



Urban Green. Integrating ecosystem extent and condition as a basis for ecosystem accounts. Examples from the Oslo region

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Abstract:

The article enhances the knowledge base for assessment of urban ecosystem services, within UN System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA EEA), which is based on spatial extent accounts (area of ecosystems) and biophysical condition accounts (ecological state of ecosystems). Case studies from the Oslo region are explored, combining land use/land cover maps from Statistics Norway with satellite data. The approach suggests that especially in an urban context, extent and condition accounts are not separate approaches as suggested by SEEA EEA but should be integrated for ecosystem accounting. Moreover, the basic spatial unit should not be fixed, as suggested by SEEA EEA, but should reflect that modelling of different ecosystem services, as basis for trade-offs in urban planning, requires different spatial units to capture urban green elements.

Keywords: Experimental ecosystem accounting, ecosystem services, urban ecosystems, spatial analysis, land use maps, land cover maps

JEL classification: Q34, Q56, Q57, Q58

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Sammendrag

Artikkelen bidrar til å styrke kunnskapsgrunnlaget for verdsetting av økosystemtjenester fra urbane økosystemer, dvs. grønne områder i by og bynære områder, basert på FNs økosystemregnskap, System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA EEA), som bygger på kartfestet arealregnskap (extent accounts) og økologisk basert naturregnskap (condition accounts). Artikkelen presenterer en studie fra Oslo og aktuelle fortetningsområder i Oslo-regionen. Urbane økosystemer er komplekse, og kunnskap om sammenheng mellom størrelse, tilstand og bruk er nødvendig for å kunne vurdere avveining mellom økosystemtjenester. Økosystemregnskap for urbane områder må spesielt legge vekt på endring i bebygd areal og grønt areal. Denne studien er basert på statistikk fra Statistisk sentralbyrå (SSB) for arealbruk til bebygd areal (arealbrukskart) kombinert med informasjon om grønne områder fra satellittbilder. Studien omfatter utvalgte områder på én kvadratkilometer nordøstover fra Oslo sentrum. Områdene som er valgt ut er sentrum, der det i dag er få boliger; et område nært sentrum med eldre boligområder; villastrøk utenfor sentrum; tettsted i nabokommune med stor pendling til Oslo, og tettsted i landkommune i grensen for pendling til Oslo.

Studien viser at kvaliteten på arealbrukskart og statistikk kan forbedres ved bruk av satellittbilder som viser grønne områder mellom bebygde byområder. Metoden med å kombinere arealbrukskart og satellittbilder kan bidra til å videreutvikle FNs økosystemregnskap (SEEA EEA). Informasjon om vegetasjon er en viktig del av kunnskapsgrunnlaget for naturregnskap (condition accounts), og denne studien av urbane økosystem viser at informasjon fra naturregnskapet styrker grunnlaget for arealregnskapet (extent accounts). Derfor bør arealregnskap og naturregnskap utvikles i sammenheng, og ikke som uavhengige tilnærminger, som lagt til grunn i FNs økosystemregnskap (SEEA EEA). Studien har fokus på to indikatorer som kan utvikles til statistiske indikatorer: grønt-andel, dvs. hvor stor andel grøntområde det er i en arealenhet, og allmenn tilgjengelighet til grøntområde, dvs. eiendomsforhold fra matrikkelen supplert med tilleggsinformasjon om allmenn tilgjengelighet, som tilgang til offentlig park eller annet offentlig grøntområde og fri ferdsel i utmark. Metoden kan bidra til å styrke utviklingen av arealbruksstatistikk, og grønt-andel på en eiendom, supplert med informasjon om allmenn tilgjengelighet, kan bli tilleggsinformasjon til arealbruksstatistikk. Årlig statistikk vil kunne forbedres ved mer nøyaktig tidfesting av når arealendringer faktisk skjer. Dette kan gi grunnlag for utvikling av et urbant økosystemregnskap som også viser endring over tid.

I videre forskning for å utvikle et urbant økosystemregnskap er det i tillegg til kunnskap om omfanget av grønne områder og hvor de er lokalisert, også behov for kunnskap om faktisk bruk av urbane økosystemer for å modellere ulike økosystemtjenester, der lokalisering av urbane grøntområder vil være en viktig faktor. I et økosystemregnskap må en ha oversikt over hvem som kan få nytte av bruk av økosystemene, og informasjon om eiendomsforhold og tilgjengelighet til grøntområder blir viktig. Da blir eiendom en viktig statistikkenehet for økosystemregnskap.

Resultatene fra analysen innebærer at videre utvikling av økosystemregnskap og arealbruksstatistikk bør bygge på fleksible arealenheter. Arealbruksstatistikk i form av kart, med fleksible arealenheter, og med data i opprinnelig geo-referert form, kan tilpasses ulike geografiske analyseenheter og avgrensning av økosystemer, slik at brukeren kan aggregere arealer, basert på eiendomsgrenser, og tilpasse arealenheten til ulike formål. Informasjon om arealbruk og arealdekke fra arealbrukskart, informasjon om eiendomsforhold fra matrikkelen og informasjon om vegetasjon fra satellittbilder kan stilles sammen i kart, på ulike måter for ulike analyseformål. Dette vil gi bedre kunnskapsgrunnlag for planprosesser og politikformål.

Kunnskap om urbane grøntområder er viktig for å analysere boligmarkedet. Nærhet til grønne områder er en av de viktigste årsakene til lokale prisforskjeller i boligmarkedet. Oslo kommune publiserte i 2018 et grønt-regnskap for å styrke kunnskapsgrunnlaget for å sikre grøntområder. Resultater fra analysen i denne artikkelen er nyttig for byplanlegging og fysisk arealplanlegging og et viktig bidrag til å forbedre kunnskapsgrunnlaget for avveining mellom ulike bærekraftsmål, som å ta vare på byens grønne områder og krav om sterkere fortetting og knutepunkts-fortetting ut fra klimamål.

1. Introduction

The article explores concepts and methods of the UN System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA EEA) applied for mapping of green urban areas as basis for mapping of urban ecosystem services. Following the development of a statistical standard for a System of Environmental-Economic Accounting (SEEA), the United Nations Statistics Division initiated development of the SEEA Experimental Ecosystem Accounting (SEEA EEA), first presented in 2014 (UN 2014), and currently being tested out and further developed (UN 2019, UN SEEA 2019, UN Ecosystem Accounting 2019). The SEEA EEA is based on spatial extent accounts (area of ecosystems) and biophysical condition accounts (ecological state of ecosystems). Urban ecosystems are complex, with elements of green in-between built-up areas, and urban ecosystem accounting needs to assess the interactions between extent, condition and use of ecosystems. A key issue in ongoing development of the SEEA EEA is to explore relations between extent and conditions accounts, i.e. if they should be separate approaches or integrated. Furthermore, it needs to be explored how extent and condition accounts can be applied as statistical units for ecosystem accounting. The SEEA EEA approach discusses ecosystem accounting in urban areas, highlighting the challenges in defining urban ecosystem extent and differentiating extent from condition (Wang et al. 2019).

The article presents an approach for capturing urban green elements, in order to improve urban ecosystem accounting and the knowledge base for assessment of urban ecosystem services. The analysis contributes to experimental application and development of the SEEA EEA for urban ecosystems, by combining land use/land cover maps with satellite images of vegetation, for selected case study areas in the Oslo region. Particular focus is on areas considered for urban densification. While the article contributes to methodological development of the SEEA EEA ecosystem accounting approach, in particular for detecting green elements within built-up urban areas, not easily identified in existing statistics, it should be emphasized that it is beyond the scope of this study to give a complete overview of urban ecosystem services in the Oslo region. The city of Oslo is surrounded by large forest areas, where legal right in Norway of public access to outfield areas, i.e. forest and mountain areas outside cultivated land, secures public access to large nature areas near the city, with great importance for recreation. In further research, the improvements in urban ecosystem accounting reported here for the case study areas can be applied to develop ecosystem accounting that covers the entire urban region with its diversity of ecosystem services and available recreation possibilities.

