial areas	Forest and woodland	Total supply
Wood provision - increment	16	9 283	9300
Wood provision - increment (cultivated)	n.a	n.a	8 300
Removals from FNAWS (non-cultivated)	0	n.a	0

Table 10. Wood provision – use table (1000 m3 overbark), 2024

	Intermediate consumption by industries	Government final consumption	Households final consumption	Gross capital formation	Exports	Total use
Wood provision - increment	9 300					9 300
Wood provision - increment (cultivated)	8 300					8 300
Removals from FNAWS (non-cultivated)	0					0

Calculating the service was tested in INCATool using both net increment and removals data for years 2022 and 2023 and national ecosystem map and CLC map. As the calculations are straightforward and depend on the input data, the results in supply and use tables gave the same output, which also corresponds to the original method. However original approach detects the presence of forest in class1 "Settlements and other artificial areas" and attributes service supply to the class whereas in INCATool the whole supply is attributed to class 4 "Forest and woodland". (See Table 9 and Table 11).

In INCATool, the map is computed in absolute units (1000 m3), whereas map computed with original methodology presents supply in m3/ha. The comparison of the maps would require additional transformations, which were not undertaken.

Table 11. Total supply of wood provision 2022-2023 based, Increment 1000 m3 overbark

	Increment FAWS 2022 CLC	Increment FAWS 2022 Estonian extent map	Increment FAWS 2023 CLC	Increment FAWS 2023 Estonian extent map
Settlements and other artificial areas	0	0	0	0
Cropland	0	0	0	0
Grassland	0	0	0	0
Forest and woodland	8 200	8 200	8 200	8 200
Heathlands and shrubs	0	0	0	0
Sparsely vegetated ecosystems	0	0	0	0
Inland wetlands	0	0	0	0
Rivers and canals	0	0	0	0
Lakes and reservoirs	0	0	0	0
Marine inlets and transitional waters	0	0	0	0
Coastal beaches, dunes and wetlands	0	0	0	0
Marine ecosystems	0	0	0	0
Total supply	**8 200**	**8 200**	**8 200**	**8 200**

4.3.2 Wood provision – monetary valuation

Wood increment and harvested timber is also included in national accounts calculations and is a SNA value. Managed and economically restricted forest lands are taken into account, strictly protected forest is excluded. For monetary valuation, the service was valued with stumpage prices calculated over increment using data from 2023, because data for 2024 was not yet available from SNA.

Standing timber that is considered under inventories of work- in-progress in national accounts and is part of output value in SNA. According to the methodology used in national accounts to obtain the value of standing timber, first, the net increment has to be calculated from wood increment, and thereafter, multiplied by stumpage prices. The calculations are made for each tree species and timber assortment both for State Forest Management Centre and other owners. First, the total volume lost due to natural death of trees is deducted from wood increment. Therefore, the increment of every tree species is reduced by the share of this approximation from the volume of increment.

In order to calculate monetary value of wood provision service, the stumpage prices were multiplied with the increment or removals (harvested wood). Calculations were done separately for increment and harvested wood but using the same stumpage prices where the increment or harvested wood was divided by timber owner (State Forest Management Centre or other ownership), assortment and stumpage prices by timber species. Data were available for both State Forest Management Centre and other ownership (including also state forests) forests. Stumpage prices are prices that are paid for standing tree for the right to harvest. Stumpage prices are direct market prices and therefore show exchange value.

Intermediate price data were available from State Forest Management Centre. In order to calculate stumpage prices felling costs had to be subtracted from intermediate prices. Felling costs consist average stem volume of harvest (calculated using height and diameter by age and tree species) and average transport distance. Felling costs were available from National Accounts.

The spatial distribution of monetary values of wood provision based on stumpage prices of increment were calculated based on the map and spatial distribution of increment produced during the valuation of the service in biophysical units. The results are presented in Table 12. The total for stumpage prices of removals is provided in the table, but spatial distribution based on ecosystem extent was not found as it is not included in the final supply and use tables.

Table 12. Stumpage prices based on net increment and removals, million EUR, 2023

	Settlements and other artificial areas	Forest and woodland	Total
Stumpage price of net increment	0.69	382.30	383
Stumpage price of removals	n.a	n.a	769

4.4 Crop pollination

According to the Regulation (EU) 691/2011, the ecosystem service pollination is defined as ecosystem contribution by wild pollinators to the production of the crops referred to in the first indent. The contributions should be reported in tonnes of pollinator-dependent crops that can be attributed to wild pollinators, by type of crop for the main types of pollinator-dependent crops comprising fruit trees, berries, tomatoes, oilseeds and "'other'".

The methodology for assessing pollination in physical units was built on previous experience and guidance in the respective guidance notes by Eurostat. Due to time constraints, the full methodology recommended in the latest guidance note could not be implemented, and the calculations were therefore carried out based on previous experience[19].. The applied model uses detailed national spatial datasets on crops and habitats but does not incorporate meteorological data and does not distinguish between short- and long-distance pollinators. As the previously applied approach was based on a model developed by Statistics Netherlands, the respective advantages and limitations of both approaches were discussed during the study visit (ANNEX 2) and subsequently addressed in written form.

The INCATool, which applies the full model as recommended in the guidance note, was tested using the default dataset provided by Eurostat. The available default data correspond to the year 2021. Due to time and resource constraints, it was not possible to prepare appropriate input data for Estonia for the year 2024 within the scope of this work. Initial test results indicated that the outputs were significantly lower than expected when compared with previously obtained results, although those were derived using a different methodology. Consequently, the use of these results was rejected, and a more detailed analysis of the input data is planned for future work. The INCATool is capable of handling large datasets efficiently. In previous calculations for the service, hardware and software

[19] Statistics Estonia, 2024. D1.9 Description of the methodology and problematic issues for ecosystem accounts (Eurostat Grant Agreement no NUMBER — 101113157 — 2022-EE-EGD) https://stat.ee/sites/default/files/2025-01/D1.9%20Description%20of%20the%20methodology%20and%20problematic%20issues%20for%20ecosystem%20accounts_0.pdf

limitations had posed challenges during the required calculations, which were not encountered when using INCATool.

For monetary valuation of the service the method and model used in physical accounting was complemented with basic prices by crop type to find the monetary value of pollinator-dependent production of crops.

4.4.1 Crop pollination – physical account

Biophysical and monetary service flow was modelled using spatial data of crops and pollinator habitats. Input data included yearly yield data for 2024 from agricultural statistics (PM0281: Agricultural land and crops by county[20]), spatial data of agricultural support and land parcels (Estonian Agricultural Registers and Information Board (ARIB)[21], ecosystem extent map), basic unit prices of agricultural crop products.

The methodology proposed by scientists of Wageningen University and Research [22] was followed for calculating and modelling of the biophysical value of the pollination service. However, it was needed to make some modifications in the methodology as original calculations in the Netherlands were done using raster data with fixed cell size, but currently Estonian spatial input was in vector format.

Crop field units with their respective grown crop, pollinator habitat units and distances between them were derived through spatial analyses. On all crop field units where a crop which requires pollination is grown and all suitable habitat units within 1750 meter radius (from the middle of crop field unit to the middle of habitat unit) of the crop field unit were chosen to the dataset on which calculations were done. Due to time constrains the spatial data was not transformed from vector to raster, therefore further calculations were done in table form and therefore the precision of the modelling also decreased.

Pollination requirement was linked to the crop field units based on the crop grown there and habitat suitability per ecosystem type was linked to habitat units.

Crops differ in pollination demand. Based on the pollination requirement of the crop, crop field units were assigned a value of pollination requirement on the scale of 0-100. The values for the pollination requirement were derived from Klein et al. (2007) and modified for Estonia with the expert knowledge of entomologist of University of Life sciences, professor Mänd in previous work on ecosystem accounting by Statistics Estonia[23].

Ecosystems are also different in suitability for habitat to pollinators. Data was collected about the suitability of the ecosystem units for the habitat for wild pollinators such as wild bees, bumblebees, butterflies, and hoverflies. Wild pollinators require sufficient resources for nesting (e.g. suitable soil substrate, tree cavities, etc.) and sufficient forage (i.e. pollen and nectar). Based on SEEA EEA report[24], and expert knowledge of entomologist of University of Life sciences, professor Mänd and ecologist of Tallinn University, associated professor Rivis, each ecosystem for the suitability for pollinators habitat on scale 0 – 100 where 100 means most suitable and 0 unsuitable, was assessed in previous work on ecosystem accounting by Statistics Estonia[25].

Using the obtained dataset the relative visitation rate (scale 0-100) in crop field unit c from surrounding habitat units h was calculated [26]

$$v_c = \sum_{h=1}^{H} S_h \frac{e^{-0.00053 d_{hc}}}{\sum e^{-0.00053 d}}$$

where

S_h represents the relative pollinator abundance (scaled 0 – 100, where 100 marks maximum suitability) in map unit h (based on the suitability for nesting and foraging for pollinators of the habitat in map unit h), habitat suitability.

[20] https://andmed.stat.ee/en/stat/majandus__pellumajandus__pellumajandussaaduste-tootmine__taimekasvatussaaduste-tootmine/PM0281/table/tableViewLayout2
[21] https://avaandmed.eesti.ee/information-holders/pollumajanduse-registrite-ja-informatsiooni-amet
[22] Remme, R., Lof, M., de Jongh, L., Hein L., Schenau, S., de Jong, R., Bogaart, P. (2018) The SEEA EEA biophysical ecosystem service supply-use account for the Netherlands. Wageningen University and Research
[23] Statistics Estonia, 2020. Development of the land account and valuation of ecosystem services regarding grassland ecosystem services (Eurostat Grant Agreement no NUMBER — 831254 — 2018-EE-ECOSYSTEMS). https://www.stat.ee/sites/default/files/2021-06/Methodological%20report_831254_2018_EE_ECOSYSTEMS_revised_version_31_03.pdf
[24] Remme, R. et al (2018) The SEEA EEA biophysical ecosystem service supply-use account for the Netherlands. Wageningen University and Research
[25] ibid
[26] Remme, R., Lof, M., de Jongh, L., Hein L., Schenau, S., de Jong, R., Bogaart, P. (2018) The SEEA EEA biophysical ecosystem service supply-use account for the Netherlands. Wageningen University and Research

d_{hc} is the distance between map unit h and the crop in map unit c.
d describes the distance between the crop field unit c and any possible ecosystem around it. $\Sigma e^{-0.00053d}$ describes the sum of all the distances between the crop field unit c and all possible ecosystems around it.

To use this equation for vector data (polygons) an estimation of the average d was needed, this was obtained based on the average area of crop field. The value of d in our test area was calculated on raster map with the help of Dr. Ir. Marjolein Lof from Wageningen University & Research. For the field with an area of 7.21 ha, which translates into a square cell measured 268x268 m it was calculated how many fields, and at what distances, an ecosystem providing pollination can potentially be connected with. If all natural vegetation within 6 km radius of the crop field is taken into account, the sum of all visitation rates ($\Sigma e^{-0.00053d}$) is 257.5922. The obtained value of d was used in the calculations as a constant. If the crop fields in the local landscape are bigger or smaller than the average size of crop field based on which the d was calculated on, it will result in an under or over estimation of pollinator visitation rate and thereof also the ecosystem service value.

Pollination P_c is a function of the relative visitation rate,

$$P_c = f(v_c)$$

where $P_c = 5v_c$ for v_c between 0 and 20 and 100 for $v_c \geq 20$.

Next potential crop production reduction which is described by crop yield (kg) = yield per hectare by county (kg/ha) *crop field area (ha) in absence of pollination was calculated. Here in the calculations changing from yield (kg) to yield (€) by incorporating average crop basic price gives the monetary value of the ecosystem service instead of biophysical. The potential crop production reduction in monetary units is then described as crop yield (€) = yield per hectare by county (kg/ha) * average crop basic price (€/kg)*crop field area (ha).

The avoided production reduction represents the use of the pollination service by the crops. Avoided production reduction in the presence of pollinators APR_c is calculated

“Avoided production reduction” = “potential production reduction” * (“pollination”)/100

The contribution (supply) of the ecosystems to the avoided production reduction, APRh is calculated:

$$APR_h = \sum_{c=1}^{C} APR_c \frac{\sum_{h=1}^{H} S_h \frac{e^{-0.00053 d_{ch}}}{\sum e^{-0.00053 d}}}{\sum_{h=1}^{H} S_h}$$

where

APR_c is the avoided production loss in the crop in map unit c,
d_{ch} is the distance between the crop c and the pollinator habitat h.
S_h is relative pollinator abundance in map unit h. Contribution to avoided production loss in crop fields by the ecosystem in map unit h is based on all crop fields that require pollination in a 6 km square around map unit h. This is calculated for all map units that contain an ecosystem that is suitable for pollinators.

The result of pollination ecosystem service was carried out in R by following the modified calculations of the modelling of avoided production reduction in the presence of pollinators. The total value of the pollination service was 105 thousand tons. The ecosystem service value by ecosystem types and crop types is shown in Table 13.

The use of the service is assigned, like the crop provision service, to the intermediate consumption by industries (agriculture activity) (Table 14).

Table 13. Supply of crop pollination ecosystem service (1000 tons) by crop types and ecosystem types, 2024

	MF.1.1 Crops (excluding fodder crops)	MF.1.1.1 Cereals	MF.1.1.4 Pulses	MF.1.1.6 Oil-bearing crops	MF.1.1.7 Vegetables	MF.1.1.8 Fruits
1 Settlements and other artificial areas	17.9	1.4	4.0	11.4	0.5	0.6
2 Cropland	2.5	0.2	0.5	1.4	0.1	0.3
3 Grassland (pastures, semi-natural and natural grassland	34.9	3.0	7.7	21.9	0.9	1.4
4 Forest and woodland	49.7	4.1	11.2	32.0	0.9	1.5
5 Heathland and shrub	0.3	0.0	0.1	0.2	0.0	0.0

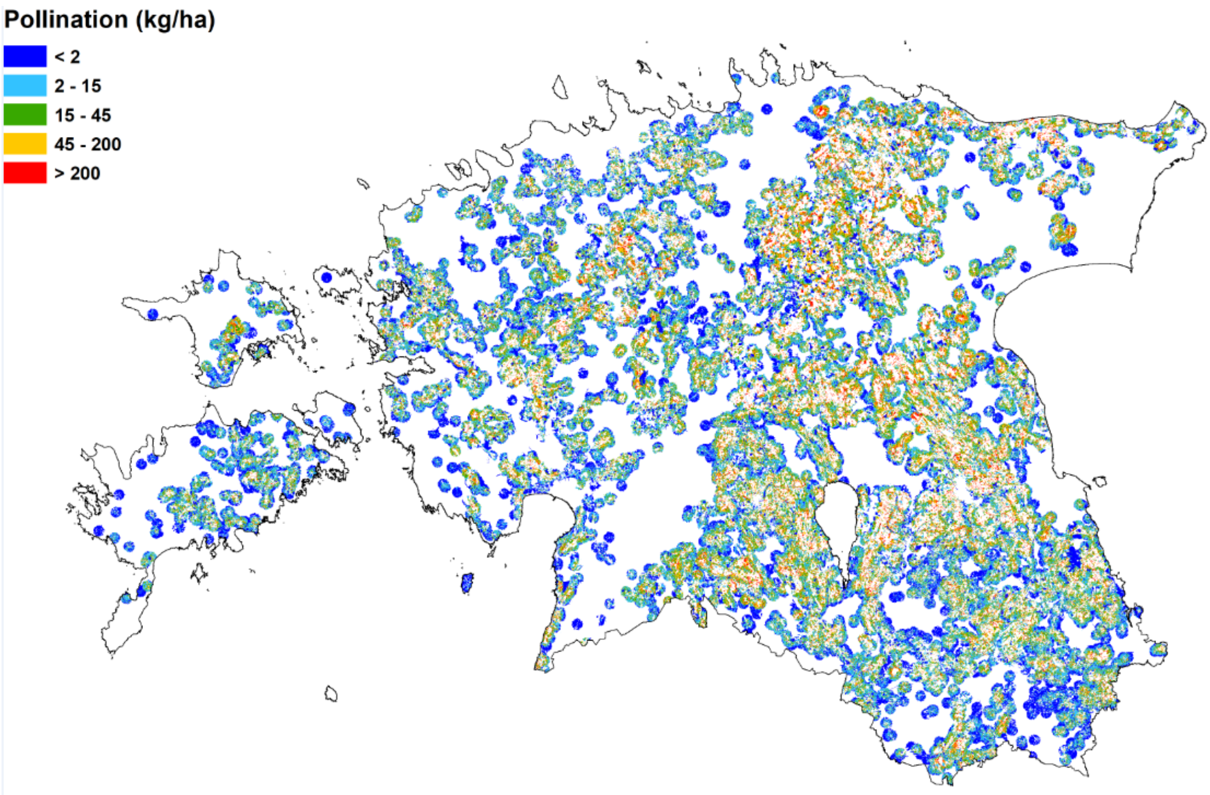
6 Sparsely vegetated ecosystems	0.1	0.0	0.0	0.0	0.0	0.0
7 Inland wetlands	0.3	0.0	0.1	0.2	0.0	0.0
11 Coastal beaches, dunes and wetlands	0.0	0.0	0.0	0.0	0.0	0.0
Total supply	105.7	8.7	23.5	67.2	2.4	3.9

Table 14. Use of crop pollination ecosystem service (1000 tons), 2024

	Intermediate consumption by industries	Government final consumption	Households final consumption	Gross capital formation	Exports	Total use
MF.1.1 Crops (excluding fodder crops)	105.71					105.71
MF.1.1.1 Cereals	8.67					8.67
MF.1.1.4 Pulses	23.54					23.54
MF.1.1.6 Oil-bearing crops	67.23					67.23
MF.1.1.7 Vegetables	2.39					2.39
MF.1.1.8 Fruits	3.87					3.87

Spatial distribution of the ecosystem service (Figure 5) was obtained simultaneously with the calculations of the model where a value based on the contribution to the increased crop yield in nearby fields was attributed to each ecosystem asset that was a suitable pollinator habitat.

Figure 5. The ecosystem service provisioning areas and values of ecosystem service of crop pollination. The areas coloured from blue to red represent service provisioning areas according to the unit value (kg/ha) supplied by ecosystem assets. Areas coloured white represent areas that do not supply the ecosystem service in the current scope of the study.



4.4.2 Pollination – monetary valuation

By incorporating average crop basic price data in the step of calculations where potential crop production reduction is calculated, the result from the model for the ecosystem service is obtained in monetary units instead of biophysical. The total monetary value of the pollination service was 62.4 million EUR in 2022. The ecosystem service value by ecosystem types and crop types is shown in Table 15.

Table 15. Supply of crop pollination in monetary values, million EUR, 2022

	MF.1.1 Crops (excluding fodder crops)	MF.1.1.1 Cereals	MF.1.1.4 Pulses	MF.1.1.6 Oil-bearing crops	MF.1.1.7 Vegetables	MF.1.1.8 Fruits
1 Settlements and other artificial areas	10.5	0.4	1.4	0.3	1.3	7.1
2 Cropland	1.8	0.1	0.6	0.0	0.2	0.9
3 Grassland (pastures, semi-natural and natural grassland	20.8	0.8	3.1	0.5	2.6	13.8
4 Forest and woodland	28.8	1.2	3.3	0.5	3.8	20.1
5 Heathland and shrub	0.2	0.0	0.0	0.0	0.0	0.1
6 Sparsely vegetated ecosystems	0.0	0.0	0.0	0.0	0.0	0.0
7 Inland wetlands	0.2	0.0	0.0	0.0	0.0	0.1
11 Coastal beaches, dunes and wetlands	0.0	0.0	0.0	0.0	0.0	0.0
Total supply	62.4	2.4	8.5	1.4	7.9	42.1

4.5 Local climate regulation

According to the Regulation (EU) 691/2011, the ecosystem service local climate regulation is defined as the ecosystem contribution to regulating ambient atmospheric conditions in urban areas through vegetation that improves the living conditions of people and supports economic production. It should be expressed and reported as the reduction of temperature in cities, due to the effect of urban vegetation, in degrees Celsius on days exceeding 25 degrees Celsius.

The assessment of the service (reduced temperature in degrees Celsius as cooling effect of vegetation) in physical units was done in co-operation with Estonian Environment. The assessment is mainly based on the methodology described in the Guidance notes on ecosystem services accounts by Eurostat (Version: December 2024)[27]. Since then the guidance note has gone through revisions and the methodology has matured, therefore there are methodological differences in the approach applied when compared to the latest available guidance note. Regardless, the results were attempted to fit in the frame of newer versions of guidance, including clarified aggregation of results. Feedback received from Eurostat, JRC, and VITO was considered, and an attempt was made to incorporate it into the developed work, particularly with regard to applying an appropriate regression from land surface temperature to air temperature as it was excluded in the national model. The results are still considered to be preliminary as compliance with latest guidance has not been achieved. In upcoming work in 2026continuing methodological development work is foreseen

Regarding technical solutions, the calculations for local climate regulation ecosystem service were scripted in Python and fully automatic, data preparation excluded, Shell script was made. It is described in ANNEX 10 and presented in Deliverable “D3.2 Python/R Scripts”.

The model for assessing the service in physical units was published in INCATool version 2.2.1[28] together with accompanying default data. However, data for Estonia was not included in the default input data. Feedback from VITO indicated that the absence of Estonian cities is due to the CITY–LAU vector file in the default GISCO dataset, which did not include polygon boundaries for Estonian cities. Revised default data are planned to be released together with INCATool version 2.3 in Q1 2026.

Due to time and resource constraints, it was not possible to prepare suitable input data for Estonia within the scope of this work. Preparation of the input data (e.g. aligning parameter codes between datasets, calculating median land surface temperatures layer with suitable parameters and masking these with the polygons for local administrative units) for INCATool differs from the inhouse developed model, making it a time-consuming work.

[27] https://ec.europa.eu/eurostat/documents/1798247/12357920/Guidance+note+on+ecosystem+services+accounts.pdf/3bc39658-8de5-79e1-e9b6-afe81141446d?t=1743161354131
[28] https://ecosystem-accounts.jrc.ec.europa.eu/inca-tool

For comparison purposes, the local climate regulation model was therefore run for nearby countries (Finland, Sweden, Lithuania, Poland) for which data were available in the default model.

The approach and results were consulted with Statistics Netherlands during the study visit (ANNEX 2) and subsequently addressed in written form. Notable issues covered included the aggregation and interpretation of results, the conversion of land surface temperature to air temperature using available data, and the limitations of the evapotranspiration dataset. The final results and remaining issues were discussed during the final seminar. (ANNEX 3).

Possible monetary valuation methods were researched during the project. Reporting average values of reduced temperature is foreseen, which leaves quantifying the total supplied and used service open for discussions if it should be connected with the reported physical indicator. Possible valuation methods would include avoided health costs or replacement costs based on the population of benefitted people and number of days exceeding 25 degrees Celsius which would quantify the supplied service.

Furthermore, to establish an appropriate link between the physical indicators calculated in the accounts and those used in assessments of avoided health costs, for example, further alignment is required. In many health impact assessments, impacts are typically expressed as changes in costs associated with a one-degree (or similar marginal) increase or decrease in temperature. Therefore, harmonisation of indicator definitions, units, and underlying assumptions is necessary to ensure consistency.

Alternative valuation method is contingent valuation method. Willingness to pay study on urban ecosystem services, which included microclimate regulation was carried out in 2019. The results were then cross walked and distributed to ecosystem types of EU ecosystem typology. The monetary valuation, as well, should be developed further.

In 2024, the number of days with maximum temperature exceeding 25°C was 36. The number of benefitting people (people living in city administrative units) was 611 917.

Supply and use tables were compiled. Eurostat questionnaire and related metadata (2024 data collection) were filled in and presented in Annex "D3.3 Dataset on ecosystem service supply-use.xlsx" (MS EXCEL file).

Following is the overview of the methodology and results, detailed description of the work done by Estonian Environment Agency is given in ANNEX 10. Statistics Estonia further analyzed and recalculated the results to ensure better consistency with the updated guidance and ecosystem extent accounts.

4.5.1 Local climate regulation – physical account

Input data

Used inputs to the cooling model, as suggested by Guidance were:

1. ***Land Surface Temperature (LST)-*** as derived from public Landsat 8/9 data, downloadable from the USGS website or preferably by Python (Py) package *Landsat Xplore*. Currently the LST values are calculated from Landsat Level 1 (L1) data, bands B4, B5, B10.
2. ***Tree cover (TCD)*** *data r*etrieved from the Copernicus High Resolution Layer. While the suggestion of the Guidance is to use data in m^2 per 100m-by-100m pixels. Still as the raw data are more precise, the data of 10m by 10m were used for possible more fine-grained analysis further aggregation in later stage. Last available data is from 2021 but data from 2018 was used as it provided better quality.
3. ***Evapotranspiration (Evap.)*** *from the vegetation,* available on the Google Earth Engine platform
4. Suggested daily **air temperature (daily absolute maximum)** was not available for Estonian cities and was excluded. Additional option in the guidance has proposed to derive air temperature based on available land surface temperature - air temperature datasets.

Method and implementation

The described below approaches, algorithms, data processing, presentation and export of map layers were implemented by Python (Py) scripts and appropriate *Py* packages and APIs (*application program interfaces*).

The analysis has been done over one – 2024 year – and 3 cities of Estonia, in the borders of the LAU (local administrative units) – **Tallinn, Tartu, Narva**.

All input datasets of LST, ET, TCD and ecosystem distribution were resampled to common grid with resolution of 30 metres and masked, using shapefiles of administrative units in order to preserve only pixels, which are situated inside polygon of the city.

Datasets of LST and ET, which are available at several observation dates, were averaged to obtain single two-dimensional dataset of each parameter.

Data from the map of ecosystems, which initially contains 29 types, was recoded into 12-class system. As a result, the city obtained a sample of data pixels, and for each of them a single value of LST, TCD, ET and code of ecosystem type was known.

Next the linear regression functions were calculated:

LST as linear function of TCD, so LST approximated as $LST = LST_{tcd0} + a_{tcd} * TCD$.

Where LST_{tcd0} is LST value, if TCD equals to zero, a_{tcd} is slope of the function.

LST as linear function of ET, so LST approximated as $LST = LST_{et0} + a_{et} * ET$.

Where LST_{et0} is LST value, if ET equals to zero, a_{et} is slope of the function.

Also, a combined TCD + ET effect is estimated by fitting of linear regression of two variables $LST = LST_0 + a_{et2} * ET + a_{tcd2} * TCD$

Where LST_0 is temperature, which should occur, if ET and TCD would equal to zero; a_{tcd2} and a_{et2} are coefficients (slopes) for the combined TCD and ET effect.

Based on the last regression function, the cooling effect was calculated at each pixel as a product of TCD and ET values with corresponding slope coefficients:

$Cooling_i = a_{et2} * ET_i + a_{tcd2} * TCD_i$

Where TCD_i and ET_i are TCD and ET values in particular pixel and $Cooling_i$ is cooling effect estimate there.

After pixel-based evaluation of cooling effect was done, the values were averaged over regions, occupied by each type of ecosystem (Cooling effect, inside the ecosystem, °C), $Cooling_{eco\_i}$. Also, the proportions of these areas in city's total area were calculated (Ecosystem proportion in city area, %), $prop_{eco\_i}$. The product of ecosystem's average cooling effect and its proportion gave value of cooling effect on the total city area (Cooling effect at city scale, °C), $Cooling_{city\_i}$:

$Cooling_{city\_i} = Cooling_{eco\_i} * prop_{eco\_i}$

At final step cooling effects of all ecosystem classes were summed, and total cooling value in the city was obtained. The calculations were done separately for each city.

Original model did not include air temperature dataset over which regression from land surface temperature to air temperature could be done. According to guidance note , this is done by using linear regression, trained with maximum air temperature data to model the missing maximum air temperature (Tair, °C) as a function of LST and latitude (representing different climate zones):

$$T_{air} = \alpha_2 + \beta_2 LST + \gamma_2 latitude$$

Per suggestion of Eurostat and VITO, an attempt to convert the already calculated cooling effect based on land surface temperature to air temperature was done, using the formula and coefficients derived from US dataset available on GISCO[29]. From the dataset, which is also used in INCATool, the computed coefficients are:

Constant: 40.74225138

For Land surface temperature: 0.256023848

For Latitude: -0.526436539

Formula: Tair = 40.74225138 + 0.256023848*LST - 0.526436539*Latitude

The formula were applied to the spatial datasets on cooling effect. However, the yielded too high estimates, around 8-9 degrees Celsius. The original values for cooling per pixel ranged from 0- 4 degrees Celsius. The theoretical calculations for applying the formula are provided in Table 16.

Based on the results, it was found that the model does not fit for Estonia and a more sophisticated model or improved regression is likely needed for Estonia. The reasons for the nonfit may include: 1)the US stations in the default data are all located between 24.5 and 49 degrees latitude which is much further south than Tallinn, 2) the second regression only relates the two temperatures and latitude, it doesn't consider altitude as variable (e.g.

[29] https://gisco-services.ec.europa.eu/pub/ecosystems_accounting/tools/input_data/version_2_2/inca_input_local_climate_regulation/inca_input_local_climate_regulation_Weather_station_data.zip

coastal climate). **Therefore, it was decided not to convert the results at this stage, and the subsequent outputs are presented as a land-surface-temperature-based cooling effect**

Table 16. Example of the results obtained after applying the regression-derived cooling effect—calculated from land-surface temperature—to the air-temperature dataset

Formula:	**Tair = 40.74225138 + 0.256023848*LST - 0.526436539*Latitude**
Intercept	40.74225
coefficient for LST (land surface temperature)	0.256024
Coefficient for Latitude	-0.52644
Tallinn latitude, (example)	59.4187
Cooling effect (land surface temperature)	**Cooling effect (air temperature) – calculated values**
0	9.462078
1	9.718102
2	9.974126
3	10.23015
4	10.48617
5	10.7422
6	10.99822
7	11.25425
8	11.51027
9	11.76629
10	12.02232
...	...
25	15.86267
26	16.1187
27	16.37472
28	16.63075
29	16.88677
30	17.14279
31	17.39882
32	17.65484
33	17.91087
34	18.16689
35	18.42291

Based on the results, it was found that the model does not fit for Estonia and a more sophisticated model or improved regression is likely needed for Estonia. The reasons for the nonfit may include: 1)the US stations in the default data are all located between 24.5 and 49 degrees latitude which is much further south than Tallinn, 2) the second regression only relates the two temperatures and latitude, it doesn't consider altitude as variable (e.g. coastal climate). **Therefore, it was decided not to convert the results at this stage, and the subsequent outputs are presented as a land-surface-temperature-based cooling effect**

Results

Table 17. Estimated average daily cooling effect for period May-September in city LAUs Tallinn, Narva, Tartu.

	Tallinn			Narva			Tartu		
Ecosystem class	Ecosystem proportion in city area, %	Cooling effect, inside the ecosystem, °C	Cooling effect at city scale, °C	Ecosystem proportion in city area, %	Cooling effect, inside the ecosystem, °C	Cooling effect at city scale, °C	Ecosystem proportion in city area, %	Cooling effect, inside the ecosystem, °C	Cooling effect at city scale, °C
Settlements and other artificial areas	77%	0.920	0.708	52%	1.03	0.538	29%	1.37	0.393
Cropland	0%	2.030	0.001	2%	1.02	0.020	30%	1.88	0.564
Grassland	1%	1.410	0.019	2%	0.93	0.023	9%	2.08	0.189
Forest and woodlands	12%	2.720	0.320	18%	2.99	0.548	27%	3.93	1.056
Heathlands and shrub	0%	1.880	0.004	0%	1.93	0.005	0%	3.44	0.015
Inland wetlands	1%	1.030	0.005	17%	1.07	0.180	2%	1.96	0.038
Sparsely vegetated ecosystems	0%	1.680	0.004	0%	2.11	0.000	0%	2.46	0.001
Rivers and canals	1%	0.000	0.000	1%	0.00	0.000	2%	0	0
Lakes and reservoirs	8%	0.000	0.000	7%	0.00	0.000	1%	0	0
Marine inlets and transitional waters	0%	0.000	0.000						
Coastal beaches, dunes and wetlands	0%	0.000	0.000						
Marine ecosystems	0%	0.000	0.000						
Total			1.062			1.313			2.258

When comparing the obtained results (Total per city) with the output from IncaTool for cities in Finland, Lithuania, Poland and Sweden (Table 18), the results for Estonia appear systematically higher, highlighting the need to apply the land-surface–air-temperature relationship. The magnitude of the effect remains uncertain because the Estonian model and the IncaTool model were executed for different years, 2024 and 2021, respectively, which limits direct comparability of the results.

Table 18. Results from the local climate regulation model in IncaTool for Finland (FI_) and Lithuania (LT_).

GISCO_ID	LAU name	Average cooling effect (degrees C)
FI_049	Espoo	0.98
FI_091	Helsinki	0.70
FI_092	Vantaa	0.54
FI_179	Jyväskylä	0.65
FI_297	Kuopio	-0.03
FI_398	Lahti	1.47
FI_564	Oulu	1.18
FI_837	Tampere	0.74
FI_853	Turku	0.52
LT_11	Alytaus miesto savivaldybė	0.97
LT_13	Vilniaus miesto savivaldybė	0.92
LT_19	Kauno miesto savivaldybė	0.73
LT_21	Klaipėdos miesto savivaldybė	0.69
LT_27	Panevėžio miesto savivaldybė	0.44
LT_29	Šiaulių miesto savivaldybė	0.42

Supply and use tables

For calculating the value of local climate regulation in the supply table the results of estimated average daily cooling obtained from combined fitting of TCD and Evap. by linear regression were averaged for all the cities in Estonia. Results are presented in

Table 19. The results are reported as averages for a day during summer period (1. May to 30. September).

Table 19. Local climate regulation – supply table (average daily reduced land surface temperature °C), 2024

Ecosystem	Local climate regulation (average daily reduced land surface temperature °C)
1 Settlements and other artificial areas	0.61
2 Cropland	0.55
3 Grassland (pastures, semi-natural and natural grassland	0.15
4 Forest and woodland	0.78
5 Heathland and shrub	0.01
6 Sparsely vegetated ecosystems	0.00
7 Inland wetlands	0.14
8 Rivers and canals	0
9 Lakes and reservoirs	0
10 Marine inlets and transitional waters	0
11 Coastal beaches, dunes and wetlands	0
12 Marine ecosystems (coastal waters, shelf and open ocean	0

It is recommended in the guidance note to report complementary variables to disentangle the supply and use of the service, especially when the service was calculated as average for the whole summer period as opposed to daily modelling on days exceeding 25 degrees Celsius.

According to hourly maximum temperature, based on weather station data[30], in 2024, in Estonia, the average number of days with maximum temperature exceeding 25°C was 36, number of days with maximum temperature exceeding 30°C was 1 and number of days with maximum temperature exceeding 35°C was 0.

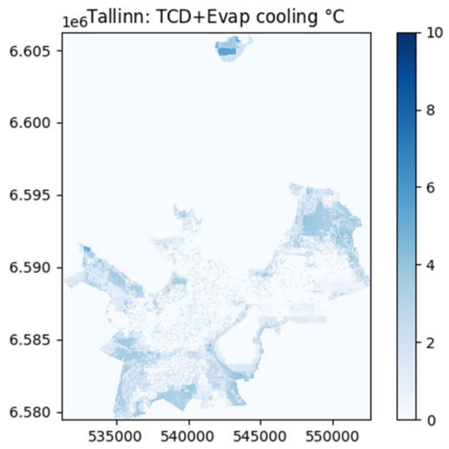
The users of the service are households (Table 20).

[30] Estonian Environment Agency, Historical weather data https://www.ilmateenistus.ee/kliima/ajaloolised-ilmaandmed/

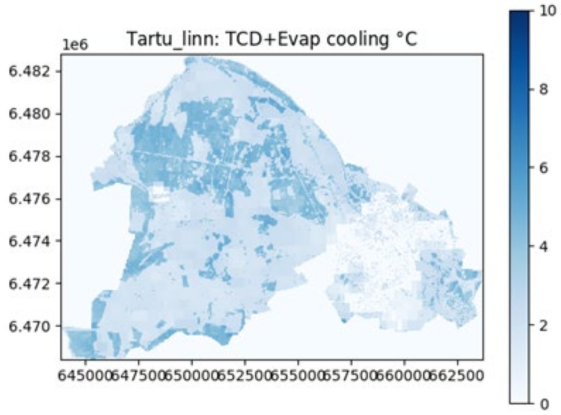
Table 20. Local climate regulation – use table (average daily reduced land surface temperature °C), 2024

	Intermediate consumption by industries	Government final consumption	Households final consumption	Gross capital formation	Exports	Total use
Local climate regulation (average daily reduced land surface temperature °C)			1.59			1.59

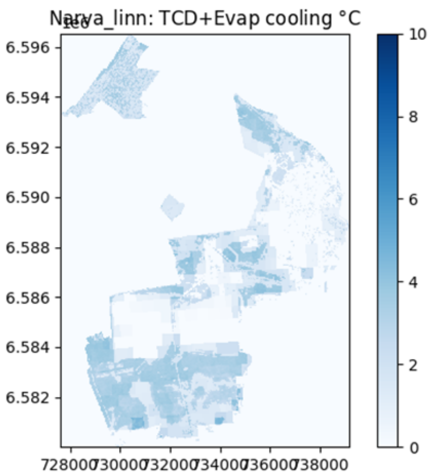
Figure 6. Local climate regulation (reduced land surface temperature °C by vegetation) in Estonian cities (Tallinn, Tartu, Narva) by local administrative unit (LAU).



Tallinn – Local climate regulation (reduced temperature °C by vegetation)



Tartu - Local climate regulation (reduced temperature °C by vegetation)



Narva - Local climate regulation (reduced temperature °C by vegetation)

4.5.2 An overview of studies on the calculation of economic value of the local climate regulation ecosystem service

The proposed legal module Ecosystem accounts defines the local climate regulation service as evaporative cooling of ambient air provided by urban trees. (Hereafter: *microclimate regulation.*) This service is of particular relevance to urban areas where most people are concentrated as well as due to the urban heat island effect where urban areas heat up more than the rural areas. According to the European Commission Eurostat guidance note (2023) the microclimate regulation is expressed and reported as the reduction of temperature in cities, due to the effect of urban vegetation on days exceeding 25 degrees Celsius (measured during a 24h period). [31]

The main aim of this paper is to give an overview of the studies where the economic value of the urban microclimate regulation has been calculated, and analyses which of these studies can be used for benefit transfer. Three limiting factors of the search was set following:

1. The study calculates the economic value of microclimate regulation in urban areas;
2. The publication period of the article is from 2010 to the present day;
3. The study was carried out in countries with similar or close socio-economic and climatic conditions to Estonia.

The following databases was used: Ecosystem Services Valuation Database (ESVD)[32], research database EBSCO *via* Tallinn University of Technology library[33], The ReseachGate[34]. Also simple Google search[35] was used. The following key words was used to search appropriate scientific articles and reports: “monetary value”, “economic value”, “value”, “microclimate regulation” “local climate regulation” “cooling”, “heat reduction”, “urban park”, “urban forest”, “urban tree”, “heatwaves”.

Below is presented study reports that may be considered to use for benefit transfer. No of these results are directly transferable as they have been carried out in countries with very different socio-economic and climatic conditions compare with Estonia.

1. McDonald and others (2020)[36] have assembled GIS-based information on tree cover and developed land-cover information for 97 US cities, housing 59 million people, and have used regression analyze to discover how much current urban tree cover reduces summer air temperatures and associated heat-related mortality, morbidity, and electricity consumption. To estimate the value of avoided morbidity a cost-of-illness approach is applied, quantifying the costs of emergency department and outpatient visits, hospitalizations, and the lost work productivity associated with these events. For estimating the value of avoided electricity consumption, data on average household residential electricity consumption and average cost per KWh of electric have used.

They found that 78% of urban dwellers are in neighbourhoods with less than 20% tree cover. Some 15.0 million people (25% of total) experience a reduction of 0.5–1.0°C from tree cover, with another 7.9 million (13% of total) experiencing a reduction of greater than 1.0°C. Relationships between temperature and health outcomes imply that urban tree cover helps avoid 245–346 deaths annually. For the 97 cities studied, the total annual economic value of avoided mortality, morbidity, and electricity consumption is an estimated $1.3–2.9 billion, or $21–49 annually per capita. Analysis estimated the value of avoiding one unit of heat-related impact, expressed in 2015 US dollars (USD, $).

The results of this study can be used for benefit transfer to calculate economic value of microclimate regulation in Estonia. During the transfer process the economic difference of the study country and Estonia must be levelled.

In the following articles, the economic value of the microclimate regulation of a specific ecosystem has been calculated using the conditional valuation method (CVM), i.e. the welfare value of the ecosystem service has been found.

2. Chen and Nakam (2015)[37] studied residents’ preference and willingness to conserve homestead woodlands in coastal villages in Okinawa Prefecture, Japan. Homestead woodlands have played a key role in protecting settlements from strong wind and storm. To evaluate residents’ willingness to conserve homestead woodlands the contingent valuation method (CVM) was used. The survey was conducted in December 2011 - January 2012. The sample size was 535, of which 480 answers were analyzed.

[31] Eurostat – Unit E2. Doc. Doc. ENV/EA/TF/2023_1/2. Guidance note for accounting for the local climate regulation ecosystem service in the EU – third draft. Task force on ecosystem accounting. 21 – 22 February 2023.
[32] https://www.esvd.net/
[33] https://taltech.ee/koik-andmebaasid
[34] https://www.researchgate.net/
[35] https://www.google.com/
[36] McDonald, R.I., Kroeger, T., Zhang P., Hamel, P (2020) The Value of US Urban Tree Cover for Reducing Heat-Related Health Impacts and Electricity Consumption. Ecosystems volume 23, pages137–150
[37] Chen, B., Nakama, Y. (2015) Residents’ preference and willingness to conserve homestead woodlands: Coastal villages in Okinawa Prefecture, Japan. Urban Forestry & Urban Greening. Volume 14 (4), pg 919-931. https://www.sciencedirect.com/science/article/pii/S1618866715001181

The majority of respondents (91%) favoured the conservation of homestead woodlands. Estimated mean and median lump sum willingness to pay (WTP) were JPY 1451 (USD 18[38]) per household and JPY 1000 (USD 12) per household, respectively.

The results of this study are useable for benefit transfer to calculate economic value of microclimate regulation of urban green areas. At the same time must consider that the willingness to pay for conservation of homestead woodlands was studied that is broader concept than microclimate regulation.

3. Zhang, *et al* (2021)[39] investigated residents' WTP for permeable pavement construction to mitigate urban heat impacts (UHI). The CVM was used and the WTP question was presented as follows: "If the Guangdong provincial government plans to replace more than 80% of the urban built-up area with permeable pavement by 2030, considering your financial condition and personal experience, would you agree to pay extra on your monthly water bill for the next 10 years to promote the construction of permeable pavement for UHI mitigation?" In questionnaire three bidding options were proposed: 5CNY, 20CNY, and 50CNY. The water bill was chosen as a payment vehicle in this study because it is compulsory and thus reduces the possibility of free riding.

799 urban residents of Guangdong Province responded to an online questionnaire. WTP intention was explored by establishing structural equation modelling based on the extended theory of planned behavior.

The findings show that the mean WTP was CNY 17.98 (USD 2.58[40]) per resident per month for permeable pavement construction for its UHI mitigation benefit. According to the official statistics, there were 115.21 million residents in Guangdong in 2019, so the present value of the total annual public WTP amounts to CNY 24.86 billion (USD 3.82 billion) per year.

Since the study does not specify how large area will be covered with permeable pavement, and how many degrees the UHI will decrease, the result obtained from benefit transfer is suitable to illustrate the situation in general.

Ecosystems that provide a microclimate regulation service are the subject of the following two studies.

4. Zhang, *et al* (2017)[41] conducted the study to estimate the economic values of and the dominant contributors to five key ecosystem services of wetlands in Beijing (total area 51 434 ha), by using the wetland inventory data in 2014 and economic valuation methods.

From June to August in Beijing, evaporation from water surfaces reaches is 363.8 mm; hence, the amount of evaporated water reaches approximately 134 million tons based on water surface ratio and wetland areas. The heat of water evaporation is 2260 kJ/kg in circumstances such as 1 standard atmospheric pressure and 100 °C; therefore, wetlands in Beijing can absorb approximately 3.03 PJ of heat through water evaporation during hot summer days, with an average value of 58.96 GJ/ha. River wetland can absorb 1.34 PJ of heat, reservoir wetland absorbs 1.15 PJ of heat as ponds, marshes and park wetlands are minor contributors to summertime heat absorption. However, reservoir wetland exhibits the highest absorption heat capacity with a value of 73.48 GJ/ha. On 2014, the price of electricity in Beijing was 0.5 RMB/kwh.

On 2014, total monetary value of the cooling effect of Beijing wetlands was calculated RMB 421 million[42] (USD 69 million) or RMB 8185 (USD 1333) per hectare.

5. Qianjiangyuan National Park in Kaihua County area is mainly (81.7%) covered by forest, remaining area is wetland and water. Zhao, *et al* (2019)[43] mapped ecosystem services of the park and calculated their economic value by using market value method and shadow engineering method. Studies were carried out in years 2005, 2010, 2015, and 2018.

According to the study methodology only wetland contributes to climate regulation. The value of regulating humidity have calculated by multiplying the average surface evaporation, steam power consumption converted from per unit volume of water and electricity price. The value of regulating temperature have calculated by multiplying the average surface evaporation, heat of vaporization of water and electricity

[38] USD 1 = 81.45 JPY (2011)
[39] Zhang, L., Yang, X., Fan, Y., Zhang, J. (2021) Utilizing the theory of planned behavior to predict willingness to pay for urban heat island effect mitigation. Building and Environment. Volume 204, 108136. https://www.sciencedirect.com/science/article/pii/S0360132321005370#bib66
[40] USD 1 = CNY 6.96 (2019)
[41] Zhang, B., Shi, Y., Liu, J., Xu, J., Xie, G. (2017) Economic values and dominant providers of key ecosystem services of wetlands in Beijing, China. Ecological Indicators. Volume 77, pg 48-58. https://www.sciencedirect.com/science/article/pii/S1470160X17300535
[42] USD 1 = RMB 6.14 (2014)
[43] Zhao, X., He, Y., Yu, C., Xu, D., & Zou, W. (2019). Assessment of Ecosystem Services Value in a National Park Pilot. Sustainability, 11(23), 6609. https://www.researchgate.net/publication/337451727_Assessment_of_Ecosystem_Services_Value_in_a_National_Park_Pilot#fullTextFileContent

price. Climate regulation service benefits people from May until September and therefor the value has calculated only for this period.

The total value of regulating humidity and temperature was RMB 0.51 billion (USD 63 million[44]), RMB 0.41 billion (USD 62 million[45]), RMB 0.27 billion (USD 42 million[46]), RMB 0.18 billion (USD 26 million[47]) in 2005, 2010, 2015 and 2018 respectively or USD 14.000, USD 13.800, USD 9.333 and USD 5.800 per one hectare of wetland in 2005, 2010, 2015 and 2018 respectively.

According to the comment of reviewer of the Ecosystem Services Valuation Database, the results seem to be too high.

In conclusion, the methods considered for benefit analysis for local climate regulation gave different results. However, as the methods are also different, the results are not easily comparable. Also, the methods mainly rely on contingent valuation (willingness to pay) and not using the quantity of the physical indicator that is currently defined as the reduction of temperature due to the effect of vegetation in cities. Therefore, no basis was found for the application of benefit transfer method for this service.

4.5.3 Local climate regulation based on CVM study – monetary valuation

Regulating the microclimate (or lowering the temperature) in an urban environment is a service that is becoming more and more actual due to the warming of the climate, the increase in the number of consumers can also be predicted geographically, including in the northernmost countries of Europe. Unlike several other ecosystem regulatory services, such as carbon sequestration, microclimate has an immediate, directly felt effect on the welfare of individuals. Therefore, microclimate regulation service of the ecosystem has, in addition to the regulatory one, a strong welfare service component, and its value can be studied not only by the biophysical methods, but also by methods characteristic of the welfare services of the ecosystem.

The ecosystem microclimate regulation service has been studied as a welfare service mostly in Asia. For example, the contingent valuation (hereafter CVM) method has been used to study the ecosystem service value of urban forests in South Korea (Jo Jang-Hwan et. al., 2020)[48] and to study the ecosystem service value of forests in Japan (Bixia Chen, Yuei Nakama, 2015)[49]. Neither of the studies cited above specifically focuses on the microclimate regulation service of the ecosystem but examines this service together with other services. The same approach is used in the study of well-being services of urban ecosystems in Estonia (Ehrlich, 2022)[50] where microclimate-regulating services of urban ecosystems are studied in one CVM study together with other services of urban ecosystems.

A contingent valuation study on ecosystem services of urban green spaces in Estonia was conducted in 2019. The survey is based on 720 respondents and the sample structure was representative of the Estonian adult population. Whereas one of the aims of the CVM study was to find the financial equivalent of nonmarket services in the urban ecosystem, the structure of the questionnaire was more complicated than typical CVM survey. In addition to the typical parts of the CVM questionnaire, such as the simulated market scenario, the willingness to pay question (discrete choice format) and the sociometric part of the respondents, the questionnaire also included additional questions on the use and sufficiency of urban green areas. To link WTP to individual services of urban ecosystems, respondents were asked to rank urban ecosystems and ecosystem services according to their subjective preferences.

The estimation of the aggregated demand curve for the preservation and maintenance of urban green spaces of Estonian`s adult population is based on the actual distribution of WTP amounts obtained from the survey. The results are generalized to the proportion of the population with positive WTP, which is 90,5 per cent i.e. about 969000 persons 18 years of age or older in Estonia as of January 1st, 2019. In calculations, one respondent corresponds to 1486 inhabitants. The annual demand for urban green spaces by the Estonian adult population expressed through WTP is approx. 17,29 million euros.

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[44] USD 1 = RMB 8.07 (2005)
[45] USD 1 = RMB 6.59 (2010)
[46] USD 1 = RMB 6.50 (2015)
[47] USD 1 = RMB 6.88 (2018)
[48] Jo Jang-Hwana, Park So-Heeb, Koo JaChoonc, Roh Taewood, Emily Marie Lime and Youn Yeo-Changb, 2020. Preferences for ecosystem services provided by urban forests in South Korea. Forest Science and Technology E-ISSN 2158-0715, 2020, VOL. 16, NO. 2, 86–103. https://doi.org/10.1080/21580103.2020.1762761
[49] Bixia Chen, Yuei Nakama, 2015. Residents' preference and willingness to conserve homestead woodlands: Coastal villages in Okinawa Prefecture, Japan. Urban Forestry & Urban Greening, Vol 14 (4), pg 919-931. https://www.sciencedirect.com/science/article/pii/S1618866715001181
[50] Ehrlich, Ü., 2022. Willingness to pay for urban ecosystem services as input for statistics: a case of Estonia. Estonian Discussions on Economic Policy, 30 (1-2), 85–103. DOI: 10.15157/tpep.vi1-2.22088.

In addition to identify willingness to pay for urban ecosystem services, an additional goal of the study was to divide willingness to pay between different services according to individuals' subjective preferences for services. The corresponding data are presented in Table 21.

Table 21. The willingness to pay of the Estonian population for urban ecosystem services.

Urban area ecosystem service	Importance	% (of inverse value)	WTP (thousand EUR)
City air purification	1.	14.9	2579.0
Photosynthesis (oxygen production)	2.	11.1	1924.8
Providing recreation and leisure opportunities	3.	10.9	1884.9
Traffic noise reduction	4.	10.3	1773.5
Habitat supply for biological species (e.g. birds)	5.	10.2	1766.1
Ensuring the diversity of urban space	6.	9.7	1673.1
Urban microclimate regulation and carbon sequestration	7.	9.7	1674.5
Offering aesthetic pleasure (flower buds, alleys)	8.	8.1	1401.7
Providing shade for people (e.g. from wind and sun)	9.	7.9	1360.7
Providing opportunities for environmental education	10.	7.2	1249.4
TOTAL		100	17287.8

The shortcoming of the study in relation to the identification of the microclimate regulation service of the urban ecosystem is the formulation of the service "Urban microclimate regulation and carbon sequestration" used in the questionnaire, which handles microclimate regulation and carbon sequestration together in one service. It can be assumed that the microclimate regulation service separately (without carbon sequestration) would have received a lower place in the ranking and thus a lower willingness to pay. However, according to the formulation in the questionnaire, individuals placed this service in seventh place (among 10 services), according to which approximately 1.7 million euros per year were attributed to this service from the total willingness to pay.

In addition to individuals' preferences for ecosystem services, the subjective importance of different urban ecosystems for people was also investigated, on the basis of which WTP was distributed among different ecosystems. The corresponding results are presented in Table 22.

Table 22. Distribution of WTP for the service "Urban microclimate regulation and carbon sequestration" between urban ecosystems.

Urban Ecosystem	WTP, thousand EUR
Big Parks	390.18
Small parks in the city centre	289.22
Tall landscaping (by the roads)	266.13
Forests within the city borders	210.82
Privately owned gardens	175.83
Lawn strips and flower pots by the sidewalks	175.35
Lawn strips by the road and between lanes	166.98
TOTAL, thousand EUR	1674.52
% of total value	9.69

People considered "Big parks" to be the most important ecosystem, whose "Urban microclimate regulation and carbon sequestration" service can be attributed 390 thousand euros per year from the total willingness to pay. "Small parks in the city center" (298 thousand euros) and "Tall landscaping" (266 thousand euros) follow. As expected, "Lawn strips and flower pots by the sidewalks" and "Lawn strips by the road and between lanes" are among the last ecosystem elements, as urban ecosystems with smaller biomass, which participate more modestly in climate regulation compared to parks.

The different urban green features were crosswalked to ecosystem types of EU ecosystem typology:

- 1.4 Urban greenspace: big parks, small parks in the city centre, tall landscaping (by the roads), forests within the city borders,
- 1.5 Other artificial areas: privately owned gardens, lawn strips and flower pots by the sidewalks, lawn strips by the road between lanes

Based on the obtained results monetary supply and use tables were compiled. The result is presented in Table 23. The service is only supplied in the ecosystem class Settlements and other artificial areas.

The users of the service are households.

Table 23. Monetary value of the supply of local climate regulation, million EUR, 2024

	Monetary value of local climate regulation services, million EUR
1 Settlements and other artificial areas	1.67
1.4 Urban greenspace	1.16
1.5 Other artificial areas	0.52

4.6 Nature-based tourism-related services

According to the Regulation (EU) 691/2011, the ecosystem service nature-based tourism-related services are defined as the ecosystem contribution, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. Those contributions should be reported in number of overnight stays in hotels, hostels, camping grounds, etc. that can be attributed to visits to ecosystems.

The methodology for assessing nature-related tourism in physical units was built on previous experience and guidance in the respective guidance notes by Eurostat. The number of overnight stays was first distributed by degree of urbanisation and further the contribution by ecosystem types was calculated using Recreation Map Potential by JRC in INCA Tool version 2.2.1[51]. Instead of using tourism statistics at NUTS 3 level as is recommended by latest guidance and INCATool user guide, NUTS level 2 data was used as to continue with previously used methodology.

NUTS 3 level tourism statistics was tested with extended calculations with INCA Tool.

For monetary valuation, the service was valued with expenditures made during the trip.

4.6.1 Nature-based tourism-related services – physical account

The number of overnight stays of tourists in hotels, hostels, camping grounds, etc., that can be attributed to visits to ecosystems is considered the mandatory indicator for the nature-based tourism-related ecosystem service.

Guidance note by Eurostat[52] requires using a three step-approach for the measurement of the indicator:

1) Collecting tourism statistics on overnight stays
2) Isolating the ecosystem contribution in general
3) Apportioning overnight stays between ecosystem types.

We used statistics on nights spent in hotels, holiday and other short-stay accommodation; camping grounds, recreational vehicle parks and trailer parks published at NUTS level 2 published by Eurostat (Online data code: TOUR_OCC_NIN2D, (https://ec.europa.eu/eurostat/databrowser/view/tour_occ_nin2d/default/table?lang=en), which is also available in Statistics Estonia Database (TU111: Accommodation by type of settlement, https://andmed.stat.ee/et/stat/majandus__turism-ja-majutus__majutus/TU111). The input data on overnight stays is given in Table 24.

[51] https://ecosystem-accounts.jrc.ec.europa.eu/inca-tool
[52] Eurostat – Unit E2. Guidance Note for Accounting for the Recreation-Related Ecosystem Service – Final Draft for Testing. (Version October 2023)

Table 24. Nights spent at tourist accommodation establishments by degree of urbanisation, 2024

	Domestic	Foreign	Total
Cities	1 020 019	2 766 430	3 786 449
Towns and suburbs	699 223	589 849	1 289 072
Rural areas	1 258 691	311 696	1 570 387
Total	2 977 933	3 667 975	6 645 908

At NUTS level 2 Estonia is considered as one region, including the bigger cities. There are more detailed tourism statistics available in Statistics Estonia, such as overnight stays by municipality level (TU112: Accommodated tourists and nights spent by county and country of residence, https://andmed.stat.ee/en/stat/majandus__turism-ja-majutus__majutus/TU112), which could be used to improve the accuracy of isolating the ecosystem contribution and the apportionment to ecosystem types in the next steps.

It is recommended that calculating the ratio of ecosystem contribution is done by applying Recreation Potential Map (RP, developed by JRC), which is based on the presence of reachable opportunities for nature-based activities (quantified using inland and water related elements). The ratio of ecosystem contribution could be then scaled based on additional data like input data on higher spatial accuracy, the degree of urbanization or trip purpose. However, as the Recreation Potential Map is not yet available for the member states to be used additional data sources could not be applied in this step and it was decided it is better to use degree of urbanization and corresponding ecosystem contribution ratios by expert judgement to reflect better the share of overnight stays that could be attributed to visits to ecosystems. Rough estimations based on available national statistics on overnight stays and trip purpose (percentage of trips for professional versus personal reasons in cities, rural areas and in between) were 20% for cities, 60% for towns and suburbs and 90% for rural areas (Table 25).

Table 25. Nights spent at tourist accommodation establishments attributed to visits to ecosystems, 2022

	Ecosystem Contributio Ratio	Domestic country	Foreign country	Total
Cities	20	204 004	553 286	757 290
Towns and suburbs	60	419 534	353 909	773 443
Rural areas	90	1 132 822	280 526	1 413 348
Total		1 756 360	1 187 722	2 944 081

The total number of overnight stays attributed to visits to ecosystems were further attributed to specific ecosystem types at level 1 on EU Ecosystem typology using the Recreation Potential Map developed by JRC (2018). In Recreation Potential Map the spatial allocation is based on a weighted distribution inside NUTS2 regions, whereby the percentage of overnights stays attributed to an ecosystem is equal to the attractiveness metric of the ecosystem divided by the sum of all attractiveness metrics within the NUTS2 region.

The calculations were done in INCA Tool version 2.2.1[53] and the model was modified to use ecosystem extent map for year 2024 created by Statistics Estonia and aforementioned degrees of urbanisation. Recreation potential map is based on CORINE Land Cover map. When using Estonian ecosystem extent map misalignments between ecosystem types occurred. For example, ecosystem types 'Settlements and other artificial areas and 'Cropland', which were attributed 0-value in default approach, now obtained values. It was decided not to modify the model further and therefore values for all ecosystem types were included. The result is presented in Table 26.

[53] https://ecosystem-accounts.jrc.ec.europa.eu/inca-tool

Table 26. Supply of Nature-based tourism-related services by ecosystem types, 2024.

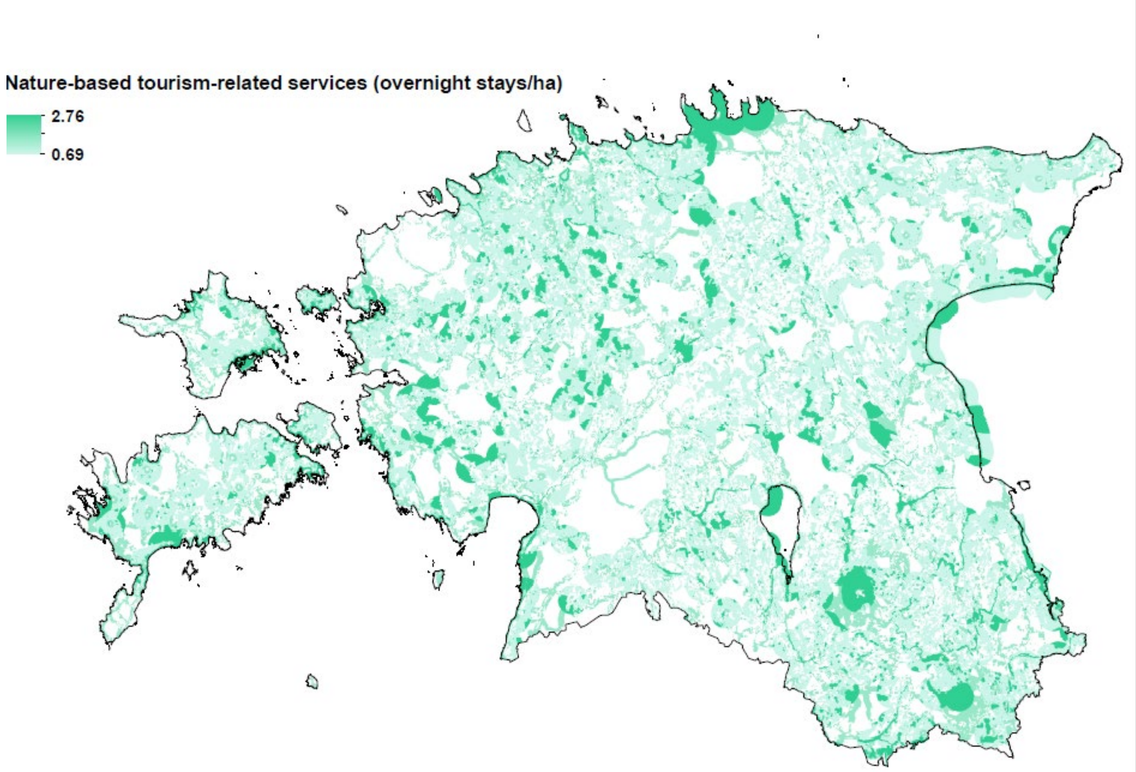
	Number of overnight stays that can be attributed to visits to ecosystems
1 Settlements and other artificial areas	189 717
2 Cropland	225 200
3 Grassland (pastures, semi-natural and natural grassland	377 575
4 Forest and woodland	1 753 096
5 Heathland and shrub	13 440
6 Sparsely vegetated ecosystems	3 172
7 Inland wetlands	211 057
8 Rivers and canals	22 244
9 Lakes and reservoirs	140 038
10 Marine inlets and transitional waters	1 025
11 Coastal beaches, dunes and wetlands	1 926
12 Marine ecosystems (coastal waters, shelf and open ocean	5 593
Total supply	2 944 083

The use of the service is divided between household and export. Domestic tourism by residents is to be reported as 'Households' final consumption'. Overnight stays performed by visitors who are not resident of the reporting country (also called inbound tourism) are to be reported as 'Exports'. The result is presented in Table 27 and as an illustrative map in Figure 7.

Table 27. Use of nature-based tourism-related services, 2024.

	Households	Export	Total use
Number of overnight stays that can be attributed to visits to ecosystems	1 756 360	1 187 723	2 944 083

Figure 7. The ecosystem service provisioning areas and values of nature-based tourism-related services.



4.6.2 Testing INCATool: Input and Processing overview for Nature-based tourism for default configurations

INCA Default Configurations

Default 1 Configuration

- Eco contribution per type of area: Lookup_default1/typeAreaContributionTable.csv
- Accessibility map: Recreation_potential_map/ROS2018_basic.tif
- Accessibility weights: Lookup_default1/accessibility_weights.csv
- Landscape attractiveness map: Recreation_potential_map/ROS2018_basic.tif
- Landscape attractiveness weights: Lookup_default1/landscape_attractiveness_weights.csv

Default 2 Configuration

- Eco contribution per type of area: Lookup_default2/typeAreaContributionTable.csv
- Area category map: Recreation_potential_map/ROS2018_basic.tif
- Area category eco contribution table: Lookup_default2/data_area_weights.csv

Both configurations require:

- Run name
- Overnight stays parameters

Source: INCA Tool: User Guide, Section 5.3 – Nature-based tourism

<u>Overnight stays 2022-2023</u>

INCA input parameters:

- Data and Reporting areas: NUTS-3.
- Land cover: CORINE 2018.
- Translation: CLCACC level 1 (level 2 gives the same results).
- Default 2 configuration.

Both Default 1 and Default 2 configurations were tested with Estonian data. While Default 1 also runs successfully, it produced less realistic supply patterns, especially for regional comparisons.

For this analysis, Default 2 configuration was used instead of Default 1, as it provided more realistic and consistent results for Estonia, particularly in terms of regional variation and supply distribution.

All the models and outputs presented in this overview are based on the Default 2 configuration, ensuring comparability across years and land cover inputs.

CORINE 2021 does not give satisfactory results: When using CORINE 2021 with provided translation table, level 1 or 2, the resulting tables are empty.

<u>Overnight stays 2024</u>

Data Source and Structure: Used data for nights spent, available in Statistics Estonia Database (TU112: ACCOMMODATED TOURISTS AND NIGHTS SPENT BY COUNTY AND COUNTRY OF RESIDENCE, TU112: ACCOMMODATED TOURISTS AND NIGHTS SPENT BY COUNTY AND COUNTRY OF RESIDENCE. Statistical database)

Data Aggregation: Grouped counties according to Estonia's NUTS3 classification into five regions (Northern, Western, Southern, Central, and Northeastern Estonia). Then summed overnight stays for counties within each NUTS-3 region.

NUTS3 Codes and Area Types: INCA tool requires a TypeOfArea field (Cities or Rural areas). Assigned Harju and Ida-Viru as Cities, and all other regions as Rural areas. Eurostat overnight stays data was used as reference.

Unique ID Issue: The original INCA table includes a unique row ID, missing from the 2024 data. Added sequential unique IDs to each row to comply with INCA tool requirements. IDs were based on previous overnight stays data for Estonia. Without the IDs an error will occur.

Input parameters:

- Data and Reporting areas: NUTS-3.
- Default 2 configuration.

- land cover map: Corine 2018.
- ecosystem translation: CLCACC level 1.
- overnight stays 2024.

Results for using CORINE Land Cover map

Table 28 Supply of nature-based tourism-related services using CORINE Land Cover map

	Number of overnight stays that can be attributed to visits to ecosystems, 2022	Number of overnight stays that can be attributed to visits to ecosystems, 2023	Number of overnight stays that can be attributed to visits to ecosystems, 2024
1 Settlements and other artificial areas	164 155	183 273	195 727
2 Cropland	667 143	711 576	738 718
3 Grassland (pastures, semi-natural and natural grassland	346 163	379 484	400 516
4 Forest and woodland	1 987 748	2 144 951	2 246 073
5 Heathland and shrub	10 352	11 078	11 670
6 Sparsely vegetated ecosystems	441	472	498
7 Inland wetlands	159 107	169 407	176 689
8 Rivers and canals	1 725	1 733	1 765
9 Lakes and reservoirs	91 266	92 593	95 277
10 Marine inlets and transitional waters	855	857	877
11 Coastal beaches, dunes and wetlands	4 272	4 622	4 885
12 Marine ecosystems (coastal waters, shelf and open ocean	0	0	0
Total supply	**3 433 227**	**3 700 046**	**3 872 695**

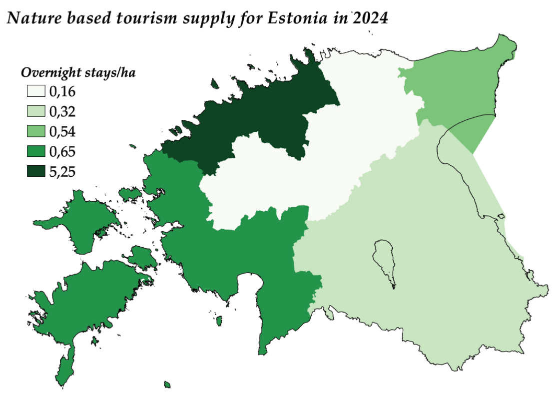
Table 29 Use of nature-based tourism-related services using CORINE Land Cover map

	Households	Export	Total use
Number of overnight stays that can be attributed to visits to ecosystems, 2022	1 677 772	1 755 455	3 433 227
Number of overnight stays that can be attributed to visits to ecosystems, 2023	1 669 008	2 031 038	3 700 046
Number of overnight stays that can be attributed to visits to ecosystems, 2024	1 659 512	2 213 183	3 872 695

Figure 8 Overnight stays tourism supply amount using CORINE extent map for years 1) 2022, 2) 2023, 3) 2024

1) 

2) 



3)

Results for using Statistics Estonia extent map

Input parameters:

- Data and Reporting areas: NUTS-3.
- Default 2 configuration.
- Land cover map: ext_eui_inca21.tif.
- Ecosystem translation: Stat_ext_ecosystem_level1_translation_ARv2.csv.
- Overnight stays 2024 (same configuration for different years).

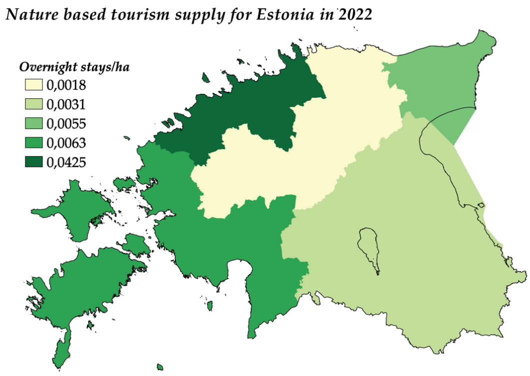
Table 30 Supply of nature-based tourism-related services using Statistics Estonia ecosystem extent map

	Number of overnight stays that can be attributed to visits to ecosystems, 2022	Number of overnight stays that can be attributed to visits to ecosystems, 2023	Number of overnight stays that can be attributed to visits to ecosystems, 2024
1 Settlements and other artificial areas	333 967	368 289	390 640
2 Cropland	502 019	538 241	558 260
3 Grassland (pastures, semi-natural and natural grassland	394 969	427 060	448 925
4 Forest and woodland	1 844 598	1 989 054	2 081 880
5 Heathland and shrub	11 160	12 021	12 650
6 Sparsely vegetated ecosystems	2 630	2 816	2 949
7 Inland wetlands	210 077	224 023	233 763
8 Rivers and canals	22 465	24 291	25 508
9 Lakes and reservoirs	98 613	100 452	103 533
10 Marine inlets and transitional waters	621	660	694
11 Coastal beaches, dunes and wetlands	2 917	3 219	3 427
12 Marine ecosystems (coastal waters, shelf and open ocean	9 149	9 870	10 410
Total supply	**3 433 185**	**3 699 996**	**3 872 639**

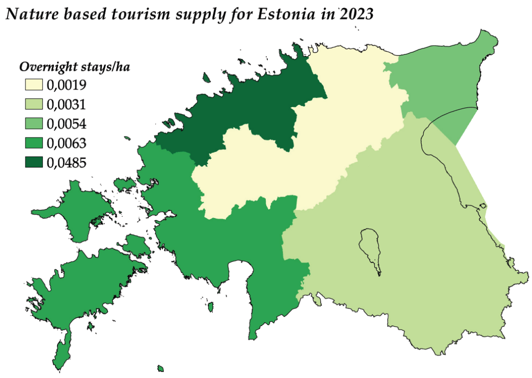
Table 31 Use of nature-based tourism-related services using Statistics Estonia ecosystem extent map,

	Households	Export	Total use
Number of overnight stays that can be attributed to visits to ecosystems, 2022	1 677 760	1 755 425	3 433 185
Number of overnight stays that can be attributed to visits to ecosystems, 2023	1 668 992	2 031 004	3 699 996
Number of overnight stays that can be attributed to visits to ecosystems, 2024	1 659 493	2 213 146	3 872 639

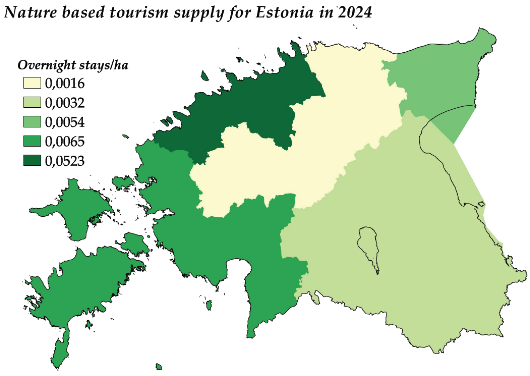
Figure 9 Overnight stays tourism supply amount using Estonian ecosystem extent map for years 1) 2022, 2) 2023, 3) 2024



1)



2)



3)

Results overview

CLC (CORINE 2018):

- Produced valid tables and spatial output.
- Both Level 1 and Level 2 translation tables gave consistent results.
- Both Default 1 and Default 2 configuration gave consistent results.
- Compatible with all years tested (2022-2024).

Stat Extent:

- After reprojecting to EPSG 3035 and proper formatting of the translation table, INCATool successfully processed the custom raster.
- Both Default 1 and Default 2 configuration gave consistent results.
- Satisfactory map and table output were generated.

Notable Spatial Pattern in Tourism Supply (2022–2024)

Across all years (2022–2024), Northern Estonia consistently provided the highest tourism supply, regardless of whether the CORINE land cover or Stat_extent raster was used.

Western Estonia was the second-highest supplier in most cases. However, an exception occurred in 2023 with the Stat_extent raster, where North-Eastern Estonia unexpectedly became the second-highest contributor to tourism supply.

This shift may reflect:

- Changes in underlying land classification or raster composition in the Stat_extent for that year.
- Local land use or infrastructure updates not captured in the broader CORINE dataset.

Possible explanation of value differences between CORINE and Stat_extent supply maps

The noticeable difference in supply values between CORINE-based maps (range: 0.1–1.4) and Stat_extent-based maps (range: 0.002–0.05) is primarily due to two factors:

1. **Ecosystem Classification**
   CORINE uses a broader and more detailed set of land classes, covering extensive and often high-supply ecosystems such as forests, coastal areas, or recreation-prone landscapes. In contrast, the Stat_extent raster is based on a simplified EU ecosystem typology with only 12 categories. These may represent smaller, more fragmented, or lower-contribution ecosystem units, leading to lower average supply values per pixel.

2. **Raster Resolution and Pixel Size**
   INCA calculates supply per raster cell. If the Stat_extent raster has a finer resolution (smaller pixels), each cell covers a smaller area and therefore contributes less in absolute terms, resulting in lower values compared to the coarser CORINE raster.

Despite differences in absolute values, both maps are valid as long as relative spatial patterns and trends remain consistent.

4.6.3 Nature-based tourism-related services – monetary valuation

For monetary valuation, the service was valued with expenditures made during the trip. Alternative valuation was done by time-use approach.

There is data available from tourism statistics on the average expenditure on an overnight domestic trip for holidays, leisure and recreation purpose (TU56: Expenditure on an overnight domestic trip of Estonian residents by main purpose of trip, https://andmed.stat.ee/en/stat/majandus__turism-ja-majutus__eesti-elanike-reisimine/TU56). In 2024 it was 221.26 EUR. The expenditure includes expenses for travel, accommodation, catering, entertainment, shopping and other money spent.

Table 32. Monetary value of the supply of nights spent at tourist accommodation establishments by ecosystem types using expenses made during the trip, million EUR, 2024

	Monetary value of nature-related tourism related services, million EUR
1 Settlements and other artificial areas	41.5
2 Cropland	50.1
3 Grassland (pastures, semi-natural and natural grassland	82.4
4 Forest and woodland	388.8
5 Heathland and shrub	2.9
6 Sparsely vegetated ecosystems	0.7
7 Inland wetlands	46.9
8 Rivers and canals	5
9 Lakes and reservoirs	31.1
10 Marine inlets and transitional waters	0.2
11 Coastal beaches, dunes and wetlands	0.4
12 Marine ecosystems (coastal waters, shelf and open ocean	1.4
Total supply	651.4

The use in monetary terms is divided similarly as was done for use in physical units.

Table 33. Use of nature-based tourism-related services, million EUR, 2024

	Households	Export	Total use
Monetary value of nature-related tourism related services , million EUR	388.6	262.8	651.4

Alternative valuation was done by applyingy the valuation by time use and use the monetary equivalent of contact time with ecosystems 56 EUR/overnight trip which was based on that 1 hour=7 EUR and that the average contact time of one person with nature (ecosystems) during one overnight trip is 8 hours. The results are seen in

Table 34.

Table 34. Monetary value of the supply of nights spent at tourist accommodation establishments by ecosystem types using time use valuation, million EUR, 2024

	Monetary value of nature-related tourism related services, million EUR
1 Settlements and other artificial areas	10.62
2 Cropland	12.61
3 Grassland (pastures, semi-natural and natural grassland	21.14
4 Forest and woodland	98.17
5 Heathland and shrub	0.75
6 Sparsely vegetated ecosystems	0.18
7 Inland wetlands	11.82
8 Rivers and canals	1.25
9 Lakes and reservoirs	7.84
10 Marine inlets and transitional waters	0.06
11 Coastal beaches, dunes and wetlands	0.11
12 Marine ecosystems (coastal waters, shelf and open ocean	0.31
Total supply	164.87

4.7 Supply and use tables

The supply and use tables record the actual flows of ecosystem services supplied by ecosystem assets and used by economic units during an accounting period and the same structure can be used for both physical and monetary terms (SEEA TR 2.27). In the project physical and monetary supply and use tables of ecosystem services for 2024 for Estonia were compiled. In several cases, the input data for monetary valuation calculations for year 2024 was not yet available (wood provision, crop pollination, air filtration, global climate regulation), therefore previously calculated values were used as placeholders. Valuations not conducted for the 2024 reference year are indicated in brackets in the ecosystem service name in the supply and use tables.

Supply and use tables give complete and structured way to present and analyse calculated values of ecosystem services. The structure of the supply and use tables are similar to tables used in National Accounts and therefore values could easily be compared.

Supply table contains information about ecosystem types and ecosystem services. Different ecosystem types are considered as suppliers and ecosystem services are products that are supplied by ecosystem types. In the supply table it can be seen which ecosystem services are provided in which ecosystem asset.

Use table gives information about users of the services by ecosystem services. Users are distributed by institutional sectors and corporations are further broken down by NACE activity. In this grant project use is distributed between corporations, general government and households. Ecosystem services in supply and use tables are the same and total value of supply is equal to use as ecosystem service is provided only if it is used.

Table 35 and Table 36 show the supply and use of ecosystem services in physical account. The table is structured according to the Eurostat questionnaire (2024 Data collection). The completed Eurostat questionnaire and associated metadata are provided in Annex “D3.3 Dataset on ecosystem service supply-use.xlsx” (MS Excel file). The services included in the table have different units, therefore summarizing over ecosystem types is not possible.

Table 37 and Table 38 show the supply and use of ecosystem services in monetary units. The services have the same unit and are potentially additive. Therefore it was possible to calculate the total supply by ecosystem types and also bring out values for subcategories of services: provisioning (includes crop provision, crop pollination, wood provision), regulating (air filtration, global climate regulation: net carbon sequestration, global climate regulation:

carbon storage, local climate regulation), cultural (nature-based tourism-related services: overnight stays). However, the gross values and also single monetary values should be treated cautiously considering the underlying assumptions of the definitions and methodologies.

Supply and use of the ecosystem services in Eurostat questionnaire format with metadata is presented in Annex "D3.3 Dataset on ecosystem service supply-use.xlsx" (MS EXCEL file).

Table 35. Supply of ecosystem services by ecosystem types (EU ecosystem typology, level 1) - physical account (2024). Results for air filtration and global climate regulation are calculated for reference year 2022 in project 101113157 — 2022-EE-EGD.

SUPPLY	UNIT	1 Settlements and other artificial areas	2 Cropland	3 Grassland	4 Forest and woodland	5 Heathland and shrub	6 Sparsely vegetated ecosystems	7 Inland wetlands	8 Rivers and canals	9 Lakes and reservoirs	10 Marine inlets and transitional waters	11 Coastal beaches, dunes and wetlands	12 Marine ecosystems	TOTAL SUPPLY
Crop provision	1000 tonnes	0	3 418	281	0	0	0	0	0	0	0	0	0	3 699.00
Crop pollination	1000 tonnes	17.87	2.47	34.93	49.70	0.33	0.06	0.35	0	0	0	0.01	0	105.71
Wood provision (increment cultivated)	1000 m3	16.85	0	0	9 283.15	0	0	0	0	0	0	0	0	9 300.00
Wood provision (removals non cultivated)	1000 m3	0	0	0	0	0	0	0	0	0	0	0	0	0
Air filtration of PM10	tonnes													
Air filtration of PM2.5	tonnes	33.70	108.07	53.76	326.17	1.62	0.33	22.42	3.31	2.60	0.00	0.06	0	552.05
Global climate regulation - net sequestration (indicator)	tonnes	631	0	46 434	452 023	0	0	0	0	0	0	0	0	499 088
Global climate sequestration - primary net sequestration (ecosystem service)	tonnes													
Global climate regulation - storage 30cm	tonnes													
Global climate regulation - storage 100cm	tonnes													
Global climate regulation - storage whole depth	tonnes	152 514 320	557 511 530	385 212 935	2 418 070 842	11 967 133	2 415 463	485 431 298	44 452 594	14 358 707	160 409	1 743 615	0	4 073 838 845
Local climate regulation	degrees C	0.61	0.55	0.15	0.78	0.01	0.00	0.14	0	0	0	0	0	1.59
Nature-based tourism	overnight	189 717	225 200	377 575	1 753 096	13 440	3 172	211 057	22 244	140 038	1 025	1 926	5 593	2 944 083
Nature-based recreation	visits													

Table 36. Use of ecosystem services by economic sectors - physical account (2024). Results for air filtration and global climate regulation are calculated for reference year 2022 in project 101113157 — 2022-EE-EGD.

USE	UNIT	Intermediate consumption by industries	Government final consumption	Households final consumption	Gross capital formation	Export	TOTAL USE
Crop provision	1000 tonnes	3 699	0	0	0	0	3 699
Crop pollination	1000 tonnes	1 665	0	0	0	0	1 665
Wood provision (increment cultivated)	1000 m3	9 300	0	0	0	0	9 300
Wood provision (removals non cultivated)	1000 m3	0	0	0	0	0	0
Air filtration of PM10	tonnes						
Air filtration of PM2.5	tonnes	0	0	552	0	0	552
Global climate regulation - net sequestration (indicator)	tonnes	0	499 088	0	0	0	499 088
Global climate sequestration - primary net sequestration (ecosystem service)	tonnes						
Global climate regulation - storage 30cm	tonnes						
Global climate regulation - storage 100cm	tonnes						
Global climate regulation - storage whole depth	tonnes	0	4 073 838 845	0	0	0	4 073 838 845
Local climate regulation	degrees C	0.00	0.00	1.59	0.00	0.00	1.59
Nature-based tourism	overnight stays	0	0	1 756 360	0	1 187 723	2 944 083
Nature-based recreation	visits						

Cell shading:

Light blue (cyan): Lower priority data.

White: Priority data. Need to be entered (no calculation).

Light grey: Priority data. The calculation of data is automatic when lower order data are provided. These cells can be edited after unlocking the cell with the button "Unlock formulas".

Table 37. Supply of ecosystem services by ecosystem types (EU ecosystem typology, level 1) - monetary account (2024), million EUR. Valuations not conducted for the 2024 reference year are indicated in brackets in the ecosystem service name.

		Ecosystem type												
Ecosystem service	**Indicator and unit**	**1 Settlements and other artificial areas**	**2 Cropland**	**3 Grassland (pastures, semi-natural and natural grassland**	**4 Forest and woodland**	**5 Heathland and shrub**	**6 Sparsely vegetated ecosystems**	**7 Inland wetlands**	**8 Rivers and canals**	**9 Lakes and reservoirs**	**10 Marine inlets and transitional waters**	**11 Coastal beaches, dunes and wetlands**	**12 Marine ecosystems**	**Total supply**
Crop provision	Rent price method		82	31										113
Crop pollination (2022)	Market value of crop yield requiring pollination	10.30	1.80	20.95	28.89	0.19	0.03	0.21				0.01		62.38
Wood provision (2023)	Stumpage value of net increment	0.7			382.3									383
Air filtration	Benefit transfer	0.0781	0.2505	0.1246	0.7561	0.0038	0.0008	0.0520	0.0077	0.0060	0.0000	0.0001	0.0000	1.28
Global climate regulation: net carbon sequestration (2022)	Revealed preference based on EU ETS price of net sequestrated carbon	0.19		14.35	139.74									154.29
Global climate regulation: carbon storage (2022)	Revealed preference based on EU ETS price of stored carbon	47 150	172 354	119 088	747 542	3 700	747	150 070	13 742	4 439	50	539		1 259 420
Local climate regulation	Willingness to pay study	1.67												1.67
Nature-based tourism-related services: overnight stays	Expenditures on overnight trip	41.5	50.1	82.4	388.8	2.9	0.7	46.9	5.0	31.1	0.2	0.4	1.4	651.4

Table 38. Use of ecosystem services by economic sectors - monetary account (2024), million EUR. Valuations not conducted for the 2024 reference year are indicated in brackets in the ecosystem service name.

	Economic sector					
Ecosystem service	**Intermediate consumption by industries**	**Government final consumption**	**Households final consumption**	**Gross capital formation**	**Exports**	**Total use**
Crop provision	113					**113**
Crop pollination (2022)	62.38					**62.38**
Wood provision (2023)	383					**383**
Air filtration (2022)			1.28			**1.28**
Global climate regulation: net carbon sequestration (2022)		154.29				**154.29**
Global climate regulation: carbon storage (2022)		1 259 420				**1 259 420**
Local climate regulation			1.67			**1.67**
Nature-based tourism-related services: overnight stays			388.6		262.8	**651.4**

4.8 Communication of the results

The report with the results is made available on Statistics Estonia web platform.

Ecosystem services maps are displayed also in web interface. The data is visualized in the application of ArcGIS Experience which was developed in current and previous projects. The development and maintenance of the web application has been co-funded by the European Union.

The application includes ecosystem extent and services.

Ecosystem extent was updated for year 2024 data by EU ecosystem typology level 2 types. Level 2 types were added to previously published results on EU ecosystem typology level 1 data. The ecosystem extent is visualized by a 500x500m square grid covering the whole of Estonia.

Data on mandatory ecosystem services according to EU regulation 691/2011 are included in the application. These include crop provision, wood provision, pollination, global climate regulation (carbon storage), air filtration, local climate regulation, and nature-based tourism. The update for year 2024 data was made for crop provision, wood provision, local climate regulation and nature-based tourism.

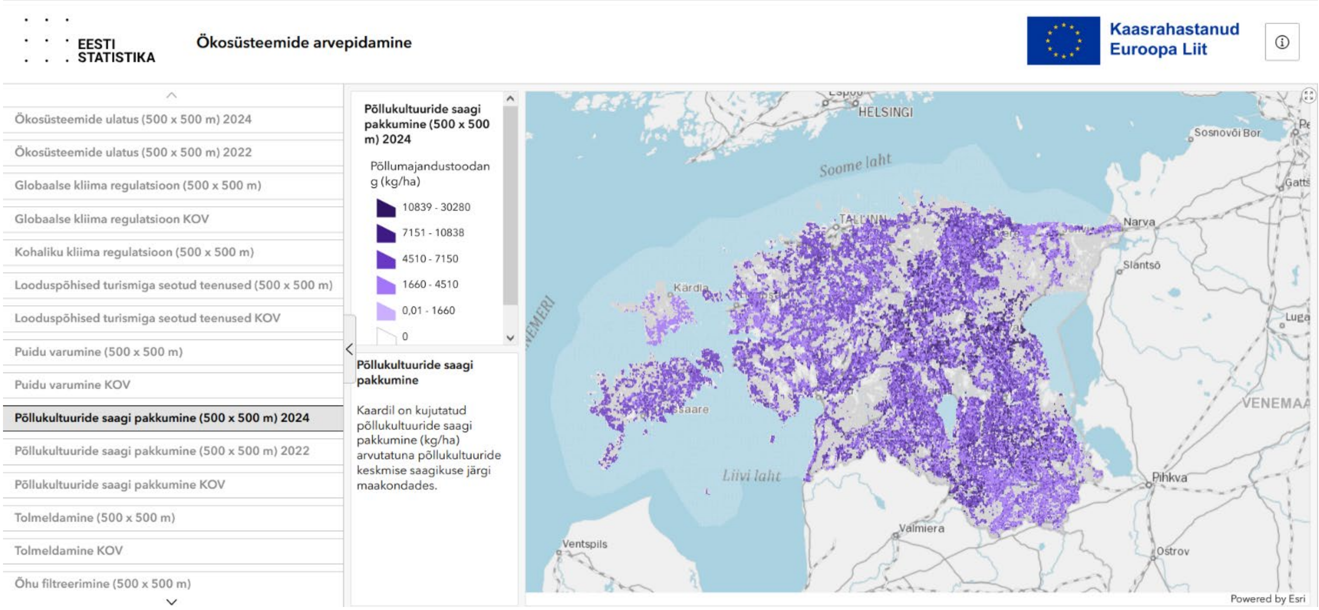
Each of the ecosystem services, apart from one, is visualized both with local municipalities and 500x500m square grids spanning the whole country. The only exception is Local Climate Regulation ecosystem service, which is limited to the three biggest cities in Estonia – Tallinn, Tartu, and Narva. These cities are covered only with 500x500m square grids up to their administrative (LAU) limits.