The study presented here explores how urban ecosystem accounts are improved by combining land use/land cover maps from Statistics Norway and satellite images. Combining the two data sources

provides information of much better quality on land use and land cover, since satellite images give information on vegetation that is not available in land use/land cover maps and moreover, visualize the urban green, i.e. green elements within built-up areas. The approach contributes to development of the SEEA EEA, by exploring integration of extent and condition accounts as basis for ecosystem accounts. Especially for urban areas, information from satellite images, which is an important part of the knowledge base for condition accounts, also contributes to improve extent accounts. Hence, the results suggest that extent and condition accounts should not be separate approaches as assumed in the SEEA EEA. Combining information from land use maps and satellite images represents an integration of extent and conditions accounts that contributes directly to conceptual and practical development of the accounts structure of the SEEA EEA, as well as to improve knowledge on ecosystem condition which is crucial for modelling the capacity for ecosystem services. A study from Canada demonstrated that combining radar data and satellite images improved urban characterization of urban ecosystems and suggested a practical method for measuring and monitoring changes in green urban areas (Grenier, Lantz, Soulard and Wang 2020).

The combination of data sources explored in this study can contribute to improve national statistics and make it more relevant for analysis of urban green areas. Annual statistics can be further improved by more accurate dating of when land use change actually takes place. Two important indicators identified in this study are the share of urban green, expressing information on vegetation from satellite images, and public access to urban green areas, i.e. cadaster information on property boundaries and supplementary information on the extent of public access. Mapping of urban green is an important building block in urban ecosystem accounting. More research is needed to develop urban ecosystem accounting and model the use of different ecosystem services. Knowledge on users of the ecosystem services is needed, and for this purpose, information on property boundaries and public access is crucial. Delineation of property boundaries become an important statistical unit for urban land use statistics. At the property level it is possible to identify the share of urban green and different types of land use/land cover and density of vegetation on the non-built-up part of the property.

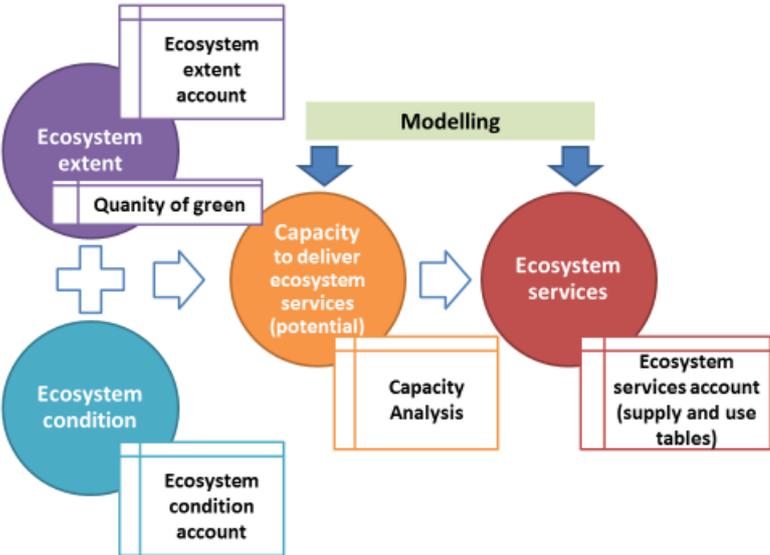
Case study areas are selected along a transect from Oslo city centre into suburban and rural areas, with the city center with few residents, a mainly residential area near the city center, a residential area outside the city centre, a suburban area in a neighboring municipality with much commuting to Oslo, and an area in a rural district at the boundary of commuting distance. The case study areas outside the city center have been selected to represent stages in the urban transformation processes currently taking place in the Oslo region, with extensive plans for urban densification around train- and metro-stations. The results presented in this article can contribute to improve the statistical knowledge base

for urban planning, land use management and policy, analysis of urban residential prices, and improve the knowledge base for trade-offs between protecting urban green areas and densification of urban areas, and thus to address several aspects of sustainable development of urban areas.

2. Central concepts in SEEA EEA Ecosystem Accounting

The purpose of the SEEA EEA is to develop a spatial and ecological basis for assessments of ecosystem services, based on spatially explicit extent accounts (area of ecosystems) and biophysical condition accounts (ecological state of ecosystems). The building blocks for developing ecosystem accounts are the ecosystem extent and ecosystem condition accounts, see Figure 1. Ecosystem extent represents the “quantity of green”, and ecosystem condition represents the “quality of green”.

Figure 1. Structure of SEEA EEA: Extent accounts and condition accounts, as basis to model capacity and use of ecosystem services



Source: Adapted¹ from Maes et al. (2018).

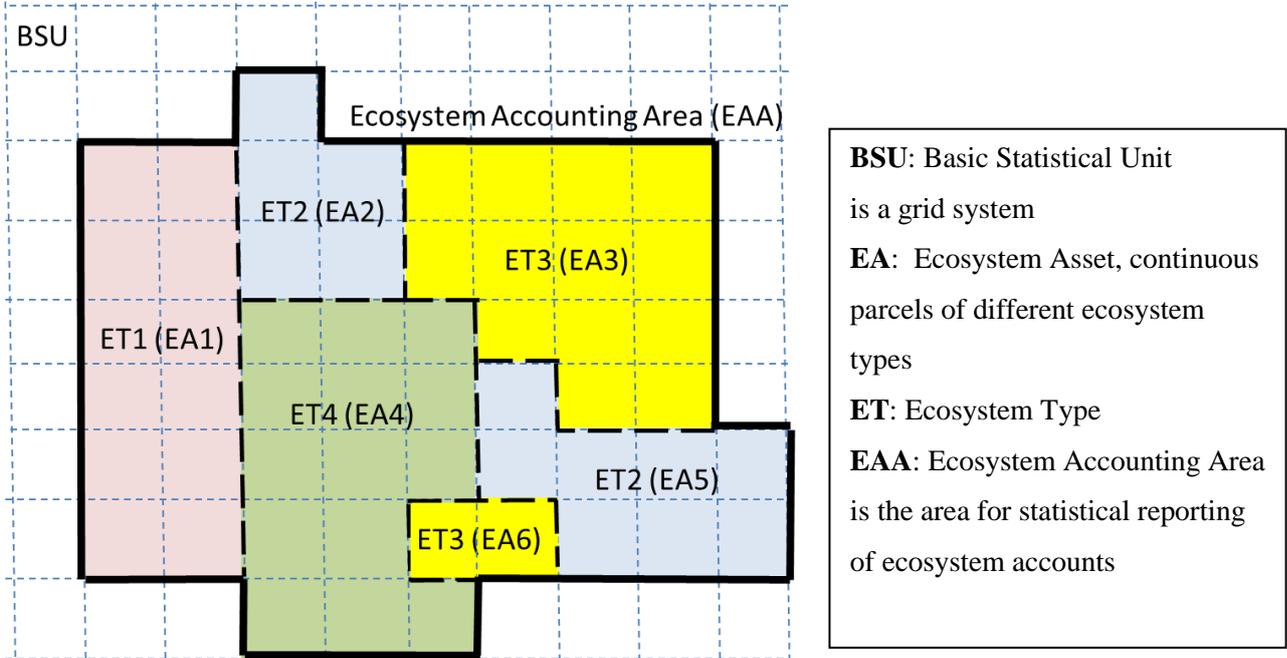
Extent and condition accounts represent a basis for modelling the capacity for different ecosystem services from the ecosystem. In developing and analyzing ecosystem accounts it is especially important to explore how current use of ecosystem services may affect the capacity of the ecosystems to provide different ecosystem services in the future. It is important that extent and condition accounts provide information on the capacity for future use of the ecosystem and ecosystem services. The information categories for both extent and condition accounts should be linked to the capacity of the

¹ We have added explanation text Quantity of green and Quality of green, and added Modelling, to emphasize the importance of modelling of use of ecosystem services to analyze the capacity for future ecosystem services.

ecosystem to sustain ecosystem services today and in the future. These accounts are the basis for analysis of ecosystem capacity. As we explore in the urban context, combining information from extent and condition accounts will contribute to increase the precision and usefulness of the information categories to give a better estimate of the ecosystem capacity to deliver specific ecosystem services.