The local municipality level provides an overview within administrative divisions, while 500x500m square grids offer more specific distribution compared to a municipality, allowing users to see more precise data. It was decided to use 500x500m square grids instead of, for example, more precise 250x250m square grids mainly for performance reasons. The use of local municipalities is vital since local governments may want and need to know what and how services are present within their territory. Users can select a service and further refine the selection by ecosystem types to see the corresponding values of the ecosystem service.

As the interface is aimed mainly for experts of national audience, the user language is Estonian. An introductory prompt introduces the user to the application and explains the data and use cases behind the application. It also guides the user in using the application.

For each visual layer, a legend is shown, explaining the contents of the map. Texts further explaining the content of each service are also available. The whole application is in line with Statistics Estonia's Corporate Visual Identity (CVI) and adheres to the internal user experience guidelines.

Figure 10. Web interface (ArcGIS Experience) for ecosystem accounts in Estonia. Currently displayed is ecosystem service crop provisioning. The dashboard includes (from the left): list of map layers in ecosystem accounts, map legend and description of the displayed map layer, visualized map is the selected map layer.



5 Analysis on semantics of ecosystem service evaluations

Analysis on semantics of ecosystem service was one of the work objectives of the Eurostat EGD EE 2024 grant. The workstream was designed to strengthen the methodological basis of ecosystem accounting and to improve the integration of monetary values into official statistics. This was not seen just a technical exercise—it was to provide semantics and transparency to the valuation methods, lowering the risk of misinterpretation and to enhance the credibility of ecosystem accounts.

Statistics Estonia worked on semantics of the ecosystem service values and was advancing both the conceptual and empirical components of the international initiative on multiple economic values connected to ecosystem services. The initiative began with a comprehensive mapping of monetary values associated with seven key ecosystem services defined under EU Regulation 691/2011. This exercise revealed a diversity of valuation methods and interpretations, underscoring the need for a structured and transparent approach.

Work in partnership with Statistics Netherlands, ISTAT, and leading academic experts in Estonia contributed to the development, testing, and communication of a semantic framework that clarifies how monetary values associated with ecosystem services arise and how they could be interpreted within the context of environmental-economic accounting. Development of the work started under the UN London Group on Environmental Economic Accounting as the 30th UN London Group (2024) explicitly requested empirical evidence to make the conceptual framework of the values related to ecosystem services [54] presented as UN London Group 2024 Issue paper: Monetary values connected to ecosystem services [55] more practical. The current task was a response to that call as well. This work also contributes to the conceptual evolution of the SEEA Ecosystem Accounting, supports Eurostat's work on environmental-economic accounting, and addresses a growing need of policy for valuation approaches that are transparent, rigorous, and ecologically grounded.

The semantics of monetary valuation was analysed first on a study visit to Statistics Netherlands. See Annex 2 for the minutes. Key points were clarified about method families: directly observable prices, revealed-preference approaches such as travel cost, cost-based approaches including restoration, replacement, avoided damage, and shadow project costs, and stated preference measures such as willingness to pay. The group noted conceptual overlaps and the risk of conflating flows versus stocks. An initial plan was developed to build a bridge between the working typology and SEEA/SNA categories, identifying which elements map cleanly to exchange values and which do not. Interpretation was emphasized as critical, since identical techniques can imply different meanings under different assumptions.

For ESP conference preparation, the team agreed to structure messaging around methodological trade-offs, interpretation and semantics, and communication strategies for diverse audiences, using service snapshots and the typology–SEEA bridge as core visuals. A plan was made to compile concise slides per service (with emphasis on regulating services) showing the methods applied, data sources, assumptions, and interpretation; include a unifying slide on methodological trade-offs and another on communication to policy; and add a finance/benefits slide to contextualize ecosystem-service values relative to biodiversity-related expenditures, avoiding double counting or category confusion. The exact structure was still under discussion, to be finalized in the coming months, tested and presented at the ESP conference, and further refined for the UN London Group meeting, where the connected-values approach and ecosystem-service semantics will be presented.

Following the study visit, the team developed a semantic framework distinguishing between actual observed values, latent or hypothetical constructs, risk-of-loss estimates, and mixed cases shaped by ecological and institutional assumptions. This framework was operationalized and empirically tested, ensuring that valuation results could be interpreted consistently across disciplines and policy contexts. A major achievement was the empirical mapping of valuation approaches—ranging from market-based and cost-based methods to preference-driven and hypothetical policy scenarios—onto the semantic matrix. This mapping clarified the interpretative meaning of each method under SEEA EA principles, reducing the risk of misinterpretation and conceptual distortion.

The framework was then applied to national data for seven ecosystem services, including crop and wood provision, pollination, climate regulation, air filtration, and nature-based tourism. This empirical work demonstrated how different valuation approaches reveal distinct layers of meaning, from real economic flows to hypothetical constructs and potential losses. It also highlighted critical risks, such as the misapplication of carbon permit prices

[54] Femia AM, Capriolo A (2022) Beyond valuation. Monetary aggregates for the SEEA-EA. The Italian proposal. One Ecosystem 7: e84689. https://doi.org/10.3897/oneeco.7.e84689.
[55] London Group 2024 Issue paper: Monetary values connected to ecosystem services (A. Femia, I. Grammatikopoulou, K. Oras, Ü. Ehrlich, A. Kadulin, S. Schürz, A. Capriolo, M. Udugama) https://seea.un.org/sites/seea.un.org/files/session_5_issue_paper_connected_values.docx https://seea.un.org/sites/seea.un.org/files/session_5_issue_paper_monetary_values.pdf

to entire national carbon stocks, and reinforced the importance of integrating physical and monetary indicators to avoid misleading conclusions.

Beyond national implementation, Statistics Estonia played a leading role in international methodological development. The team presented its work at the UN London Group on Environmental Economic Accounting and the Ecosystem Services Partnership World Conference, contributing to global discussions on valuation standards and semantic clarity. These efforts supported EU-level harmonization and informed future SEEA EA guidance, positioning Estonia as a methodological innovator in environmental-economic accounting.

Looking forward, expert feedback confirmed the robustness of the framework while identifying areas for refinement. Priorities include strengthening ecological linkages, incorporating uncertainty metrics, and expanding dynamic analysis through Environmentally Extended Input–Output models. Communication tools such as dashboards and metadata templates were recommended to enhance usability for policymakers. Strategic next steps involve operationalizing the framework within national accounts, enabling sectoral dependency analysis and scenario modelling to quantify ecosystem-related risks for the economy.

In conclusion, this work demonstrates that credible monetary valuation of ecosystem services requires more than technical precision—it demands semantic clarity, interdisciplinary collaboration, and institutional legitimacy. By embedding plural values within a coherent interpretative structure, Statistics Estonia has laid the foundation for valuations that are scientifically sound, statistically robust, and policy-relevant, offering a model for other countries seeking to align economic systems with ecological realities.

5.1 Empirical application of the semantic framework

5.1.1 Application of the semantic framework

The developed semantic framework of connected values of ecosystem services distinguishes clearly between monetary values or transactions connected to ecosystem services. These connected values include:

- actual monetary values observed in real economic transactions.
- latent or hypothetical values that appear only under specific institutional arrangements, policy scenarios, or counterfactual conditions.
- values that would disappear in cases of ecosystem degradation or loss (risk-of-loss/cost-of-inaction);
- and mixed cases in which both ecological and socio-institutional assumptions shape the meaning of the value.

With the guidance from Femia (ISTAT), Statistics Estonia applied the semantic framework to detailed national data across the seven ecosystem services defined in EU Regulation 691/2011 (crop provision, wood provision, pollination, global climate regulation, air filtration, local climate regulation, and nature-based tourism). In close cooperation with Statistics Netherlands, figures from the ecosystem accounts of the Netherlands were also integrated into the framework. These figures from Statistics Netherlands served not only as a comparison for the monetary valuation results but also to test the integrity of the framework.

The connected monetary values of ecosystem services - ranging from market transactions and resource rents to restoration costs, WTP values, avoided damages, dependency-based estimates, and hypothetical marketization values—were allocated into the framework (Figure 11, ANNEX 8). The incorporation of valuation methods into the SEEA CF and SEEA EA was also considered and included in the framework matrix. As a result, the matrix facilitated a better understanding of the value itself and the underlying meaning of the flow of ecosystem services, revealing how different valuation approaches expose various layers of interpretation:

- Which values represent real economic activity?
- Which describe hypothetical policy scenarios?
- Which illustrate hidden dependencies or potential losses?
- Which expose gaps between ecological reality and financial incentives?
- This exercise produced empirical demonstrations of the semantic framework.

The semantics and theoretical framework by Femia et al.[56] and empirical application by Oras et al.[57] were presented at the 31st London Group on Environmental Accounting.

[56] Femia et al., 2025: Treatment of Multiple Economic Values Connected to Ecosystems – Theoretical aspects. 31st UN London Group on Environmental Accounting, 2025 https://seea.un.org/sites/seea.un.org/files/femia_et_al_0.pdf
[57] Oras et al., 2025: Empirical insights into the multiple economic values of ecosystems: applications and reflections. 31st UN London Group on Environmental Accounting, 2025 https://seea.un.org/sites/seea.un.org/files/oras_et_al.pdf

Figure 11. Semantics of the applied connected ecosystem services monetary values framework. Adapted from Oars et al. (2025)

REFERENCE SCHEME FOR THE CLASSIFICATION OF VALUES CONNECTED TO ECOSYSTEM SERVICES ACCORDING TO THE FEATURES OF THE CALCULATION SCENARIO

			Ecosystem service in scenario	
			Ecosystem service exists	Ecosystem service does not exist hypothesis
Connected monetary value (transaction/asset, etc.) in scenario	exists (scenario coincides with reality)	Ecosystem services are traded as private usage rights	Rent of the land, directly observable prices applied to actually traded volumes, observed value of actually observed transactions in tradable permits	
		Ecosystem services are potentially traded as private usage rights	Directly observable prices applied to potentially for sale permits of using the ES	
		ES is used for producing other goods or services	Resource rent, Residual value, Hedonic pricing	
		Other (outside or inside of SEEA-EA, within SEEA CF, other satelllie accounts or SNA)	Travel cost method, effective carbon rates	
	"would appear" (does not exist in reality, does in the scenario)	Economic activity that avoids the need for the ES		Abatement costs, substitution costs, averting behaviour
		ES restoration as economic activity*		Restoration costs
		Marketisation of the ES (with or without perfect price discrimination)	Prices applied to quantities of ES not actually traded or tradable under current institutional arrangements, WTP for maintaining ES	
	"would disappear" (exists in reality, is lost in the scenario)	Existing economic activies can no longer thrive, and/or assets are damaged («other negative changes in value») because of the lack of the ES		Social cost of lacking ES, expected damages

* Restoration costs usually refer to the restoration of whole ecosystems. It is however possible to think about the restoration of a single ES, that leaves the rest unchanged. E.g. if an area is made suitable (e.g. reclaimed from venoms) for wild animals and/or these are reintroduced in the area. Pollinators could be one case

5.1.2 Interpretation of the results

Recent advances in the System of Environmental-Economic Accounting (SEEA EA) and related initiatives emphasize the need for semantic clarity in valuation exercises. Monetary values connected to ecosystem services are not interchangeable; they represent distinct scenarios and assumptions, from observable market transactions to hypothetical policy-driven constructs and estimates of potential losses. Without explicit interpretation, these figures risk misinforming decision-making by implying substitutability where none exists or by obscuring ecological thresholds that cannot be crossed without irreversible consequences.

Statistics Estonia, in collaboration with national and international experts, has demonstrated how plural values can be revealed through the analysis of seven ecosystem services within the connected monetary values framework, as outlined in the London Group article by Oras et al. (2025). The empirical examples for Estonia and the Netherlands were analyzed and interpreted to ensure that the valuation outcomes were ecologically meaningful, statistically sound, and applicable to policy contexts—without implying full substitutability of natural systems. The For each service, an analysis was written to provide a textual overview, addressing the following key points:

j. explaining the difference between observable market flows and hypothetical constructs;
k. clarifying the irreversibility and non-substitutability of ecological functions (e.g., soils, pollinators, old-growth carbon stocks);
l. demonstrating the risks of interpreting hypothetical price-based valuations (e.g., applying ETS carbon prices to entire national carbon stocks);
m. highlighting the value of integrating physical and monetary indicators to avoid misleading conclusions.

This interpretative work strengthens the foundation for using valuation results responsibly within SEEA EA implementation and EU policy processes.

Insights into the contributions of individual ecosystem services have enriched discussions on plural values and monetary valuation. Ecosystem services are inherently multidimensional, providing benefits that span ecological, economic, and social domains. Capturing this complexity requires moving beyond static valuations to frameworks that articulate the plural values—such as actual, latent, and risk-based values—that are embedded within different institutional and ecological contexts. Using pollination and global climate regulation as examples, the application of the framework is discussed below. These cases demonstrate that valuation is not about assigning a single "price tag" to nature but about mapping a continuum of meanings that inform governance, risk assessment, and strategic investment in ecosystem resilience.

5.1.2.1 Illustrating plural values through ecosystem service analysis: the case of pollination and climate regulation

The analysis of ecosystem services offers a unique lens for understanding the plurality of values embedded in nature's contributions to human well-being. Rather than converging on a single monetary figure, valuation exercises reveal a spectrum of meanings—actual, latent, and risk-based—each reflecting distinct ecological and institutional contexts. Two services, pollination and global climate regulation, exemplify this complexity.

Pollination demonstrates how observable market flows underrepresent ecological dependencies. Direct subsidies for pollinator-friendly habitats in Estonia amount to approximately €0.57 million, yet dependency-based estimates attribute €62 million of crop production to pollination annually. Restoration costs and willingness-to-pay (WTP) figures add further layers, highlighting that preventive measures are economically preferable to restoration. These valuations do not merely quantify economic flows; they expose governance gaps and the hidden reliance of agricultural systems on ecological integrity.

Global climate regulation presents an even more intricate semantic landscape. Actual transactions—such as €249 million in emission permit trading—capture only a narrow dimension of value. Hypothetical applications of EU ETS prices to Estonia's carbon stock yield figures exceeding €1.2 trillion, while social cost of carbon estimates surpass 57 times national GDP. These valuations, though divergent, are not contradictory; they represent alternative scenarios—market-based, policy-driven, and risk-of-loss perspectives—each essential for understanding the stakes of ecosystem degradation.

This plurality underscores a critical point: monetary values connected to ecosystem services are not interchangeable indicators of "price." They are interpretative constructs that illuminate different facets of ecological dependence, institutional arrangements, and societal risk. By mapping these layers within a semantic framework, ecosystem accounting moves beyond static valuation toward a dynamic tool for policy design, enabling comparisons between the costs of action and inaction and reinforcing the urgency of safeguarding irreplaceable ecological functions.

5.2 Mapping of the monetary values connected to ecosystem services

Several previous studies on the extensive nationwide monetary valuation of ecosystem services in Estonia conducted by Statistics Estonia[58] and additionally by the Estonian MAES 2nd project[59], revealed that a multitude of different monetary valuation methods were used and results obtained were different. The monetary value of a single ecosystem service has been interpreted in multiple, sometimes conflicting ways across studies, experts, and institutions. It turned out that different assessments were often referring to different underlying concepts, even when the numerical values appeared similar.

To address this, a dedicated group of researchers was convened to jointly identify, compile, and map all monetary values that had been published for these ecosystem services in Estonia. The work focused on the seven services defined in EU Regulation 691/2011 (crop provision, wood provision, pollination, global climate regulation, air filtration, local climate regulation, and nature-based tourism), and the results are presented in ANNEX 7.

Across the meetings and expert exchanges, the concept of the plural values of ecosystem services was analysed. Experts emphasized that plural values require the integration of ecological science, economics, social research,

[58] 1 Statistics Estonia, 2020. Development of the land account and valuation of ecosystem services regarding grassland ecosystem services (Eurostat Grant Agreement no NUMBER — 831254 — 2018-EE-ECOSYSTEMS). https://www.stat.ee/sites/default/files/2021-06/Methodological%20report_831254_2018_EE_ECOSYSTEMS_revised_version_31_03.pdf

2 Statistics Estonia, 2021. "Development of the ecosystem accounts" (Eurostat Grant Agreement no NUMBER — 881542-2019-ENVECO) https://www.stat.ee/sites/default/files/2021-07/D1.1%20Final%20methodological%20report_July_2021.pdf

3 Statistics Estonia, 2023. D1.8 Description of the methodology for advancing ecosystem accounts, methodology "Development of the environmental accounts" (Eurostat Grant Agreement no NUMBER — 101022852-2020-EE-ENVACC) https://www.stat.ee/sites/default/files/2023-09/D1_8_%20Description%20of%20the%20methodology%20for%20advancing%20ecosystem%20accounts%2C%20methodology%20_101022852_2020-EE-ENVACC_k%C3%BClj.pdf
4 Statistics Estonia, 2024. D1.9 Description of the methodology and problematic issues for ecosystem accounts (Eurostat Grant Agreement no NUMBER — 101113157 — 2022-EE-EGD) https://stat.ee/sites/default/files/2025-01/D1.9%20Description%20of%20the%20methodology%20and%20problematic%20issues%20for%20ecosystem%20accounts_0.pdf

[59] 5 Helm, A., Kull, A., Kiisel, M., Poltimäe, H., Rosenvald, R., Veromann, E., Reitalu, T., Kmoch, A., Virro, H., Mõisja, K., Nurm, H-I., Prangel, E., Vain, K, Sepp, K., Lõhmus, A., Linder, M., Otsus, M., Uuemaa, E. (2023). Eesti maismaaökosüsteemide hüvede (ökosüsteemiteenuste) majandusliku väärtuse üleriigiline hindamine ja kaardistamine. Tehniline lõpparuanne. Riigihange "Maismaaökosüsteemiteenuste üleriigiline rahaline hindamine, sh metoodika väljatöötamine" (viitenumber 235366, Keskkonnaagentuur). Tartu Ülikool. Eesti Maaülikool. ISBN 978-9985-4-1398-2

and official statistical methodology. For this reason, close cooperation between national statistical offices and the research community was recognized as essential while already drafting a project plan.

First, it was noted that ecosystem valuation relies on ecological and economic expertise that is not typically available within national statistical institutions. Understanding ecosystem functions such as pollination, soil formation, carbon storage, or hydrological regulation requires specialist scientific knowledge. Researchers contribute the ability to interpret these ecological processes, identify realistic assumptions, and avoid models that oversimplify system dynamics. At the same time, statistical offices play a crucial role in ensuring that data and methods are translated into structured, comparable, and transparent statistical outputs. As discussed, neither community can produce credible valuation results in isolation; both perspectives are required to ensure scientific correctness and statistical reliability.

It was also discussed that methods for evaluating ecosystem services evolve much more rapidly in research communities than in official statistics. New modelling approaches, behavioral methods, and risk-based frameworks are continually being developed. Participants agreed that statistical offices benefit from working with researchers to stay aligned with methodological advances while adapting them into formats suitable for official use. Without such cooperation, there is a risk that statistical systems would lag behind scientific knowledge or adopt new methods without a full understanding of their assumptions and limitations.

Another recurring point in the discussion was that many alternative values are not directly observable. They depend on counterfactuals, ecological modelling, hypothetical scenarios, willingness-to-pay studies, or damage avoidance calculations. These approaches have long-standing traditions in research but are less common in official statistics, which typically rely on observed economic transactions. It was therefore emphasized that researchers and statisticians must co-produce these values: researchers develop scientifically grounded models, while statistical offices ensure documentation, quality assurance, and adherence to SEEA EA and SNA principles. This collaborative process helps prevent modelled or hypothetical values from being misinterpreted as market prices or real economic flows.

The group also discussed the need to safeguard correct interpretation and avoid misuse of valuation results. Because monetary values are sensitive to ecological assumptions, policy settings, and time horizons, they can easily be misunderstood or overinterpreted. Researchers help clarify the scientific meaning and limitations of results, while statistical offices ensure clear metadata, consistent terminology, and distinction between actual, latent, and at-risk values. Together, they provide the semantic transparency needed to ensure that valuations support policy making rather than distort it.

A further point raised was the importance of legitimacy. Ecosystem accounts gain strength when they are perceived as both scientifically robust and institutionally trustworthy. As discussed, valuations produced solely by researchers may lack the neutrality associated with official statistics, while those produced solely by statistical offices may be viewed as insufficiently grounded in ecological science. Joint work combines methodological innovation with institutional authority, increasing acceptance among policymakers, ministries, and the wider public.

Participants also stressed that the topic itself requires collaboration because monetary valuation crosses disciplinary boundaries. It involves ecology, economics, modelling, sociology, landscape science, accounting, and governance. No single institution holds expertise across this entire spectrum. Collaboration mirrors the interdisciplinary nature of the challenge itself and allows different value dimensions—biophysical, economic, cultural, institutional, and risk-based—to be integrated into a coherent and interpretable system.

Finally, it was noted that international frameworks explicitly support such cooperation. SEEA EA calls for the integration of ecological science and accounting principles; IPBES emphasizes the inclusion of multiple ways of valuing nature; and Eurostat encourages Member States to build partnerships between statistical offices and research institutions. As discussed, collaboration is therefore not only beneficial but aligned with international expectations for credible and policy-relevant ecosystem accounting.

In summary, the discussions throughout the project converged on a clear conclusion: statistical offices and researchers must work together because their roles are complementary and mutually reinforcing. Researchers provide the scientific depth and modelling capacity needed to characterize ecosystem processes and non-market values, while statistical offices ensure methodological consistency, quality assurance, and transparency. Only through such collaboration can plural values be represented in a way that is scientifically sound, statistically robust, and meaningful for policy.

5.3 Advancing the semantic framework of monetary values connected to ecosystem services

The empirical results of the monetary valuation of ecosystem services in Estonia were mapped in a matrix (ANNEX 7), where the seven ecosystem services defined in EU Regulation 691/2011 (crop provision, wood provision, pollination, global climate regulation, air filtration, local climate regulation, and nature-based tourism) are organized by the valuation methods used. These methods include:

- market-based approaches (resource rent, land rent, stumpage value, ETS permit trading).
- cost-based approaches (restoration, replacement, avoidance/abatement).
- preference-based methods (willingness to pay).
- dependency-based production function approaches.
- hypothetical policy-driven values (efficient carbon pricing, social cost of carbon).

After collating and comparing valuation methods for ecosystem services relevant to Estonia, the results were at first laid in a combined framework of SNA/ SEEA EA ecosystems services typology and the treatment of connected monetary values based on a typology previously presented to the 30th London Group[60]. The approach, while partly aligned with SEEA and SNA concepts, also incorporates connected values such as replacement or restoration cost and opportunity cost that do not always meet narrow exchange-value criteria. It was discussed at the study visit at Statistics Netherlands (ANNEX 2) and the focus was set on building a bridge between the working typology and SEEA/SNA categories, marking what maps cleanly to exchange values and what does not.

The alignment with SEEA EA methods and typology was seen as important so that the concept would not drift away from generally agreed principles and recommendations in Feasibility study by Eurostat[61]. However, during consultations, the concept leaned more into the approach of monetary values connected to ecosystem services, because ecosystem service values emerge along a continuum — from the natural function of ecosystems to the benefits people actually experience, and the connected values framework helps us map and communicate the different layers of values[62], each capturing a different stage in the value chain, such as

- ecological production/provisioning
- direct ecosystem contribution — the measurable indicator for the flow of the service, such as how many people visit nature and benefit from it.
- intermediate economic value, reflected in observable economic activity: what people pay for entry, transport, or guided tours.
- societal benefit — often less visible, but no less important. Recreation, for instance, contributes to mental well-being, reduces healthcare costs, and strengthens community cohesion.

By clearly mapping these layers, we avoid oversimplification and misinterpretation. Additional semantical layers enable holistic view and multistakeholder understanding how flows of ecosystem services and connected monetary values/transactions are identified and treated. This work contributes to the methodological foundation for consistent and transparent valuation practices. It aims to ensure that monetary valuation supports decision-making without over-reducing complex ecological processes.

The concept of connected monetary values and transactions, specifically in relation to how ecosystem services interact with the environment and society was tested. The key achievement was the operationalization and empirical testing of the semantic matrix for connected ecosystem values. Statistics Estonia with Statistics Netherlands and Istat contributed to:

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[60] Femia AM, Capriolo A (2022) Beyond valuation. Monetary aggregates for the SEEA-EA. The Italian proposal. One Ecosystem 7: e84689. https://doi.org/10.3897/oneeco.7.e84689.
London Group 2024 Issue paper: Monetary values connected to ecosystem services (A. Femia, I. Grammatikopoulou, K. Oras, Ü. Ehrlich, A. Kadulin, S. Schürz, A. Capriolo, M. Udugama) https://seea.un.org/sites/seea.un.org/files/session_5_issue_paper_connected_values.docx https://seea.un.org/sites/seea.un.org/files/session_5_issue_paper_monetary_values.pdf
[61] Eurostat – Unit E2. Doc. ENV/EA/TF/2025_1/3. Methodological and feasibility study on Monetary valuation. Revised annotated draft. Task force on ecosystem accounting. 26-27 February 2025.
[62] Barton, David & Caparros, Alejandro & Conner, Nicholas & Edens, B & Piaggio, Matías & Turpie, J. (2019). SEEA Experimental Ecosystem Accounting Revision Expert Consultation Working group 5: Valuation and accounting treatments Discussion paper 5.1: Defining exchange and welfare values, articulating institutional arrangements and establishing the valuation context for ecosystem accounting.. https://www.researchgate.net/figure/Plural-values-in-the-system-of-ecosystem-accounts-Source-adapted-from-Barton-et-al_fig4_346642690

- developing the layered conceptual structure from ecological functioning to economic benefits;
- building the semantic matrix and applying it to diverse valuation methods;
- documenting the assumptions and scenarios underlying each valuation result;
- identifying and preventing misinterpretations that commonly arise when monetary values are taken at face value;
- translating complex valuation practices into a shared language understandable to ecologists, economists, statisticians, and policymakers.

5.4 Expert feedback and future directions

After the completion of the main part of the work, feedback on the application of the multi-layer framework of connected monetary values of ecosystem services was gathered through targeted questions posed to the expert group. Four key areas were addressed: (1) further development of the multi-layered approach, (2) availability of additional relevant figures for ecosystem services, (3) potential need for framework revision if new values do not fit, and (4) identification of values that could be removed without loss.

Inputs were collected via written and online consultations with the expert group, such as methodological workshop on November 25. The results were discussed during the final methodological seminar on December 3, 2025 (ANNEX 3). The consolidated suggestions are outlined and summarized below.

5.4.1 Further development of the multi-layered approach

General agreement: The framework is conceptually strong, but its development should continue along several lines.

Key proposed improvements:

a. Methodological refinement

- Incorporate uncertainty metrics and data-quality indicators (Sepp, Oras).
- Strengthen the link between valuation layers and ecological realities (thresholds, irreversibility, resilience, (Helm, Sepp).
- Formalise classification rules for mapping valuation methods to semantic cells (Oras).
- Clarify meanings and policy uses of the different value categories (Schenau).
- Clarify specificities of different kinds of ecosystem services (provisioning, regulative, cultural) (Femia, Helm)

Feedback from the expert group (ANNEX 8)

The multi-layered approach to monetary values connected to ecosystems can be further developed by more systematically linking each valuation layer to the ecological conditions that underpin ecosystem service provision. In particular, incorporating ecological thresholds, irreversibility, and ecosystem resilience into the semantic framework would strengthen its interpretive power and policy relevance.

Similarly, ecosystem resilience- the capacity to absorb disturbances while maintaining functionality - affects the meaning of connected monetary values. Values linked to resilient systems (e.g. annual biomass growth in managed forests) differ fundamentally from those associated with fragile or slow-recovering systems (e.g. carbon storage in old-growth forests or peatlands). Making this distinction explicit within the framework would improve the interpretation of monetary figures across different ecosystem services.

Ecological thresholds mark points beyond which ecosystem functioning may change abruptly or collapse, rendering services difficult or impossible to restore. Explicitly acknowledging such thresholds within valuation layers would help distinguish monetary values that imply genuine substitutability from those that merely signal dependence. For instance, replacement or adaptation costs associated with pollination or soil-related services should be interpreted in light of ecological evidence showing that these services rely on complex biological systems that cannot be fully replicated once critical thresholds are crossed. In such cases, monetary estimates represent warning indicators of potential loss rather than feasible substitutes.

Uncertainty and data quality could be expressed within each valuation layer using a simple, standardised annotation. For example, market-based values for crop or timber production could be labelled as high-confidence, observed, while avoided-damage estimates for air filtration could be classified as medium-confidence, model-based, and contingent valuation results as low-confidence, perception-based. Applying such qualitative confidence classes consistently would improve transparency and comparability across services and valuation methods without adding methodological complexity.

Overall, these refinements would not alter the structure of the framework but would improve its alignment with ecological realities, reduce the risk of misinterpretation, and support more informed and cautious use of monetary values in ecosystem-related decision-making.

b. Integration with national statistical systems

- Align more explicitly with SEEA EA, SNA, MAIA (Oras, Schenau, Kadulin).
- Develop metadata templates explaining each figure's origin, meaning, and limitations (Oras).
- Improve compatibility with accounting requirements through more standardised, comparable figures (Kadulin).
- Üllas Ehrlich stresses defining whether the aim is a statistical overview, or a decision-support tool comparing competing resource-use scenarios.
- Communication tools (dashboards, dependency profiles) are recommended (Oras)

c. Expand analytical scope

- Extend framework to dynamic, sectoral, economy-wide analysis using Environmentally Extended Input–Output (EEIO) tables (Oras, Femia).
- Capture temporal changes in value flows as ecosystems and policies evolve.

d. Communication and policy relevance

- Provide decision-support dashboards to convey results clearly (Oras).
- Accompany valuations with explanatory text on limitations (Kadulin).

e. Conceptual clarity

- Emphasise the distinction between ecosystem service connected monetary values and the intrinsic/ecological value of ecosystems (Aun).

f. Standardisation vs flexibility

Some argued for simplification for accounting purposes (Kadulin), others called for expanded ecological realism for policy-making.

In conclusion: current ecosystem service valuation framework was considered to be conceptually strong, but further development was seen to be essential to enhance methodological rigor, integration, and policy relevance. Key improvements could include refining methods to better reflect ecological realities such as thresholds, irreversibility, and resilience, while incorporating uncertainty metrics and data-quality indicators. Formal classification rules for mapping valuation methods to semantic categories and clearer definitions of value types and ecosystem service classes were seen to possibly strengthen conceptual clarity.

Integration with national statistical systems was raised as another question. Alignment with SEEA EA, SNA, and MAIA standards, supported by metadata templates and standardized figures, could improve compatibility with accounting requirements. It was seen important to clarify whether the framework serves primarily as a statistical overview or a decision-support tool.

Communication tools such as dashboards and dependency profiles could be developed.

Expanding analytical scope through dynamic, sectoral, economy-wide analysis using Environmentally Extended Input–Output (EEIO) tables was seen to enable tracking of temporal changes in value flows. Conceptual clarity must also emphasize the distinction between monetary values linked to ecosystem services and intrinsic ecological value. Finally, the framework could balance standardization for accounting purposes with flexibility to capture ecological complexity for policymaking.

5.4.2 Additional relevant figures for ecosystem services

Application of the ecosystem service valuation framework was considered to be sound, but its effectiveness was seen could be enhanced by integrating additional indicators. While no major new national datasets exist, still several potential figures could be added without changing the framework. For crop provision, these could for example include insurance payouts, avoided soil management costs, and sustainability-linked subsidies. Pollination indicators might cover yield variability and price differences for pollinator-dependent crops. Climate regulation could use carbon price trajectories, avoided social costs of climate extremes, and land-use emissions. Air filtration and local climate regulation could draw on health burden data, cooling energy use, and urban heat metrics, while nature-based tourism could include visitor expenditure by region and season.

The main constraint was considered not to be conceptual but practical: data availability and modelling capacity. Many indicators exist in theory but lack empirical application for Estonia. Addressing this gap was seen to require targeted data collection and methodological work to unlock the full potential of the framework.

5.4.3 Need for Revision of the Framework if new values do not fit

The existing ecosystem service valuation framework was considered conceptually robust, requiring no immediate revisions. New data and indicators was considered to be integrated within the current structure without difficulty. Revisions would only become necessary under specific circumstances: the emergence of entirely new valuation methods that do not align with existing semantic categories, or policy demands for fundamentally different value types. Additional refinements could include distinguishing between stocks and flows and systematically reflecting substitution effects. Overall, challenges was seen to be related to data availability and interpretation rather than the framework's design, confirming its adaptability for future enhancements.

5.4.4 Values that could be dropped without real loss

There is broad agreement around several categories that could be removed:

a. Hypothetical or unrealistic replacement cost estimates

- For functions that cannot realistically be replaced (Oras, Sepp), soil replacement cost is specifically criticised (Helm, Kadulin, Oras).
- Replacement values for irreplaceable functions (e.g., old-growth carbon storage) should not be used. Hypothetical or unrealistic replacement-cost estimates: drop the substitution in case of the stocks and keep them just for the flows (soil substitution example for example, Helm, Schenau)

b. Very small or outdated WTP values

- Especially when WTP duplicates market prices already observed (Kadulin, Sepp).

Feedback from the expert group (ANNEX 8)

The contingent valuation method and willingness to pay method remain and will remain relevant for a long time; nevertheless, these methods were developed to determine whether, in a specific location, assigning public or common goods to private use increases or decreases social welfare. (For example, whether damming a particular river to produce electricity increases or decreases social welfare.)

Methods for calculating the value of public goods and externalities that were developed in the last century were designed to determine whether, in a specific location, assigning public or common goods to private use increases or decreases social welfare. (For example, whether damming a particular river to produce electricity increases or decreases social welfare.) Textbooks on monetary valuation methodologies state for each method that it is not suitable for calculating the monetary value of large-scale public and common goods (such as the greenhouse effect, the ozone layer, global fish stocks, etc.).

The respondents' willing to pay for different ecosystem services and the difference between other observed values, is linked to the level of awareness (knowledge and understanding) and socio economic aspects of respondence. Hence, these, even low values, have the meaning.

The reasons for low willingness to pay are also important (those arising from the method itself versus genuinely low willingness to pay).

c. Double-counted downstream industry outputs

- Particularly turnover/production figures that reflect economic activity (full turnover of timber industry treated as ES value), not ecosystem contribution (Oras).

d. Highly speculative marketisation scenarios

- Examples: applying carbon permit prices to entire national carbon stock (Oras).

General principle: Values that add noise, confusion, or conceptual distortion should be removed.

1. Highly hypothetical marketisation values

Most contributors noted that no values need to be removed for structural reasons; dropping values is mainly a matter of improving clarity and avoiding conceptual confusion.

There was broad agreement certain valuation categories add little analytical value and should be excluded to improve clarity. These include hypothetical or unrealistic replacement-cost estimates, particularly for functions that cannot be substituted, such as soil or old-growth carbon storage. Very small or outdated willingness-to-pay (WTP) figures, especially when duplicating observed market prices, could also be dropped. Double-counted downstream industry outputs—such as full timber industry turnover treated as ecosystem value—was considered to be another source of distortion. Finally, highly speculative marketisation scenarios, like applying carbon permit prices to entire national carbon stocks, was considered to be avoided. Overall, removing values that introduce noise or conceptual confusion was seen to strengthen the framework without structural changes.

5.4.5 Overall conclusions

Expert feedback confirms that the multi-layered valuation framework was considered to be conceptually strong and supported. It might provide a meaningful structure for distinguishing actual, institutional, hypothetical, and risk-related monetary values, with no major conceptual flaws identified. The greatest opportunities for improvement lie in strengthening ecological and methodological dimensions—explicitly linking ecological processes to valuation layers, clarifying stock–flow distinctions, and incorporating uncertainty and data-quality indicators. Expanding dynamic analysis through Environmentally Extended Input–Output (EEIO) tables would enable sector-level dependency mapping, time series, and scenario modelling, transforming the framework from a static classification into an operational tool for national accounting and policy evaluation.

Current limitations stem from data gaps rather than structural issues. Most additional indicators could fit the existing framework but require modelling and data development, particularly for Estonia. At the same time, values that create conceptual distortion—such as unrealistic replacement costs, outdated WTP figures, double-counted industry outputs, and speculative marketization scenarios—should be removed to sharpen analytical clarity.

Going forward, clarity of purpose is essential. For statistical reporting, standardization and simplicity are key, while policy-making demands ecological realism, risk assessment, and scenario modelling. Operationalizing the framework through integration with SEEA EA, SNA, and EEIO will elevate it into a quantitative decision-support system capable of tracing economy-wide ecosystem dependencies.

5.4.6 Proposed viable next steps for future development dependent on financing

. If financing could be secured, the following steps could be taken:

Methodological and semantic clarifications could be finalized, including creating a standardized metadata template for all ecosystem-related values to ensure transparency and consistency.

Data quality could be improved by removing categories that could mislead interpretation, such as unrealistic replacement-cost estimates, double-counted outputs, hypothetical full carbon stock monetization, and outdated willingness-to-pay figures.

Additional empirical indicators could be identified and prioritized, for example pollination yield variability, health burden data linked to air filtration, regional tourism expenditure, crop insurance and subsidy structures, and carbon price trajectories.

Communication tools could be developed, including explanatory guides, visual summaries, and dashboards to make results accessible for policymakers.

Pilot studies for dynamic analysis could be launched, focusing on Environmentally Extended Input–Output (EEIO) models for selected services such as crop provision or climate regulation to map sectoral dependencies.

Findings could be integrated into international frameworks by aligning with SEEA EA, SNA, and Eurostat standards, and publishing methodological notes and pilot results for global sharing.

A multi-year valuation system could be built, combining physical flows, monetary values, and EEIO linkages into time series, enabling scenario modelling for risks such as pollination decline or carbon-price fluctuations.

5.5 Communication on international level and national level

Statistics Estonia actively disseminated the results and contributed to international dialogue on the semantics and treatment of connected values of ecosystem services. The work was discussed with Statistics Netherlands, ISTAT and national academic experts throughout the development of the topic in the current grant.

The development of the framework was discussed first with Statistics Netherlands during study visit under the topic of ecosystem accounts in May 2025 (see chapter 5.3, ANNEX 2 for more details), the initial application of the framework was presented in 11th ESP World Conference in June 2025, and the results of the empirical work were presented at the 31st meeting of the UN London Group on Environmental Economic in Tallinn in September 2025, and final discussion on the feedback and future developments took place at the final methodological seminar on ecosystem accounts in December 2025 (see chapter 5.4, ANNEX 3) for more details.

5.5.1 Presentation at the UN London Group on Environmental Economic Accounting

The semantics and theoretical framework by Femia et al. and empirical application by Oras et al. were presented at the 31st London Group on Environmental Accounting.

At the 31st UN London Group meeting in Tallinn (September 2025), Statistics Estonia together with the partners presented the results of the empirical work on semantic structuring of monetary values connected to ecosystem services[63]. The session focused on how to communicate complex valuation results clearly and make them relevant for policy. The results were communicated by: Kaia Oras, Kätlin Aun, Sjoerd Schenau (Statistics Netherlands), with contributions from academic partners: Aveliina Helm (University of Tartu) Aki Kadulin (Estonian University of Life Sciences), and Üllas Ehrlich (Tallinn University of Technology).

The presentation explained why monetary figures require careful interpretation and introduced a reference scheme that organizes values into categories: actual market transactions, latent values that could appear under new institutional settings, and risk-based values that would disappear if ecosystems degrade. Framework was illustrated with empirical examples from Estonia and the Netherlands for seven ecosystem services, including crop and wood provision, pollination, global climate regulation, air filtration, local climate regulation and nature-based tourism.

Visual presentation was accompanied by explanations, used to show how different valuation approaches fit into the semantic structure, helping to compare prevention costs with restoration costs and understand the economic consequences of ecological loss. The discussion emphasized that the goal is not to assign a single "price tag" to nature but to communicate plural values transparently, supporting informed decisions and avoiding misleading narratives.

The London Group acknowledged the feasibility and transparency of the approach and remarked that including a guide for interpretation and/or a mapping to different uses and users of these values would be valuable.

5.5.2 Contribution to Ecosystem Services Partnership conference, early application and intermediate results

Statistics Estonia (Kätlin Aun) presented the framework and initial results on the interpretation of the connected monetary values on the 11th Ecosystem Services Partnership World Conference (11th ESP World Conference), session T7b – Making Nature Count: Global and local applications of monetary valuation for transformation to nature-inclusive decision-making with the presentation "Valuing Nature's Contributions: Mapping and Semantics of the Methods for Ecosystem Service Valuation"[64]. The presentation (other authors: Kaia Oras, Sjoerd Schenau, Aveliina Helm, Eve Veroman, Üllas Ehrlich, Helen Poltimäe, Maie Kiisel, Aki Kadulin) showcased the findings from valuation methods explored within the framework of Eurostat grants supporting environmental-economic accounting. Statistics Estonia, in collaboration with Statistics Netherlands, national experts and stakeholders has been evaluating a range of monetary valuation methods to assess ecosystem services and analyzing their treatment. Emphasis was placed on how valuation approaches recommended by the UN SEEA EA and Eurostat can be assessed for methodological soundness, compatibility with the System of National Accounts, and sensitivity to ecological realities in the connected monetary values framework. The complexities of valuing regulatory services such as pollination, climate regulation, and air filtration were highlighted, along with the need for transparency to ensure ecosystem accounting becomes a reliable tool for policy alignment, sustainable resource management, and bridging the biodiversity finance gap.

5.5.3 Communication on final methodological seminar

On 3 December 2025, a methodological seminar was held. One of the agenda items was to discuss the application, results, feedback and future development of the multi-layered connected monetary values of ecosystem services framework. The seminar brought together experts from key institutions, including Statistics Estonia, Environment Agency, Estonian University of Life Sciences, University of Tartu, TalTech, and international partners from Statistics Netherlands and ISTAT (Italy). The session focused on expert feedback, methodological refinements, data integration, and strategic directions for operationalizing the framework.

The seminar emphasized the importance of strengthening the methodological basis for ecosystem accounting under the Eurostat EGD EE 2024 grant, aiming to integrate monetary values into official statistics for informed sustainability and resilience policies. Clear semantics and transparent valuation methods are essential to avoid

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[63] Oras et al., 2025: Empirical insights into the multiple economic values of ecosystems: applications and reflections. 31st UN London Group on Environmental Accounting, 2025 https://seea.un.org/sites/seea.un.org/files/oras_et_al.pdf
https://seea.un.org/sites/seea.un.org/files/2_empirical_insight_24_09.pdf
[64] https://fsd866.sharepoint.com/:f:/g/EoWs3BIu-wFFia8KBK3XCwgB6PZhBj3FEc4QB0fsHesTXA

misinterpretation and maintain credibility. Estonia's work responds to the UN London Group's call for empirical evidence to operationalize the conceptual framework.

The multi-layered approach—distinguishing actual, institutional, hypothetical, and risk-related values—was tested using data from Estonia and the Netherlands. Aldo Femia introduced a scenario-based semantic matrix linking ecosystem service status (existing, absent, restored) with economic consequences (current activity value, replacement/restoration cost, avoided damage). Monetary values were considered to be conditional estimates requiring documented assumptions and methods.

Empirical work, which populated the framework with figures for key services, revealing how different valuation layers convey different narratives were discussed. Experts agreed that the framework is conceptually strong but recommended refinements: link layers to ecological realities, add uncertainty metrics, create metadata templates, align with SEEA EA and SNA, expand dynamic analysis via EEIO tables, and improve communication tools. It was suggested that unrealistic replacement costs, outdated WTP figures, double-counted outputs, and speculative marketization scenarios could be removed.

Next steps could include semantic clarification, adding empirical indicators (e.g., pollination variability, health costs, tourism expenditure), developing dashboards, and piloting EEIO-based studies. Longer-term goals could involve building a dynamic, multi-year valuation system and scenario models for risk and adaptation. It was agreed that Estonia's and Dutch efforts demonstrated feasibility and transparency, earning recognition from the UN London Group, which encouraged continued refinement and international sharing.

5.5.4 Exchange Meeting on Ecosystem Accounts between Statistics Estonia, representatives of the People's Republic of China, and the World Bank

Exchange Meeting on Ecosystem Accounts was held at Statistics Estonia on 17.10.2025, bringing together representatives from the People's Republic of China, the World Bank, and Statistics Estonia. The purpose of the meeting was to share experiences and discuss how countries are implementing the SEEA Ecosystem Accounting standard adopted in 2021.

The meeting was opened by the Director of Statistics Estonia, who emphasized the importance of international cooperation and knowledge sharing. He highlighted that although Estonia is a small country, it has served as a tester for several concepts and methodologies, actively contributing to the global development of ecosystem accounting.

Statistics Estonia presented their experience in ecosystem accounting, including the compilation of ecosystem extent accounts, the assessment of ecosystem services in urban areas, application of monetary valuation, calculation of gross ecosystem product, and the treatment of links between land ownership and ecosystems. These two areas—services in urban areas and the land ownership dimension—were of particular interest to the visiting colleagues, and Estonia was happy to share its experiences with experiments and solutions.

The discussions during the meeting were substantive and productive, broadening both sides' understanding of how to better integrate ecosystem accounting with economic and spatial data. It was noted that calculated aggregated indexes (e.g. GEP) and monetary values of ecosystem services should follow a proven system, and the applied methods should serve practical purposes—for example, considering the value of services in land-use planning and providing input for policy-making. At the same time, approaches should recognize the diversity of values beyond monetary aspects, ensuring that decisions reflect ecological, social, and cultural dimensions. World Bank representatives emphasized Estonia's practical contribution and readiness to test new approaches.

5.6 Summary

Statistics Estonia provided significant contribution and practical methodological advances in empirical testing and hence also developing the framework of connected monetary values of ecosystem services. By applying a comprehensive semantic framework, the team ensured that monetary valuation remains meaningful, transparent, and ecologically grounded. The work demonstrates one possibility how plural and context-dependent ecosystem values can be integrated into environmental-economic accounting while preserving statistical integrity and supporting informed policymaking.

Collaboration of Statistics Estonia, Statistics Netherlands, ISTAT and expert feedback was incorporated into refining the semantic matrix and its empirical application, strengthening both conceptual clarity and practical usability. The work was presented in ESP conference and UN London Group, supporting its integration into ongoing global development efforts, such as shaping future standards for SEEA EA and related frameworks.

6 Compilation of the ecosystem services index

Statistics Estonia tested the calculation of CBD (Convention on Biological Diversity indicator) indicator B1: Services provided by ecosystems, according to metadata[65] and guidance by Statistics Netherlands. The index is linked to the GBF indicator B1, so Estonia's approach must align with international guidance. This was a test by Statistics Estonia, Ministry of Climate has yet to decide on a methodology for reporting to CBD. The results and issues were discussed at the final seminar (see ANNEX 3)

The proposed indicator is defined as the average rate of change in the provision of a set of ecosystem services in a particular time period compared to a baseline year, for a country or globally. The indicator is computed in three stages: 1) selection of ecosystem services for inclusion in the indicator, 2) compilation of ecosystem services accounts, and 3) calculation of an aggregate index based on information from the accounts.

The selection of services was based on the current list of ecosystem services reported in the ecosystem services account under Regulation EU 691/2011. Ecosystem services account in physical units have been calculated for years 2020, 2022 and 2024 in Estonia. Considering the indicators for the services, it was possible to find the total supplied services and fill the gaps in the timeseries without fully compiling ecosystem services account. In several cases the total supply of the service was available from external sources (crop production, wood provision, carbon sequestration, nature tourism) or it was possible to make an estimation based on the methodology of calculating the service (air filtration, carbon storage). However disaggregation by ecosystem type or user requires that the service is fully assessed in the ecosystem account. In addition, data could not be derived without the full ecosystem accounts in case of pollination and local climate regulation. For the years when no ecosystem account is available, modelling for these services was not done, therefore these services were currently excluded from the calculation of the index, but can be added later. It was possible to extend the time series back to 2018 (Table 39).

Table 39. Ecosystem services account, 2018-2024 Estonia

	Indicator	2018	2019	2020	2021	2022	2023	2024
Provisioning services								
Crop production	crop production in thousand tonnes	2 845	4 508	4 563	3 865	4 399	3 581	3 698
Pollination	production of pollinator-dependent crops in thousand tonnes	..	..	75	..	106	..	..
Wood provision	net increment in thousand m3	11 400	10 400	9 600	8 700	8 200	8 200	8 300
Regulating services								
Air filtration	tonnes of PM2.5 adsorbed	697	580	554	529	552	523	..
Global climate regulation: net carbon sequestration	tonnes of net sequestration of carbon	0	0	91 472	249 984	572 591	47 888	..
Global climate regulation: carbon storage	tonnes of stored organic carbon	4 073 838 845	4 073 838 845	4 073 838 845	4 073 838 845	4 073 838 845	4 073 838 845	..
Local climate regulation	cooling in degrees C	..	..	..	..	..	..	..
Cultural services								
Nature tourism	number of overnight stays	2 985 459	3 161 484	1 961 073	2 084 992	2 810 186	2 898 177	2 944 081

Indicator B1: Services provided by ecosystems was calculated based on the timeseries for ecosystem series in physical units. The time series data extends back to 2018 in Estonia, which was currently taken as base year for the calculation of trends. The proposed baseline year for global reporting under the GBF is likely to be 2020, or alternatively an average of the values between 2010 and 2020. The aggregated indicator(s) for B1 were calculated based on an aggregation method using a geometric mean of trends of ecosystem services. The chain method for calculating the geometric mean has the advantage that it allows for different time series lengths with different

[65] Metadata Factsheet. B.1 Services provided by ecosystems https://www.gbf-indicators.org/metadata/headline/B-1

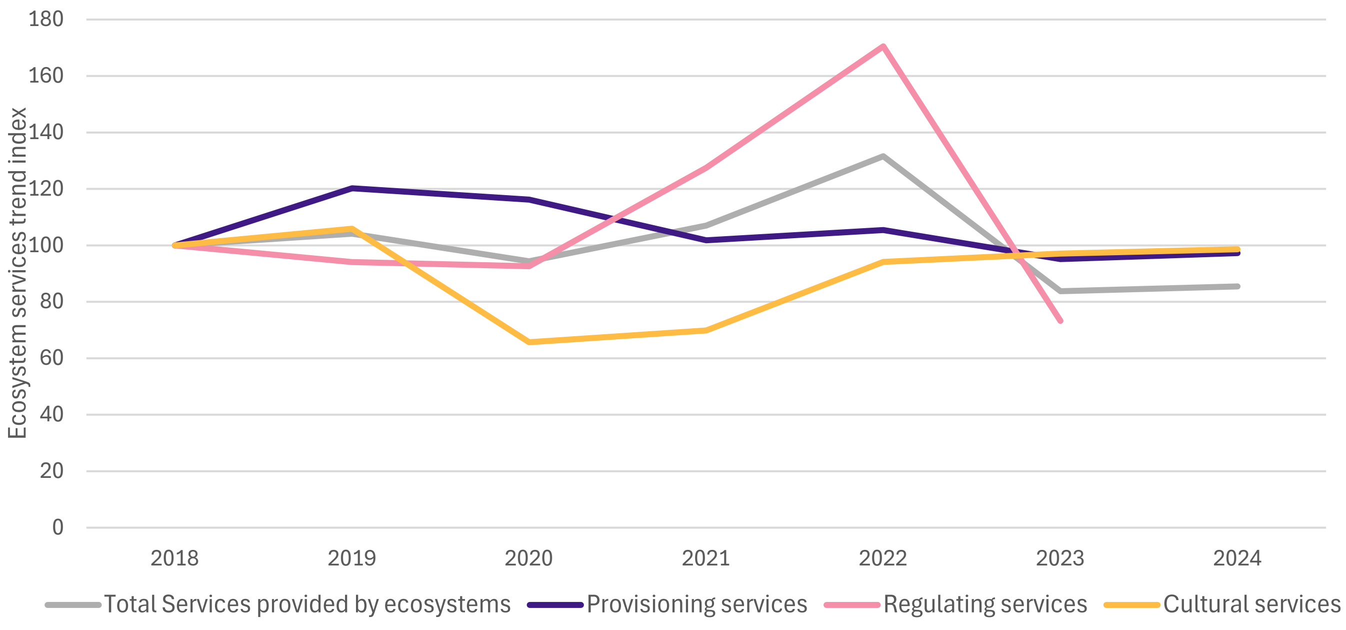
starting years for different ecosystem services, which means that additional ecosystem services can be added to the index as datasets and accounts for additional ecosystem services become available.

In addition to a single aggregate index, three sub-indices, one for each broad category of ecosystem services (i.e. provisioning, regulating and cultural) have been calculated (Table 40). Because trends in provisioning, regulating and cultural ecosystem services often move in different directions, which can be masked by the overall index, it will be important to present the overall index and the three sub-indices together, not just the overall index (Figure 12).

Table 40. Ecosystem services trend index. Aggregation is done for ecosystem services total provision and division to provisioning, regulating and cultural ecosystem services. Base year is 2018.

	2018	2019	2020	2021	2022	2023	2024
Total Services provided by ecosystems	100	104.11	94.34	107.00	131.58	83.76	85.46
Provisioning services	100	120.23	116.21	101.83	105.46	95.14	97.27
Regulating services	100	94.06	92.62	127.50	170.51	73.25	..
Cultural services	100	105.90	65.69	69.84	94.13	97.08	98.61

Figure 12. Ecosystem services trend index. Aggregation is done for ecosystem services total provision and division to provisioning, regulating and cultural ecosystem services. Base year is 2018.



The test case brought up several issues that need further considerations.

n. In case of global climate, carbon storage the index remains unchanged as the service was considered relatively unchanged in time and therefore the same input data was used for years 2018-2023.
o. There are negative net carbon sequestration values in some years, which are considered as 0 values in service provisioning as negative values are not reported. How to treat 0 values in trend calculations?
p. Six ecosystem services were used in calculation of the aggregate trend index. Statistics Estonia is uncertain whether it is sufficiently representative.
q. The metadata suggests addressing missing values by using ARIES for SEEA or other global modelling platforms based on existing global data, subject to criteria, standards and quality assurance including

national validation through appropriate institutional processes involving relevant national experts. However, we raise a concern regarding whether this approach is appropriate, as it could be perceived as a change in methodology. Such a change would likely affect the results, not only reflecting the change in trend but also introducing potential discrepancies due to the shift in methodology for the calculated missing value.

r. As the index depend on the number of services and which services are included in the calculations, then it needs more consideration, which contribute to the goal of the index of tracking the sustainable use of ecosystem services. Should provisioning services be included if their contribution to sustainability is uncertain? It was also questioned how do we ensure the index reflects real ecological change rather than methodological adjustments?

s. According to metadata, in addition to the aggregate index in biophysical terms, aggregate measures of ecosystem services in monetary terms could be reported by Parties as a component or complementary indicator. If monetary ecosystem services accounts have been developed, aggregate measures in monetary terms can be derived by summing total supply or use for each ecosystem service for the same period, with care taken to use constant prices across accounting periods to ensure that the values are expressed in real rather than nominal terms. The monetary value of ecosystem services can be expressed as a percentage of gross value added (GVA) from the national (economic) accounts. Estonia has calculated monetary values for ecosystem services in ecosystem accounts. However there are substantial data gaps in the time series and these cannot be estimated without the full ecosystem account. It remains to be tested in the future.

t. Metadata proposes disaggregation by ecosystem types (for example by realm, biome or ecosystem functional group). It may be possible to disaggregate by type of user (business, households and government – the economic units typically included in ecosystem services accounts). Subnational disaggregation may be important and useful at the country level (for example, disaggregation to provinces and municipalities). We think disaggregation by ecosystem types also helps to track which ecosystem types are most prone to change in supplying the service.

It was found that the results are rather difficult to interpret, therefore additionally index based on ratio of change of the supply of services compared to the supply of services in base year (base year was taken to be 2018) was calculated for comparison. First, ratio of change from base year (2018) was calculated for each ecosystem service separately (Figure 13). Then a geometric mean was taken aggregating all services (Total Services provisioning), and sub classes (provisioning, regulating, cultural), calculating trend index (Figure 14).

Figure 13. Change ratio of services supply compared to base year. Base year is 2018.

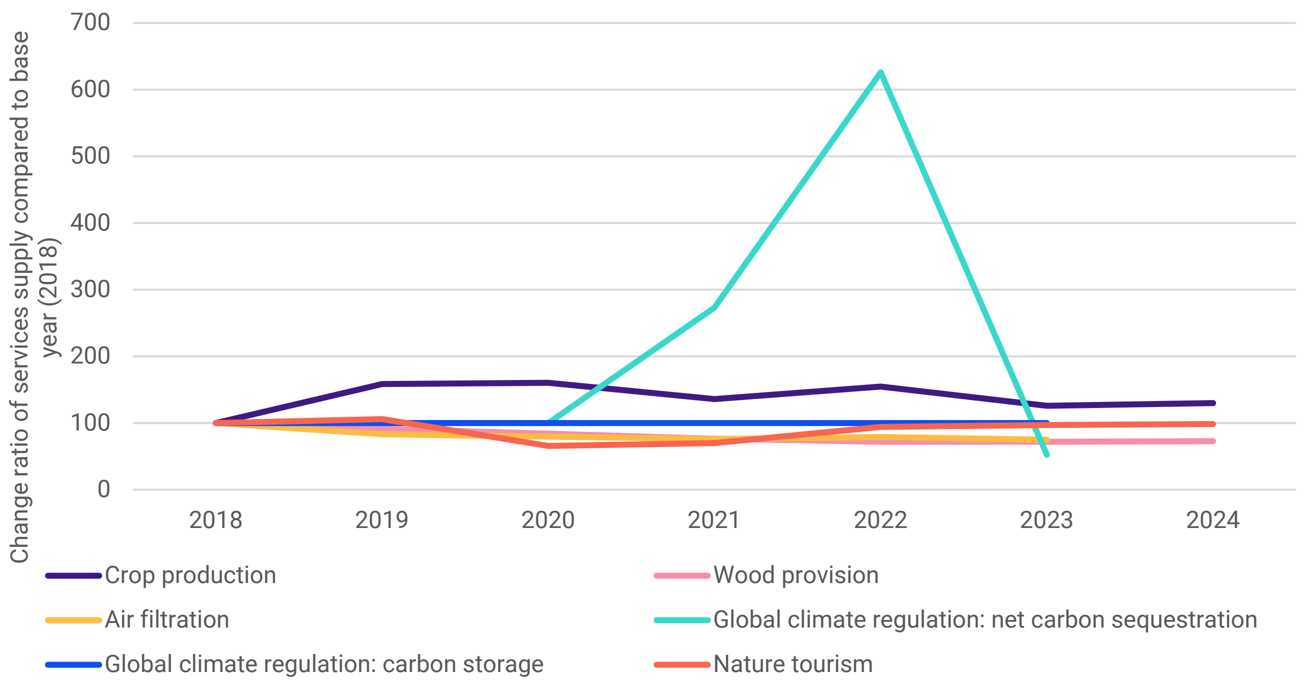
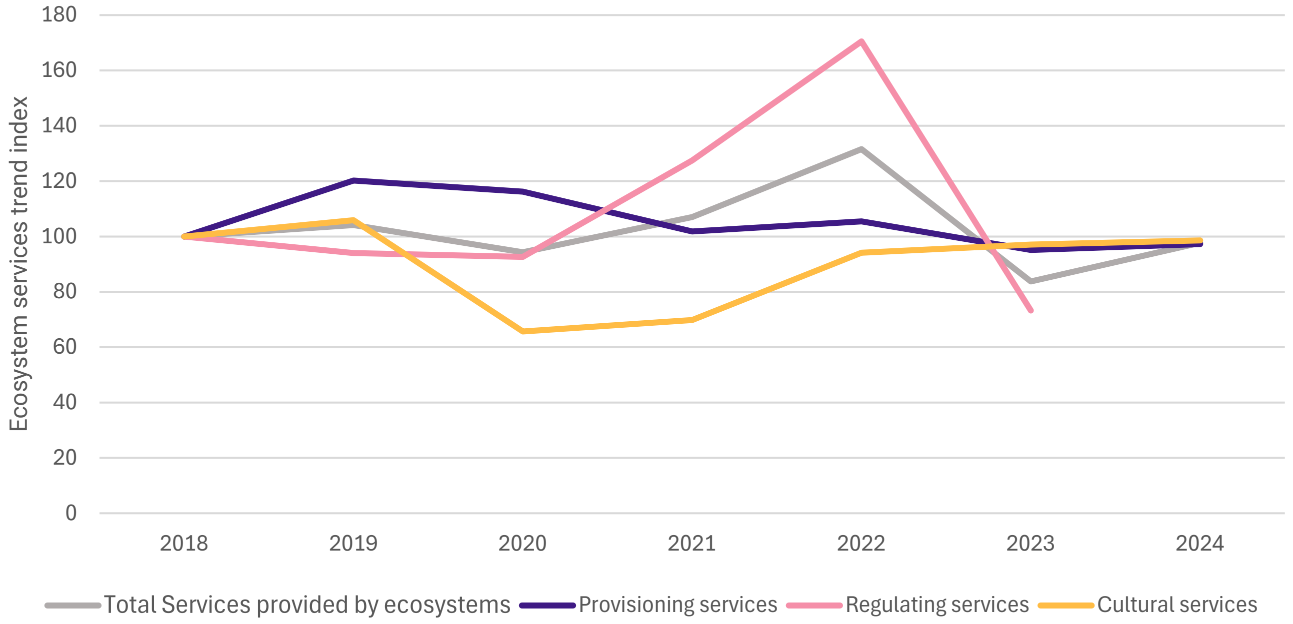


Figure 14. Ecosystem services trend index calculated as geometric mean of change ratio of supply of services compared to the supply of services in the base year.



Using the original methodology for calculating indicator B1 (using a geometric and chain method) and calculating the trend based on base year yielded the same results, except for the total services in the last year in the timeseries (2024).

When aggregating to total services provided by ecosystems, the missing value for regulating services in 2024 does not have as significant effect on the aggregated figure when using the chain method (85.5 in Figure 13) as is the effect when using a simple base year ratio (97.7 in Figure 14). It enforces what was given in the metadata factsheet that the chain method for calculating the geometric mean has the advantage that it allows for different time series lengths with different starting years for different ecosystem services, which means that additional ecosystem services can be added to the index as datasets and accounts for additional ecosystem services become available. However, the issues mentioned previously, such as incomplete time series and 0-values, still stand.

It is an ongoing task to understand how the CBD index aligns with ecosystem service accounting and whether adjustments are needed for clarity. The Ministry of Climate in Estonia has yet to develop a methodology for CBD reporting but the task is foreseen in the future.

7 Development of a partner-inclusive system for ecosystem accounts

The development of a partner-inclusive system is a strategic priority aimed at improving the efficiency, consistency, and usability of environmental data for ecosystem accounts in Estonia. This task focuses on creating an integrated framework that harmonizes data, methodologies, and outputs across key institutions, ensuring that ecosystem accounting processes are streamlined and aligned with both statistical and spatial planning needs. Currently, data and processes are fragmented across institutions, creating risks of duplication, gaps, and conflicting interpretations.

For Statistics Estonia, the Estonian Environment Agency, as the main holder of environmental data and analytical expertise, plays a central role of a partners in this development. Therefore, the main task was to institutionalize collaboration between Statistics Office and Environment Agency for ecosystem accounting. The focus was on creating a transparent, predictable, and inclusive system where all partners have clearly defined roles, responsibilities, and access to data. In addition, collaboration with Estonian Environmental Research Centre, which also manages environmental data on a smaller scale, and the Ministry of Climate, responsible for coordinating data and related developments, was essential to ensure coherence and integration across the system.

Involving the partners assures:

1. shared ownership: Statistics Office and Estonian Environmental Agency both agreed that ecosystem accounts require multi-source data and joint methodological development with clearly defined roles.
2. long-term stability: moving away from yearly ad-hoc agreements for obtaining input data toward permanent documentation of methods and update cycles.
3. accessibility: ensure partners have permanent access to agreed datasets (e.g., PKÜ, Natura inventories, ELME data layers on ecosystems) without repeated negotiations. The datasets will be maintained and updated regularly.

The roles were defined as follows:

1. Statistics Estonia:
    a. Harmonize dataset descriptions (see ANNEX 4)
    b. Lead statistical integration and reporting.
    c. Update data transfer agreements.
    d. Formalize data exchange agreements for 2026 and beyond
    e. Develop regular production for air filtration and microclimate regulation ecosystem service in collaboration with relevant partners, foreseen in 2026.
2. Environment Agency:
    a. Maintain ELME ecosystem related data and layers
    b. Maintain environmental data used as inputs for ecosystem accounts
    c. Enable access and transmission to agreed datasets
3. Other partners and data:
    a. Agricultural Registers and Information Board has effective agreement on agricultural spatial data transmission with Statistica Estonia. Further activities include linking data needs of ecosystem accounts to the existing database.
    b. Estonian Environmental Research Centre manages environmental data on air quality. The dataflows and agreements for routine work will be decided in 2026.
    c. Remote sensing data, such as Landsat land surface temperature and Copernicus datasets, is planned to be considered for integration into the routine data flow in collaboration with relevant partners.
    d. Eurostat and JRC (Joint Research Centre) have developed and shared several datasets for assessing ecosystem services, e.g. Recreation Potential Map. Where applicable, these datasets will be considered for adoption by Statistics Estonia and, together with information from data holders, will be described and potentially integrated into the routine data flow.

In the light of specifying the roles and data availability, a discussion between representatives of Statistics Estonia, the Ministry of Climate, and the Environment Agency was held, where the semantic framework for monetary valuation methods of ecosystem services and the test calculations of the CBF indicator B1 ("services provided by ecosystems") were presented and it was agreed that activities related to the application and analysis of monetary valuation methods can proceed according to the plan and as needed. Environment Agency would serve as the primary point of contact for further cooperation, but more detailed arrangements will need clarification in the future.

The Ministry of Climate will begin preparing CBD reporting next year, including the description of relevant indicators. The contact person from Ministry of Climate was determined. Statistics Estonia does not have an obligation to report CBD indicators to Eurostat. However, mapping the intersections between accounting systems and global reporting frameworks is part of the work of the UN Statistics Division, which is why Statistics Estonia conducted the test calculation of indicator B1 within a grant-funded development project financed by Eurostat. Further cooperation opportunities will be clarified in the future.

7.1.1 Data Capture, establishment of routine procedures

There were several dialogues with Environment Agency on the topic how the roles of the institutions will be defined in preparation for the regular reporting of ecosystem accounts to Eurostat in 2026. ‘

This included identifying the input data (indicators, map layers, register extracts), describing it (responsible institutions, applied methodologies, update frequencies, harmonizing data names and ensuring consistent metadata) and setting up transmission rules (deadlines, transmission pathways).

Within the framework of the *Development of a partner-inclusive system for ecosystem accounts*, the Estonian Environment Agency has made a substantial contribution to strengthening close and systematic cooperation with Statistics Estonia.

From a data governance perspective, workflows have been streamlined, the structure of datasets delivered through harmonized data transmission has been standardized, and agreements have been concluded to ensure efficient and sustainable cooperation in the future.

The process has initiated the development of joint workflows across multiple domains, including methodological development of data, data exchange mechanisms, and the formulation of shared institutional positions on ecosystem accounting and related biodiversity-topics.

As an illustration of this coordinated approach, a representative of the Estonian Environment Agency participated in a London Group meeting, representing the shared perspectives of both Statistics Estonia and the Estonian Environment Agency. Representatives of Ministry of Climate contributed to the opening of the London Group sharing the important aspects of collaboration between the institutions.

Conditional agreements have been reached regarding the timetable and methodological alignment of carbon-related spatial data layers in the future. The Estonian Environment Agency holds unique and methodologically complex datasets; however, a key challenge lies in transforming these datasets into forms that are technically and methodologically suitable for end users, including official statistics.

An important achievement of the partner-inclusive system development process has been the process of development of a shared understanding of the concept of different ecosystems. Analysis of the comparison of ecosystem extent maps compiled in Statistics Estonia and Environmental Agency was one task which contributed to the goal. In 2025, the Estonian Environment Agency has been developing the forest mask - a spatial dataset enabling the consistent delineation of forest land area and extent in accordance with both national definitions and the FRA framework. Annual production of this forest mask generates input datasets whose use within Statistics Estonia’s production workflows has been discussed, with initial implementation steps already planned as the dataset provides most up to date information on forest land.

The overarching objective of the cooperation between the two institutions is the cross-use and re-use of data and the production of official statistics based on jointly agreed, relevant datasets.

In addition, in 2025 the Estonian Environment Agency carried out broader mapping of user needs related to ecosystem datasets, with Statistics Estonia providing critical input for further development, including automation of data production processes, workflow structuring, and identification of required datasets.

Development of a partner-inclusive system comprised and resulted in joint schedule for ecosystem data production (“ecosystem data production calendar”), listing:

- Data,
- Deadlines,
- Update frequencies,
- Responsible institutions,
- Applied methodologies.

Data transmission is planned with Environment Agency for following datasets:

1. Ecosystem Extent Account:
    a. Spatial datasets: ELF Natura Inventory, Semi-natural communities, Natura habitats, PKÜ semi-natural communities, Forest Registry
2. Ecosystem Condition Account
    a. bird indices, deadwood volume, net increment, removals
    b. canopy coverage spatial dataset
3. Ecosystem Services Account
    a. net increment, removals
    b. Spatial datasets: Forest Registry

The description of datasets is presented in ANNEX 4: Description of datasets and metainformation for data transmission as part of the framework of data transmission between Statistics Estonian and Estonian Environment Agency. Formalizing data exchange agreements is process for the 2026.

Future workflows in 2026 will include adding indicators currently in development and data from other institutions, e.g addition of carbon related datasets that is currently in development by Environment Agency and data on particulate matter, which agreement will be discussed with Estonian Environment Research Centre, also remote sensing data capture.

Harmonized data transmission, particularly for spatial datasets used in compiling the ecosystem extent account, will significantly improve the routine compilation process for statistical purposes. The Environment Agency uses the same datasets to produce ecosystem extent maps, with an emphasis on ecological detail. Establishing a common understanding of these datasets and the methodologies applied, combined with harmonized data from registries, ensured that the two ecosystem extent datasets are comparable and that any differences are clearly documented (see chapter 2.3 for more detail).

Annual data capture will rely primarily on a formal data-sharing agreement between Statistics Estonia and the Environment Agency which is planned for 2026. Metadata and file structure standards (formats, classifiers, extraction timeframes) are currently in definition phase to ensure consistency.

ANNEX 1. Kick-off seminar

Minutes of the Meeting

Title: Development of Ecosystem Accounting – Partner Seminar

Date: 19 February 2025

Organizers: Statistics Estonia

Participants

Statistics Estonia: Kaia Oras, Katlin Aun, Aki Kadulin, Argo Ronk

Ministry of Regional Affairs and Agriculture (agri.ee): Reelika Paadam, Siim Suure, Veronika Vallner-Kranich, Sandra Salom

Ministry of Climate / Environmental Agency: Krisela Uussaar, Hanna Hermlin, Sander Ahi, Madli Linder, Mart Kiis

TalTech: Üllas Ehrlich

University of Tartu: Elisabeth Prangel

1. **Overview**
   Kaia Oras gave an overview of the seminar objectives and introduced the agenda, which included: Ecosystem accounting and recent developments, Work under Eurostat development grant 101113157 (2024-EE-EGD), Planned activities for 2025 and sub-tasks, Future plans and cooperation, Discussion on initial priorities, Ecosystem classification (translation, second level), Cooperation on monetary valuation of ecosystem services, Feasibility study on ecosystem service valuation, Workflow for valuation methods and values related to ecosystem services

- **Ecosystem accounting in EU Regulation 691/2011**
  First reporting year is 2024 and data transmission to Eurostat in 2026. Work in 2025 includes developing indicators and reporting tables with preparing for regular compilation starting 2026. EU support for the development of methodology and initial data until 2026; from 2027 onward, national budget will finance ongoing work.

7. Planned Sub-Tasks for 2025

- Development of ecosystem extent, condition, and service accounts
- Metadata preparation and publication readiness
- Partner-inclusive system for data flows
- Methodological improvements and alignment with Eurostat guidance

3.1. Quick overview of the ecosystem services account was provided, which currently includes eight services: Crop provision, Pollination (linked to crop provision data), Timber provision (connected to forest accounting), Air filtration (in cooperation with the Estonian Environmental Research Centre), Global climate regulation (covering carbon stock and carbon sequestration), Local climate regulation (vegetation cooling effect in urban areas, temperature reduction), Nature-based tourism services (measured by overnight stays attributable to surrounding ecosystems). The work is ongoing to make the compilation of these services regular from 2026. Close cooperation with the Environmental Agency for most of the services.

Special emphasis is on: global climate regulation: awaiting new methodological solutions. Local climate regulation: methodology developed last year, continuation planned this year, importance of documenting methods and data.

Plans for communication, analysis, and publishing articles for international expert groups (as Kaia will elaborate later) were introduced.

3.2 Quick overview of the condition account was provided. The ecosystem condition account includes values calculated as national averages for the following indicators: Urban green areas, PM2.5 concentration in cities (fine particulate matter < 2.5 micrometres), Organic carbon stock in the plough layer of agricultural land, Organic carbon stock in the topsoil of grasslands, Farmland bird index (for agricultural landscapes), Deadwood volume, Canopy cover in forests, Forest bird index, Share of artificial impervious surfaces in coastal areas.

Many indicators overlap with other reporting frameworks (e.g., biodiversity restoration regulation and global initiatives). Data owners are mainly the Environmental Agency, except for PM2.5 and air pollution data, which come from EKUK (Estonian Environmental Research Centre). Close cooperation is ongoing to ensure regular compilation of these indicators. Each indicator requires methodological documentation and metadata preparation.

Kaia Oras concluded that Eurostat's methodology has become more specific: This year marks the start of reporting obligations. At the Eurostat Task Force meeting on 26 February, the methodological guidance on ecosystem condition indicators will be discussed. The draft was published last week and is under review. Comments are requested before and after the meeting; final approval by member states is expected in May 2025, after which the guidance will remain stable for the first reporting period. The goal is to Align Eurostat condition indicators with the EU Nature Restoration Regulation to ensure methodological consistency.

8. Ecosystem Classification

Translation and adaptation of second-level ecosystem types was discussed. The first level translation was completed last year and is officially aligned with the EU regulation. The second level currently has no official translation; a draft has been prepared and needs review. The classification covers terrestrial, inland water, and marine ecosystems: Terrestrial and inland water classes are based on CORINE Land Cover. Marine classes follow a global ecosystem typology, reviewed with marine scientists.

Input from researchers is highly valued for finalizing translations this year.

The second-level classification is applied in extent accounts Service accounts (ecosystem services are reported by ecosystem type in a cross-matrix). It also has relevance for condition accounts.

Next steps were discussed:

- Review and finalize second-level translations will be coordinated by Kätlin Aun.
- Collect expert input for both terrestrial and marine ecosystem classes.
- Ensure consistency across accounts (extent, services, condition).
- Translate and finalize the second level of the ecosystem classification.

5. Indicators in global reporting and Policy Links

5.1 Biodiversity Convention Monitoring. Monitoring will start in 2026, aligned with ecosystem accounting steps. Four indicators are related to indicators in environmental accounts (Central Framework and Ecosystem Accounting). Cooperation is needed for indicators linked to environmental protection expenditure and biodiversity-related subsidies. Collaboration with Statistics Netherlands on methodology for ecosystem service index is foreseen.

Conclusions:

- Ecosystem accounts support Kunming–Montreal Global Biodiversity Framework targets.
- Indicators linked to CBD reporting obligations (national reports due 2026 and 2029).
- Planned cooperation with Statistics Netherlands on trend analysis for ecosystem services.

9. International Engagement: Estonia will host the UN London Group meeting in September 2025, where following topics are included:

- Monetary valuation of ecosystem services (semantic and methodological issues).
- Integration of ecosystem accounts with other dimensions (e.g., land ownership, carbon sequestration in emission accounts).

10. Monetary Valuation of Ecosystem Services

At the end of last year (December), Estonia reviewed and commented on the Eurostat feasibility study draft for monetary valuation of ecosystem services. The document has since evolved significantly; comments are requested by 25 February and throughout the year. The European Commission has 18 months to finalize the study, expected by summer 2026. Purpose of the Document is to make ecosystem services more visible and traceable. Monetary accounting is seen as one way to achieve better visibility. Estonia submitted initial positions last year; further evaluation and comments are needed.

Monetary values aim to integrate use value, scarcity, demand, and substitutability into a common scale. The document outlines a six-step process, and a hierarchy of valuation methods Preferred methods are where service value is directly observable. Challenges remain for public goods (lack of market prices). Semantics is considered important as values tend to be low compared to actual importance. However, there is lack of consensus on preferred methods and risk of misinterpretation when monetary figures are presented without context.

International and EU-Level Work: Monetary valuation chapters in SEEA EA are not yet part of the international standard (currently optional). Eurostat and member states are developing an extended concept of “connected or dependent values” for ecosystem services. Eurostat Task Force and UN London Group are discussing the methodological issues Estonia will host the UN London Group meeting in September 2025, where monetary valuation and extended concepts will be key topics.

Next Steps on reviewing valuation methods and semantics:

- Engage experts in reviewing valuation methods and semantic implications.
- Continue collaboration on methodological development and integration of extended concepts.
- It was discussed what could be the best way for analyses of the the connected values: It was proposed that monetary valuation approaches for ecosystem services will be organized into a systematic matrix.
- Experts are invited to review and suggest additional contributors in Estonia beyond those already identified (e.g., Helen Poltimäe, Üllas Ehrlich, Maie Kiisel, Aija Kosk, Kalev Sepp)

Immediate Requests for feedback (Deadline for comments: 25 February 2025)

- Comments and proposals on the 2025 activity plan.
- Condition indicator document (link provided).
- Eurostat feasibility study on valuation methods.
- Extended concept of connected/dependent values for ecosystem services.

11. Local and International Cooperation

Contribution to UN London Group, Eurostat Task Force, OECD/UNECE seminars. Planned articles and presentations for international forums, e.g. ESP (Ecosystem Services Partnership) conference.

Climate Ministry confirmed alignment with the Nature Restoration Regulation and readiness to provide input, but requested clear, targeted guidance on where feedback is most needed due to document complexity.

Developing partner-inclusive systems for compiling ecosystem accounts will continue in cooperation with Estonian Environment Agency. Agreements and contracts will be made with local experts and relevant Institutions on relevant tasks.

12. Timeline for 2025

Jan–Mar: Preparations, partner agreements. Detailed schedule will be finalized in March.

Jan–Oct: Data processing. Methodological development and metadata preparation.

Apr–Nov: Design of routine processes for 2026 reporting.

Oct–Nov: Final results seminar.

Dec: Technical documentation and publication.

Two official summaries will be produced for the meeting: in Estonian and in English for Eurostat reporting.

ANNEX 2. Study visit

Minutes of the study visit " Development of the environmental accounts"

June 2-3, 2025

Statistics Netherlands

Henri Faasdreef 312

PO Box 24500

2490HA The Hague

THE NETHERLANDS

List of participants:

Statistics Estonia

Name	**Position, function**
Ms Kaia Oras	Lead expert of environment statistics and accounts in Environment Economic Statistics Service, responsible for environmental accounts compilation;
Ms Grete Luukas	Leading analyst, responsible for the compiling of the monetary environmental accounts;
Ms Hanna Pentsa	Leading analyst, responsible for EGSS and climate related expenditures
Ms Kätlin Aun	Leading analyst, responsible for ecosystem account
Mr Raigo Rückenberg	Leading analyst, responsible for the compiling of the environmental subsidies' accounts

Statistics Netherlands

Name	**Position, function**
Mr Sjoerd Schenau	Project leader Environmental Accounts (physical and monetary)
Mr Patrick Bogaart	Researcher in ecosystem accounts
Mr Olaf Koops	Researcher in environmental accounts
Ms Marieke Rensman	Researcher in environmental accounts
Ms Myrthe Bruning	Researcher in environmental accounts
Ms Jocelyn van Berkel	Researcher in ecosystem/ environmental accounts
Mr Frank Prins	Researcher in ecosystem/ environmental accounts

Minutes

Progress on the advancements, meeting agenda and the objectives of the meetings were discussed.

Kaia Oras gave an overview of the project objectives, state of the art and the expectations of the study visit

Ecosystem accounting

Objective: Enhancements of the evaluation methodology for ecosystem accounts: producing data, metadata and automatization of the compilation for the ecosystem services data (focusing on the pollination, nature-based tourism, local climate regulation, global climate regulation) and considering other relevant services and issues of ecosystem accounts of concern like condition indicators and for example links to CBD reporting and EU nature restoration law

Ecosystem services physical valuation and workflows: Jocelyn, Marjolein, tbc, Patrick, Kätlin, Argo, Claudia

The session focused on carbon sequestration methods, local climate regulation 83onsisten, pollination data needs, and indicator alignment.

Statistics Netherlands relies on empirical net sequestration rates by ecosystem type from field measurements while developing net primary production maps from remote sensing. Differences from LULUCF methods were noted. Accounts will also draw on national soil surveys and 3D geological models for peatlands. Emissions in peatlands were discussed, including redistribution of municipal totals via spatial models accounting for groundwater depth and peat thickness. The ambition is to produce consistent storage and flow estimates, while documenting divergences from LULUCF and data-updating cycles. On emissions in peatlands, earlier work used municipal totals redistributed via spatial models accounting for groundwater depth and peat thickness, with managed and unmanaged contexts discussed. Policy attention on raising water tables, alternative land uses, and mitigation pilots was noted, together with data gaps on actual water-level management and decomposition rates at scale.

For local climate regulation, Eurostat's guidance-note approach —which regresses land surface temperature against tree cover and (evapotranspiration variables—with Netherlands' operational urban models that integrate sky-view factor (radiative geometry), building morphology, wind, and radiation in 10 m grids, and treat water bodies cautiously (cooler by day, potential heat source at night). The central accounting challenge remains how to pass from maps to supply–use tables: whether to sum or area-weight averages, how to define days or hours under a temperature threshold (≥ 25 °C), and how to capture the use side (e.g., cooling benefits scaled by the number of exposed people). The group discussed augmenting sparse satellite scenes with reanalysis products to improve temporal coverage, recognizing licensing and capacity constraints. Evapotranspiration dataset was discussed whether it describes potential or real evapotranspiration, which is dependent on water availability.

It was agreed to revisit the topic in the autumn when both countries have advanced with their work.

On pollination, the bottleneck is spatial data on landscape elements such as hedgerows. The trajectory toward pollinator monitoring in the Netherlands as part of the Nature Restoration Law indicator set and the global biodiversity headline indicators was discussed. In the interim, species-occurrence repositories (e.g., citizen-science data) can support occupancy modelling and suitability mapping, provided observation bias is corrected and interpretations avoid over-reading distribution trends when abundance declines-occurrence repositories was discussed, with caution about observation bias.

It was agreed to revisit the topic 83onsisn when both countries have advanced with their work.

Ecosystem accounts, links to CBD reporting and EU nature restoration law: Patrick, Frank/Shaya, Kätlin; Kaia

Indicator alignment between ecosystem accounting and the Nature Restoration Law and GBF was reviewed, noting that many headline indicators can be populated from accounting inputs (e.g., extent of natural ecosystems via the ecosystem type map; deadwood in forests; tree-cover density adapted to urban areas), while others remain outside the accounts' scope (e.g., favourable conservation status under the Habitats Directive).

Vulnerability to heatwaves and ecosystem service local climate regulation: possible synergies: Fiona Smith, Kätlin, Kaia

Analysis for heat-stress vulnerability was introduced by Statistics Netherlands. Statistics Netherlands maintains high-resolution gridded data (100×100 m and 500×500 m) on demographics and socio-economics (age, gender, household composition, income, energy poverty), housing characteristics (tenure, building type, year built, energy label), and population density, which are linked to urban heat island (UHI) metrics and summer-day thresholds (commonly ≥ 25 °C). Composite vulnerability indices are constructed via normalization and weighting, with outputs available at grid and municipality level, and with counts and shares of vulnerable/exposed groups.

Monetary valuation options were discussed, including replacement-cost analogies and avoided health costs. Replacement-cost analogies (e.g., cooling by air conditioning) are conceptually possible but often ill-posed for open spaces and may diverge from actual behavior. Related/avoided costs pathways—such as health-care costs, hospital admissions, mortality, and productivity impacts—were seen as more policy-relevant, provided that epidemiological relationships can be credibly linked to temperature increments at the right spatial and temporal resolution. Statistics Netherlands holds restricted health microdata (mortality and hospitalizations) under stringent permissions and is coordinating with the National Public Health Institute and a PhD project; Estonia's access regime and resources were noted as open questions. Estonia's existing UHI mapping (largely satellite-based and city-focused, with clear hotspots also over extractive landscapes such as open peat/oil-shale areas) was compared with the broader needs of local climate regulation service accounting, which requires quantifying the cooling effect attributable to vegetation rather than solely mapping UHI intensity.

Methodological alignment with Eurostat guidance was recognized as a priority, while acknowledging data and capacity constraints. The idea of monetizing local climate regulation via avoided health impacts was retained as a promising line for the second half of the year once physical quantification stabilizes.

Ecosystem services economic evaluations: Sjoerd, Jocelyn, Kätlin, Kaia

The purpose of ecosystem accounting is to record the benefits from nature to society in both physical and monetary terms, therefore, recognizing that different valuation methods convey different economic meanings. A distinction was re-emphasized between approaches that value benefits to users (aligned with SEEA exchange values) and approaches that reflect maintenance or replacement perspectives (e.g., management/restoration/replacement costs), which are informative but not always commensurate with exchange-value concepts in the core accounts.

The feasibility of monetary valuation methods was discussed service by service, emphasizing that replacement cost should only be used where feasible, least-cost alternatives exist and where the counterfactual is realistic, and that restoration cost is rarely attributable to single services because ecosystems co-produce many services. A cautionary Estonian example on soil replacement illustrated the scale and hypothetical nature of some calculations. For culture and recreation, the Netherlands has valued spending (tourism and day recreation), yielding large figures given population and travel behavior; Estonia's lower population density implies smaller totals even if per-capita values are meaningful. On regulating services, flows are often modest in monetary terms except carbon when stock values and high shadow/replacement prices are used.

The Netherlands' experimental GEP (Gross Ecosystem Product) work was described: 11–12 services are aggregated, with timber and carbon significant, and recreation/tourism also large on the spending basis. Scenario work with university partners explores future GEP under land-use pathways. Policymakers have responded positively, asking for practical applications (e.g., comparing benefits with conservation expenditures). The group noted that embedding results into cost–benefit analysis and environmental impact assessment remains challenging because consultants apply entrenched toolkits and may perceive official statistics as too aggregated for project-level appraisal.

It was agreed to share the material on GEP application in the Netherlands.

Ecosystem services valuation matrix: Kätlin, Kaia, Sjoerd

The discussion opened with a review of ongoing work to collate and compare valuation methods for ecosystem services relevant to Estonia. Estonia shared a draft valuation matrix on 29.05, summarising current monetary valuation methods applied to ecosystem services. The table includes service categories (e.g. provisioning, regulating, cultural), applied valuation methods (e.g. market price, avoided cost, benefit transfer). The shared online table is being populated with parallel methods per service, acknowledging that different methods yield different magnitudes and interpretations.

The working typology draws on a paper previously presented to the London Group and while partly aligned with SEEA and SNA concepts, also incorporates connected values such as replacement or restoration cost and opportunity cost that do not always meet narrow exchange-value criteria. Sjoerd Schenau suggested to base the table with SEEA EA methods so it wouldn't drift away from generally agreed principles.

Key points were clarified about method families: directly observable prices, revealed-preference approaches such as travel cost, cost-based approaches including restoration, replacement, avoided damage, and shadow project costs, and stated preference measures such as willingness to pay. The group noted conceptual overlaps and the risk of conflating flows versus stocks.

The plan is to build a bridge between the working typology and SEEA/SNA categories, marking what maps cleanly to exchange values and what does not. Interpretation was emphasized as critical: identical techniques can imply different meanings under different assumptions.

For conference preparation, the team agreed to structure messaging around methodological trade-offs, interpretation and semantics, and communication strategies for diverse audiences, with service snapshots and a typology–SEEA bridge as core visuals. The plan was formed to compile concise slides per service (with emphasis on regulating services) showing the method(s) applied, data sources, assumptions, and interpretation; include a unifying slide on method trade-offs and another on communication to policy. A finance/benefits slide to contextualize ecosystem-service values relative to biodiversity-related expenditures, avoiding double counting or category confusion, will be added. The exact structure of the approach was still disputed and was considered to be developed in a period of coming months, tested and presented for the ESP conference for the presentation on valuation of the ecosystem services and further discussed to be available for the UN London Group meeting when the connected values approach and ecosystem services semantics will be presented.

Discussion on a new grant. List of issues for future discussion.

1. Integrated monetary accounts concerning EGSS, EPEA, ESST, REMEA, integration to the common environment and resource management framework. Development of technical solution for the integration of accounts. Analysing of the feasibility of the creation of the relevant IT solutions (NL is using R for EPEA, excel for EGSS, taxes are done by automated solutions focus is on reducing the use of excel).