In further development of the SEEA EEA, it is essential that the statistical unit for ecosystem extent can be linked to the supply and use of the ecosystem services. Accordingly, in Figure 1, there are feedback loops to the analysis of ecosystem capacity and the characteristics for ecosystem condition. Ecosystems are spatial objects that vary in size, and the statistical unit needs to be defined in terms of a spatial dimension. In SEEA EEA, the basis for extent accounts are spatial units, see Figure 2.

Figure 2. Relationships between spatial units for SEEA EEA ecosystem accounting (extent accounts)



Source: Adapted from SEEA EEA Figure 2.4 (UN 2014).

The basic concepts for spatial units in SEEA EEA ecosystem accounting (Figure 2) are Basic Spatial Unit (BSU), Ecosystem Asset (EA) and Ecosystem Type (ET) in an Ecosystem Accounting Area (EAA). BSU is a unit in a grid system, that may vary in size and can be aggregated or disaggregated. In principle the EAs should be homogeneous and distinct spatial areas forming the conceptual base for

ecosystem accounting and integration of relevant statistics.² ETs are aggregates of individual EAs of a specific type of ecosystem (e.g. deciduous forests). ETs are identified and delineated in the process of ecosystem accounting. An EEA, which is the area the statistics is produced for, may vary in size and is normally an administrative area, but could also be defined by natural boundaries, e. g. watersheds.

Statistical units are basic building blocks in all types of official statistics, e.g. persons, households, social groups, companies, properties, industrial sectors, public sector units, municipalities, regions and nations. Such units are well defined and classified, often as part of international standard classification systems. Nature and ecosystems cannot be classified in the same way. Borders between ecosystems are usually not distinct, and although ecologists describe ecosystems as geographical units, they are aware that these units are linked in a complex ecological and spatial web that makes it difficult to define specific units. Ecologically, connections between ecosystems may be as important as the borders between them. Ecosystem condition, in Figure 1, is generally measured by collating indicators for various ecosystem characteristics for different Ecosystem Types (ETs). In ecosystem accounting, ecosystem condition indicators should be chosen that are predictors of ecosystem services. Within this broad framing there are different approaches to the measurement of ecosystem condition, ranging from more aggregated to more detailed data on vegetation, biodiversity, soil type, hydrology and climate.

As statistical measurement generally assumes a fixed statistical unit, the SEEA EEA aims to define a fixed spatial unit (BSU) for the extent and condition accounts. However, in the urban context, it is less meaningful to define a fixed spatial unit in a patch-work of urban green elements, e.g. individual trees in the city. Different ecosystem services are based on different types of spatial units, and we need different types of spatial units to model different ecosystem services, as basis for the analysis of trade-offs between ecosystem services, such as trade-offs between urban densification and protecting urban green space. Hence, in the urban context, the spatial unit should not be fixed, as suggested by SEEA EEA, but reflect that modelling of different ecosystem services, in order to analyze trade-offs in urban planning, requires different spatial units. In urban areas, there is a large overall pressure on remaining natural green spaces, and their value is very high, for sustaining biodiversity, and for environmental amenities for the population. For urban ecosystems there is a need to deal with the complexity of how ecosystem services are generated and being used.

² A key question in ecosystem accounting is the use of Ecosystem Asset (EA) and to what extent they represent statistical spatial units and how they can be linked to other statistical units and spatial information categories. This issue is beyond the scope of this article.

The system of ecosystem accounts consists of four core ecosystem accounts, see Table 1, being linked together through definitions and classification and through geographical references. The starting point for ecosystem accounting is organizing information on the extent (area) of different ecosystem types within a country or region. Extent and condition accounts in Figure 1 comprise the first two rows in Table 1 (and are basis for rows 3 and 4). A complete system of ecosystem accounts can be represented as a table of status and change in the quantity (extent) and quality (condition) of the ecosystems, where the first row of Table 1 reflects the basic logic of ecosystem accounts for an area, with an opening extent account (in hectares or km²), additions and reductions in extent, and a closing extent account. The case studies in this article present status at a given time, not change over time. The structure of a basic ecosystem extent account can be illustrated in maps, giving a spatial representation of the ecosystem. An ecosystem account table can be made for the chosen ecosystem types, usually being classified in terms of land cover or land use. In the urban context, they are intertwined.

Table 1: The SEEA EEA core ecosystem accounts

1.	Ecosystem extent account – spatial and physical terms
2.	Ecosystem condition account – spatial and biophysical terms
3.	Ecosystem services supply and use account– physical terms
4.	Ecosystem services supply and use account – monetary terms

Source: Adapted from UN Ecosystem Accounting (2019): Technical Recommendations.

In this article we focus on the first two rows of Table 1, the extent and condition accounts, based on a spatial representation of ecosystems and their biophysical properties. These two accounts are the building blocks for ecosystem accounting. We explore the knowledge base required for subsequent modelling of ecosystem services supply and use account, assessed in physical and monetary terms (row 3 and 4 in Table 1). This is necessary to show how ecosystem services are distributed spatially and who are the users of the ecosystem services. However, this modelling is beyond the scope of this article.

3. Integration of extent and condition accounts in the context of urban green

In an urban context, land use information can be used to map green structures like parks, agricultural patches and sports fields, but natural green elements that are intertwined in the urban mosaic will not be identified by land use maps. We have to find ways to supplement the information from land use maps in order to identify green areas. This can be supplemented with information about who is the

user of green areas and who might benefit from urban ecosystem services. Property information from the cadastre might be used as statistical units, and information on legal access to land is important in order to assess accessibility to green areas and the possibility to provide recreational ecosystem services, an important aspect of the knowledge base for physical planning and urban land use policy. The accessibility to the urban green spaces may be more or less regulated, ranging from private gardens without public access, to public parks and green corridors.

The EU has identified urban ecosystems as one of the major types of ecosystem and has developed a method for selecting indicators for ecosystem condition in all seven major terrestrial ecosystems prioritized in EU environmental policies, based on pressures, types of ecosystem services and policy relevance (Maes et al. 2018). The most important pressure type in urban ecosystems is land conversion. The most important indicator for ecosystem services is urban green space. According to Maes et al., the five most important indicators for urban ecosystem condition are (1) annual land conversion to built-up area, (2) percentage share of urban green area and built-up area, (3) size of conservation areas, (4) canopy areas of trees, and (5) agricultural land (Maes et al. 2018). These five indicators are however as much extent variables as condition indicators, and thus illustrate the ambiguity of the concepts of extent and condition. The need for a multi-layer system to include different sources of information on ecosystem extent and condition is generally being accepted within the SEEA EEA (UN 2019).

Urban green areas will vary from areas with natural vegetation to areas with no natural vegetation. Even areas with natural vegetation will be impacted by the use by the urban population. There will be a mosaic of urban green areas with different land use and land cover, from agriculture and forestry in the periphery of the urban area, to an increasing complexity of land use towards the city center where built-up land use will dominate, and where only single trees and patches of “artificial” green, e.g. lawns may be expected. In urban ecosystems, “artificial” green areas, e.g. lawns and urban gardens on roof-tops, provide challenges for determining when a change in ecosystem condition becomes a change in extent and vice versa.