2. Ecosystem accounts and monetary valuation:

Valuation methods, physical. Automation of assessments (Now in the grant: Services will comprise crop provision, pollination, wood provision and if feasible some calculation stages regarding global and local climate regulation, air filtration and nature-based tourism. Final set of the services to be automatized will be clarified). Carbon seq with, air filtration with EKUK. Estonian Environment Agency wanted to develop greenery in cities and a permeable surface on the coast.

3. Better consistency between energy flow accounts, air emission accounts and taxes accounts, as well as national accounts. Harmonisation of data sources, wider use of administrative sources (Tax and Customs Board? Petrol station data?) and automation of accounting. Mapping, Automated solution or proposal based on SUT macro, for VAL VAT (relation to monetary calculations)

4. PEDS are not part of the grant project in Estonia.

ANNEX 3. Final methodological seminar

Minutes of the Final Methodological Seminar on Ecosystem Accounts (Estonia)

Date: 3 December 2025

Statistics Estonia (Stat EE): Kaia Oras, Katlin Aun, Grete Luukas, Argo Ronk

Ministry of Climate (Environment Agency): Krisela Uussaar, Sander Ahi, Aleksei Vastsenko, Hanna Hermlin, Madli Linder, Kairi Vint, Ahto Mets, Taavi Pipar

Estonian University of Life Sciences: Aki Kadulin, Kalev Sepp

University of Tartu: Aveliina Helm

TalTech: Ullas Ehrlich, Aija Kosk

Statistics Netherlands: Sjoerd Schenau, Patrick Bogaart

ISTAT (Italy): Aldo Femia

Executive Summary

The seminar reviewed Estonia's progress in ecosystem accounting and presented methodological developments in extent, condition, and services accounts. Key outcomes include automation of extent account workflows, harmonization of ecosystem maps, compiling of supply and use tables for services, conceptual advances in monetary valuation semantics, and discussion of ecosystem condition indicators alignment with EU Nature Restoration Regulation,

Opening and Context

Kaia Oras thanked all participants for their valuable contributions and presented the development work and the main results accomplished together during 2025. She highlighted that significant progress has been made under the Eurostat grant, focusing on ecosystem extent, services, and condition accounts. The team continued improving the software initiated under the previous grant to automate calculations of ecosystem extent, and outputs were prepared at EU typology levels I and II. For ecosystem services, data compilation included crops, timber, pollination, air filtration, climate regulation, and nature-based tourism, complemented by the development of supply and use tables and consultations with national data holders. Work on ecosystem condition accounts advanced through testing Eurostat methodologies and assessing the feasibility of regular data flows.

Kaia also touched upon the methodological developments both physical and monetary valuation methods, as these were a key focus, including refining approaches for monetary valuation of ecosystem services, conducting consultations with Estonian experts and international partners, and contributing actively to global forums such as the UN London Group and Eurostat Working Group. Kaia also touched on issue paper on monetary values which was prepared and empirically tested using Estonian and Dutch data.

Activities in 2025 were summarized, including earlier seminars, followed by five task force meetings and consultations, Study visit to Statistics Netherlands and active participation in UN London Group and Baltic States cooperation. Work streams included extent accounts, services accounts, condition accounts, and development of an integrated system for continuous statistical production starting in 2026.

One of the strategic topics discussed during the seminar was the creation of a partner-inclusive system for ecosystem accounts. Kaia Oras introduced this as a cornerstone for Estonia's future work, emphasizing that ecosystem accounting depends on diverse datasets—spatial maps, ecological indicators, and monitoring data—currently scattered across institutions. Kaia emphasized on the efforts of the creation of a partner-inclusive system for ecosystem accounting in 2025, which establishes joint governance principles, permanent methods, and open access to critical datasets. "We need to integrate these flows into a continuous statistical production system, starting from 2026, when regular reporting becomes mandatory," Kaia noted. Kaia reflected on the roles of Statistics Estonia, Estonian Environment Agency, and other partners to ensure harmonization and stable data exchange.

Despite challenges such as still the development phase guidance materials, limited data availability, and the need for specialized expertise, the work progressed according to plan. International cooperation and methodological refinement remain central to achieving good results. The next steps include harmonizing data layers, updating data exchange agreements with preparations underway for regular reporting starting in 2026

Kaia then outlined the roadmap:

- Mapping all existing datasets and responsibilities has been done already.
- Drafting a joint covenant for data sharing and method harmonization.
- Piloting integrated workflows in 2026 for extent and condition accounts and expanding to ecosystem services and valuation in 2027.

The discussion also referenced the upcoming 2026 institutional contract, which will focus on data capture, management, and transformation. This contract is intended to modernize workflows and improved integration of datasets. Kaia explained that the continuous contract will enable us to move from ad-hoc queries to permanent, automated data flows. It's about building a system that is efficient, transparent, and future proof. This contract will support development of open-source spatial tools for reproducibility. Integration of research outputs from soil governance projects and climate regulation assessments, and harmonization with nature restoration regulation and CBD reporting requirements would be included in the system. The experts agreed that this partner-inclusive system, backed by the 2026 contract, is essential for Estonia to meet international reporting obligations and provide robust, transparent data for environmental policy.

Discussion:

Aldo Femia (Statistics Italy) added: "This is a virtuous approach. Harmonizing production systems and sharing expertise will strengthen both statistical quality and policy relevance."

Feedback from the Climate Ministry line focusing on Nature Restoration Regulation

Madli Linder (Estonian Environment Agency) outlined the EU Nature Restoration Regulation.

Madli presented the EU Nature Restoration Regulation, which aims to restore degraded ecosystems across Europe, targeting at least 20% of land and sea areas by 2030 and all ecosystems in need by 2050. The regulation supports biodiversity recovery, climate change mitigation, and food security. It entered into force in August 2024, and Estonia must prepare its national restoration plan by September 2026, with comprehensive reporting every six years starting in 2031.

Key elements of the plan include:

- Mapping areas for restoration and defining measures to prevent habitat deterioration.
- Selecting indicators for monitoring progress.
- Targets for terrestrial, freshwater, marine ecosystems, river connectivity, pollinators, agricultural land, forests, and urban green spaces.

Several indicator overlap or share similarities with ecosystem condition account, such as soil organic carbon, common bird indices, deadwood, and urban green space. The decision on the methodology and indicators for reporting under NRR has not yet been made.

Questions and Discussion:

Indicator Selection: A question was raised about whether soil organic carbon will definitely be chosen as a monitored indicator. Madli clarified that the decision is not final yet; Estonia must select two indicators from the proposed list for agricultural ecosystems.

Linkages and Methodology: Patrick Bogaart shared that in the Netherlands, ministries were initially unaware of the linkages between Restoration Law and ecosystem accounts. He explained ongoing efforts to integrate these frameworks, especially for monitoring. Patrick also raised concerns about differences in scope: Restoration Law focuses on habitats under the Habitat Directive, while ecosystem accounts cover broader ecosystem types. Madli responded that Estonian Environment Agency has a wider approach for ecosystem maps, which includes mapping condition for all ecosystems, not just Natura habitats, using aggregated methodologies developed under the ELME project.

Conceptual Challenges: Patrick noted that ecosystem accounts currently resemble indicator systems rather than full accounting frameworks, as they lack independent estimation of supply and use. This sparked a brief exchange on the need for harmonization and clarity in definitions.

Alignment challenge: How to reconcile habitat-focused restoration targets with broader ecosystem accounts?

Ecosystem Extent Account

Argo Ronk presented the progress on compiling the 2024 ecosystem extent account, which provides up-to-date information on the areas of different ecosystem types and serves as a foundation for condition and services accounts. Full national coverage is achieved for ecosystem extent, including marine ecosystems. For Estonia, over 3.2 million polygons are mapped, with more than 120 detailed mapping units (almost 200 when marine areas included).

The work followed Eurostat's guidance and EU ecosystem typology (Levels 1–3), ensuring harmonized classification across countries. The input data (Estonian Topographic database, meadows database, Natura 2000 habitats inventory, semi-natural habitats, wetlands data, forests from Forest registry, agricultural land and semi-natural habitats) and methodology for the compilation of Estonian ecosystem extent account were described in detail.

Automation of workflows using Python and GIS tools, reducing manual work and improving consistency was successful. Besides the compilation of the map from input data layers, the aggregation from detailed Level 3 classes to Level 2 and Level 1 for reporting were included in the scrips and workflow for identifying continuous and discontinuous settlement areas and marine area were also scripted. The automation for EU ecosystem typology aggregation and classification is now largely complete. Future work will focus on streamlining data preprocessing to enable faster account compilation in 2026.

Kätlin Aun introduced the translation of EU ecosystem typology from English to Estonian. Level 1 classes were translated in 2024 for the translation of EU Regulation 691/2011. Level 2 classes were translated with the help of existing literature, experts from Estonian Environment Agency, Ministry of Climate and University of Tartu Marine Institute.

Comparison with Environment Agency maps

Argo Ronk shared preliminary results comparing Statistics Estonia's ecosystem extent map with the Environmental Agency's ecosystem base map. The comparisons were made at the most detailed typological level comparing whether the ecosystems are classified similarly under EU ecosystem typology level 1 class. Similarity was 81%, slightly lower than last year (87%).

Main differences are seen between settlement areas (methodological issue), forest classification, and wetlands. Discrepancies stem from different update cycles, classification rules, and use of additional data (e.g., vegetation height models by the Agency). Classifications rules differ in case of settlement areas where continuous and discontinuous settlement area in EU ecosystem typology incorporates more natural ecosystems. The "other open areas" class causes differences because in the EA map this class has been specified in more detail.

Marine, coastal and transitional areas: Hanna Hermlin clarified that the Agency's maps currently focus on dry land, explaining why the area of ecosystems in coastal areas differ significantly. Updates are planned for next year. Including inland waterbodies is also planned in 2026.

Discussion:

Methodological challenges: Aldo Femia noted that Italy is in the process of compiling ecosystem extent map and comparing with other national ecosystem maps can be used as comparison and quality assessment.

Data sources: Questions arose about whether Estonia uses Earth observation data for high-resolution ecosystem maps; Argo explained that local inventories and topographic databases are the main sources, supplemented by detailed habitat maps.

Future improvements: Patrick Bogaart inquired whether Estonia has done crosswalk to IUCN GET. Estonia has tested applying IUCN GET in previous works but is not applying it currently. In case the need arises for future global reporting, then adjustments need to be made.

Condition Accounts

Kätlin Aun introduced ecosystem condition account, explaining the indicators which are mandatory under EU Regulation 691/2011 for reporting: green areas in cities, PM2.5 concentration, soil organic carbon, bird indices, deadwood, tree cover density coastal artificial area. She showed calculated values for the account of year 2024, where the data was available, and explained the data availability, calculations and how these indicators align with the Nature Restoration Law, complimenting the previously presented topic on feedback on Climate Ministry on NRR. She acknowledged that the condition account, which includes only national averages for mandatory indicators under EU Regulation 691/2011, does not capture the ecological functions of ecosystems in detail.

Kätlin highlighted the progress made—most indicators for 2024 were compiled—but the challenge is that some data still rely on older reference years, and two indicators had to use placeholders because updated measurements weren't available. She pointed out that urban green areas are tricky: Estonia's large administrative units include rural land, which distorts the picture of actual city greenery. Plans for 2026 include updating methodologies for green areas and coastal impervious surfaces, using remote sensing data, and aligning the latter with NRR methodology. In case of soil carbon, it relies on future data flow from The Land and Soil Use research and development project (ends in 2026/2027)

Discussion:

Patrick Bogaart highlighted gaps in environmental accounts regulation (few indicators per ecosystem type) and suggested leveraging Habitat Directive methods while avoiding excessive data demands.

Ecosystem Services Accounts

Kätlin Aun presented the progress on compiling ecosystem services accounts for Estonia, including eight ecosystem services: crop provisioning, pollination, wood provisioning, global climate regulation, local climate regulation, air filtration, nature-based tourism-related services.

She described how work followed Eurostat's guidance and aimed to produce supply and use tables in both biophysical and monetary units. The aim was to compile the account for 2024, in cases when the data was still incomplete, methods and arrangements were introduced to produce it in 2026.

Crop provisioning: Calculated using material flow accounts, disaggregation can be done based on agriculture statistics; monetary valuation based on average land rental prices.

Pollination: Estimated as the additional crop yield attributable to wild pollinators; connected with crop provisioning service, reporting to be done according to material flow accounts reporting units, calculated based on spatial model based on the location on crip fields and pollinator habitats. Current work based on the model developed in the Netherlands, which diverges from Eurostat guidelines and INCAtool model in some aspects.

Wood provisioning: Service is described as net increment (mandatory indicator) and removals (voluntary), which data is collected also for forest accounts. Monetary valuation is based on stumpage price, which is also aligned with EFA.

Global climate regulation: Indicators are carbon sequestration (data from Estonia's greenhouse gas inventory, available in 2026) and carbon stock (data from the ELME project, 2023). The improved data is foreseen to be obtained in 2026/2027 in relation to the The Land and Soil Use research and development project, which is ongoing in Estonia. Monetary valuation used EU ETS carbon prices.

Air filtration: Calculated as PM2.5 deposition on vegetation; data from the Estonian Environmental Research Centre becomes available in 2026; calculations are made spatially incorporating different spatial datasets. Monetary valuation based on external health cost estimates.

Nature-based tourism-related services: Estimated through overnight stays in accommodations, which can be attributed to ecosystems. Calculations are made using tourism statistics in IncaTool. Monetary valuation is based on tourism expenditure data.

Local climate regulation: The development of the methodology for local climate regulation was one of the focuses in the work. Developed in collaboration with the Environment Agency using Copernicus tree cover data, Landsat land surface temperature data, Evaporation dataset with regression models. The calculation process is automatized with Python scripts. Attempt to convert land surface temperature-based calculations to air temperature was made, but the results need validation. Aggregation of the results for SUT was discussed as it is an ongoing discussion in Eurostat Task Force also.

Discussion:

Aldo Femia questioned the meaning of the 0.7°C cooling effect, noting it seems low and suggested linking results to population exposure for meaningful valuation. He also raised concerns about attributing supply without considering demand (e.g., sparsely populated areas vs. dense urban areas). Kätlin agreed and proposed incorporating population distribution into future, especially considering monetary valuation. It was agreed that the results need validation and explaining the results is still underway.

Mechanisms Behind Cooling Effect: Patrick Bogaart asked whether shading or evapotranspiration contributes more to cooling. Aleksei Vaštšenko confirmed that both factors were modelled separately and can be analysed further; preliminary indications suggest shading has a stronger effect, especially during drought periods.

Data Challenges: Kätlin noted that lack of high-resolution air temperature data inside cities required using general conversion formulas instead of regression based on local data. Aldo observed occasional counterintuitive results (vegetated pixels showing higher temperatures), likely due to regression artifacts, and suggested truncating negative effects.

Other Technical Points: Discussion touched on fodder crop classification for provisioning services and deviations from Eurostat guidance. Estonia agreed to the deviations, as using detailed agricultural data refined allocations.

Monetary Valuation and semantics

Kaia opened the point by explaining why this work was necessary and why it mattered from the perspective of the Eurostat EGD EE 2024 grant. The grant foresees to strengthen the methodological basis of ecosystem accounting and to improve the integration of monetary values into official statistics. This is not just a technical exercise—it is about enabling countries to produce data that supports policy decisions on sustainability, resource use, and economic resilience. Without clear semantics and transparent valuation methods, figures risk being misinterpreted, and the credibility of ecosystem accounts suffers. The UN London Group had also explicitly requested empirical evidence to make the conceptual framework more practical, and this project was Estonia's response to that call.

The workflow started by mapping valuation methods used in Estonia and the Netherlands, bringing together national expertise and international input. They analysed the semantics of monetary valuation—what does it mean when we say a service is "worth" a certain amount? Is it a real market transaction, a hypothetical avoided cost, or a potential loss if the service disappears? To answer these questions, the multi-layered framework that distinguishes actual, institutional, hypothetical, and risk-related transactions related to ecosystem services was selected for testing and development.

Aldo Femia explained monetary values in ecosystem accounting as indicators of economic dependency. He introduced a scenario-based semantic framework that categorizes valuation approaches according to the assumptions behind them.

The framework is built on two dimensions:

- status of the ecosystem service in the scenario: ES exists (current reality), ES disappears (hypothetical absence), ES is restored or substituted (hypothetical intervention).
- type of consequence for the economic transaction considered: value of existing activities supported by the service, cost of replacing or restoring the service, avoided damage or social cost if the service is maintained.

Key Blocks in the Matrix were described as follows:

- Upper Left Block: Valuation concerns the existing ecosystem service and current economic activities. Example: Market-based prices for timber or crops.
- Mid Left Block: Hypothetical scenario where the service disappears. The value is derived from the loss of economic activities dependent on that service. Example: Agricultural output lost without pollination.
- Bottom Right Block: Social cost of lacking the service or cost of restoring it. Example: Restoration costs for wetlands or substitution costs for carbon sequestration.

Aldo explained that monetary values are conditional estimates, they depend on assumptions, models, and hypothetical settings and that official statistics should document the reasoning chain: data sources, assumptions, and calculation methods, for understanding the "value" we put on ecosystem and that pricing of ecosystem services is a policy choice, not a statistical decision.

Kaia Oras presented the empirical work, where the framework was populated with figures obtained by various monetary valuation methods for key ecosystem services in Estonia and the Netherlands, which were analysed for connected values and scenarios, showing how different layers of valuation tell different stories.

Kaia emphasised that this was not just about numbers but about meaning. Experts reviewed the framework and agreed it is conceptually rather strong, but they called for refinements: link valuation layers to ecological realities like thresholds and resilience, add uncertainty metrics, and create metadata templates to explain each figure's origin and limitations. They also recommended aligning the framework with SEEA EA and SNA for statistical coherence, expanding to dynamic analysis using environmentally extended input–output tables, and improving communication tools such as dashboards and user guides.

She then addressed which values should stay and which should go. Unrealistic replacement costs, outdated willingness-to-pay figures, double-counted downstream outputs, and speculative marketisation scenarios add confusion and should be removed. What remains should clearly show the actual and potential economic importance of ecosystem services.

In conclusion, Kaia stressed that the framework is robust; the main gaps are data-related, not conceptual. The possible next steps could include finalising semantic clarification, identifying additional empirical data—such as pollination yield variability, health costs linked to air filtration, and tourism expenditure—, developing dashboards, and launching pilot studies using input–output analysis for crop provision and climate regulation. But this all depends on financing what is not clear currently yet. Longer-term goals involve building a dynamic, multi-year valuation system and developing scenario models for risk and adaptation.

She closed by noting that Estonia's and Dutch work demonstrates the feasibility and transparency of this approach and positions these countries as a leading case studies in multi-layered ecosystem service valuation. The ultimate aim could be to integrate these methods into SEEA EA and national accounting methods, turning a conceptual framework into a practical decision-support tool.

Kaia provided the information that framework was presented earlier at the UN London Group on Environmental Accounting, where it received recognition as the group acknowledged the feasibility and transparency of taken approach. They recommended developing a guide for interpretation and mapping values to different uses and users. The Group encouraged Estonia to continue refining the framework and share lessons internationally, noting its potential to improve communication between statisticians and policymakers.

Discussion:

Drop unrealistic replacement cost estimates and speculative marketization scenarios.

Provide clear interpretation and link values to policy contexts.

Explore integration with extended input-output tables to assess sectoral dependencies.

Participants agreed on the need for clear semantics and documentation of assumptions. Estonia shared its mapping of valuation methods and final evaluation of the results and confirmed plans to publish the results.

Conclusions on multi-layered connected values application framework

Experts agreed that the multi-layered valuation framework is conceptually strong and transparent, offering a clear way to present different monetary perspectives for ecosystem services.

Aveliina Helm (University of Tartu) highlighted its value for showing ecological dependency, especially for irreplaceable services like pollination.

Sjoerd Schenau (Statistics Netherlands) called for detailed metadata and interpretation guides for policymakers.

Aldo Femia (Statistics Netherlands) emphasized the need to distinguish economic vs. ecological importance and set boundaries for hypothetical scenarios and specify the roles of ESS.

The UN London Group on Environmental Accounting has welcomed Estonia's approach, praised its feasibility and transparency, and recommended developing interpretation guidance and sharing lessons internationally.

The discussion on the CBD index of ecosystem services (Convention on Biological Diversity indicator)

Initial results of Statistics Estonia's testing the calculation of CBD indicator B1: Services provided by ecosystems were introduced. The index measures the average rate of change in the provision of a set of ecosystem services in a particular time period compared to a baseline year, for a country or globally. It builds on the timeseries of ecosystem services account.

First, Estonia selected the ecosystem services to include—provisioning, regulating, and cultural services—and compiled time series data starting from 2018. Then, using the chain index method, they aggregated these services into a single indicator that reflects overall change. This approach allows flexibility: new services can be added, and different time series lengths can be handled without breaking the calculation. The index helps policymakers see whether ecosystems are improving or degrading in terms of the services they provide. It can also be broken down by service groups or ecosystem types, offering insights into which areas need attention.

Some services lacked complete time series, forcing estimates or placeholders. Negative values—such as years when carbon sequestration turned into emissions—created mathematical issues. The index is work in progress. Questions remain about how to treat missing data, zero values, the number of services included, and whether provisioning services should be included if their sustainability is uncertain. With the initial results and identified issues which rose during calculations, it was discussed and analysed what the index shows and whether its interpretation needs refinement.

Discussion:

No conclusions were made on the topic. It was noted as an ongoing task, with emphasis on understanding how the CBD index aligns with ecosystem service accounting and whether adjustments are needed for clarity. As the index depend on the number of services and which services are included in the calculations, then it needs more consideration, which contribute to the goal of the index of tracking the sustainable use of ecosystem services. Should provisioning services be included if their contribution to sustainability is uncertain? It was also questioned how do we ensure the index reflects real ecological change rather than methodological adjustments?

Third, integration with global frameworks was emphasized. The index is linked to the GBF indicator B1, so Estonia's approach must align with international guidance. This was a test by Statistics Estonia, Te Ministry of Climate has yet to develop reporting to CBD. In the Netherlands the calculation of index B1 was calculated for reporting to CBD. Sjoerd Schenau noted that other countries face similar challenges and that UNSD is working on refining the methodology.

Other issues and conclusions.

Further work includes finalising extent and services accounts for 2024; prepare for regular reporting in 2026.

Analyse ecosystem maps between Statistics Estonia and Environment Agency; address settlement and coastal classification differences.

Organize a focused technical session on local climate regulation methodology and interpretation (next week).

Share written materials and presentations for comments

Closing

The chair thanked all contributors and emphasized maintaining momentum as the work transitions to operational phase in 2026.

Compiled: 5.12.2025, Statistics Estonia

ANNEX 4. Description of datasets and metainformation for data transmission

Dataset descriptions for data transmission from Estonian Environment Agency

Table name:	**Indicators**				
Extraction condition:					
Deadline:	**TBD**				
No.	**Field name/code**	**Field format**	**Description**	**Unit**	**List/Classifier**
		number	Common agricultural landscape bird index	Aggregate index for the country	
		number	Common forest bird index	Aggregate index for the country	
		number	Deadwood of commercial timber species, total	m³/ha	
		number	Dead standing wood of commercial timber species	m³/ha	
		number	Dead lying wood of commercial timber species	m³/ha	
		number	Forest increment	m³	
		number	Removals	m³	
		.tif	Tree cover density	%	

Table name: elf_inventuurid_region.shp		
Extraction condition: ELFi Natura inventuur. KRATT andmebaas seisuga 05.01.26		
Deadline:		
No.	**Field name/code**	**Field format**
	kood	Double
	nimi	String
	paal97	String
	paal97_kaa	String
	n2k_tyyp	String
	n2k_kaasne	String
	kaasneva_p	String
	lkseisund	String
	esindusl	String
	yldhinnang	String

	paev	String
	kuu	String
	aasta	String
	vaatleja	String
	kuivendami	String
	strukt	String
	funkts	String
	taast	String
	kvaliteet	String
	kaardistus	String
Table name: KR_plk_region.shp		
Extraction condition: Poollooduslikud kooslused. KRATT andmebaas seisuga 05.01.26.		
Deadline:		
No.	**Field name/code**	**Field format**
	id	Double
	pohityyp	String
	tyybid	String
	paal_97	String
	esinduslik	String
	str_sail	String
	funkt_sail	String
	taastatavs	String
	lk_seisund	String
	uldine_lk	String
	markused	String
	maj_persp	String
	rannaala	String
	inventisik	String
	andmete_kp	Date
	kaitst_ala	String
	natura_ala	String
	kr_kood	String
Table name: natura_elupaik_region.shp		

Extraction condition: Natura elupaigad. KRATT andmebaas seisuga 05.01.26.		
Deadline:		
No.	**Field name/code**	**Field format**
	id	Double
	pohityyp	String
	pohityyp_p	Double
	andmestik	String
	kr_kood	String
	tyybid	String
	tyybid_p	String
	paal_97	String
	esinduslik	String
	str_sail	String
	funkt_sail	String
	taastatavs	String
	lk_seisund	String
	uldine_lk	String
	markused	String
	inventisik	String
	invent_kpv	Date
	kaitst_ala	String
	natura_ala	String
	muut_aeg	Date
Table name: Niidud_region.shp		
Extraction condition: PKÜ poollooduslike koosluste andmed. KRATT andmebaas seisuga 05.01.26.		
Deadline:		
No.	**Field name/code**	**Field format**
	koodn	Double
	pindala	Double
	paev	String
	kuu	String
	aasta	String
	vaatleja	String
	kktyyp	String

	niiskusrez	String
	niidetavus	String
	niitmine	String
	karjatamin	String
	geobot	String
	florist	String
	esteet	String
	natura_koo	String
Table name: PLK_region.shp		
Extraction condition:		
Deadline:		
No.	**Field name/code**	**Field format**
	id	Double
	pohityyp	String
	tyybid	String
	paal_97	String
	esinduslik	String
	str_sail	String
	funkt_sail	String
	taastatavs	String
	lk_seisund	String
	uldine_lk	String
	markused	String
	maj_persp	String
	rannaala	String
	inventisik	String
	andmete_kp	Date
	kaitst_ala	String
Table name: eraldised_stat.shp		
Extraction condition: Metsaregister. Metsaregistri andmed seisuga 05.01.26		
Deadline:		
No.	**Field name/code**	**Field format**
	id	Double
	invent_kp	Date

	registreer	String
	katastri_n	String
	kvartali_n	String
	eraldise_n	Short
	pindala	Double
	kuivendatu	Short
	kasvukoha_	String
	boniteedi_	String
	arengukl_k	String
	peapuuliik	String
	keskm_vanu	Long
	tagavara_1	Long
	tagavara_2	Long
	rpindala_1	Double
	rpindala_2	Double
	liitus_a	Double
	omandivorm	String
	koosseis	String
	a	String
	h	String

ANNEX 5. Details of data used in compiling ecosystem extent account.

Attributes for the data used in order of compiling ecosystem extent map for the year 2024

Priority	Data	Source	Classification	Data Type	Date accessed	Link
1	Agricultural land and semi-natural habitats (Support bases)	Estonian Agricultural Registers and Information Board	Original/local	Vector	29.01.2024	https://kls.pria.ee/kaart/
2	Forest types	Forest registry of Estonia	Original/local	Vector	15.01.2024	https://register.metsad.ee/#/
3	Wetlands	Estonian Nature Foundation	Natura 2000 habitats	Vector	29.01.2024	EELIS (Estonian Nature Information System – Environmental Register): Environmental Agency
4	Semi-natural habitats which are eligible for support	Estonian Nature Information System	Natura 2000 habitats	Vector	29.01.2024	EELIS (Estonian Nature Information System – Environmental Register): Environmental Agency
5	Natura 2000 habitats (Annex I habitats)	Estonian Nature Information System	Natura 2000 habitats	Vector	29.01.2024	EELIS (Estonian Nature Information System – Environmental Register): Environmental Agency
6	Meadows	Estonian Seminatural Community Conservation Association	Natura 2000 habitats	Vector	29.01.2024	EELIS (Estonian Nature Information System – Environmental Register): Environmental Agency
7	Estonian Topographic Database	Land and Spatial Development Board	Original/local	Vector	03.01.2024	https://geoportaal.maaamet.ee/est/Ruumiandmed/Eesti-topograafia-andmekogu-p79.html

ANNEX 6. Estonian translation of EU ecosystem typology

EU ecosystem typology (Version: December 2024)	EU ecosystem typology Estonian
1.1 Continuous settlement area	Tiheasustusala
1.2 Discontinuous settlement area	Hajaasustusala
1.3 Infrastructure	Tööstus-, kaubandus- ja transpordialad / Taristu
1.4 Urban greenspace	Rohealad
1.5 Other artificial areas	Muud tehisalad
1. Settlements and other artificial areas	Asula ja muu tehisala
2.1 Annual cropland	Külvikorras põld
2.2 Rice fields	Riisipõllud
2.3 Permanent crops	Püsikultuurid
2.4 Agro-forestry areas	Agrometsanduslikud alad
2.5 Mixed farmland	Heterogeensed põllumajandusmaad
2.6 Other farmland	Muud põllumajandusmaad
2. Cropland	Põllumajandusmaa
3.1 Sown pastures and grass (modified grasslands)	Kultuurrohumaad ja -karjamaad
3.2 Natural and semi-natural grasslands	Looduslikud ja poollooduslikud rohumaad
3. Grassland	Rohumaa (karjamaa, poollooduslik ja looduslik rohumaa)
4.1 Broadleaved deciduous forest	Heitlehised lehtmetsad
4.2 Coniferous forests	Okasmetsad
4.3 Broadleaved evergreen forest	Laialehised igihaljad metsad
4.4 Mixed forests	Segametsad
4.5 Transitional forest and woodland shrub	Üleminekulised metsaalad
4.6 Plantations	Istandused
4. Forest and woodlands	Mets ja muu puittaimestikuga kooslus
5.1 Tundra	Tundra
5.2 Scrub and heathland	Loopealsed põõsastikud, nõmmrabad ja nõmmed
5.3 Sclerophyllous vegetation	Jäiklehine taimestik
5. Heathlands and shrub	Nõmm ja põõsastik
6.1 Bare rocks	Paljandid
6.2 Semi-desert, desert and other sparsely vegetated areas	Poolkõrbelised, kõrbelised ja teised hõredalt taimestunud alad
6.3 Ice sheets, glaciers and perennial snowfields	Jääkilbid, liustikud ja igilumega alad
6. Sparsely vegetated ecosystems	Hõreda taimkattega ökosüsteem
7.1 Inland marshes and other wetlands on mineral soil	Sisemaasood ja teised liigniisked alad mineraalmuldadel
7.2 Mires, bogs and fens	Madal-, siirde- ja kõrgsood
7. Inland wetlands	Sisemaa märgala
8.1 Rivers and streams	Jõed ja ojad
8.2 Canals, ditches and drains	Kanalid, kraavid ja dreenid
8. Rivers and canals	Jõgi ja kanal
9.1 Lakes and ponds	Järved ja tiigid
9.2 Artificial reservoirs	Veehoidlad
9.3 Geothermal pools and wetlands (Iceland)	Geotermilised järved ja märgalad (Island)
9. Lakes and reservoirs	Järv ja veehoidla
10.1 Coastal lagoons	Rannikulõukad
10.2 Estuaries and bays	Jõgede lehtersuudmed ja lahed
10.3 Intertidal flats	Loodetevööndi laugmadalikud

10. Marine inlets and transitional waters	Mereabajas ja siirdevesi
11.1 Artificial shorelines	Tehislikud rannikud
11.2 Coastal dunes, beaches and sandy and muddy shores	Mererand, rannikuluited ning liivased ja mudased kaldad
11.3 Rocky shores	Kivine rand
11.4 Coastal saltmarshes and salines	Padurannad ja rannikusoolakud
11. Coastal beaches, dunes and wetlands	Mererand, rannikuluide ja rannikumärgala
12.1 Marine macrophyte habitats	Meretaimede kasvukohad
12.2 Coral reefs	Korallrahud
12.3 Worm reefs	Polüheetrahud
12.4 Shellfish beds and reefs	Karpide kooslused ja rahud
12.5 Subtidal sand beds and mud plains	Sublitoraali liivased ja mudased tasandikud
12.6 Subtidal rocky substrates	Sublitoraali kivised elupaigad
12.7 Continental and island slopes	Mandri- ja saarte nõlvad
12.8 Deepwater benthic and pelagic ecosystems	Süvavee põhja- ja pelaagilised ökosüsteemid
12.9 Deepwater coastal inlets (fjords)	Süvavee abajad (fjordid)
12.10 Sea ice	Merejää
12. Marine ecosystems	Mereökosüsteem (rannikuvesi, mandrilava ja avameri)

ANNEX 7. Results of the mapping of the monetary values connected to ecosystem services

Table 1. Overview of ecosystem services:

Ecosystem service	Indicator and unit
Crop Provisioning	Crop provisioning (Economic output of crop production, thousand tons)
Crop Pollination	Crop pollination (production of pollinator-dependent crops, thousand tons)
Timber Provisioning	Timber provisioning (net increment, thousand m³)
Air Filtration	Air filtration (deposited PM2.5, tons)
Global Climate Regulation: Net Carbon Sequestration	Global climate regulation: net carbon sequestration (net amount of carbon bound, tons)
Global Climate Regulation: Carbon Stock	Global climate regulation: carbon stock (stored amount of carbon, tons)
Local Climate Regulation	Local climate regulation (reduced temperature, degrees Celsius)
Nature-Based Tourism Services	Nature-based tourism services (number of overnight stays)

For more detailed definitions, see: Annex IX, Section 3, Point 4 https://eur-lex.europa.eu/legal-content/ET/TXT/?uri=CELEX%3A02011R0691-20250101

Table 2: Monetary valuation methods for ecosystem services. Information in the table is presented as method – reference. Where reference is not given, it is a hypothetical method, which has not been applied in Estonia or nearby regions

	Actual transactions in right to use the ES	*Rent-like*	*Restoration costs*	*Substitution costs*	*Dependent activities (Travel Costs, Avoided damage costs)*	*Hypothetical compensation costs (Shadow project costs)*	*Opportunity costs costs of alternative uses)*	*Subjective*
Corresponding methods in SEEA EA and/or literature	*Directly observable prices*	*Residual value, Resource rent, Hedonic pricing, Prices from similar markets, Productivity (Residual value, Resource rent, Hedonic pricing, Prices from similar markets, Productivity change, Simulated Exchange Value)*	*Restoration costs*	*Replacement costs*	*Travel Costs, Avoided damage costs*	*Shadow project costs*	*Opportunity costs of alternative uses*	*Willingness to pay for having the ES, willingness to accept for not having it (Choice experiment)*
Crop provision	Market value of crop yield -1 Field Data Collection and InVEST Modelling -7	Rental price -1,2,3,4 Resource Rental-1,2,3,4 Resource rent -8 Market price/resource rental -9	Cost of methods of increasing reduced soil fertility Transition to regenerative and ecological agriculture	Fertile soil replacement -5 Importing food from foreign countries		Cost of replacing fertile soil -5		

	Actual transactions in right to use the ES	*Rent-like*	*Restoration costs*	*Substitution costs*	*Dependent activities (Travel Costs, Avoided damage costs)*	*Hypothetical compensation costs (Shadow project costs)*	*Opportunity costs costs of alternative uses)*	*Subjective*
Of which: pollination	Market price method -10	Change in production (has been interpreted as avoided cost in studies carried out in Estonia)	Creating pollinator-friendly areas within agroecosystems (field strips with flowering wild plants); establishing foraging habitats for bees (support measure available)	hand pollination, renting pollinators. -20	Avoided costs: market value of the yield from pollination-dependent crops -1,2,3,4,5,9			Willingness to pay (WTP)-1,2,3
Wood provision	Stumpage price-2,3,4, 16 Timber stock in market prices- 3,4 Rapid assessment method using official national accounts statistics (highlights the ecological contribution of the service to biomass provision in both biophysical and economic terms) – 8 Market price of the standing tree stem – 11 Stumpage value approach, property price approach, net present value -12							WTP -2
Air filtration					Avoided costs (external costs) - 4 Avoided health expenses Method of avoided costs - 13			WTP- 1,2,3
Local climate regulation (cooling effect of plants in cities)		Hedonic pricing of property value near green areas -18		Value of energy and water savings (replacement by cooling systems) - 19 Cost of artificial shading (sunshades) for estimating the shading value provided by urban trees: 17	Avoided health costs			WTP 1,2,3
Global climate regulation	Field data collection and InVEST modelling – 7	EU ETS CO_2 market price -1,2,3,4, CO_2 market price -13			Social cost of carbon -5			WTP -1,2,3

	Actual transactions in right to use the ES	*Rent-like*	*Restoration costs*	*Substitution costs*	*Dependent activities (Travel Costs, Avoided damage costs)*	*Hypothetical compensation costs (Shadow project costs)*	*Opportunity costs costs of alternative uses)*	*Subjective*
					Avoided cost of emission reduction - 11			
Nature based tourism (nature tourism, recreation)					Consumer expendiure costs-1,2,3,4, Travel sosst -1,2 Travel cost method - 15 Travel cost method -9		Time use alternative cost –2,3,6	WTP –1,2,3, 14, 16 Consumer surplus – 15

Table 3: Results for ecosystem service valuation methods (numerical values and metadata). Data is presented as: Valuation method: value in EUR (brief description/assumptions; year of result, x if unavailable) – reference.

	Actual transactions in right to use the ES	*Rent-like*	*Restoration costs*	*Substitution costs*	*Dependent activities (Travel Costs, Avoided damage costs)*	*Hypothetical compensation costs (Shadow project costs)*	*Opportunity costs costs of alternative uses)*	*Subjective*
Crop provision	Crop provision market value. 300 EUR (2018) –1 Crop provision (rice): US$ 7,710 – 10,650 per hectare per year – 7	Rent price: €100 million (unit rent price of agricultural land × area, annual flow; 2022) –4, resource rent (2020): 14.9 million EUR –3		Replacement of fertile soil (x)_ 41 300 million EUR - 5	Not applicable	Not applicable	Not applicable	WTP
Of which: pollination	This is accounting for 0.32 billion US$ of the 1.44 billion US$ provided by bee pollination to the total value of 2.90 billion US$ made with strawberry selling in the European Union 2009. -10		Measure to support bee foraging areas (€255.80/ha in 2024) – establishing a pollinator-attractive field (costs include soil preparation, seed costs, labour costs, and foregone income from cash crops minus the state support of €255.80 per hectare).		Avoided costs: €29 million (market value of the yield from pollination-dependent crops, annual flow; 2022) –4 Avoided costs: €63.1 million (aggregate estimate of the economic value of crops based on market prices, according to the InVEST model, reflecting the share of yield attributable to local natural pollinators) – source -5 €0.169 million (2014) – 9	Hand pollination – n working hours × labour cost = xxx euros (depends on wage level; certainly several times more expensive than insect pollination service)	Not applicable	WTP-1,2,3

	Actual transactions in right to use the ES	*Rent-like*	*Restoration costs*	*Substitution costs*	*Dependent activities (Travel Costs, Avoided damage costs)*	*Hypothetical compensation costs (Shadow project costs)*	*Opportunity costs costs of alternative uses)*	*Subjective*
					€0.189 million (2021) – 9			
Wood provision	Net increment at stumpage prices: €516 million (2022) – reference 4 Harvested wood at stumpage prices: €769 million (2022) – reference 4 Market value of timber stock: €15 billion (based on the intermediate price of stem roundwood, and the price of chipped wood from shrubs and branches; multiplied by estimated stock) – reference 5 Timber productivity: €892.5 million (2012) – AiK8 Timber productivity: €1,060.2 million (2018)AiK8 Timber stock – asset value (100-200 €/ha/year AiK11 **E.P.** Period 2010-2014 (Finland) Timber stock value:	Property prce method: 47.22 billon euros (base of property tax per period not for year) E.P (Hurskainen et al. (2021) 12	Restaration after fellings? - KA	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

	Actual transactions in right to use the ES	Rent-like	Restoration costs	Substitution costs	Dependent activities (Travel Costs, Avoided damage costs)	Hypothetical compensation costs (Shadow project costs)	Opportunity costs costs of alternative uses)	Subjective
	Stumpage prices: 65.05 billion euros NPV: 89.48 billion euros (Hurskainen et al. (2021) 12 E.P. reference 14. In Germany total value of timber (2014) 3542 milj. Eur/year. - 14							
Air filtration	Not applicable	Not applicable	Not applicable	Not applicable	Avoided damage cost (external costs by benefit transfer) : 167 mln EUR (2022) -4 **E.P.** (Aevermann, Schmude. 2015) Air filtration in Schlosspark Nymphenburg 392 170 eur/yr -13	Not applicable	Not applicable	WTP -1,2,3
Local climate regulation (cooling effect of plants in cities)	Not applicable	Not applicable	Not applicable	3-10% higher real estate prices, 18	Avoided damage cost, Avoided health damage costs,	Not applicable	Not applicable	WTP -1,2,3
Global climate regulation	Soil carbon sequestration service 38,2–51,9 t(C)/ha/yr, value 13 150–17 890 US$/ha/a. AiK7	EU ETS: 154 mln EUR (carbon net sequestration, 2022) -4, EU ETS: 80 544 mln EUR (carbon stock, 2022) -4, Social cost-5, avoided damage **E.P.** (Aevermann, Schmude. 2015)			CO_2 sequestration 168-371 €/ha/year AiK11			WTP -1,2,3

	Actual transactions in right to use the ES	*Rent-like*	*Restoration costs*	*Substitution costs*	*Dependent activities (Travel Costs, Avoided damage costs)*	*Hypothetical compensation costs (Shadow project costs)*	*Opportunity costs costs of alternative uses)*	*Subjective*
		Carbon sequestration Schlosspark Nymphenburg 15 080 eur/yr -13						
Nature based tourism (nature tourism, recreation)					Consumer costs: 576 mln EUR (Overnight domestic travel expenses) -4, Travel cost method Total cost year 2014. 1,25 milon €. 2021. 1,23 milion €. 2014. 7,55 €/per person 2021. 7,56 €/per person. AiK9		Time alternatiive cost –(time spent in natuure x hourly salary) 2,3 Time alternatiive cost:xx EUR (time spent in natuure x hourly salary , France, 20xx)-6	WTP -1,2,3 **E.P. Reference** 14. WTP (diferent periods during 2008-2014 Germany) 1. For biodiversity 2200 mil eur/year 2. Forest related recreation 1928 mil eur/year - 14 **E.P.** reference 15. 42,080 SEK/year (2016, Sweden). In article there are diferent values depending whether how often people go to forest, how lõng is the distance ect.