In urban ecosystem accounting, the challenge is to replicate a spatially diverse mosaic of urban green in a useful way through integration of the information in extent and condition accounts. Different categories of urban green areas may be assessed from different sources. Land use maps give information on land use categories, e.g. forest, agriculture and built-up land, and include green elements such as public parks, sport facilities, and cemeteries. Satellite images give information of the ecosystem condition, in terms of trees, grassland, or other types of vegetation. It is important to

explore how the extent accounts are based on elements from the condition accounts, in order to capture the mosaic of urban green spaces, describe the spatial change in green share, and facilitate modelling of capacity for different ecosystem services. Spatial changes in ecosystem extent may be connected to the actual use of the ecosystem services and may thus facilitate the modelling of ecosystem capacity.

The results reported in this article illustrate that a combination of land use/land cover classification at the cadastre level for ecosystem extent combined with detailed satellite data of land cover provides a much higher quality of the interpretation of extent and condition variables. This is not only a result of overlay techniques, but a result of applying knowledge from satellite data of land cover, since built-up land in urban areas can have different degrees of green areas.

The next step in ecosystem accounting, after establishing extent and condition accounts, is the modelling of ecosystem services and use of ecosystem services. The resulting assessments of ecosystem services and how they impact the ecosystem capacity, provide knowledge for analysis of societal trade-offs between prioritized ecosystem services and policy choices involved. It is important to select a geographical reporting unit matched by maps available to the public and the management agencies. With a flexible spatial unit, the analysis can be based on a spatial representation of ecosystem, with focus on areas that represent different combinations of ecosystem services, areas important for biodiversity, areas with different types of users, and areas representing important trade-offs. This flexibility in spatial units will also make it easier to apply the large amount of available geospatial data, as well as big data platforms for information on transactions and prices on housing.

The article presents case studies of combining land use/land cover maps and satellite images with examples from the Oslo region. The data consist of high-quality land use statistics from administrative data sources being used in measuring ecosystem extent, combined with high quality data sources on land cover from the Sentinel-2 satellite. The high spatial resolution of the data will allow for combining these data and integrating them into a concept of ecosystem extent that increases the precision of the combined data sets and illustrates the integration of extent accounts and condition accounts by using the same data sets. This integration also illustrates that a flexible spatial unit, defined for different ecosystem services, is useful in the urban context, for assessments of different types of ecosystem services.

4. Methodology and data sources

Combining administrative spatial data sources like cadastral data with high quality land use maps as a strategy to achieve a map for ecosystem extent units has recently been adopted in the UK (EFTEC 2017, Office for National Statistics ONS 2019a) and the Netherlands (de Jong et al. 2017, Remme et al. 2014, 2018). To increase the element of urban green in the land use data, the data have been supplemented with land cover maps derived from satellite imagery.

Land cover maps derived from the freely available Sentinel-2 satellite imagery at 10-meter resolution seem promising for this purpose because of the frequent revisit time. Alternatively, imagery from the Rapid Eye satellite at 5 meters resolution may be purchased. This has recently been used in Germany for a detailed mapping of urban greens in private and public properties in two German cities (Haase et al. 2019).

Sentinel-2 is particularly well-suited to detecting vegetation because it has four additional spectral bands for capturing the red-edge spectrum (a total of 13 spectral bands). However, these vegetation-specific bands are at 20 m spatial resolution which may not be sufficient to capture the variation in urban environments. Rapid Eye has better resolution and daily revisits (Sentinel-2 -2 passes every two days in Norway), but only has 5 bands, one of which is red-edge. In this study we demonstrate the use of Sentinel-2 imagery (see 4.2). We also present aerial photos to show location of buildings and built-up areas.

4.1 Current land use classification approach by Statistics Norway for land use/land cover maps

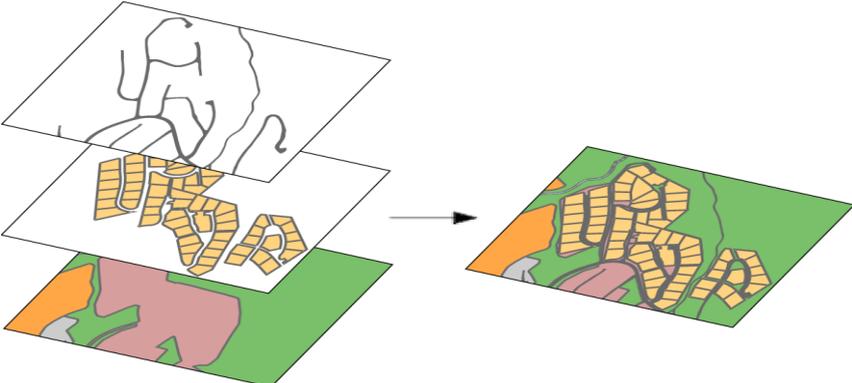
Statistics Norway publishes annual statistics on land use and land resources in Norway. The statistics are based on the combination of a wide range of digital map data put together into one detailed, nationwide map of land use and land resources. The most important data sources are:

- The cadastre (“Matrikkelen”): National register of properties and buildings
- Common map database (FKB “Felles Kartdata Base”): Collection of accurate maps (1:5 000) for a wide range of elements such as buildings, roads, harbours and other infrastructure, industrial sites, sport-grounds, playgrounds and parks.
- Area Resource (AR5) map: Accurate land cover map (1:5 000)

The land use/land cover map is made using the best quality data available. However, when optimal data cannot be obtained, data of simpler quality are utilized. For example, roads mapped as detailed

polygons are used where such data exist, but if data are not available, roads are represented by lines and extended by a buffer zone to give it a polygon representation. The method is in practice an automatic geographic information system (GIS) that delimits, classifies and puts the data together into a hierarchy, using the data sets with highest accuracy first. The principle is shown in Figure 3, but in reality, many more datasets are involved (Steinnes, 2013). The resulting land use/land cover map (Figure 3) is both as updated and complete as possible.

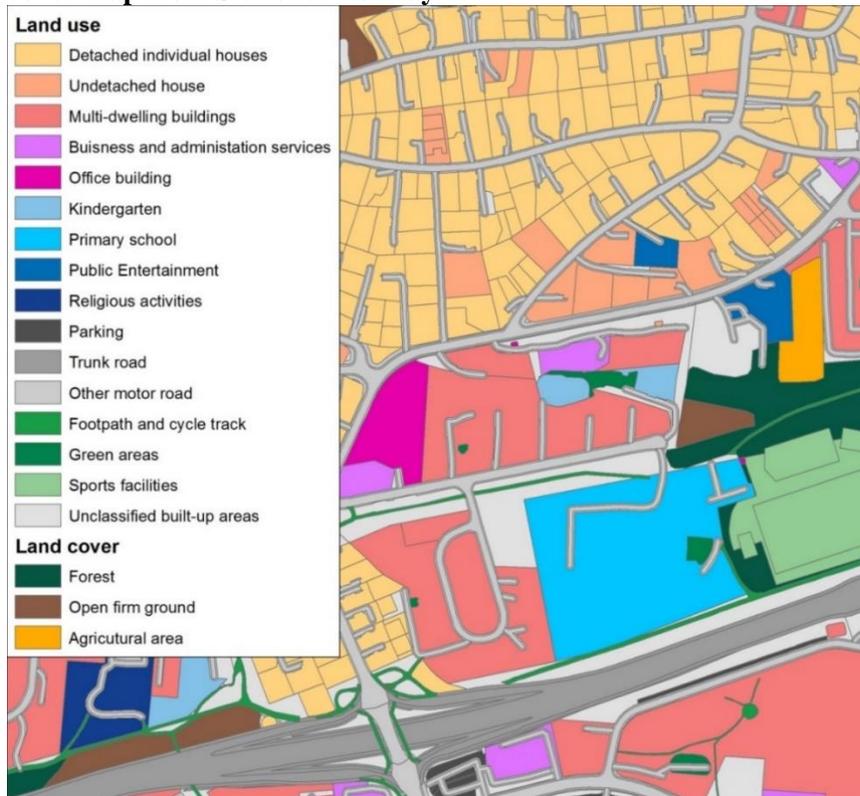
Figure 3. Principle of overlaying different maps in Statistics Norway’s land use/land cover map



Source: AR5: Land cover map (1:5000) (bottom layer), Cadastre: National register of properties and buildings (middle layer) and FKB (Common map data base): Land use maps (1:5000) (top layer).