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ANNEX 8. Multiple economic values of ecosystems: results from applying the framework of connected monetary values

Figure 1. Semantics of the applied connected ecosystem services monetary values framework

<table>
<tr><th colspan="5">REFERENCE SCHEME FOR THE CLASSIFICATION OF VALUES CONNECTED TO ECOSYSTEM SERVICES ACCORDING TO THE FEATURES OF THE CALCULATION SCENARIO</th></tr>
<tr><th colspan="3" rowspan="2"></th><th colspan="2">Ecosystem service in scenario</th></tr>
<tr><th>Ecosystem service exists</th><th>Ecosystem service does not exist hypothesis</th></tr>
<tr><td rowspan="8">Connected monetary value (transaction/asset, etc.) in scenario</td><td rowspan="4">exists (scenario coincides with reality)</td><td>Ecosystem services are traded as private usage rights</td><td>Rent of the land, directly observable prices applied to actually traded volumes, observed value of actually observed transactions in tradable permits</td><td></td></tr>
<tr><td>Ecosystem services are potentially traded as private usage rights</td><td>Directly observable prices applied to potentially for sale permits of using the ES</td><td></td></tr>
<tr><td>ES is used for producing other goods or services</td><td>Resource rent, Residual value, Hedonic pricing</td><td></td></tr>
<tr><td>Other (outside or inside of SEEA-EA, within SEEA CF, other satelllie accounts or SNA)</td><td>Travel cost method, effective carbon rates</td><td></td></tr>
<tr><td rowspan="3">"would appear" (does not exist in reality, does in the scenario)</td><td>Economic activity that avoids the need for the ES</td><td></td><td>Abatement costs, substitution costs, averting behaviour</td></tr>
<tr><td>ES restoration as economic activity*</td><td></td><td>Restoration costs</td></tr>
<tr><td>Marketisation of the ES (with or without perfect price discrimination)</td><td>Prices applied to quantities of ES not actually traded or tradable under current institutional arrangements, WTP for maintaining ES</td><td></td></tr>
<tr><td>"would disappear" (exists in reality, is lost in the scenario)</td><td>Existing economic activies can no longer thrive, and/or assets are damaged («other negative changes in value») because of the lack of the ES</td><td></td><td>Social cost of lacking ES, expected damages</td></tr>
<tr><td colspan="5">* Restoration costs usually refer to the restoration of whole ecosystems. It is however possible to think about the restoration of a single ES, that leaves the rest unchanged. E.g. if an area is made suitable (e.g. reclaimed from venoms) for wild animals and/or these are reintroduced in the area. Pollinators could be one case</td></tr>
</table>

Figure 2. Monetary values connected to the Crop provision ES (million euro)

			Ecosystem service in scenorio	
			Ecosystem service exists	Ecosystem service does not exist hypothesis
Connected monetary value (transaction/asset, etc.) in scenario	exists (scenario coincides with reality)	ES traded as a right of private usage (observed transactions volumes)	**100** (land rent, use rights on assets)	
			590 (land rent, use rights on assets)	
		ES potentially traded as a right of private usage (observed prices applied to stocks)		
		ES is used for producing other goods or service	**14.9** (resource rent of NACE A.1)	
			959 (resource rent NACE A.1)	
		Other (outside or inside of SEEA-EA, within SEEA CF, other satelllie accounts or SNA)	**300** (crops, final product)	
			4 769 (crops, final product)	
			agricultural subsidies (organic farmic, general support scheme, etc)	
	"would appear" (does not exist in reality, does in the scenario)	Avoiding the need of the ES as economic activity		
		ES restoration as economic activity		**1500** (replacement of soil, NPV 3% DR, 50 years, total soil asset value 41300).
		Marketisation of the ES	**1.4** (WTP for maintaining supply of agricultural production)	
	"would disappear" (exists in reality, is lost in the scenario)	Existing economic activies can no longer thrive, and/or assets are damaged («other negative changes in value») because of the lack of the ES		

Estonian figures
Dutch figures
Further possible connected values

Figure 3. Monetary values connected to the Wood provision ES (million euro)

			Ecosystem service in scenorio	
			Ecosystem service exists	Ecosystem service does not exist hypothesis
Connected monetary value (transaction/asset, etc.) in scenario	exists (scenario coincides with reality)	ES traded as a right of private usage (observed transactions volumes)		
		ES potentially traded as a right of private usage (observed prices applied to stocks)	**20 639** Timber asset value - Net income (NPV) (a)	
			3 900 (land value) (a)	
		ES is used for producing other goods or services	**86** (Land value annuity method - rent on land only)	
			171 (residual value, resource rent of forest activity A02)	
			20 (residual value of forest activity A02)	
		Other (outside or inside of SEEA-EA, within SEEA CF, other satelllie accounts or SNA)	**762** Harvest at stumpage prices	
			565 Net increment from FAWS plus removals from OWL and FNNAWS in stumpage prices	
			99 (timber felled /per year and in stumpage prices - harvest)	
			1,5 (reforestration subsidy 2022)	
	"would appear" (does not exist in reality, does in the scenario)	Avoiding the need of the ES as economic activity		
		ES restoration as economic activity		
		Marketisation of the ES		
	"would disappear" (exists in reality, is lost in the scenario)	Existing economic activies can no longer thrive, and/or assets are damaged («other negative changes in value») because of the lack of the ES		

(a) the price here is not an observed, but an estimated one (resource rent by the appropriation method)

Estonian figures	
Dutch figures	

Figure 4. Monetary values connected to the Crop pollination ES (million euro)

Connected monetary value (transaction/asset, etc.) in scenario		Ecosystem service in scenario: Ecosystem service exists	Ecosystem service in scenario: Ecosystem service does not exist hypothesis
exists (scenario coincides with reality)	Ecosystem services are traded as private usage rights		
exists (scenario coincides with reality)	Ecosystem services are potentially traded as private usage rights		
exists (scenario coincides with reality)	ES is used for producing other goods or services		
exists (scenario coincides with reality)	Other (outside or inside of SEEA-EA, within SEEA CF, other satelllie accounts or SNA)	**0.57** (payment for ecosystem services, subsidy on establishing fields that are attractive for foraging to pollinators) **256 €/ha** (restoration subsidy), if applied to actually benefitting areas	
"would appear" (does not exist in reality, does in the scenario)	Economic activity that avoids the need for the ES		Hand pollination/designated pollination by domesticated bee species (substitution cost - averting behaviour)
"would appear" (does not exist in reality, does in the scenario)	ES restoration as economic activity*		**256 €/ha** (restoration cost), if applied to areas providing the service
"would appear" (does not exist in reality, does in the scenario)	Marketisation of the ES	**3.3** (WTP for enabling pollination and honey collection)	
"would disappear" (exists in reality, is lost in the scenario)	Existing economic activies can no longer thrive, and/or assets are damaged («other negative changes in value») because of the lack of the ES		**62.4** (production change - dependency rate) **134** (production change - dependency rate)

Legend:
- **Estonian** figures
- **Dutch** figures
- Further possible connected values

Figure 5. Monetary values connected to the Global Climate Regulation ES (million euro)

			Ecosystem service in scenario	
			Ecosystem service exists	**Ecosystem service does not exist hypothesis**
Connected monetary value (transaction/asset, etc.) in scenario	**exists (scenario coincides with reality)**	**Ecosystem services are traded as private usage rights**	**249** (Directly observed volume of actual transactions in tradable permits)	
		Ecosystem services are traded as potentially private usage rights	Directly observable prices applied to the existing stock of tradable permits held by economic units	
		ES is used for producing other goods or services		
		Other (outside or inside of SEEA-EA, within SEEA CF, other satelllie accounts or SNA)	Effective carbon rate payments, total	
	"would appear" (does not exist in reality, does in the scenario)	**Economic activity that avoids the need for the ES**		**1 681 788** (C stock - Abatement cost)
				184 (C sequestration - Efficient carbon rate - averting behaviour)
		ES restoration as economic activity		Cost of planting and raising trees
		Marketisation of the ES	**1 259 582** Directly observable prices (EU ETS price) of which: 1 259 427 stock, 154 sequestration	
			13 (C sequestration - Contingent valuation (WTP for maintaining ecosyst. C capture))	
	"would disappear" (exists in reality, is lost in the scenario)	**Existing economic activies can no longer thrive, and/or assets are damaged («other negative changes in value») because of the lack of the ES**		**2 514 829** (C stock - Social cost of having C in atmosphere)
				36.3 – 185.7 (C sequestration - Social cost of carbon)
		Estonian figures		
		Dutch figures		

Figure 6. Monetary values connected to the Air filtration ES (million euro)

			Ecosystem service in scenario	
			Ecosystem service exists	**Ecosystem service does not exist hypothesis**
Connected monetary value (transaction/asset, etc.) in scenario	**exists (scenario coincides with reality)**	**Ecosystem services are traded as private usage rights**		
		The ES is appropriated and potentially traded as a right to use on its own		
		ES is used for producing other goods or services		
		Other (outside or inside of SEEA-EA, within SEEA CF, other satelllie accounts or SNA)		
	"would appear" (does not exist in reality, does in the scenario)	**Economic activity that avoids the need for the ES**		
		ES restoration as economic activity		
		Marketisation of the ES	**5** (WTP)	
	"would disappear" (exists in reality, is lost in the scenario)	**Existing economic activies can no longer thrive, and/or assets are damaged («other negative changes in value») because of the lack of the ES**		**1,3** (Avoided health cost, value transfer)
				167 (avoided damage: avoided health effects and avoided mortality)
	Estonian figures			
	Dutch figures			
	Further possible connected values			

Figure 7. Monetary values connected to the Local climate regulation ES (million euro)

			Ecosystem service in scenario	
			Ecosystem service exists	Ecosystem service does not exist hypothesis
Connected monetary value (transaction/asset, etc.) in scenario	exists (scenario coincides with reality)	Ecosystem services are traded as private usage rights		
		Ecosystem services are potentially traded as private usage rights		
		ES is used for producing other goods or services	3-10% higher real estate prices (hedonic pricing)	
		Other (outside or inside of SEEA-EA, within SEEA CF, other satelllie accounts or SNA)		
	"would appear" (does not exist in reality, does in the scenario)	Economic activity that avoids the need for the ES		Cooling, shading by artificial means (substitution cost - averting behaviour)
		Ecosystem service restoration as economic activity*		
		Marketisation of the ecosystem service	**1.67** (WTP for preservation and maintenance of urban green spaces that provide microclimate regulation)	
	"would disappear" (exists in reality, is lost in the scenario)	Existing economic activies can no longer thrive, and/or assets are damaged («other negative changes in value») because of the lack of the ES		Avoided health damage costs

Estonian figures
Dutch figures
Further possible connected values

Figure 8. Monetary values connected to the Nature-based tourism ES (million euro)

			Ecosystem service in scenario	
			Ecosystem service exists	Ecosystem service does not exist hypothesis
Connected monetary value (transaction/asset, etc.) in scenario	exists (scenario coincides with reality)	The ES is appropriated and actually traded as a right to use on its own		
		The ES is appropriated and potentially traded as a right to use on its own		
		ES is used for producing other goods or services		
		Other (outside or inside of SEEA-EA, within SEEA CF, other satelllie accounts or SNA)	**576** (travel costs, accommodation costs, other costs)	
			3 390 (travel costs, accommodation costs, other costs) of which **1150** travel costs	
	"would appear" (does not exist in reality, does in the scenario)	Economic activity that avoids the need for the ES		
		ES restoration as economic activity		Restoration of the ecosystem regarding attracative characteristics for recreation
		Marketisation of the ES	**157** (alternative use of time)	
			25 (WTP for maintaining the infrastructure necessary for recreation in nature)	
	"would disappear" (exists in reality, is lost in the scenario)	Existing economic activies can no longer thrive, and/or assets are damaged («other negative changes in value») because of the lack of the ES		

Estonian figures
Dutch figures
Further possible connected values

Expert group feedback on further development of the multi-layered approach

The multi-layered approach to monetary values connected to ecosystems can be further developed by more systematically linking each valuation layer to the ecological conditions that underpin ecosystem service provision. In particular, incorporating ecological thresholds, irreversibility, and ecosystem resilience into the semantic framework would strengthen its interpretive power and policy relevance.

Similarly, ecosystem resilience- the capacity to absorb disturbances while maintaining functionality - affects the meaning of connected monetary values. Values linked to resilient systems (e.g. annual biomass growth in managed forests) differ fundamentally from those associated with fragile or slow-recovering systems (e.g. carbon storage in old-growth forests or peatlands). Making this distinction explicit within the framework would improve the interpretation of monetary figures across different ecosystem services.

Ecological thresholds mark points beyond which ecosystem functioning may change abruptly or collapse, rendering services difficult or impossible to restore. Explicitly acknowledging such thresholds within valuation layers would help distinguish monetary values that imply genuine substitutability from those that merely signal dependence. For instance, replacement or adaptation costs associated with pollination or soil-related services should be interpreted in light of ecological evidence showing that these services rely on complex biological systems that cannot be fully replicated once critical thresholds are crossed. In such cases, monetary estimates represent warning indicators of potential loss rather than feasible substitutes.

A concrete illustration can be drawn from crop pollination. Monetary values based on avoided yield loss or substitution costs may suggest that pollination is replaceable through managed bees or manual pollination. However, ecological research shows that wild pollinator diversity underpins long-term yield stability and system resilience. Once pollinator populations fall below critical thresholds, substitution becomes economically unviable and ecologically incomplete. Explicitly linking such valuation layers to known ecological thresholds would clarify that these monetary estimates represent risk signals rather than realistic replacement options.

Linking semantic valuation layers to ecological processes: an illustration of possible approach using pollination and climate regulation.

The multi-layered framework for monetary values connected to ecosystem services is a valuable approach that highlights the need to recognise and interpret the wide diversity of outcomes produced by different ecosystem service valuation methods. One important aspect that could further complement the framework is making the **ecological foundations of each service explicit alongside each valuation layer**.

While the current framework successfully distinguishes between actual, latent, and risk-based monetary values, it is both relevant and feasible to further clarify **which ecological processes and conditions make these values possible in the first place**. <u>Presenting ecological foundations in parallel with monetary values</u> would make them more visible and help avoid the risk that monetary figures are interpreted independently of the ecological reality that underpins them.

To strengthen the interpretation of monetary values and better link them to ecological reality, I propose accompanying each ecosystem service in the framework with a short, standardised **<u>ecological context box</u>** (Table 1). The aim is to summarise, in very concise form, the key ecological aspects that determine whether and how the service can be delivered. The purpose is not to monetise these aspects, but to make explicit the **ecological conditions and limits within which monetary valuation results should be interpreted.**

Table 1. Proposal for 'standardised ecological context box'

Ecological feature	Short description of what to cover	Example: pollination service	Example: climate regulation
Key ecological background	Key ecological conditions enabling the service, including dependence on habitat extent, condition, and spatial configuration.	Depends on diversity, abundance, and connectivity of wild pollinators and on the extent and condition of natural and semi-natural habitats providing floral resources and nesting sites.	Depends on extent, integrity, and long-term stability of carbon-rich ecosystems (forests, peatlands, wetlands, soils), shaped by ecosystem type, age

			structure, hydrology, and disturbance regime.
Key ecological functions	Core ecological processes and interactions generating the service but not monetarily assessable.	Plant–pollinator interaction networks, seasonal foraging dynamics, population turnover, and processes supporting floral diversity (e.g. extensive management of semi-natural grasslands).	Photosynthesis, biomass accumulation, soil carbon formation, microbial processes, and hydrological regulation governing sequestration and long-term carbon storage.
Restoration and substitution feasibility	Feasibility of restoring or substituting the service if lost, including constraints and time lags.	Low substitutability: technical or manual substitutes are costly and inefficient, and managed pollinators cannot fully replace the functions provided by wild pollinator communities. Medium restoration feasibility: restoration is possible where source populations persist, but requires landscape-scale habitat recovery and entails substantially higher costs than maintaining existing habitats.	Very low substitutability; technical mitigation may replace flows but not stocks. Restoration is slow and uncertain, often requiring decades.
Ecological implications for economic valuation	How ecological characteristics affect interpretation of monetary values.	High risk-of-loss relevance; hypothetical or low marketisation potential should not obscure the strong ecological importance of pollination and the dependence of agricultural production on this service.	High irreversibility risk; market prices capture only a fraction of value and should not be interpreted as substitutability.

The same ecological-context approach can be applied to a wide range of ecosystem services, including but not limited to:

- **Global climate regulation** (carbon sequestration and storage in forests, grasslands, wetlands, soils)
- **Local climate regulation** (urban cooling, heat mitigation through green infrastructure, microclimatic conditions)
- **Crop provision** (soil fertility, soil biodiversity, water availability, agroecosystem integrity)
- **Wood provision** (forest age, structure and composition, resilience through biodiversity and heterogeneity, growth dynamics, disturbance regimes)
- **Water purification and nutrient retention** (wetlands, riparian zones, buffer areas, soil processes)
- **Flood regulation** (floodplains, wetlands, vegetation structure)
- **Soil erosion control** (vegetation cover, root systems, land management)
- **Air filtration** (vegetation structure, canopy density, proximity to emission sources)
- **Nature-based recreation and tourism** (biodiversity, landscape heterogeneity, accessibility)

For each of these services, the ecological context box can be tailored to highlight key background conditions, core functions, restoration and substitution feasibility, and implications for interpreting monetary values. This ensures that valuation remains grounded in ecosystem functioning while retaining flexibility for use across different policy and accounting contexts.

A second example concerns soil-related ecosystem services. Replacement-cost estimates for topsoil can be calculated and placed within a hypothetical valuation layer, yet soil formation is an extremely slow and path-dependent process. By explicitly acknowledging irreversibility, the framework would make clear that such values indicate dependence on natural capital stocks, not feasible restoration pathways.

Uncertainty and data quality

Uncertainty and data quality could be expressed within each valuation layer using a simple, standardised annotation. For example, market-based values for crop or timber production could be labelled as high-confidence, observed, while avoided-damage estimates for air filtration could be classified as medium-confidence, model-based, and contingent valuation results as low-confidence, perception-based. Applying such qualitative confidence classes consistently would improve transparency and comparability across services and valuation methods without adding methodological complexity.

Overall, these refinements would not alter the structure of the framework but would improve its alignment with ecological realities, reduce the risk of misinterpretation, and support more informed and cautious use of monetary values in ecosystem-related decision-making.

ANNEX 9. Methodologies for ecosystem services

7.2 Air filtration

According to amendment of Regulation (EU) 691/2011, the ecosystem service air filtration is defined as the ecosystem contribution to filtering air-borne pollutants through the deposition, uptake, fixing and storage of pollutants by ecosystem components (particularly trees). This mitigates the harmful effects of the pollutants. The contributions should be reported in tonnes of particulate matter adsorbed.

The respective guidance notes by Eurostat[66] further details that PM10 includes particles up to 10 μm in aerodynamic diameter, whereas PM2.5 represents the fraction of particles up to 2.5 μm in aerodynamic diameter. While measuring the service for PM2.5 is more relevant from the beneficiary's perspective, the choice of selecting PM2.5 or PM10, as indicator for this ecosystem service also depends on the availability of national data on (i) air quality and (ii) the capacity of vegetation to adsorb PM.

Due to PM2.5 being more relevant than PM10, 2.5 was chosen as an indicator for the assessment of air filtration ecosystem service. The assessment of the service (deposition of PM2.5) in physical units was done in co-operation with the Department of Air and Climate of Estonian Environmental Research Centre (EKUK).

For monetary valuation of the service, a benefit transfer method was applied.

7.2.1 Air filtration – physical account

The PM concentration ($PM_{2.5}$) C_{PM} was used to calculate the amount of deposition. Following emissions assessments and modeling were carried out for the year 20224:

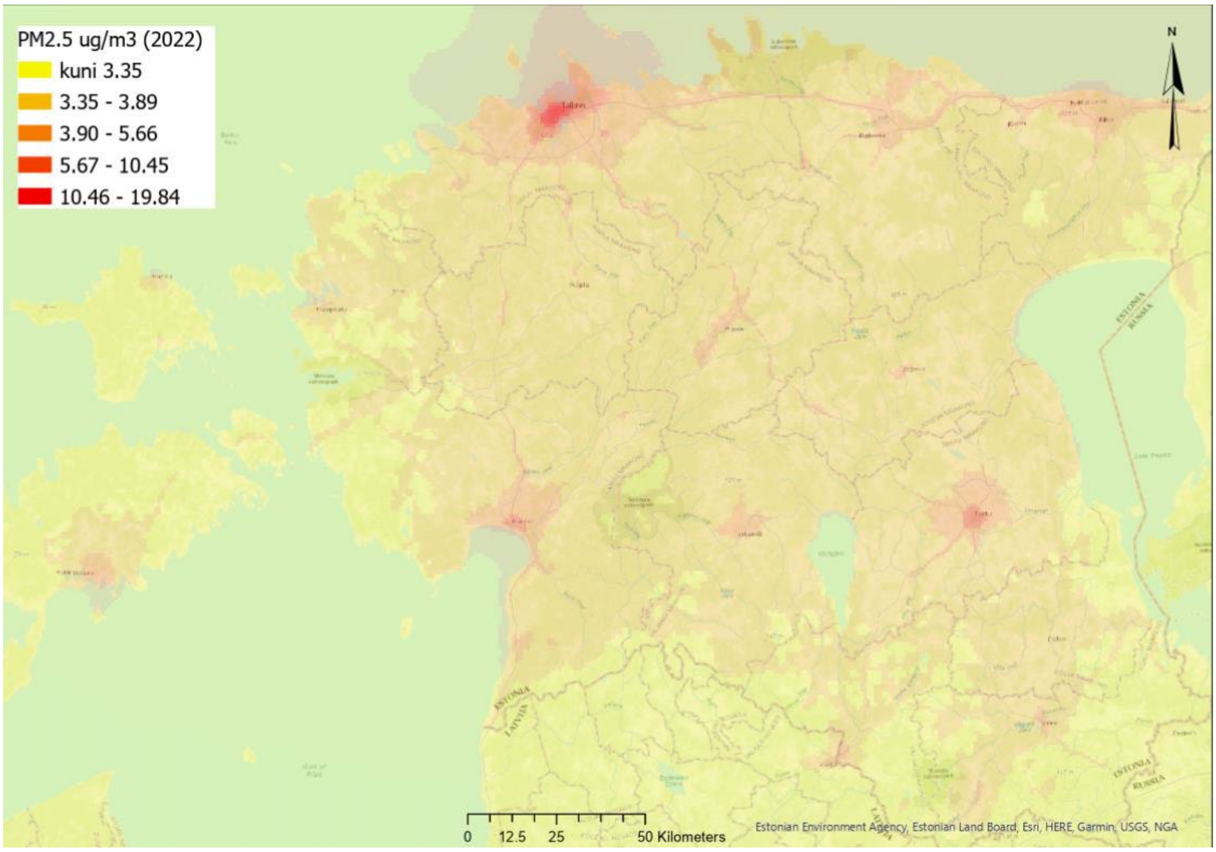
- Fine particles ($PM_{2.5}$) from all anthropogenic sources, like:
  - Traffic,
  - Residential wood combustion,
  - Energy and industrial sector,
  - Agriculture

National emissions data (2022) was used as input for the emissions, which were validated with air quality monitoring results.

The emission dataset was imported into the Airviro modeling system and emission sources were identified as grid sources. The modeling utilized meteorological observation data from the year 2022. The Eulerian grid dispersion model was used. For the modeling of the entire Estonia, the size of the modeling grid cell of 1000x1000 m was used. Hourly results from the dispersion model were aggregated into annual average value, where each grid cell in the modeling grid corresponded to the arithmetic mean of the calculated hourly average values for that grid cell. The modeling results (*Figure 15*) were compared to monitoring data at monitoring points. The model was considered reliable if sufficient agreement was obtained at all monitoring points.

[66] Eurostat – Unit E2. Guidance note for accounting for the air filtration ecosystem service in the EU – draft for a brief review by 04/12/2023 by the TF (before written consultation by the Environmental Accounts Working Groups) (November 2023)

Figure 15. Modelled $PM_{2.5}$ yearly concentration, µg/m³



For the deposition velocity Copernicus Land Monitoring service was used, where the open access LAI data with 1000 metre spatial resolution (*Figure 17*) and for the 2022 vegetation period (May to end of August), was used. In order to compute the deposition for a certain time period, the instantaneous deposition must be multiplied for the number of seconds of the selected period. The following equation yields the Vd in a certain pixel for a certain period:

$Vd = Vd_{(LAI)} \times LAI$ (Equation 1)

With:
Vd = Deposition velocity for PM per period in cm/s, adjusted by actual LAI. In the case of $PM_{2.5}$, but not PM_{10}, Vd is amongst others influenced by wind speed (see Annex 1).
$Vd_{(LAI)}$ = Deposition velocity values for PM per unit of LAI and period, in cm/s, see Table 1
LAI = Leaf Area Index per period.

Table 41. $Vd_{2.5LAI}$ as a function of wind speed

Wind speed (m/s)	$Vd_{(LAI)}$ (cm/s)
0	0.000
1	0.030
2	0.087
3	0.143
4	0.160
5	0.176
6	0.182
7	0.504
8	0.819
9	0.810
10	1.836
11	1.772
12	1.688
13	1.625

A basic method of annual average Vd(PM2.5) was used according to equation 1.

Yearly average wind speed data from Copernicus was used and are presented in Figure 16.

Figure 16. Copernicus wind speed data, m/s

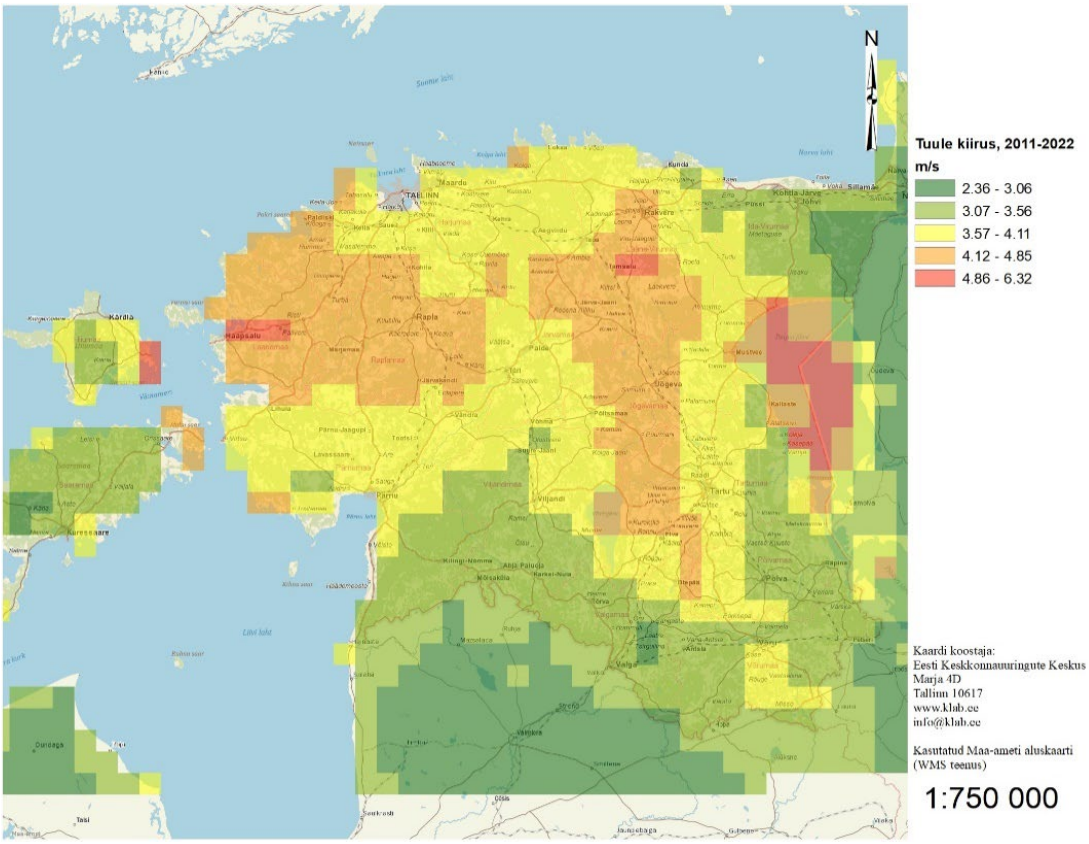
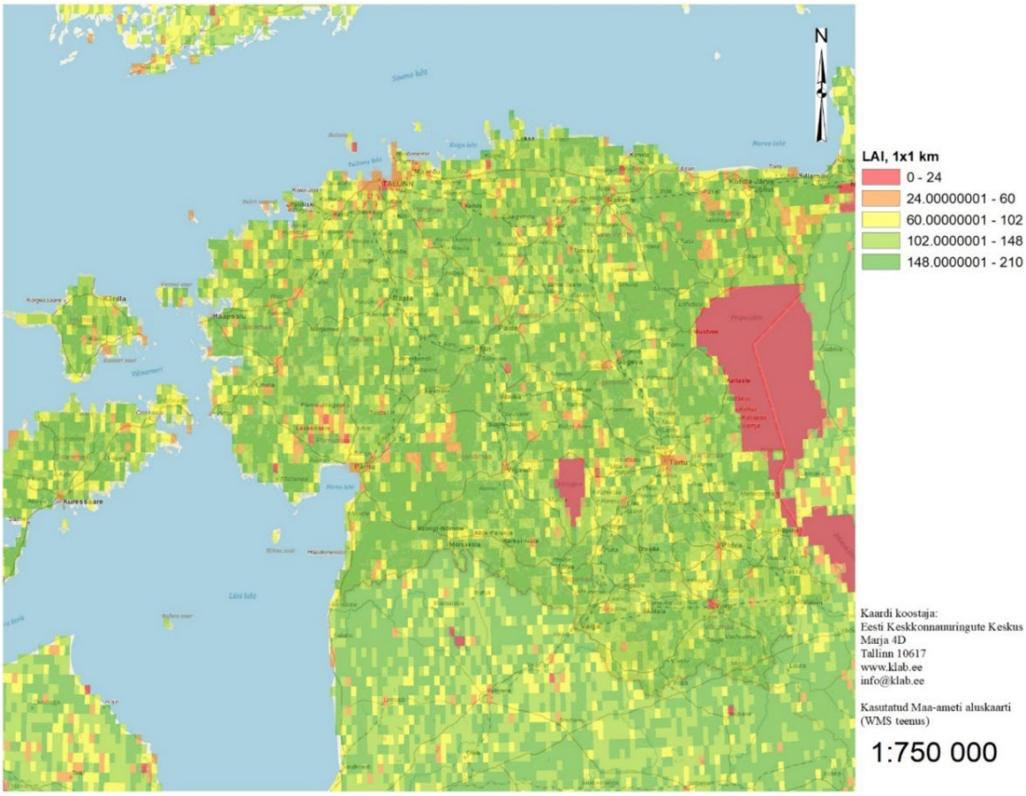


Figure 17. Used LAI data



Based on $PM_{2.5}$ concentration and Vd data the PM2.5 deposition was calculated, using following formula:

$PM_{2.5}$ deposition (tonnes/km^2/year) = Vd (cm/s) × C_{PM} (µg/m^3) × 3.1536 ×10^{-3} (Equation 2)

Total $PM_{2.5}$ deposition (tonnes/year) = ∑ PM deposition (tonnes/km^2/year) (Equation 3)

$PM_{2.5}$ deposition (tonnes/km^2/year) are presented in Figure 18 and in total 552 tonnes of $PM_{2.5}$ was adsorbed due to air filtration in 2022. In 2020, the result, using the same methodology, was 554 tonnes of PM2.5 are adsorbed.

The obtained map for deposited PM2.5 was combined with ecosystem extent map and division between ecosystem types was found (Table 42). The users of the service are households (Table 43).

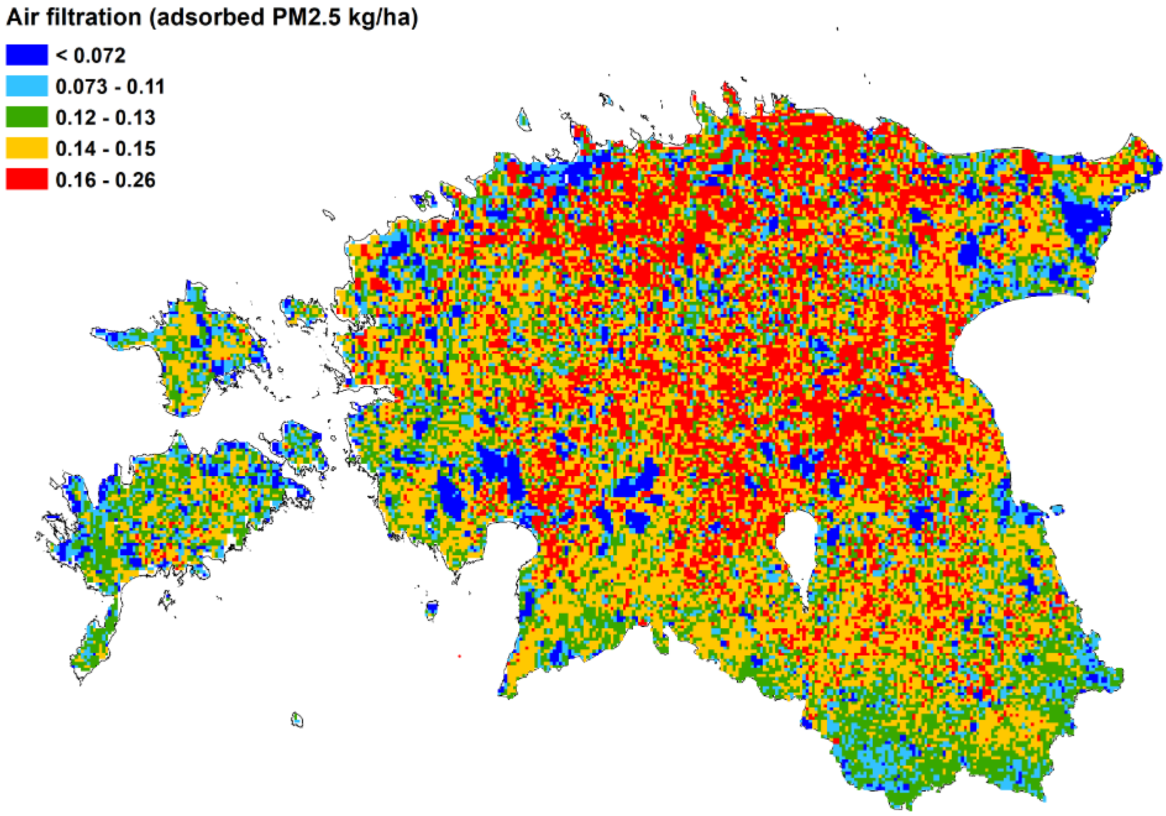
Table 42. Air filtration – supply table (tonnes of PM2.5 adsorbed), 2022

Ecosystem	Air filtration (Tonnes of PM2.5 adsorbed)
1 Settlements and other artificial areas	33.703
2 Cropland	108.068
3 Grassland (pastures, semi-natural and natural grassland	53.763
4 Forest and woodland	326.169
5 Heathland and shrub	1.619
6 Sparsely vegetated ecosystems	0.334
7 Inland wetlands	22.417
8 Rivers and canals	3.310
9 Lakes and reservoirs	2.603
10 Marine inlets and transitional waters	0.011
11 Coastal beaches, dunes and wetlands	0.062
12 Marine ecosystems (coastal waters, shelf and open ocean	0.002
Total supply	552.061

Table 43. Air filtration – use table (tonnes of PM2.5 adsorbed), 2022

	Intermediate consumption by industries	Government final consumption	Households final consumption	Gross capital formation	Exports	Total use
Tonnes of PM2.5 adsorbed			552.061			552.061

Figure 18. Air filtration ecosystem service (PM2.5 deposition in kg/ha). The areas coloured from blue to red represent service provisioning areas according to the physical unit value kg/ha). Areas coloured white represent areas that do not supply the ecosystem service.



7.2.2 Air filtration – monetary valuation

The monetary value of air filtration was evaluated using benefit transfer method based on a study by Baro et al. (2014)[67].

Baro et al. (2014) conducted research within the administrative boundaries of the municipality of Barcelona, Spain. There is 1.62 million inhabitants in an area of 101.21 km^2. The total green space within the municipality of Barcelona amounts to 28.93 km^2 representing 28.59 % of the municipal area and a ratio of 17.91 m^2 per inhabitant. In the last decade, the city has repeatedly exceeded the EU limit values for average annual concentrations of nitrogen dioxide (NO2) and PM10 pollutants (40 lg m^3 for both pollutants).

The i-Tree Eco model was used to quantify ecosystem services and disservices in Barcelona. The Public Health Agency of Barcelona provided PM10 concentration data from the 13 operational monitoring stations of the city during the year 2008. The i-Tree Eco model estimates dry deposition of air pollutants (i.e., pollution removal during non-precipitation periods), which takes place in urban trees and shrub masses. Externality value applied to the case study is transferred from U.S report where PM10 = 6614 USD per ton (year 2007) [68].

[67] Baro, F., Chaparro, L., Gomez-Baggethun, E., Langemeyer, J., Nowak, D.J., Terradas, J. (2014) Contribution of Ecosystem Services to Air Quality and Climate Change Mitigation Policies: The Case of Urban Forests in Barcelona, Spain. AMBIO 2014, 43:466–479
[68] Murray, F.J., L. Marsh, and P.A. Bradford. 1994. New York state energy plan Vol. II: issue reports. Albany, NY: New York State Energy Research and Development Authority.

Air filtration in case of PM10 removal by Barcelona trees and shrubs is estimated at 166.0 tons per year with an economic value of 1,097,964 USD per year (USD 2008 year).

Based on the findings of the selected study, the following assumptions were made to calculate the monetary value of PM2.5 deposition by Estonian ecosystems in 2022:

1. Adsorbed PM2.5 was 552 tons in 2022,
2. The monetary value of PM10 absorption by trees and bushes was 6614 USD/ton (year 2007) [69];
3. According to the Estonian ambient air monitoring map[70] PM10 measured in Estonian air contains an average of 40% PM2.5 over the last 10 years;
4. The exchange rate of the euro and the US dollar in 2022 was 1.173[71].

Total monetary value of Estonian ecosystem ability to deposit PM2.5 is 1.28 million EUR in 2022. The value of the PM 2.5 deposition by ecosystem is presented in Table 44.

Table 44.Physical and monetary value of deposited PM2.5 by ecosystem types, 2022

Ecosystem	Air filtration (tonnes of PM2.5 adsorbed)	Monetary value of PM2.5 deposition, thousand EUR
1 Settlements and other artificial areas	33.703	78.124
2 Cropland	108.068	250.502
3 Grassland (pastures, semi-natural and natural grassland	53.763	124.622
4 Forest and woodland	326.169	756.059
5 Heathland and shrub	1.619	3.753
6 Sparsely vegetated ecosystems	0.334	0.775
7 Inland wetlands	22.417	51.964
8 Rivers and canals	3.310	7.673
9 Lakes and reservoirs	2.603	6.033
10 Marine inlets and transitional waters	0.011	0.024
11 Coastal beaches, dunes and wetlands	0.062	0.145
12 Marine ecosystems (coastal waters, shelf and open ocean	0.002	0.004
Total supply	552.061	1284.172

7.3 Global climate regulation

According to the amendment of Regulation (EU) 691/2011, the ecosystem service local climate regulation is defined as the ecosystem contribution to reducing concentrations of greenhouse gases in the atmosphere through the removal (net sequestration) of carbon from the atmosphere and the retention (storage) of carbon in ecosystems. The contributions should be reported in terms of tonnes of net sequestration of carbon and tonnes of organic carbon stored in terrestrial ecosystems, including above ground and below ground stock.

It is noted in the respective guidance note by Eurostat that LULUCF sector (land use and land use change) in national greenhouse gas (GHG) inventories provide much of the data required to account for net carbon sequestration and carbon storage. In this work data on sequestration and emissions from GHG was used. Existing international reporting data from Greenhouse gas inventories can be easily used as input data, however alignment

[69] Murray, F.J., L. Marsh, and P.A. Bradford. 1994. New York state energy plan Vol. II: issue reports. Albany, NY: New York State Energy Research and Development Authority.
[70] https://xn--huseire-00a.ee/?zoomLevel=8&lat=58.88711&lng=25.569944
[71] https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm

between ecosystem types in LULUCF and ecosystem extent needs to be tackled separately considering also which data need to be included or are included in LULUCF (managed vs unmanaged land). The latter aspect is important when dealing with natural wetlands which can be potential carbon sinks and, in this case, additional data sources need to included. In current work natural wetlands were excluded but it is foreseen that detailed spatial data for carbon sequestration becomes available in the future and then estimations can be made

To calculate carbon storage separate spatial datasets for carbon stock in soil and carbon stock in woody above- and below-ground biomass produced in ELME2 project were used. The used soil carbon map is foreseen to be updated regularly in the future by Estonian Environment Agency, but specifics are not yet clear. It is also a possibility that more relevant data is compiled during currently ongoing projects, for example project "Land and Soil Use Management System for Effective and Sustainable Use of Soil Services, Biodiversity Protection, and Climate Impact Reduction" which is led by the Ministry of Climate (completion by 2027). In the same project workflow updated data on carbon capture would be produced.

Average EU ETS price in 2022 was combined with physical indicators (net sequestration and carbon storage) to find the economic value of the service.

7.3.1 Global climate regulation – physical account

The data from National Inventory Report of greenhouse gas emissions in Estonia 1990-2022[72] was used to find carbon-related greenhouse gas (CO2, CH4) removals and emissions.

Net CO2 and CH4 flows are given in kilotons and these were converted to tons of carbon by using conversion factors: 1 ton CO2 equals 0.27 ton C and 1 ton CH4 equals 0.75 ton C respectively (Table 45).

Table 45. Carbon-related greenhouse gas removals and emissions, 2020, kt (kt=thousand tons). The signs for removals are negative (–) and for emissions positive (+).

Land-use category	CO2, kt	CH4, kt	CO2-C, kt C (CO2 = 0.273C)	CH4-C, kt C (CH4 = 0.75C)	N2O, kt
A. Forest land	-1676.4963	2.6731	-452.6540	2.0048	0.9121
B. Cropland	844.4111	NO,NE,NA	227.9910		0.0243
C. Grassland	-171.9770	0.0001	-46.4338	0.0001	0.0000
D. Wetlands	1305.1405	0.0041	352.3879	0.0031	0.0077
E. Settlements	308.8507	NO,NE	83.3897		0.0411
F. Other land	29.2455	NO	7.8963		0.0048
G. Harvested wood products	-641.5779				
H. Other (please specify)	NO	NO			NO
Total LULUCF	-2.4034	2.6773	-0.6489	2.0080	1.0027

*NO (not occurring, IE (included elsewhere), NE (not estimated), NA (not applicable)

It can be seen that forest and grasslands are the only land-use categories where carbon is sequestered and not emitted. Harvested wood products (HWP) are excluded from the service value, since HWPs are reported in a separate category in the GHG inventories.

LULUCF includes only managed land. All forest is managed in Estonia. Managed land for wetlands category includes only peatlands drained and managed for peat extraction and excludes natural unmanaged wetlands. Wetlands, peatlands in particular, in their natural state are known to be carbon sinks, therefore they can be potential service providers. This aspect is also mentioned in the guidance note for global climate regulation. The guidance note gives further recommendations how to find carbon sequestration for unmanaged wetlands that are not included in LULUCF. An easy approach would be to estimate average per hectare annual carbon sequestration in unmanaged wetlands based on literature and to then to multiply that with the area of these wetlands. The guidance note proposes that as a default value, in case no national data are available, the net C sequestration in European

[72] https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/national-inventory-submissions-2022

undrained temperate peatlands can be assumed to be 0.56 (+ 0.19) tons C per hectare per year in all ecosystem types. It is assumed that peatlands in their natural state remove approximately 2 tons of CO2 (0.54 tons of C) per hectare in Estonia[73]. However, it is also noted by experts that due to drainage, which affects the majority of peatlands in Estonia directly or indirectly, wetlands in total have turned from being CO2 sinks to CO2 sources[74]. In this case, more detailed data and especially spatial data are necessary. Currently net sequestration in unmanaged wetlands is not included in the global climate service indicator 'net sequestration'.

Based on the suggestion by experts an assumption was made, that the annual net increment of stands has a strong correlation with carbon sequestration. Therefore, the contribution to the supply of the service by different forest ecosystems (Table 46) was obtained by the spatial allocation of carbon sequestration in forests based on net increment (see Figure 4. Wood provisioning (based on net increment) areas and values. The areas coloured from blue to red represent service provisioning areas according to the physical unit value m3/ha). Areas coloured white represent areas that do not supply the ecosystem service.). The dataset and calculation of increment is described in chapters of wood provision. The total value of sequestered CO_2 is based on the National Inventory Report of greenhouse gas inventory, no calculations were done to assess the carbon content in the biomass of forest increment. For grasslands the carbon sequestration was distributed per ecosystem area.

Carbon storage was estimated based on separate spatial datasets for carbon stock in soil and carbon stock in woody above- and below-ground biomass prepared in ELME2 project[75]. To calculate carbon storage for ecosystem types, the datasets for carbon stock in soil and carbon stock in woody above- and below-ground biomass were combined with the extent map and for every ecosystem asset an average value of the stock in tons C/ha was found. Distribution between ecosystem types was then found by aggregating by ecosystem type. The results can be seen in Table 46 Illustrative map on the spatial distribution of carbon stock is presented in

[73] Estonian Ministry of Environment, Draft "Eesti turbaalade kaitse ja säästliku kasutamise alused" (05.10.2010)
[74] Ilomets, M., 2005. Turba juurdekasv Eesti soodes. Tallinna ülikool, ökoloogia instituut.
[75] „The nation wide assessment and mapping of ecosystem services". Project "Establishment of tools for integrating socioeconomic and climate change data into assessing and forecasting biodiversity status, and ensuring data availability" (ELME) http://www.keskkonnaagentuur.ee/elme

Figure 19.

Table 47 shows the use of the global climate regulation service, the user of the service is government.