The land use/land cover maps give a considerable amount of information detail about the type of urban development and built-up areas, as illustrated in Figure 4. However, other than clearly delineated green areas, such as parks and sports areas, the green elements in-between the urban mosaic are not visible.

Figure 4. The result of combining maps from different sources, an example of a land use/land cover map from Statistics Norway



This area from Sinsen north-east of Oslo city center illustrates the complexity of information that may be obtained for the classification of land use.

4.2 Satellite data from Sentinel-2 land cover maps

Sentinel-2 is a high-resolution multi-spectral earth observation mission of the EU Copernicus Programme, developed and operated by the European Space Agency. It consists of two polar-orbiting satellites (Sentinel-2A and Sentinel-2B), enabling revisit time 2-3 days in mid-latitudes. Each satellite carries an optical instrument that samples 13 spectral bands in visible, near-infrared and short wave infrared spectral range. Spatial resolution of the imagery varies between 10, 30 and 60 m. The objective of the Sentinel-2 mission is referred to as application in land monitoring, emergency management, security and climate change monitoring. (European Space Agency ESA 2019).

It is important to use satellite imagery from the leaf-on period (between June and August) to capture the full extent of vegetation. In this study, Sentinel-2 imagery acquired for two cloud-free days in the summer of 2017 was combined to derive a land cover map of the case study area. Satellite imagery was classified into five land cover classes, water, tree canopy, grass, built-up land, and agriculture, by a “random forest” classification model (Liaw and Wiener 2002, Prasad et al. 2006, Chan and Paelinckx 2008, Rodriguez-Galiano et al. 2012, Immitzer et al. 2016). Training data for the classification model were 20 000 points randomly distributed across the study area. After exclusion of

549 invalid points, land cover class was assigned to each remaining training point manually based on an orthophoto³ image, or automatically, using the Statistics Norway land use/land cover map in scale 1:5 000. In addition, the Normalized Difference Vegetation Index (NDVI) map was computed. Spatial resolution of resulting raster maps is 10 m.

We achieved 83 % overall classification accuracy, however, there is a large variation amongst precision of land cover classes. The highest precision (93 %) was achieved for land cover classes tree canopy and water, whilst the precision of land cover classes agriculture, built-up land, and grass is relatively low (75 %, 67 % and 23 %, respectively). Both open soil and agricultural vegetation were included in the training data, and this led to misclassification in urban areas. The agriculture class was not differentiated based on the current state of the crops (if they were growing, ready for harvest or harvested), but only on the land use definition (from AR5). This variation between exposed soil (when crops are harvested) and vegetation reduced the classification accuracy. The lowest precision was achieved for the class grass, as grass was often misclassified as tree canopy.⁴ In principle, for analysis of urban ecosystem all the green areas might be put into one common class. By including radar imagery from Sentinel-1 one might have been able to decrease these misclassifications (Clerici et al. 2017). Furthermore, lower precision of the class built-up land is explained by misclassification of impervious areas (e.g. parking lots) with open soil, as well as misclassification of building shadows with water.

4.3 Methodology, combining map and satellite data

The land cover classification raster map from Sentinel-2 imagery obtained by the above-mentioned approach⁵ was then vectorized and intersected⁶ with the land use/land cover map from Statistics Norway. In the land use/land cover map for built-up land, we know actual land use from cadastre data, but not the land cover. For example, the red areas, i.e. known land use, unknown land cover, in Figure 5 may be a parking lot or they may be trees or a garden with grass. The Sentinel-2 map enables detection of land cover such as tree canopy in Figure 5.

³ An orthophoto is an aerial photograph or satellite imagery geometrically corrected such that the scale is uniform and the photo corresponds to a given map projection.

⁴ Adding LiDAR information on height of vegetation will be extremely helpful with detecting vegetation types.

⁵ In combining the land use/land cover map and Sentinel-2 map, the Sentinel-2 map is no longer in raster form.

⁶ This approach ensures that sections of pixels located at borders of SSB land use areas are included in the result, which is particularly important for narrow polygons.

In order to make it easier to compare the two maps, in Figure 5, the Sentinel-2 land cover map is visualized as semi-transparent on top of an orthophoto, in order to show the streets and buildings. The concepts of land use/land cover are often misinterpreted because the difference is not always obvious (several classes may overlap) when comparing a land use/land cover map with a land cover map (Sentinel-2).

“Green areas” in Figure 5 are defined as green spaces within built-up areas, rather than actual green land cover. The cadastre data identify land use types and the FKB identify built structures. Thus, these data sources are not suited for identifying ecosystem extent. While AR5 is based on land cover, it is not updated uniformly across the country. Moreover, in urban areas much of the green areas are within built-up areas. Thus, land use/land cover maps in urban areas will only give limited information about urban green, because very much of the urban green is classified as developed land. Developed land is not only built-up land, but also parks, lawns etc. within the urban area. By combining the data sources, it is possible to estimate how large share of the “red” area in Figure 5, the unknown land cover in the land use/land cover map, that actually is green, i.e. with trees and lawns.

Figure 5. Principle for combination of Statistics Norway land use/land cover maps and Sentinel-2 land cover classification (raster map). Example from a case study area (Akersveien)



5. Combination of land use/land cover data and satellite data for urban case study areas in the Oslo region

An urban area may be defined in different ways, depending on the purpose of statistics, analysis and research and on the type of policy that relevant knowledge is being called for. Eurostat defines a functional urban area as a city and its commuting zone, i.e. an urban area consists of a densely inhabited city and a less densely populated commuting zone whose labour market is highly integrated with the city (Eurostat 2020).

Table 2 gives indicators for distance, population and labour market for the five selected case study areas in the Oslo region along a transect of urban areas in the city and in the commuting zone. The Oslo region has about 1.2 million inhabitants and the area is approximately 5 500 km². In the case study areas outside the city there are so far no large urban concentrations, however, these areas are considered for concentrated urban development in connection with regional transportation plans, in order to increase public transportation and reduce climate emissions from transportation. The distance between the case study areas is shorter near the city centre.

The article presents results for five case study areas. In the main text results are presented, as characteristic examples of the method, for two case study areas, the city center around the main street Karl Johan, and the residential area Grefsen, with abundant green in private gardens, while the other three case studies, Akersveien, Nittedal and Årnes, are presented in the Appendix. These areas represent increasing distance from Oslo city centre. The two case study areas outside Oslo, Nittedal and Årnes, are located in the north-east direction, where there are no other big cities, and commuting will mainly be to Oslo.

Table 2. Indicators of distance, population and labor market for case study areas in the Oslo region

Name, Municipality	Distance from city center, km	Population per km ²	Jobs per km ²	Characterization
Old city center, Karl Johan street, Oslo	0	6 674	62 419	Central, railway station
Akersveien, Oslo	1	16 374	11 181	Urbanized
Grefsen, Oslo	8	6 296	4 078	Dense single-housing
Nittedal	16	2 223	245	Commuter distance, 30 minutes by train
Årnes	80	1 404	2 365	Rural, 50 minutes by train

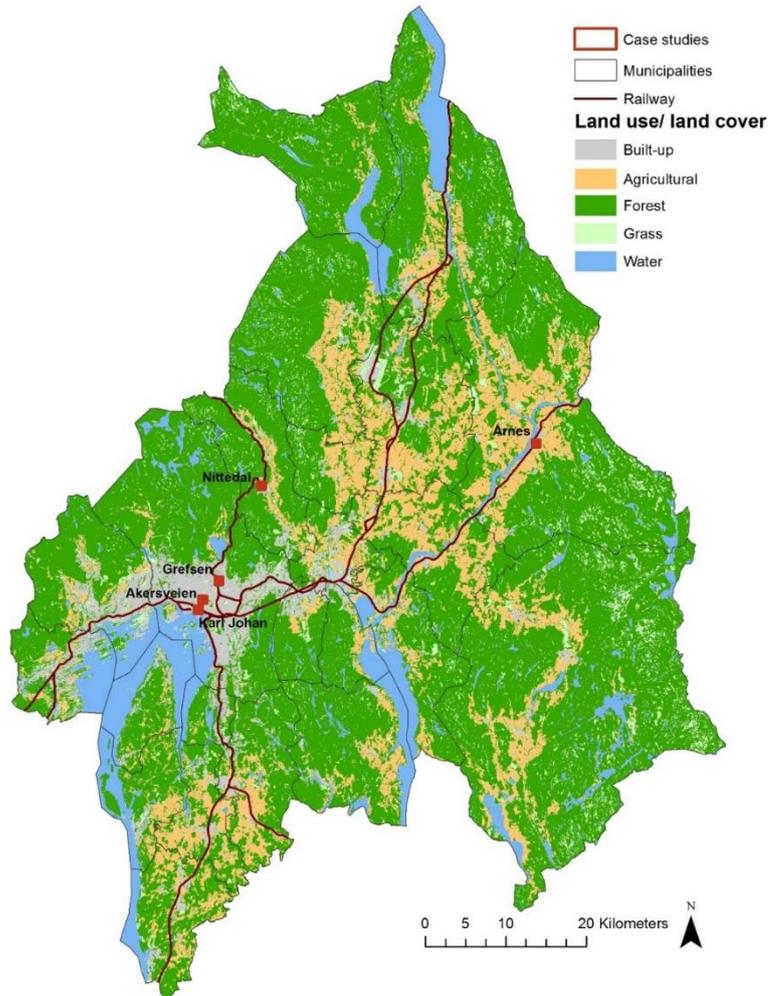
Note: The number of jobs in the city center may be exaggerated as in some cases all employees are assigned to the main office.

Source: Statistics Norway

For the Oslo region, the land use/land cover maps from Statistics Norway and Sentinel-2 maps provide the same general picture for agricultural land and forest (Figures 6 and 7), since the classes for forest and agriculture are based on the same data sets (AR5), although forest land cover may be picked up by Sentinel-2 as agricultural land, however, for the built-up area, they are based on completely different types of data, the land use data being administrative data sets classifying the entire area of a property by land use type (Figure 6), while the focus of the satellite images is the vegetation type (Figure 7). The Oslo region comprises two different counties, Oslo and Akershus (now Viken), with a common regional strategy focusing on efficient public transport systems, densification of buildings, and the

reduction of GHG-emissions, while having a strong focus on the green urban structure (Oslo municipality and Akershus county 2015).

Figure 6. Land use/land cover map from Statistics Norway for the Oslo region in 2017. Case study areas along an urban-rural gradient



Case study areas were selected along a transect, from the city center of Oslo and northeastwards. The case study areas outside the city center were selected because of their relevance for the planned urban transformation processes, of where many residential areas in and near the city center, are planned to be transformed into densely populated areas with apartment buildings, as well as transformation from agricultural land to urban areas outside the city. The distances between the case study areas are different, however, the case study areas outside the city center have been selected to represent different examples of the urban transformation processes currently taking place in the region, with plans for urban densification, around train- and metro-stations. The case studies areas have been selected in a north-east direction where there is a corridor of urbanized areas.

The two first case studies are the city center (the main street Karl Johan) and a mainly residential area (Akersveien) just outside/still inside the city centre. The third case study area is a residential area (Grefsen) in Oslo with plans for large scale densification. The fourth case study area (Nittedal) is well within commuter distance and has been largely developed recently. The fifth case study area (Årnes) is much further, at the border of commuter distance, and still with much green area. In the direction of this transect there is a long distance to the next city further north, hence the influence of Oslo dominates the urbanization pattern. Each case study area is 1 km² or 100 ha. We expect to observe different types and amount of green areas and structure along this transect because densities and building structure will change with distance to the city center. This may also give differences in data quality and interpretation of both extent and condition of urban areas and natural habitats.

Figure 7. Land cover (Sentinel-2 land cover classification) in the Oslo region in 2017. Case study areas along an urban-rural gradient



In the following analysis of the case study areas, the first step is to combine the different data-sources, from Statistics Norway (SSB) land use/land cover maps and Sentinel-2 map and explore the share of urban green areas. This is displayed in figures for each case study area with four types of maps⁷: (A) Land use/land cover maps, (B) Aerial photo to show location of buildings and built-up areas, (C) Sentinel-2, NDVI and orthophoto, (D) Private and public green areas. Map D is the contribution of our analysis and represents the proposed combination of information on the green share and the public access. The share of urban green is also visualized by statistics, i.e. the share of green calculated from the two data sources, are displayed in bar diagrams, where the red areas represent areas with known land use and unknown land cover. The following analysis of combining the maps and summarizing the land use information in bar diagrams forms the basis for comparing the information content of the land use/land cover maps and Sentinel-2 satellite data maps. The urban green elements only appear when these two data sources are combined, expressing the need for integration of the information basis for extent and condition accounts.

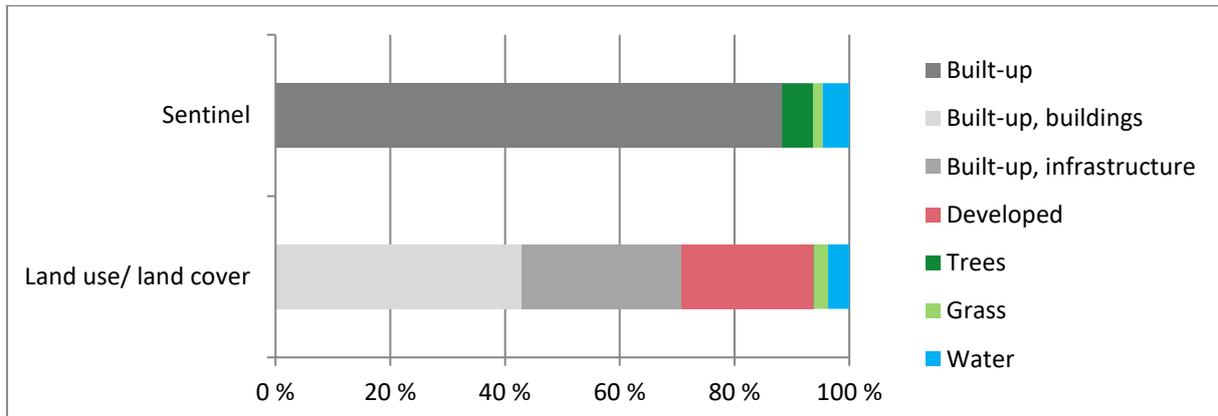
5.1 Case study area: Old city center, Karl Johan street, Oslo

In the old city center of Oslo, around the main street of Karl Johan, with an old quarter in the south east in map A (Figure 9), a stringent and planned city structure from the 1600s is still visible, outlined both to avoid fires, but also with defined open spaces. The open areas are large areas close to the water front with still some harbor functions, a lot of that area being just public space.