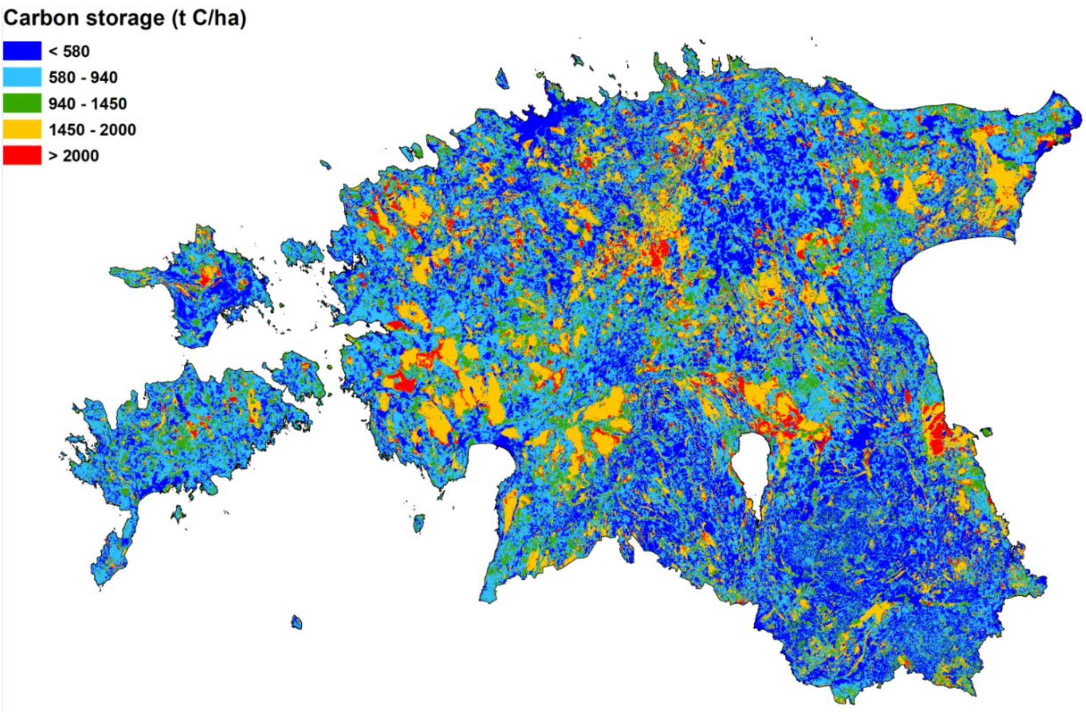
Table 46. Supply of global climate regulation, tonnes, 2022

	Net carbon sequestration (tonnes)	Stored organic carbon (tonnes)
1 Settlements and other artificial areas	630.6	152 514 320
2 Cropland		557 511 530
3 Grassland (pastures, semi-natural and natural grassland	46 433.8	385 212 935
4 Forest and woodland	452 023.4	2 418 070 842
5 Heathland and shrub		11 967 133
6 Sparsely vegetated ecosystems		2 415 463
7 Inland wetlands		485 431 298
8 Rivers and canals		44 452 594
9 Lakes and reservoirs		14 358 707
10 Marine inlets and transitional waters		160 409
11 Coastal beaches, dunes and wetlands		1 743 615
Total supply	**499 087.8**	**4 073 838 845**

Table 47. Global climate regulation – use table, 2022

	Intermediate consumption by industries	Government final consumption	Households final consumption	Gross capital formation	Exports	Total use
Net carbon sequestration (tonnes)		499 087.8				**499 087.8**
Stored organic carbon (tonnes)		4 073 838 845				**4 073 838 845**

Figure 19. The ecosystem service provisioning areas and values of carbon storage. The areas coloured from blue to red represent service provisioning areas according to the physical unit value t C/ha). Areas coloured white represent areas that do not supply the ecosystem service.



7.3.2 Global climate regulation – monetary valuation

Payment for ecosystem services (PES) schemes was considered the best technique to assess the monetary value of the service. European Union (EU) Emissions Trading System was chosen as an appropriate PES scheme and the yearly average European Union Allowance (EUA) price (€/t CO2) was chosen as a unit price. The calculated yearly average EUA price for year 2022 was 83.47 €/t CO2[76].

CO2 net sequestration was multiplied with the EUA price. Carbon stock in tons C was first converted to carbon stock in tons CO2 (ton CO2=3.67 ton C) and then multiplied with the EUA price. The results and division by ecosystem types are presented in Table 48.

The use of the service is attributed to government as was the case in physical account of global climate regulation ecosystem service.

[76] https://icapcarbonaction.com/en/ets-prices

Table 48.Supply of global climate regulation, million EUR, 2022

	Net carbon sequestration (tonnes)	Monetary value of net CO2 sequestration, million EUR	Stored organic carbon (tonnes)	Monetary value of stored organic carbon, million EUR
1 Settlements and other artificial areas	630.6	0.19	152 514 320	47 150
2 Cropland			557 511 530	172 354
3 Grassland (pastures, semi-natural and natural grassland	46 433.8	14.35	385 212 935	119 088
4 Forest and woodland	452 023.4	139.74	2 418 070 842	747 542
5 Heathland and shrub			11 967 133	3 700
6 Sparsely vegetated ecosystems			2 415 463	747
7 Inland wetlands			485 431 298	150 070
8 Rivers and canals			44 452 594	13 742
9 Lakes and reservoirs			14 358 707	4 439
10 Marine inlets and transitional waters			160 409	50
11 Coastal beaches, dunes and wetlands			1 743 615	539
Total supply	499 087.8	154.29	4 073 838 845	1 259 420

ANNEX 10. Detailed methodology and analysis for local climate regulation ecosystem service

1. Task description

The present study was conducted within the grant agreement „*Development of the environmental accounts 101197994 — 2024-EE-EGD*“. The goal was to optimize calculations of vegetation cooling effect on local climate during heat wave situations and to make these calculations for Estonian largest cities Tallinn, Tartu and Narva for period May-September 2024.

The aim of such calculations is to evaluate the influence of this environmental factor on citizens' life quality.

The previous work on this topic involved calculations of the cooling effect in year 2022 (Statistics Estonia. (2024). *Development of the forestry, environmental subsidies and ecosystem accounts: D1.9 Description of the methodology and problematic issues for ecosystem accounts (Final methodological report).* Project No. 101113157 (Eurostat Grant Agreement 2022-EE-EGD)., Available: https://stat.ee/sites/default/files/2025-01/D1.9%20Description%20of%20the%20methodology%20and%20problematic%20issues%20for%20ecosystem%20accounts_0.pdf). Materials from the previous work were used. They contained Python scripts and some input datasets.

2. Calculations of vegetation cooling effect for 2022 and 2024

2.1. Study areas

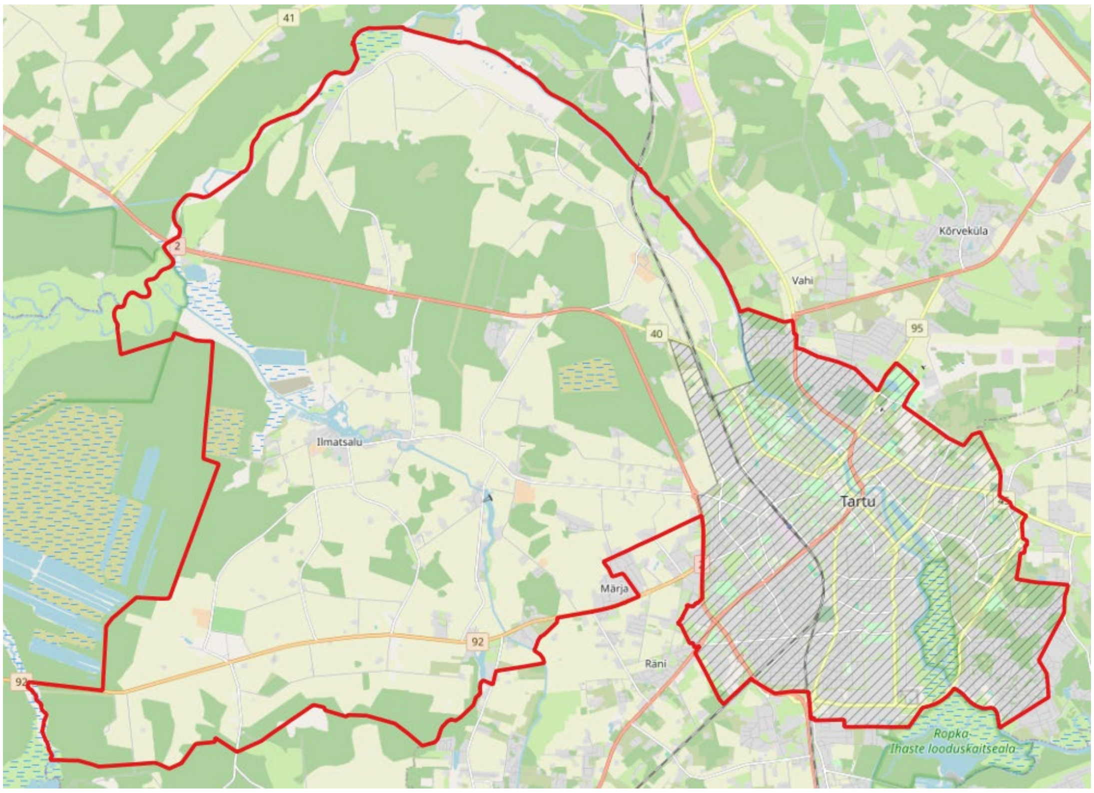
Calculations of vegetation cooling effect needed to be done for three largest Estonian cities: Tallinn, Tartu, Narva. Precise information about their territory was taken from Estonian Land and Spatial Development Board (input datasets are described in more details in section 2.2). Official borders of these administrative units are shown on figure 1.

Figure 1. Administrative borders of Tallinn, Tartu, Narva municipalities in 2024.

Tartu municipality includes large part of rural area of fields and forests, which even exceeds an urbanized part.

There is also available a settlement polygon dataset for Tartu, which contains only the territory of this town. Both municipality and settlement polygons are shown in figure 2, where the smaller territory is hatched.

Figure 2. Tartu municipality and settlement polygons.



The administrative boundaries for the city of Tartu are officially the same as its municipal territory (polygon with red line, figure 2), but the citizens are mainly located in its smaller urbanized part, which is hatched on the figure. So, in context of goals of this survey, it is appropriate to observe the cooling effect in its smaller, urbanized part as the effects would be more significant to the populace. Calculations for the settlement territory were done accordingly in addition to the municipality of Tartu. To distinguish these areas from this point forward in this document, Tartu's municipality polygon is named „Large Tartu" and settlement polygon is named „Small Tartu".

2.2. Input data

2.2.1. Datasets needed for the programs

The calculation method requires several types of input data. The scripts from the previous study are designed to work with initial data from specific sources.

The datasets, needed for the cooling effect calculation are:

1. Land Surface Temperature (LST) – the product of temperature was calculated in Estonian Environment Agency from Landsat 8 and Landsat 9 observations bands 4, 5, 10, which were downloaded as a „Landsat Collection 2 Level-1" datasets from portal of United States Geological Survey (USGS) (https://www.usgs.gov/about/about-us/who-we-are).
2. Tree Cover Density (TCD) – data from Copernicus Land Monitoring Service (CLMS) (https://land.copernicus.eu/en/products/high-resolution-layer-forests-and-tree-cover/tree-cover-density-2021-raster-10-m-100-m-europe-yearly#general_info).
3. Evapotranspiration (ET) – dataset from product „PML_V2 0.1.8: Coupled Evapotranspiration and Gross Primary Product (GPP)" of Google Earth Engine Data Catalog (https://developers.google.com/earth-engine/datasets/catalog/CAS_IGSNRR_PML_V2_v018#description).
4. Ecosystems map – dataset from Statistics Estonia, which shows territorial distribution of different ecosystem types.
5. Maps of administrative units – datasets of borders of municipalities and settlements from Estonian Land and Spatial Development Board (https://geoportaal.maaamet.ee/eng/spatial-data/administrative-and-settlement-division-p312.html).

The calculations had to be performed for period of 1st May to 30th September 2024. For this period of time only data of administrative units' borders and Landsat observations were available. Other datasets were taken from previous years.

There were two alternatives: to modify the programs for utilizing other datasets or to agree with using of older data. Due to project deadlines, the second option was selected, because the search of available data and modification of programs could demand too much time.

Usage of ET, TCD and ecosystem types' distribution data from previous years is considered to be acceptable, because city's environment usually does not change much in several years.

Available ET and LST datasets were additionally filtered, according to weather conditions, as their usefulness depends on weather. Due to that, for each city its own list of used files was formed.

In the next sections all datasets are described in more detail.

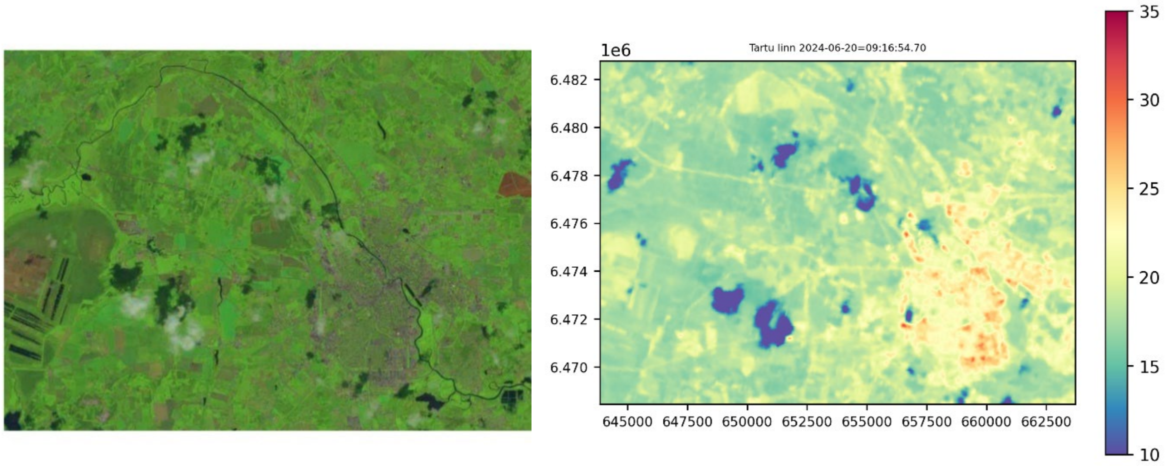
2.2.2. Land Surface Temperature

LST is a product, which contains temperature values at subsatellite surface. LST values for this study were calculated from Landsat 8 and Landsat 9 observations in channels 4 (0,66 µm), 5 (0,87 µm), 10 (10,8 µm) with resolution of 30 metres. The data was downloaded from USGS portal. The datasets also contained observations in other spectral channels and composite pictures, which were used for additional visual inspection of the scenes. Also, metadata of the products contained an automatic estimate of cloud cover per cent over the observed area.

The LST product does not show air temperature, it contains values of surface temperatures of waterbodies or land objects, like roads, tops of trees, roofs. These values can be both higher or lower in comparison to air temperature, which would be measured at weather station. Also, as clouds are opaque for infrared radiation, the product is very sensitive to cloudiness, and correct values can be obtained only in cloud-free conditions.

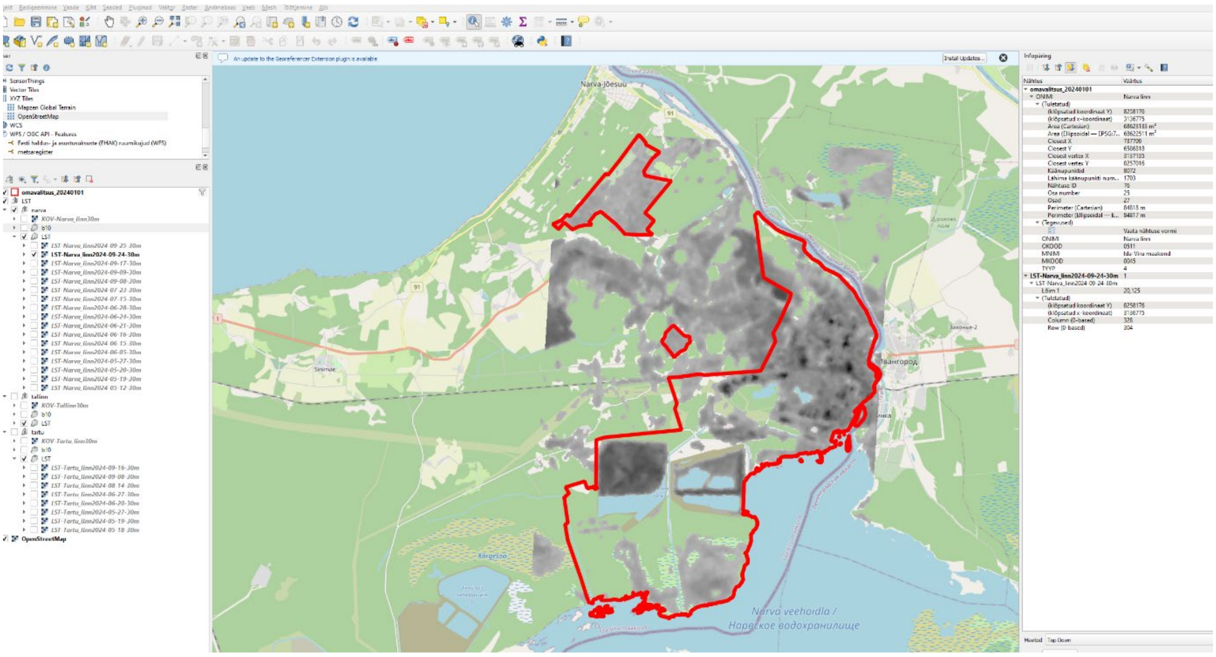
For the present study, all available datasets from period May-September 2024 were downloaded, if their cloud coverage did not exceed 50 %. At the next step these datasets were inspected in program QGIS, and observations, where clouds were present over cities' territory, were filtered out. This step was very essential, because the presence of clouds distorts temperature patterns at study area, which is not acceptable in context of the present work. Figure 3 gives an example of LST pattern distortion by little cloudiness.

Figure 3. Distortion of LST pattern by Cumulus clouds over Tartu, 2024-06-20. Left – satellite picture in visible channels, right – LST pattern.



At second step the remaining LST datasets were filtered according to temperature values. As the goal is to evaluate cooling effect during hot days, only datasets, where temperatures at +15°C and higher dominate in the study areas, were kept. It was done by visual inspection of LST data in QGIS, example is at figure 4.

Figure 4. LST dataset 2024-09-24 at Narva. Values below +15°C are transparent.



In the example at figure 4 temperatures over +15°C occupy more than half of city area, so this dataset was accepted.

LST level +15°C corresponds to quite cool weather, but putting higher threshold would result in too few samples.

2.2.3. Evapotranspiration

Evapotranspiration product from Google Earth Engine contains several fields, which are connected to evaporation processes in the environment:

1. Gross primary production (GPP), gC/m^2/day,
2. Vegetation transpiration (Ec), mm/day,
3. Soil evaporation (Es), mm/day,
4. Interception from vegetation canopy (Ei), mm/day, this parameter characterizes precipitation amount, which was caught by vegetation canopy,
5. Evaporation from water bodies, snow, and ice (ET_water), mm/day.

Product spatial resolution is 500 m.

Evapotranspiration from vegetation is considered as sum of transpiration (Ec) and precipitation interception (Ei).

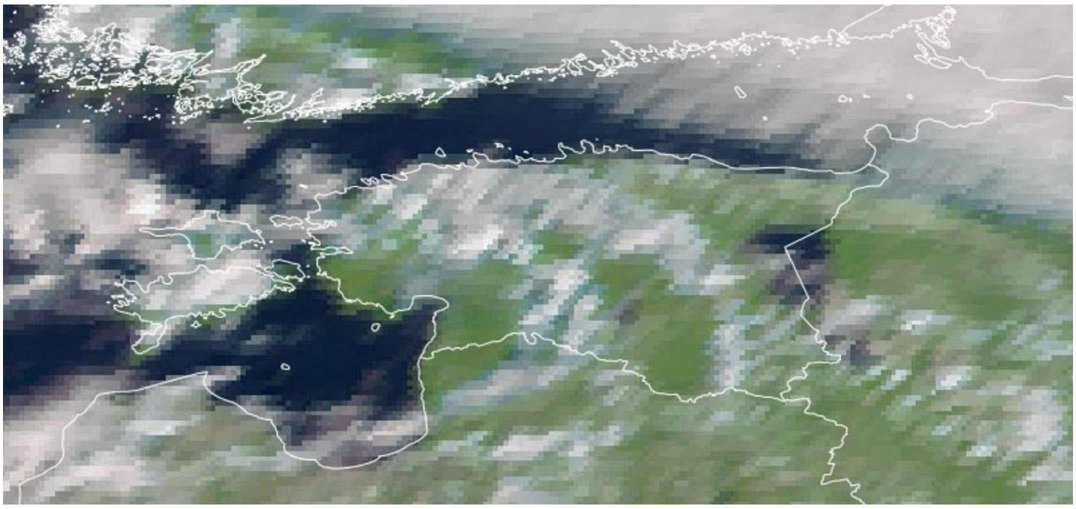
The newest data are available from 2022 and 2023 with 8-day step. Datasets were selected from period May-September of these two years.

Evapotranspiration depends mainly on surface properties and weather. It is assumed that surface properties did not change significantly between years 2022 and 2024. Also the dates, when weather corresponded to the study goals, were selected. It means, that ET data were taken, if weather at particular date and location was warm and sunny.

At first stage only dates, when daily 2m temperature maximum at nearest weather station was at least +20°C, were selected. For Tallinn the nearest was Tallinn-Harku weather station, for Narva city it was Narva weather station, for Tartu it was Tartu-Tõravere. Other dates were filtered out.

At second stage cloudiness was checked. The date was selected, if during the day at 05:00 to 15:00 UTC weather was cloud-free or there was only little cloudiness over study area. It was done by visual inspection of Meteosat images with 1-hour time step at Eumetview site (https://view.eumetsat.int/). Example of satellite images is on figure 5.

Figure 5. Meteosat image example at Eumetview page.

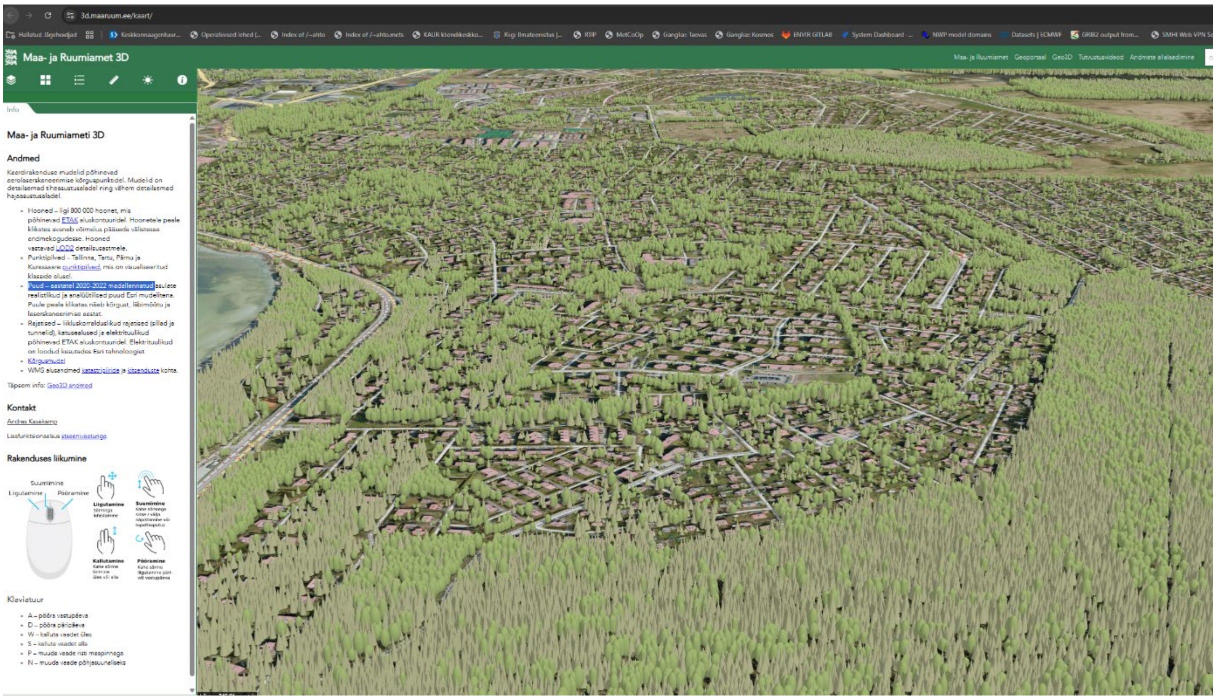


2.2.4. Tree Cover Density

Tree Cover Density product shows, which part of area is covered by trees, where values vary from 0 to 100 per cent. TCD data with resolution at 10 metres are available at CLMS webpage from years 2018 and 2021. The product description at this website mentions, that values from the whole range 0%-100% are preserved: „*All HRL (High Resolution Layer) Forest, Grasslands, and Croplands products since 2017 have been produced in parallel in a harmonised manner within the High Resolution Layer – Vegetated Land Cover Characteristics (HRL-VLCC) portfolio. Targeting vegetated land cover, the HRL-VLCC layers are focused on the mapping of vegetation cover which is generally above 30% of the surface; an exception to this is tree cover for which the objective is to map tree cover with a continuous range of 1-100% Tree Cover Density (i.e. also below 30%) layer as far as detectable from 10m resolution satellite imagery.*" (https://land.copernicus.eu/en/products/high-resolution-layer-forests-and-tree-cover?tab=technical_summary). But during inspection of data for both years 2018 and 2021, which were downloaded in the present work (autumn 2025), it was seen, that actually lower TCD values were substituted by zero. Contrary to that, TCD dataset of year 2018, which was obtained for previous survey, contained low TCD values.

Figure 6 shows 3-dimensional model of vegetation in Tallinn. The data was taken from Estonian Land and Spatial Development Board (https://3d.maaruum.ee/kaart/), and it was collected during years 2020-2022.

Figure 6. 3-dimensional vegetation model in Tallinn.



This figure 6 depicts Tallinn North-Eastern part, Pirita district, where residential areas consist of private houses and also there are many forested areas. Area of private houses usually has sparse tree cover, its TCD cannot be high, but is definitely above zero.

Figure 7 shows TCD datasets, as they were displayed in QGIS for the same territory. Left image is newly downloaded data of year 2018, and right part is data of year 2018, which was downloaded for previous study.

Figure 7. TCD from newly downloaded year 2018 dataset (left) and earlier downloaded data of year 2018 (right).

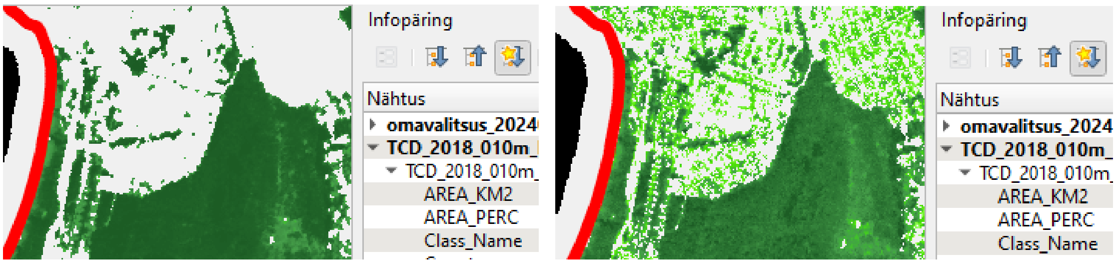
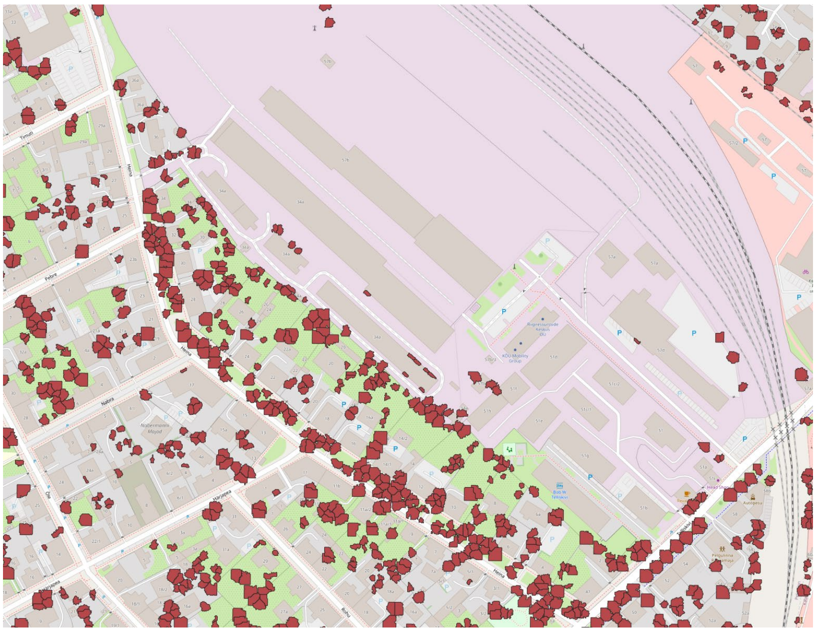


Figure 7 shows, that newly downloaded datasets actually do not represent sparse tree cover in residential area. Dataset of year 2021 has the same peculiarity. It is possible, that Copernicus have changed the methodology of their TCD product, but the information at the webpage is outdated.

In context of the present study, the vegetation located in residential areas is very important, so its neglection is unacceptable. Due to that older dataset of year 2018 was selected for the calculations.

An alternative data source for TCD can be found from dataset of year 2024 by Estonian Land and Spatial Development Board (https://geoportaal.maaamet.ee/eng/spatial-data/geo3d/download-3d-data-p837.html), where polygons of tree crowns are given for city areas. An example of its visualization is on figure 8.

Figure 8. Example of tree crown polygon product visualization in QGIS.



Such input data enables calculation of TCD with high resolution.

2.2.5. Ecosystems' map

The ecosystems' map of year 2022 was provided by the Statistics Estonia in form of .tif file. It gives territorial distribution of different types of environments in Estonia. The ecosystems are divided into 29 categories, which are listed in table 1.

Table 1. Classification of ecosystems in source data.

Code	Meaning of ecosystem type
1	Annual croplands
2	Permanent crops
3	Sown pastures and fields (modified grasslands)
4	Broadlieved decidous forest
5	Coniferous forests
6	Mixed forests
7	Natural and semi-natural grasslands
8	Inland marshes and other wetlands on mineral soil
9	Heathland and (sub-) alpine shrub
10	Other artificial areas
11	Mires, bogs and fens
12	Lakes and ponds
13	Semi-desert, desert and other sparsely vegetated areas
14	Infrastructure and industrial areas
15	Mixed farmland
16	Canals, ditches and drains
17	Artificial reservoirs
18	Rivers and streams
19	Continuous settlement area
20	Discontinuous settlement area
21	Urban greenspace
22	Coastal dunes, beaches and sandy and muddy shores
23	Bare rocks
24	Subtidal sand beds and mud plains
25	Coastal lagoons
26	Estuaries and bays
27	Rocky shores
28	Subtidal rocky substrates
29	Marine ecosystems (coastal waters, shelf and open ocean)

Spatial resolution of the map is 10 metres.

2.2.6. Administrative units' shapefiles

Administrative units' datafiles for year 2024 were downloaded from Estonian Land and Spatial Development Board source (https://geoportaal.maaamet.ee/eng/spatial-data/administrative-and-settlement-division-p312.html). The description of the dataset is taken from their webpage: *„Data of administrative and settlement units is derived from the Land Cadastre. Attribute data is derived from the official Estonian Administrative and Settlement Classification (EHAK) maintained by the Statistics Estonia. A regular snapshot is taken on January 1 each year, but intermediary snapshots are taken when the changes in the Cadastre are significant. The data is available at three levels: counties, municipalities and settlements.“* Data scale is 1:10000.

2.3. Methodology of cooling effect calculation

All input datasets of LST, ET, TCD and ecosystem distribution were resampled to common grid with resolution of 30 metres and masked, using shapefiles of administrative units in order to preserve only pixels, which are situated inside polygon of the city.

Datasets of LST and ET, which are available at several observation dates, were averaged to obtain single two-dimensional dataset of each parameter.

Data from the map of ecosystems, which initially contains 29 types, was recoded into 12-class system (table 2).

Table 2. Classes of ecosystems represented in the study.

Code	Meaning of ecosystem type
1	Settlements and other artificial areas
2	Cropland
3	Grassland
4	Forest and woodland
5	Heathland and shrub
6	Sparsely vegetated ecosystems
7	Inland wetlands
8	Rivers and canals
9	Lakes and reservoirs
10	Marine inlets and transitional waters
11	Coastal beaches; dunes and wetlands
12	Marine ecosystems

As a result, the city obtained a sample of data pixels, and for each of them a single value of LST, TCD, ET and code of ecosystem type was known.

Next the linear regression functions were calculated:

LST as linear function of TCD, so LST approximated as $LST = LST_{tcd0} + a_{tcd} * TCD$.

Where LST_{tcd0} is LST value, if TCD equals to zero, a_{tcd} is slope of the function.

LST as linear function of ET, so LST approximated as $LST = LST_{et0} + a_{et} * ET$.

Where LST_{et0} is LST value, if ET equals to zero, a_{et} is slope of the function.

Also, a combined TCD + ET effect is estimated by fitting of linear regression of two variables $LST = LST_0 + a_{et2} * ET + a_{tcd2} * TCD$

Where LST_0 is temperature, which should occur, if ET and TCD would equal to zero; a_{tcd2} and a_{et2} are coefficients (slopes) for the combined TCD and ET effect.

Based on the last regression function, the cooling effect was calculated at each pixel as a product of TCD and ET values with corresponding slope coefficients:

$Cooling_i = a_{et2} * ET_i + a_{tcd2} * TCD_i$

Where TCD_i and ET_i are TCD and ET values in particular pixel and $Cooling_i$ is cooling effect estimate there.

After pixel-based evaluation of cooling effect was done, the values were averaged over regions, occupied by each type of ecosystem (Cooling effect, inside the ecosystem, °C), $Cooling_{eco\_i}$. Also, the proportions of these areas in city's total area were calculated (Ecosystem proportion in city area, %), $prop_{eco\_i}$. The product of ecosystem's average cooling effect and its proportion gave value of cooling effect on the total city area (Cooling effect at city scale, °C), $Cooling_{city\_i}$:

$Cooling_{city\_i} = Cooling_{eco\_i} * prop_{eco\_i}$

At final step cooling effects of all ecosystem classes were summed, and total cooling value in the city was obtained.

The calculations were done separately for each city.

2.4. Research of year 2022 cooling effect

A research for the same cities with same methodology, as for present study, was previously conducted to evaluate a cooling effect in May-September 2022.

Similar datasets were used, but one essential difference was in the rules for selection of Landsat data: in the previous survey satellite scenes with cloud cover up to 15% (for the whole image) were allowed. As clouds can seriously distort LST patterns, in the present work only images with cloud-free sky over the cities were used.

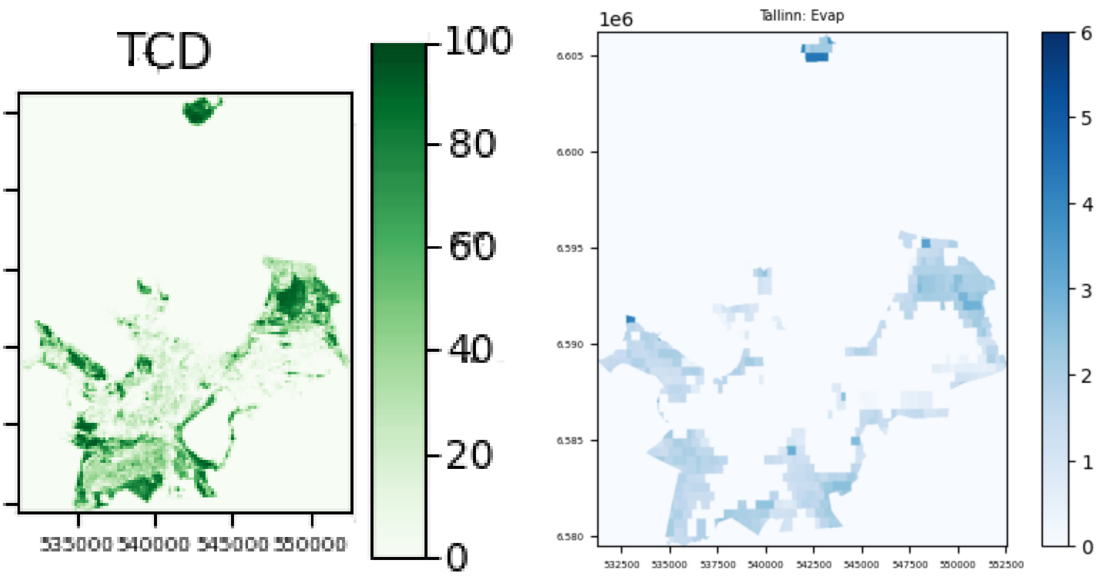
Despite this difference in LST data sample formation, the results of previous and present works are comparable, and them both are shown in section of calculation outputs.

2.5. Cooling effect calculation results

2.5.1. Tallinn

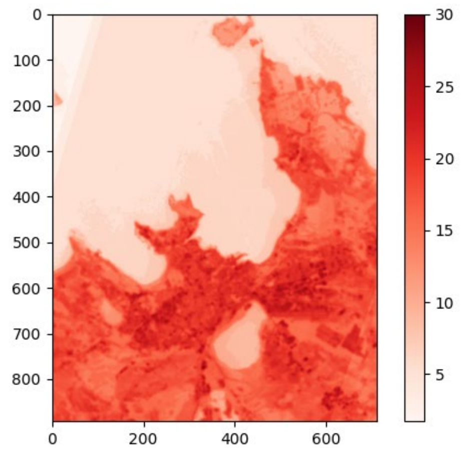
Maps of TCD and ET mean values of year 2024 survey are shown on figure 9.

Figure 9. TCD and ET mean values, 2024, Tallinn.



Average LST pattern from year 2024 observations is on figure 10.

Figure 10. Average LST values, 2024, Tallinn



Map of ecosystem types in EU 12-class system (from year 2022) and cooling effect is on figures 11 and 12.

Figure 11. Map of ecosystem types (2022), Tallinn.

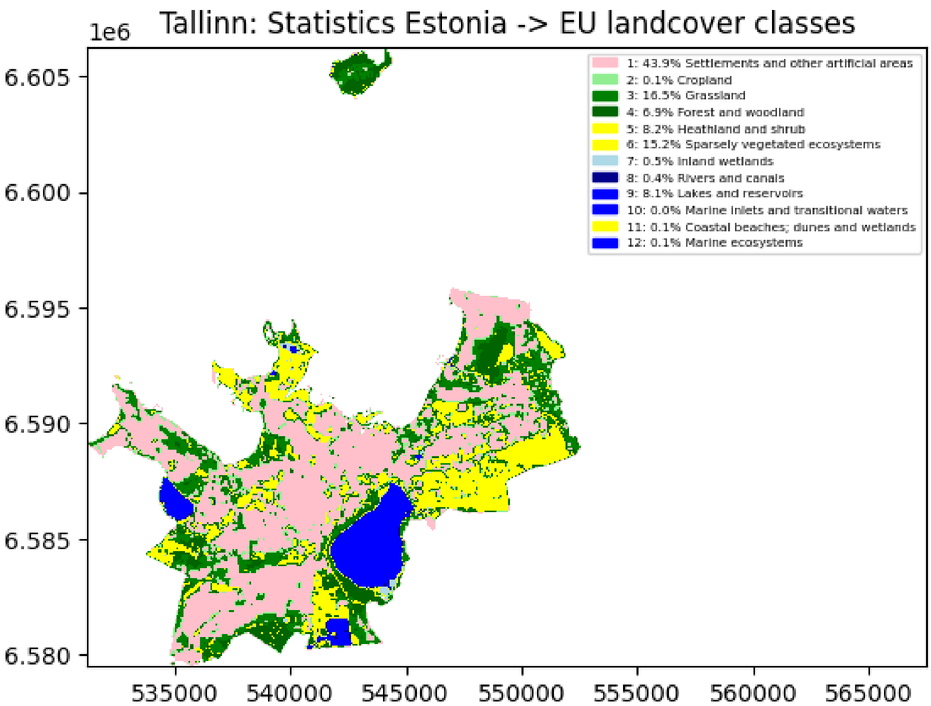
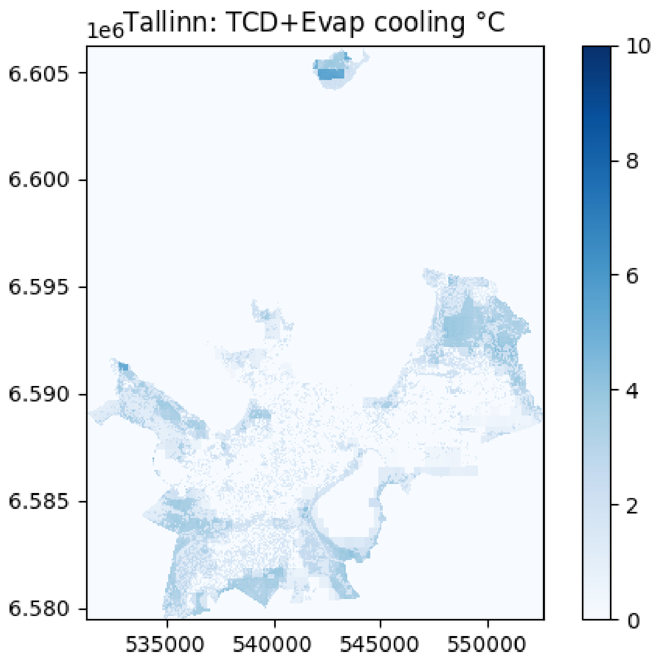


Figure 12. Cooling effect, 2024, Tallinn.

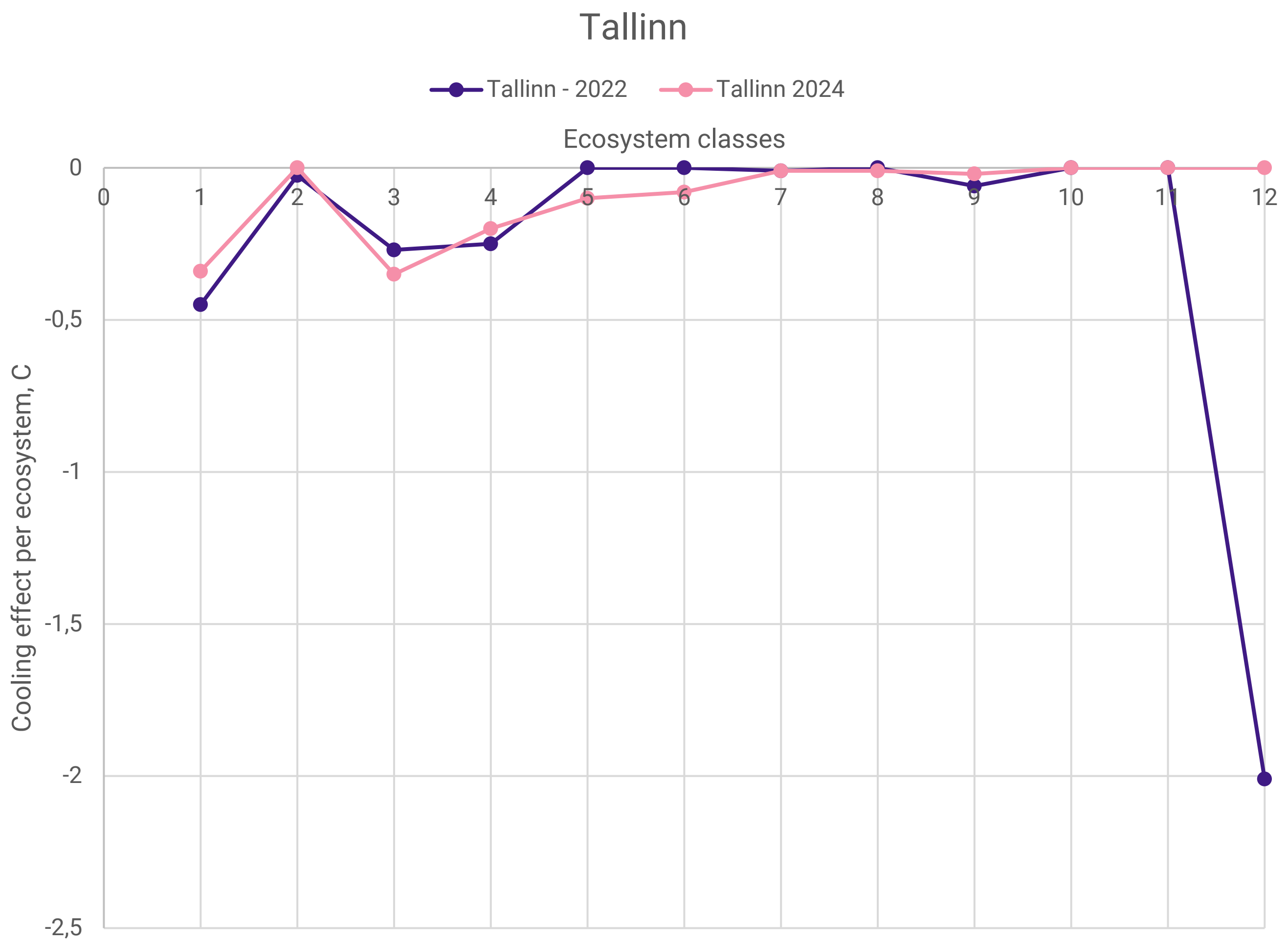


Numerical values of the calculated cooling effect per each ecosystem type are given in table 2 and figure 13. The values are given for present study (year 2024) and the previous study of year 2022 to enable their comparison. For year 2022 only values of cooling effect are available, for year 2024 study also proportions of each ecosystem in total city area are given.