The satellite picture in map C (Figure 9), shows that there are green areas, mostly trees, around the old Akershus Fortress, but also along the main street Karl Johan with public space with little grass, but a lot of large trees. The same can be seen around the cathedral and the stock market exchange building. The street structure in map C is not from the satellite map, but from an underlying photo in map B, to make it easier to compare two maps A and C. In map C, we observe misclassification of building shadows as water in the city center. In the case of building shadows, it is easy to filter out these misclassifications. Sentinel-2 also provides a differentiation of tree canopy from grass which is a simple indicator of green space condition, not covered by AR5. Map D shows that there are not any private green areas in the city center. The light grey areas are private apartment buildings.

⁷ Map legend is the same in all case study areas, whether or not the actual land use/land cover occurs.

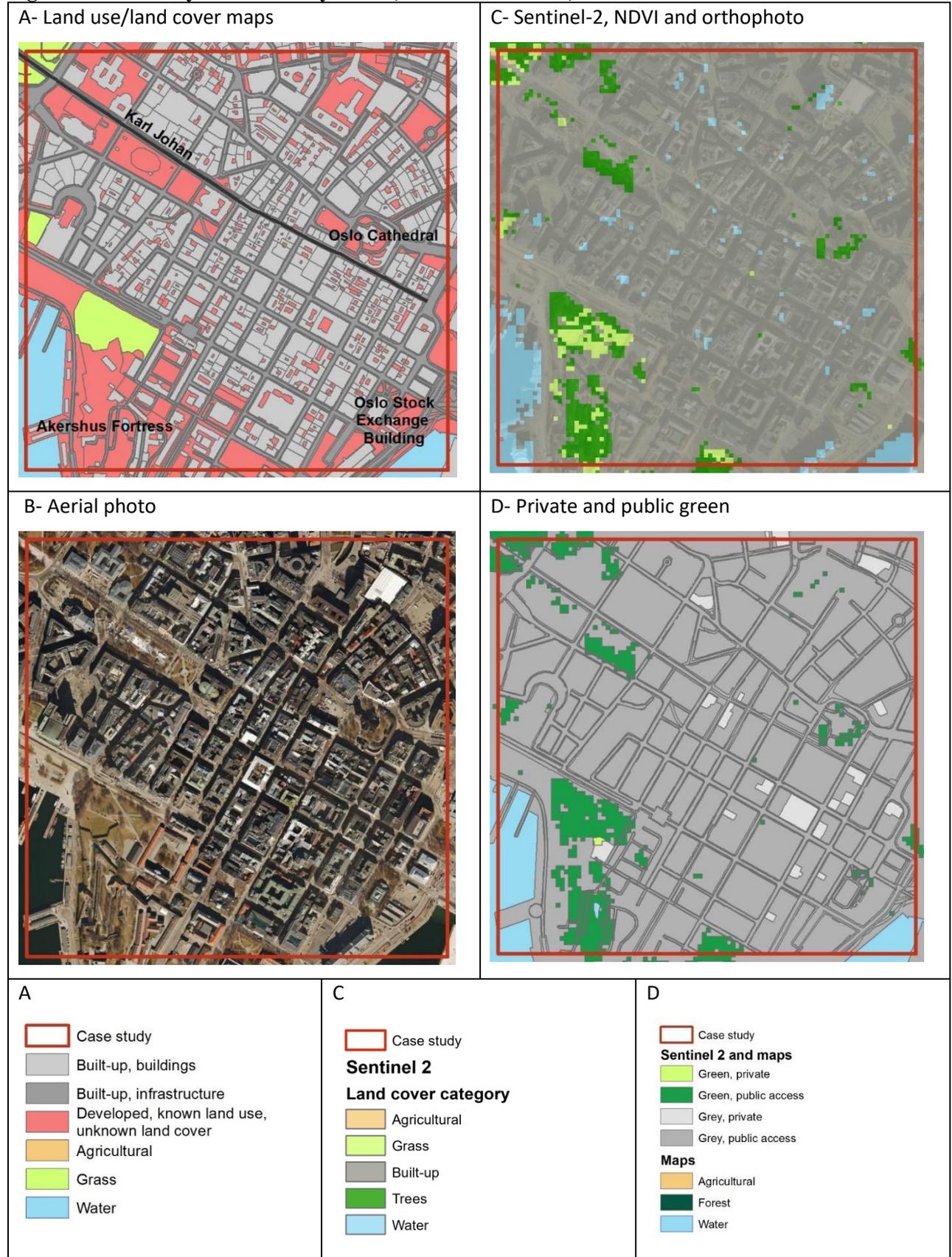
Figure 8. Old city center, Karl Johan street, Oslo. Comparing the information content of the map of land use/land cover and the map of Sentinel-2 satellite data



The Sentinel-2 data and the land use/land cover data provide different statistics on the share of urban green and share of built-up, as shown in Figure 8. The red area is known land use, unknown land cover. The data of the land use/land cover statistics regarding built-up and developed land differentiates between buildings (close to 45 per cent of the total area) and infrastructure (mostly roads, about 25 per cent). Of the open non-built-up land in developed areas, a substantial part is trees, which are not captured in the land use/land cover maps. Sentinel-2 overestimates water, due to misclassification of building shadows as water, but has probably better estimates for grassland.

An interesting feature is that open non-built-up land in developed areas is over 15 per cent, which is high, compared to what is anticipated for areas of city centres (UN Habitat 2014). Most of it seems as well to be parks accessible to the public, and the ownership distribution could be checked in the cadastral records. The share of non-built-up land in the Oslo city center, 15 per cent, can be contrasted with the recommendations from the UN Habitat recommendations from 2014 (UN Habitat 2014) about open land in cities, which should be at least 15 per cent (5 per cent black, 5 per cent grey and 5 per cent green), although it may be discussed whether it is less relevant to compare recommendations at city level, with a case study from the urban core, which is also primarily a non-residential area. However, it remains to explore urban ecosystem quality in terms of ecological characteristics and accessibility and suitability for public recreation and compare with the Oslo municipality study (Oslo municipality 2018).

Figure 9. Case study area: Old city center, Karl Johan street, Oslo



5.3 Case study area: Grefsen, Oslo

Grefsen is a typical residential area of Oslo, densely developed with mostly single-family residences surrounded by gardens, and the area is close to the city center, easily accessible by tram and metro. Originally the gardens parceled out late in the 1800s in this residential area were quite large. A certain amount of “normal” densification has taken place, in terms of building additional single-family homes in the gardens, as indicated by map B (Figure 11).

The Grefsen area epitomizes the trade-off between concentrated urban densification for climate mitigation and protecting the green areas of the city. Some years ago, the Oslo city planning authorities proposed a densification zone (map B) with 12 story buildings which would dramatically have changed the area. Peoples’ protests were massive and at present the proposal has been withdrawn and removed from the city plan. Most of the area of Grefsen is developed (map A) and apart from the private gardens, there is not much open green area left, but as can be observed from the Sentinel-2 map (map C), this is a very green area despite its closeness to the city center.

The densification process, clearly anchored in political ambitions to increase availability of housing, has been going on for decades, but it has been carried out with a strong regulation of building heights. In addition to the availability of public transportation nearby, and a tram line going through the residential area, there is a well-developed road system. In this rather affluent middle-class residential area, the car has been an important transportation mode. Today bicycle has become a very popular transportation mode because of the relative short distance to the city center.

Map C shows that the Sentinel-2 classification has misclassified some areas as agricultural areas, although they clearly are not. In this case, they mainly belong to two large sport facilities. Altogether, the vegetation of the Grefsen area is a mix of trees and lawns, representing an attractive urban landscape, as would be expected in a 70-100 years old residential area.