Table 2. Cooling effect per ecosystem type in Tallinn, years 2022 and 2024.

Ecosystem class		Tallinn			
		2022	2024		
Code	Ecosystem description	Cooling effect at city scale, °C	Ecosystem proportion in city area, %	Cooling effect, inside the ecosystem, °C	Cooling effect at city scale, °C
1	Settlements and other artificial areas	**-0,45**	43,9	-0,78	**-0,34**
2	Cropland	**-0,025**	0,1	-1,98	**-0,0**
3	Grassland	**-0,27**	16,5	-2,11	**-0,35**
4	Forest and woodland	**-0,25**	6,9	-2,88	**-0,2**
5	Heathland and shrub	**0**	8,2	-1,19	**-0,1**
6	Sparsely vegetated ecosystems	**0**	15,2	-0,52	**-0,08**
7	Inland wetlands	**-0,01**	0,5	-1,75	**-0,01**
8	Rivers and canals	**0**	0,4	-1,9	**-0,01**
9	Lakes and reservoirs	**-0,06**	8,1	-0,3	**-0,02**
10	Marine inlets and transitional waters	**0**	0,0	0,0	**0,0**
11	Coastal beaches; dunes and wetlands	**0**	0,1	-0,73	**-0,0**
12	Marine ecosystems	**-2,01**	0,1	-0,28	**-0,0**
Total		**-3,075**	100,0		**-1,11**

Figure 13. Cooling effect per ecosystem type in Tallinn, years 2022 and 2024.

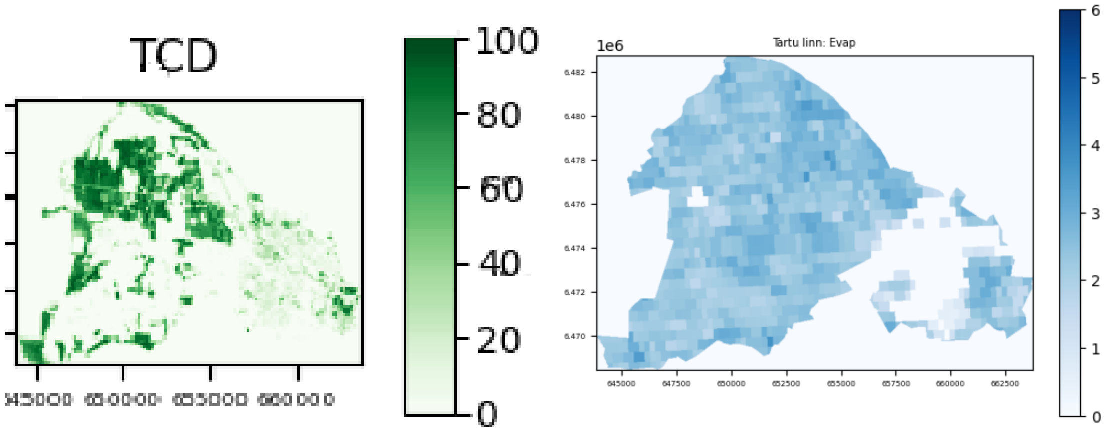


2.5.2. Tartu

As it was discussed in part 2.1, Tartu municipality includes a large rural area, which microclimate does not affect citizens' daily routines significantly. Due to that, Tartu city cooling effect was calculated two times: „Large Tartu" is the area of municipality, for which also the previous scores of year 2022 were calculated; and „Small Tartu" – the area of the settlement, which contains most of the urbanized areas and citizens.

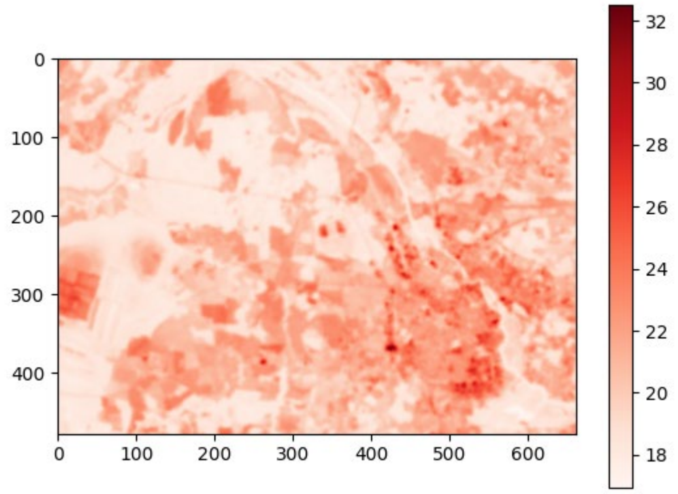
Maps of TCD and ET mean values of year 2024 survey are shown on figure 14 („Large Tartu").

Figure 14. TCD and ET mean values, 2024, „Large Tartu".



Average LST pattern from year 2024 observations is on figure 15.

Figure 15. Average LST values, 2024, „Large Tartu".



Map of ecosystem types in EU 12-class system (from year 2022) and cooling effect is on figures 16 and 17. Cooling effect is calculated separately for „Large Tartu" and „Small Tartu".

Figure 16. Map of ecosystem types (2022), „Large Tartu".

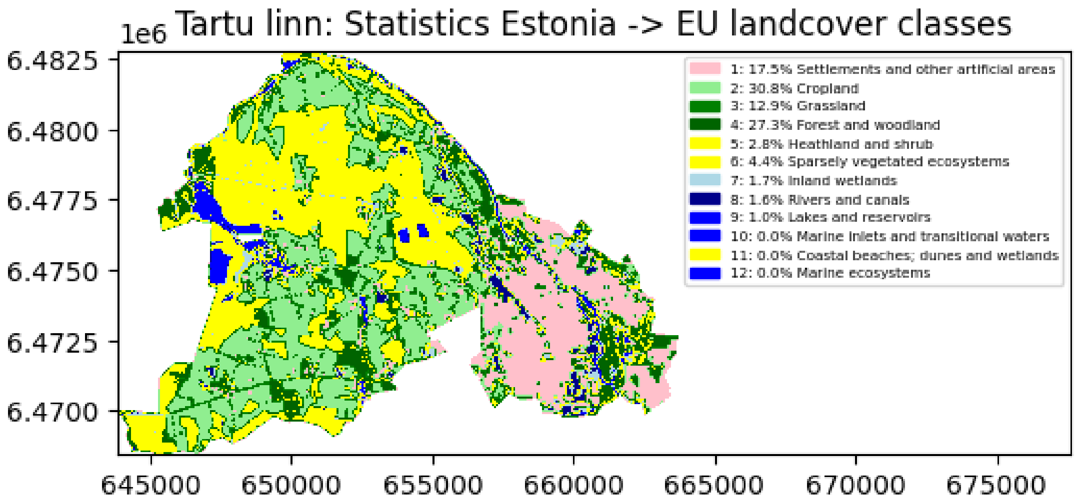
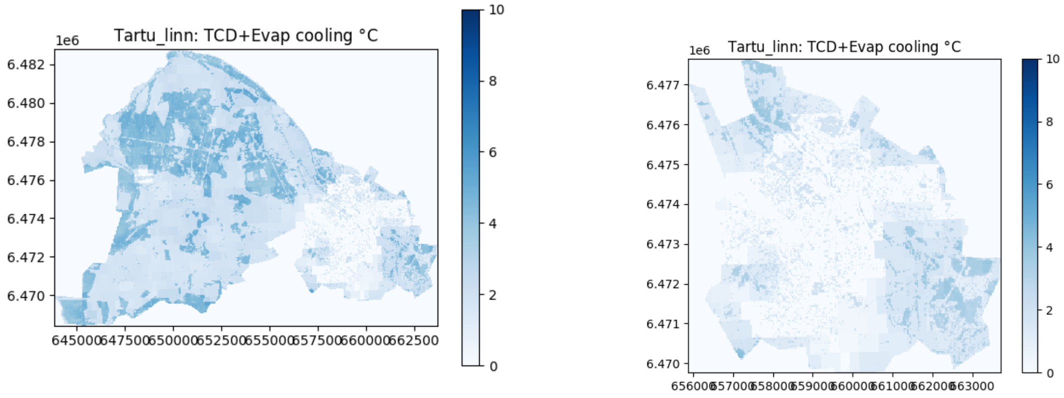


Figure 17. Cooling effect, 2024, Tartu. Left is „Large Tartu“, right is „Small Tartu“.

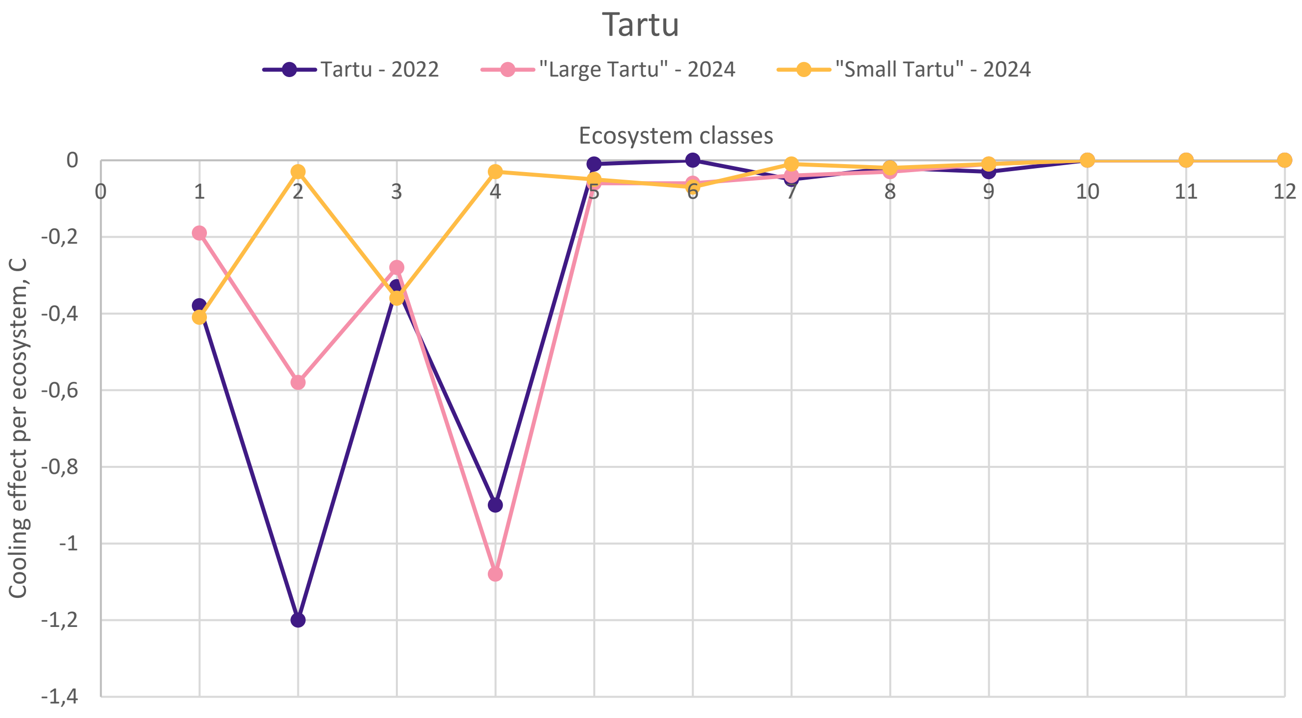


Numerical values of the calculated cooling effect per ecosystem type are given in table 3 and figure 18. The values are given for present study (year 2024) for both „Large Tartu“ and „Small Tartu“ and for the previous study of year 2022 to enable their comparison. For year 2022 only values of cooling effect in “Large Tartu” are available For year 2024 research, the proportions of each ecosystem in total city area are also given.

Table 3. Cooling effect per ecosystem type in Tartu, years 2022 and 2024.

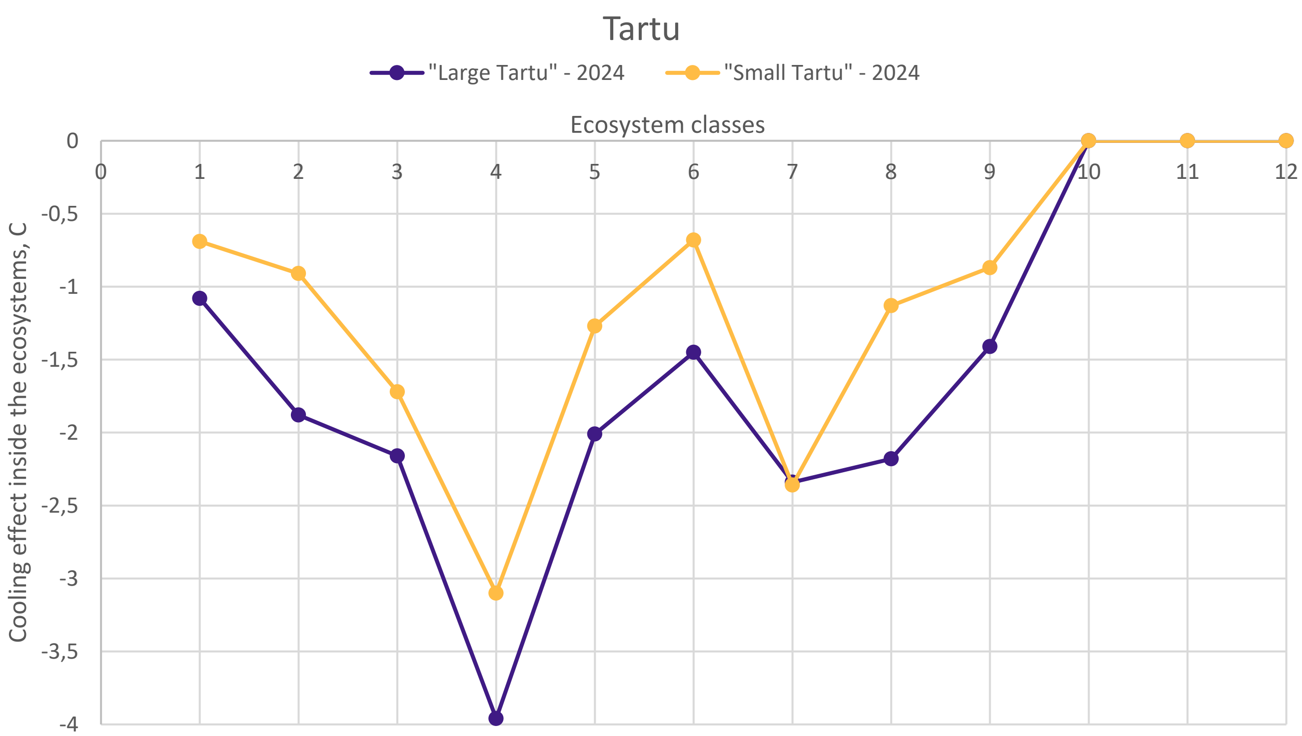
Ecosystem class		2022	2024					
			„Large Tartu“			„Small Tartu“		
Code	Description	Cooling effect at city scale, °C	Ecosystem proportion in city area, %	Cooling effect, inside the ecosystem, °C	Cooling effect at city scale, °C	Ecosystem proportion in city area, %	Cooling effect, inside the ecosystem, °C	Cooling effect at city scale, °C
1	Settlements and other artificial areas	**-0,38**	17,5	-1,08	**-0,19**	58,8	-0,69	**-0,41**
2	Cropland	**-1,2**	30,8	-1,88	**-0,58**	2,9	-0,91	**-0,03**
3	Grassland	**-0,33**	12,9	-2,16	**-0,28**	20,9	-1,72	**-0,36**
4	Forest and woodland	**-0,9**	27,3	-3,96	**-1,08**	1,0	-3,1	**-0,03**
5	Heathland and shrub	**-0,01**	2,8	-2,01	**-0,06**	3,7	-1,27	**-0,05**
6	Sparsely vegetated ecosystems	**0**	4,4	-1,45	**-0,06**	9,8	-0,68	**-0,07**
7	Inland wetlands	**-0,05**	1,7	-2,34	**-0,04**	0,5	-2,36	**-0,01**
8	Rivers and canals	**-0,02**	1,6	-2,18	**-0,03**	1,7	-1,13	**-0,02**
9	Lakes and reservoirs	**-0,03**	1,0	-1,41	**-0,01**	0,8	-0,87	**-0,01**
10	Marine inlets and transitional waters	**0**	0,0	0,0	**0,0**	0,0	0,0	**0,0**
11	Coastal beaches; dunes and wetlands	**0**	0,0	0,0	**0,0**	0,0	0,0	**0,0**
12	Marine ecosystems	**0**	0,0	0,0	**0,0**	0,0	0,0	**0,0**
Total		**-2,92**	100,0		**-2,33**	100,1		**-0,99**

Figure 18. Cooling effect per ecosystem type in Tartu, years 2022 and 2024.



As cooling effects in Tartu city were additionally calculated for the settlement (smaller) polygon, which contains mostly urbanized part of the municipality's territory, the cooling effect magnitudes inside the ecosystem classes also could be compared. The result is at figure 19.

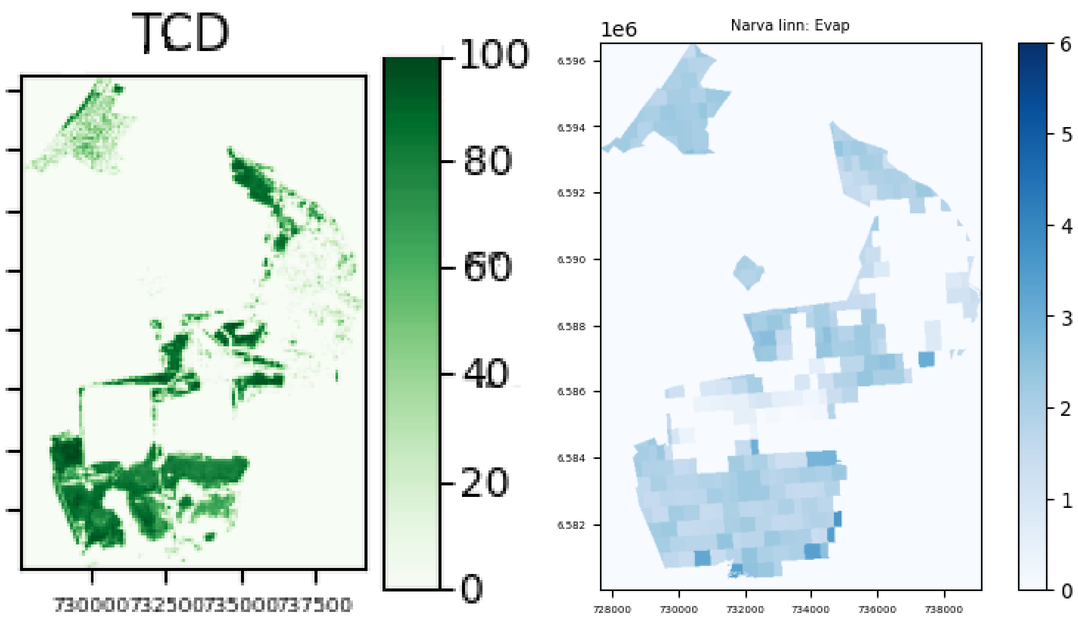
Figure 19. Comparison of cooling effect magnitudes inside the ecosystem classes in „Large Tartu“ and „Small Tartu“ polygons.



2.5.3. Narva

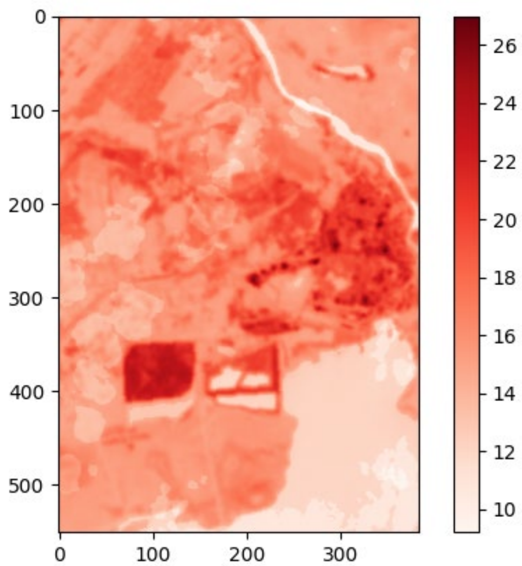
Maps of TCD and ET mean values of year 2024 survey are shown on figure 20.

Figure 20. TCD and ET mean values, 2024, Narva.



Average LST pattern from year 2024 observations is on figure 21.

Figure 21. Average LST values, 2024, Narva



Map of ecosystem types in EU 12-class system (from year 2022) and cooling effect is on figures 22 and 23.

Figure 22. Map of ecosystem types (2022), Narva.

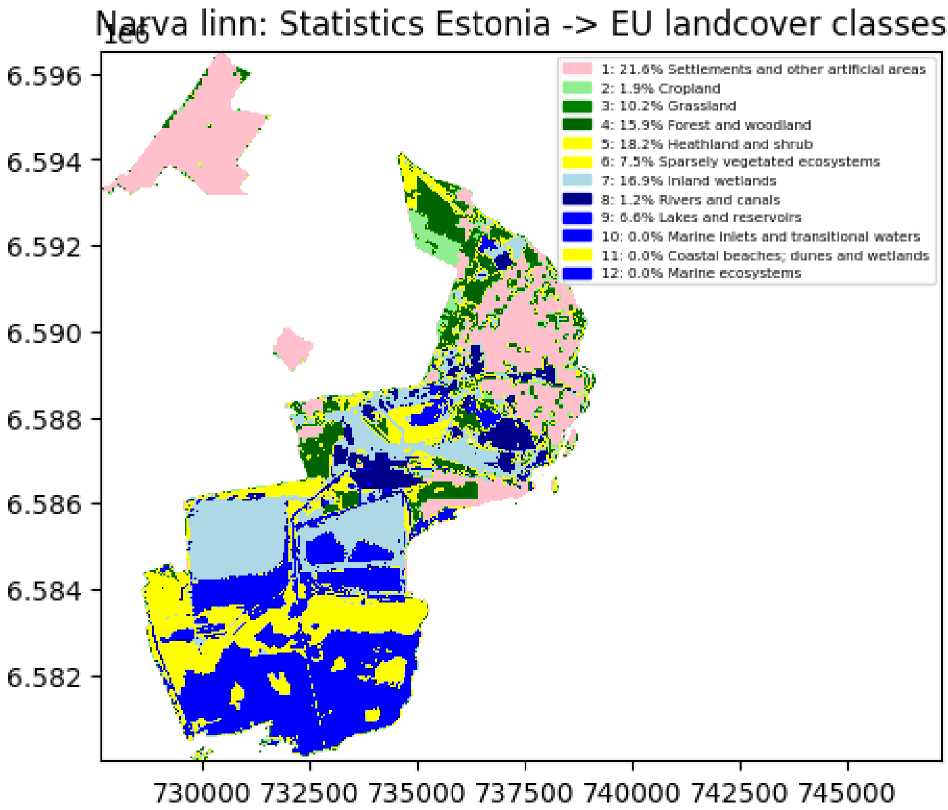
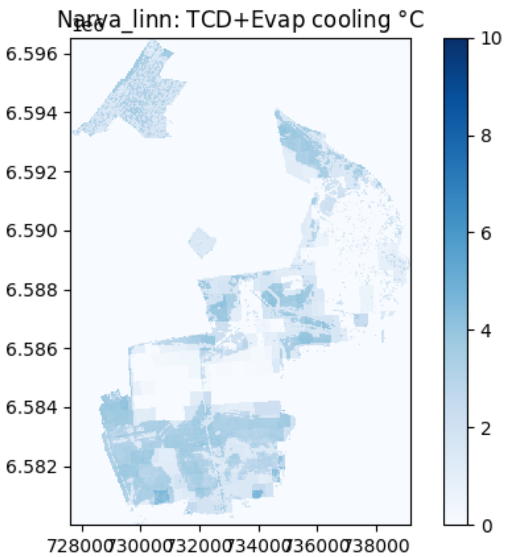


Figure 23. Cooling effect, 2024, Narva.

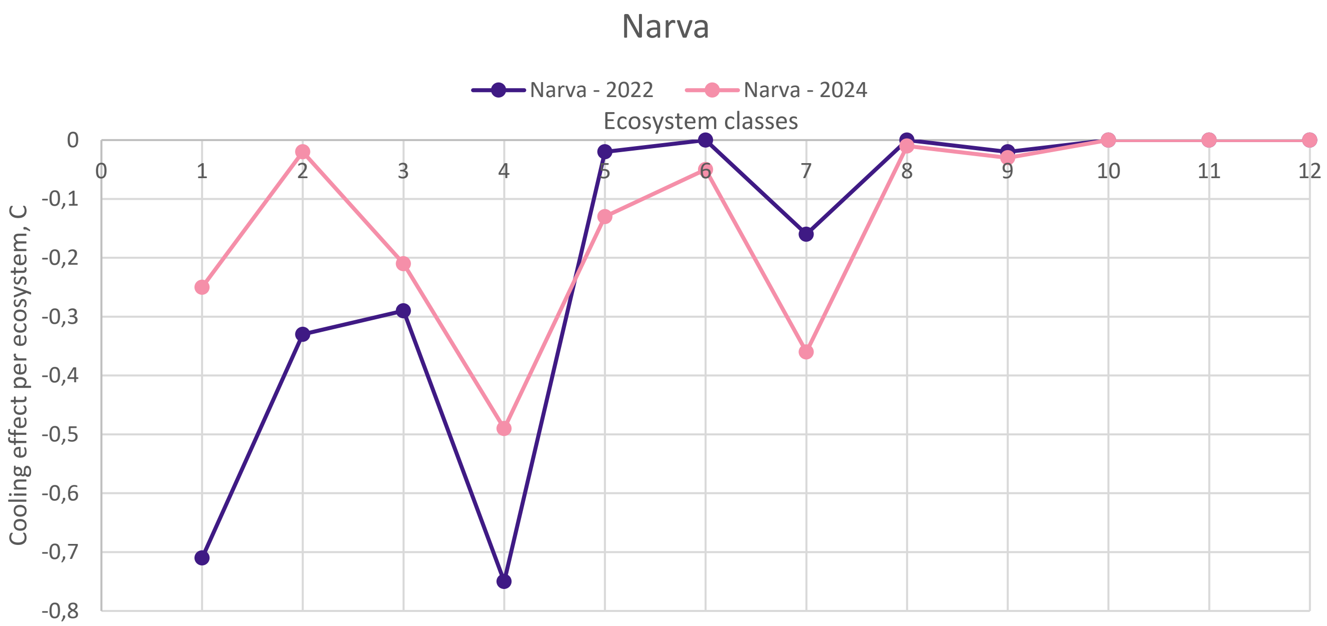


Numerical values of the calculated cooling effect per ecosystem type are given in table 4 and figure 24. The values are given for present survey (year 2024) and the previous study of year 2022 to enable their comparison. For year 2022 only values of cooling effect are available. For year 2024 study, the proportions of each ecosystem in total city area are also given.

Table 4. Cooling effect per ecosystem type in Narva, years 2022 and 2024.

Ecosystem class		Narva			
		2022	2024		
Code	Ecosystem description	Cooling effect at city scale, °C	Ecosystem proportion in city area, %	Cooling effect, inside the ecosystem, °C	Cooling effect at city scale, °C
1	Settlements and other artificial areas	**-0,71**	21,6	-1,16	**-0,25**
2	Cropland	**-0,33**	1,9	-1,05	**-0,02**
3	Grassland	**-0,29**	10,2	-2,06	**-0,21**
4	Forest and woodland	**-0,75**	15,9	-3,1	**-0,49**
5	Heathland and shrub	**-0,02**	18,2	-0,71	**-0,13**
6	Sparsely vegetated ecosystems	**0**	7,5	-0,6	**-0,05**
7	Inland wetlands	**-0,16**	16,9	-2,11	**-0,36**
8	Rivers and canals	**0**	1,2	-1,16	**-0,01**
9	Lakes and reservoirs	**-0,02**	6,6	-0,52	**-0,03**
10	Marine inlets and transitional waters	**0**	0,0	0,0	**0,0**
11	Coastal beaches; dunes and wetlands	**0**	0,0	0,0	**0,0**
12	Marine ecosystems	**0**	0,0	0,0	**0,0**
Total		**-2,28**	100,0		**-1,55**

Figure 24. Cooling effect per ecosystem type in Narva, years 2022 and 2024.



3. Interpretation of results

Calculations have been done for three largest Estonian cities. The results contain total magnitudes of cooling effect inside the city, the magnitudes of cooling effect inside each particular ecosystem type and the contribution of each ecosystem into total cooling.

Calculation results of year 2024 mainly correspond to those of year 2022 with exception of estimation of marine ecosystems' contribution into Tallinn climate. Value of year 2022 is -2,01°C, and this forms main part of total cooling in Tallinn. For year 2024 contribution of marine ecosystems is equal to 0°C. Marine ecosystems form only

0,1% of Tallinn's territory, which means, that their influence on total cooling cannot be large. Therefore, the value -0,0°C for year 2024 looks reasonable, contrary to estimation from the previous study.

From different environment types, which are largely represented in cities' areas, the strongest cooling effect is in forests and woodlands: approximately -3°C or even more. But the contribution patterns of different types of environment into total cooling on the territory are unique in each city, as that depends also on contribution of the ecosystem into city's area.

These patterns are mainly similar in results of years 2022 and 2024.

For Tartu, in addition to calculations for the municipality area (polygon „Large Tartu"), the calculation for settlement area („Small Tartu") was also done. Generally, the cooling effect for „Small Tartu" was much weaker than for the municipality area, and the patterns of each ecosystem contributions were significantly different. The cooling effect estimations, calculated at settlement's polygon, should be more representative in relation to citizens' everyday life, than the values from the municipality area.

The cooling effects of the same ecosystems were also compared at the settlement, which contains more urbanized areas („Small Tartu") and the municipality, which contains large part of rural areas („Large Tartu"). Almost all ecosystems from urbanized territory have weaker cooling effect, than same ecosystems from mainly rural areas.

4. Technical realization of calculations

4.1. Script management

The calculations of vegetation cooling effect were conducted, using Python scripts composed for study of year 2022. The received Python scripts were not connected to each other in joint workflow. Due to that initial solution demanded much manual work to run a dataflow between different stages of calculations.

To optimize these procedures, a Shell script **Jahutav-moju-4.sh** was written. This program united the whole cycle of calculations for the selected territories. After input datasets were formed, a manual intervention was needed only once in order to start a calculation.

During the work it was found, that calculation results of vegetation cooling effect at Tartu municipality may not be representative enough in context of citizens' everyday life. Due to that, it was decided to run an additional calculation on the settlement area (look section 2.1). Additional calculations demanded some modifications in the scripts, and in order to avoid increasing complexity of the programs, an additional set of scripts was written for this calculation cycle. An additional Shell script has name **Jahutav-moju-4--VT.sh**.

The optimized scripts accompanied with input datasets and results of the calculations were provided to Statistics Estonia during the project.

4.2. System requirements

The programs are designed to work in **Linux** environment. **Python version 3.7.12** was used.

For running the calculations these Python modules should be installed:

1. pillow
2. matplotlib
3. geopandas
4. rasterio
5. pygame
6. scikit-image
7. scikit-learn
8. GDAL (libgdal >= 3.8.5 !)

In the present work Python modules were managed using **miniconda**, but it is not mandatory.

4.3. Running the scripts

Starting the Shell script was done with the following commands:

For Tallinn city:

bash -x Jahutav-moju-4.sh Tallinn LST---Tallinn-loetelu---2024---LUHIKE.txt /home/aleksei/proj/Jahutav-moju/src/bin/EVAPfailid---Tallinn.txt extent22_euii.tif.vat.dbf extent22_euii.tif

For Tartu municipality (“Large Tartu”):

bash -x Jahutav-moju-4.sh Tartu_linn LST---Tartu-loetelu---2024---LUHIKE.txt /home/aleksei/proj/Jahutav-moju/src/bin/EVAPfailid---Tartu.txt extent22_euii.tif.vat.dbf extent22_euii.tif

Additional calculation for Tartu settlement (“Small Tartu”):

bash -x Jahutav-moju-4--VT.sh Tartu_linn LST---Tartu-loetelu---2024---LUHIKE.txt /home/aleksei/proj/Jahutav-moju/src/bin/EVAPfailid---Tartu.txt extent22_euii.tif.vat.dbf extent22_euii.tif

For Narva city:

bash -x Jahutav-moju-4.sh Narva_linn LST---Narva-loetelu---2024---LUHIKE.txt /home/aleksei/proj/Jahutav-moju/src/bin/EVAPfailid---Narva.txt extent22_euii.tif.vat.dbf extent22_euii.tif

Argument descriptions for Tallinn example:

Tallinn – Name of city,

LST---Tallinn-loetelu---2024---LUHIKE.txt – name of text file, which contains a list of selected datasets for temperature calculation (see section 2.2),

/home/aleksei/proj/Jahutav-moju/src/bin/EVAPfailid---Tallinn.txt – name of text file, which contains a list of selected datasets of evapotranspiration (see section 2.2),

extent22_euii.tif.vat.dbf – file of ecosystems map (see section 2.2),

extent22_euii.tif – file of ecosystems map (see section 2.2).

The Shell script contains lines (lines 35-41), where folders with particular data are declared. These names correspond to folder structure of the computer, where calculations were run. Another file system would have different folder names.

Also, the Shell script contains row **source /opt/etc/P_dirs** and entries **$P_Proj**, **$P_work**, **$P_out**, **$P_exit**, which reflect peculiarities of computer system of Estonian Environment Agency, and in other systems these entries will be useless.

Folders, which are created and used by the Shell script:

WORK – a folder, where the program works. This folder is emptied at the beginning of each run.

OUTvahepealne – a folder, where the program saves intermediary files to enable their later usage.

OUT – a folder, where an output data can be saved. At the moment nothing is created there.

Settings of Shell script **Jahutav-moju-4.sh** at lines 18-22 enable acceleration of repeated calculations for same territory. If input datasets are already preprocessed by Python scripts and saved in **OUTvahepealne** folder, entry **PASS=$YES** allows to skip repeated preprocessing. At first run it is impossible to skip this stage, so there should be something different from entry **$YES**.

The Shell script is divided into several sections, which contain particular stages of the calculation:

Lines 73-107 – preprocessing of Landsat observations, calculation of Land Surface Temperature. Python script **osa_3a1_LST_maskeerimine.py** is used. As preprocessing of these data is quite memory-consuming, it can occasionally fail. In order to fix the problem, this section of Shell script contains checking of output presence. In case of fails, calculation of missing dataset will be repeated. In case of erroneous input datasets this will lead to endless loop, which will demand manual interruption.

Lines 110-119 – masking of territory outside the city area. Python script **osa_2_KOVist_TIFF.py** is used.

Lines 122-137 – calculation of summer average evapotranspiration dataset. Python script **osa_4e2_evap1d_Nx_parandus.py** is used.

Lines 140-153 – masking out TCD data outside the city area. Python script **osa_4e3_TCD_ainultTiffi.py** is used.

Lines 156-169 – preprocessing of ecosystems' map. Python script **osa_4e1_STA_EU12kaart.py** is used.

Lines 172-197 – calculation of regression functions. Python script **osa_4e4_regressioon.py** is used.

Lines 200-218 – pixel-based calculation of cooling effect. Python script **osa_4e5_jahutusRasterLinnale4_KOVipiires.py** is used.

Lines 221-232 – calculation of cooling effect per each ecosystem type and for the whole city area. Python script **osa_4e7_jahutusPerEU12klass.py** is used.

The scheme of data flow during the calculation process with filename examples is given in appendix 1. Some technical peculiarities of the scripts are also mentioned on the scheme.

Besides the files, which are shown on the dataflow scheme, as they are necessary for obtaining final results, the Python scripts produce many additional outputs, which provide better understanding about values of different parameters in the calculation. List of such files with their explanation is given in appendix 2.

5. Conclusion

Corresponding to tasks of grant agreement „*Development of the environmental accounts 101197994 — 2024-EE-EGD*", the study of vegetation cooling effect in Tallinn, Tartu and Narva was conducted. Calculations were performed, using Python scripts from previous study of year 2022. The workflow was optimised for functioning in a Linux system environment to reduce amount of manual work.

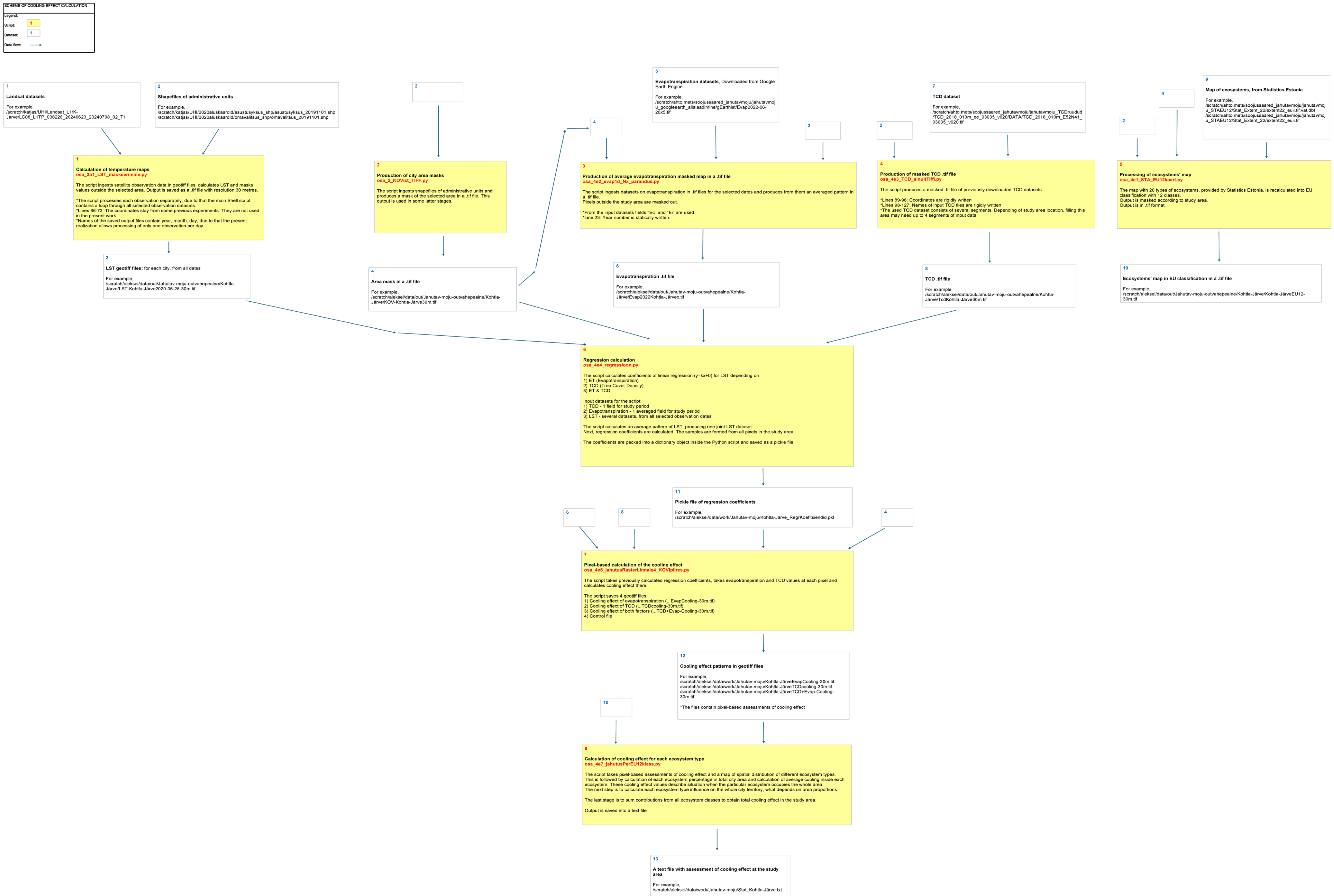
Some necessary input datasets were not available for year 2024, and it was decided to use data from previous years. The assumption was made, that urban environment usually do not change significantly during the period of several years.

The results of calculations of year 2024 mainly show good correspondence to numbers of year 2022.

As demonstrated in sections 2.1 and 2.5.2, the territory of municipalities can include a large part of rural areas consisting of fields and forests, which, in Tartu's case, even exceeds the urbanized area. This indicates that statistics based on administrative units' municipal territories may misrepresent the actual situation in cities. The example of Tartu shows how the use of settlement polygons as the spatial basis for calculations can significantly alter the results. To more accurately capture the cooling effects of urban vegetation, we recommend using settlement polygon layers rather than municipality territories when conducting such analyses.

For future development, it is considered to replace Copernicus TCD data with locally produced datasets to ensure the use of the most up-to-date and accurate information in calculations.

Appendix 1. Dataflow scheme



Appendix 2. Additional outputs of cooling effect calculations

Here is given a list of files, which are saved during the cycle of cooling effect calculations for Tallinn city.

Contents of **OUTvahepealne** folder:

LST-Tallinn2024-08-14-30m.tif – Land Surface Temperature maps at different observation times

LST-Tallinn2024-08-14-30m_2024-08-14T092331.96Z.png

LST-Tallinn2024-08-30-30m.tif

LST-Tallinn2024-08-30-30m_2024-08-30T092339.81Z.png

LST-Tallinn2024-05-01-30m.tif

LST-Tallinn2024-05-01-30m_2024-05-01T092900.19Z.png

LST-Tallinn2024-05-17-30m.tif

LST-Tallinn2024-05-17-30m_2024-05-17T092847.18Z.png

LST-Tallinn2024-09-06-30m.tif

LST-Tallinn2024-09-06-30m_2024-09-06T092933.75Z.png

LST-Tallinn2024-09-07-30m.tif

LST-Tallinn2024-09-07-30m_2024-09-07T092336.29Z.png

LST-Tallinn2024-08-13-30m.tif

LST-Tallinn2024-08-13-30m_2024-08-13T092915.24Z.png

LST-Tallinn2024-09-05-30m.tif

LST-Tallinn2024-09-05-30m_2024-09-05T093531.59Z.png

LST-Tallinn2024-05-18-30m.tif

LST-Tallinn2024-05-18-30m_2024-05-18T092321.24Z.png

LST-Tallinn2024-06-26-30m.tif

LST-Tallinn2024-06-26-30m_2024-06-26T092843.04Z.png

KOV-Tallinn30m.tif – mask of city area as a .tif file

Evap2022-07-20Tallinn.png – Evapotranspiration maps at different observation times

Evap2022-08-05Tallinn.png

Evap2022-08-13Tallinn.png

Evap2023-07-12Tallinn.png

Evap2022Tallinn.png – average pattern of evapotranspiration (number of year was not changed from previous survey)

Evap2022Tallinnx.tif

EstMapEvapArray.png – Tree Cover Density map (entry „Evap" was written in the script by mistake)

TcdTallinn30m.tif – Tree Cover Density map

Tallinnstat28-30m.png – ecosystems' map in classification with 28 types

TallinnEU12-30m.png – ecosystems' map in classification with 12 types

TallinnEU12-30m.tif

Contents of **WORK** folder:

osa_3a1_LST_maskeerimine.py – symbolic links to Python scripts

osa_2_KOVist_TIFF.py

osa_4e3_TCD_ainultTiffi.py

osa_4e2_evap1d_Nx_parandus.py

osa_4e4_regressioon.py

osa_4e1_STA_EU12kaart.py

osa_4e7_jahutusPerEU12klass.py

osa_4e5_jahutusRasterLinnale4_KOVipiires.py

LSTloigatud_Tallinn_.TXT – list of Landsat observation datasets

TXTlstfiles.txt – list of Land Surface Temperature maps

dataLstAver.png – averaged Land Surface Temperature pattern

LST_Evap_TCD_K-Jarve_2018_2022.png – joined image of LST, evapotranspiration and TCD patterns (number of years and city name was not changed from previous survey)

Tallinn_RegrKoefitsiendid.pkl – pickle file, containing regression coefficients

Tallinn-TCDcooling.png – map of cooling effect part, which is connected to TCD values

Tallinn-EvapCooling.png – map of cooling effect part, which is connected to evapotranspiration values

Tallinn-TCD+Evap-cooling.png – map of total cooling effect from TCD and evapotranspiration

TallinnTCDcooling-30m.tif – map of cooling effect part, which is connected to TCD values

TallinnEvapCooling-30m.tif – map of cooling effect part, which is connected to evapotranspiration values

TallinnTCD+Evap-Cooling-30m.tif – map of total cooling effect from TCD and evapotranspiration

Tallinn-Evap-NaN.png – control image

Tallinn_tif_dic.pickle – list of cooling effect components in a pickle file

TallinnEvap-NaN-30m.tif – control image

Stat_Tallinn.txt – final statistics