Figure 10. The residential area Grefsen, Oslo. Comparing the information content of the map of land use/land cover and the map of Sentinel-2 satellite data

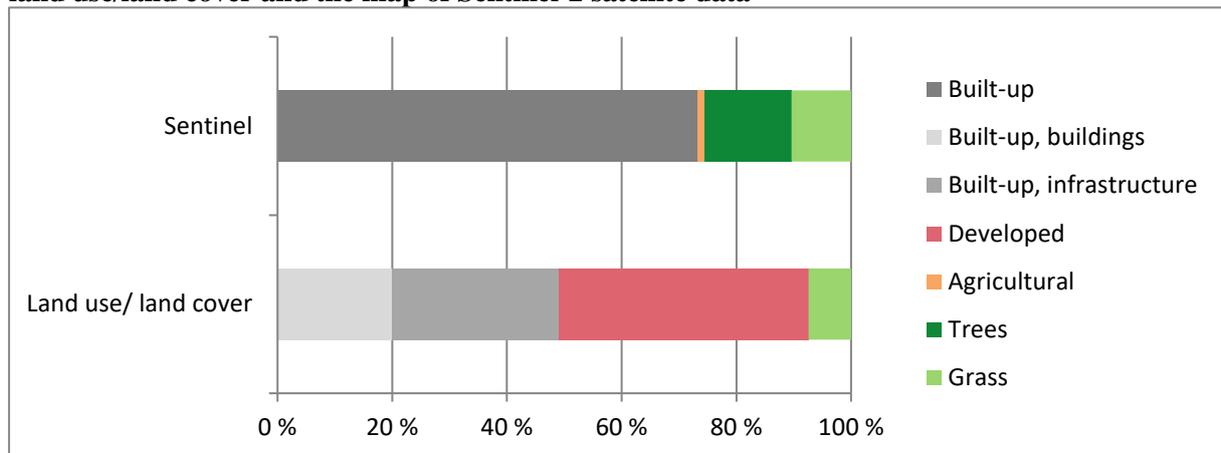


Figure 10 illustrates the differences in information content between the map of land use/land cover and the map of Sentinel-2 satellite data. The statistics for this comparison are quite as expected, moving out from the city center. Here the urban green areas are mostly private gardens. In this case study area, private green areas are much larger than public green areas, although there are several quite large public green areas as well, many of them are sports and school facilities.

Figure 11. Case study area: Grefsen, Oslo



6 Discussion

6.1 Combination of data sources

The case studies have demonstrated that combination of the land cover/land use classifications, both in land use/land cover maps and Sentinel-2 satellite maps, is important for the interpretation of the maps, in terms of actual distribution between built-up areas and green areas, and hence, for the choice of methods for establishing extent accounts. Moreover, using the knowledge about the classification categories gives basis for interpretation rules, required in order to develop statistics, where we need to make rules for interpretation of satellite images, and the analysis of the case study areas illustrates what type of interpretation rules that are needed.

From the land use/land cover maps it is possible to sort out the actual area covered by buildings, and to the extent possible, the area with vegetation and type of vegetation of the parcel that can be sorted out by the satellite maps. In fact, at the property level it is possible to sort out different types of land use/land cover and density of vegetation on the non-built-up part of the property. Combining the data sources makes it possible to establish rules for interpretation about which classification source to use when they give contradicting information.

Table 3 summarizes how information from the two data sources are particularly relevant for the case study areas.

Table 3. Comparing information content in land use/land cover and Sentinel-2 in the case studies.

Case Study	Land use/land cover	Sentinel-2
Old city center, Karl Johan street, Oslo	Streets, public places, markets, and private and public buildings. Large public areas alongside the water front, but limited green areas. Some large plots of grasslands are public parks.	Trees and grassland areas can be separated. The data sources allow to separate private green from public green. There are no private residential green areas in the city centre. Building shadows are misclassified as water.
Akersveien, Oslo	Public parks and graveyards, Water, allotment garden for residents.	Lots of trees and green space, no water identified. The river is dominated by vegetation. Agriculture misclassified
Grefsen, Oslo	No public green except sport areas and public institutions.	No streets, lots of trees and green space in private gardens. Misclassification of agriculture.
Nittedal	Buildings and infrastructure. Forest, water and agriculture are more accurately identified by land use maps.	Private greens and trees. Not much green in the new developed area. Agriculture misclassified, some water is classified as forest, possibly riparian forest.
Årnes	Little green in the old part of the town. Some new residential expansion on agricultural land.	Private green dominates in the residential areas. Large public green areas that could be developed, not using agricultural land.

Table 4. Land use in the case study areas, per cent and hectares (ha)

	Karl Johan	Akersveien	Grefsen	Nittedal	Årnes
Sentinel-2 (Map C)					
Built-up	88.3	68.9	73.2	46.0	44.5
Agricultural		1.1	1.3	2.0	19.9
Trees	5.4	25.9	15.1	36.1	25.3
Grass	1.7	3.9	10.4	15.7	9.1
Water	4.6	0.1		0.2	1.2
Land use/land cover (Map A)					
Built-up	70.7	52.7	49.0	28.5	26.8
Developed	23.0	25.6	43.5	56.5	40.1
Agricultural		1.4		0.6	18.8
Trees	0.0	2.4		10.5	2.6
Grass	2.5	16.1	7.4	3.2	10.5
Water	3.7	1.9		0.7	1.2

Note: The number of hectares corresponds to the percentages as each case study area is 100 ha. Sums may equal 99.9 due to rounding.

Tables 4, 5 and 6 are generated on the basis of maps, to illustrate the difference in information content. Table 4 illustrates the difference in land use from Sentinel-2 land cover map and land use/land cover

maps from Statistics Norway. To compare, we need to consider the categories “built-up” and “developed” land, as shown in Table 5, and private and public green, as shown in Table 6.

Table 5. Developed areas by Sentinel-2 class and land use/land cover from maps, hectares (ha)

	Karl Johan	Akersveien	Grefsen	Nittedal	Årnes
Panel 1 - Sentinel-2 within developed areas (red areas in map A)					
Developed, built-up	18.8	19.9	29.7	26.8	20.8
Developed, grass	0.6	0.6	5.3	9.7	4.5
Developed, agricultural	0.0	0.1	0.1	1.0	1.2
Developed, trees	3.1	5.0	8.4	19.1	13.3
Developed, water	0.6	0.0	0.0	0.0	0.2
Panel 2 - From land use/ land cover maps (areas that are not red in map A)					
Built-up, buildings	42.9	29.9	20.0	13.0	10.8
Built-up, infrastructure	27.8	22.8	29.0	15.5	16.0
Agricultural	0.0	1.4	0.0	0.6	18.8
Forest	0.0	2.4	0.0	10.5	2.6
Grass	2.5	16.1	7.4	3.2	10.5
Water	3.7	1.9	0.0	0.7	1.2
Panel 3 - Combination land use/ land cover maps and Sentinel-2					
Buildings	42.9	29.9	20.0	13.0	10.8
Infrastructure	27.8	22.8	29.0	15.5	16.0
Other artificial surface	18.8	19.9	29.7	26.8	20.8
Agriculture	0.0	1.4	0.0	0.6	18.8
Trees/forest	3.1	7.4	8.4	29.6	16.0
Grass	3.1	16.8	12.9	13.8	16.3
Water	4.3	1.9	0.0	0.7	1.4

Table 5 compares information on the categories “built-up” and “developed” land, from both data sources and summarizes the discussion for the case study areas of how to combine the information.

Table 6. Land use and public and private green areas in the case study areas (map D), hectares (ha)

	Karl Johan	Akersveien	Grefsen	Nittedal	Årnes
Combination, maps and Sentinel-2					
Green, private	0.0	3.5	15.7	30.7	15.8
Green, public access	7.0	23.2	11.1	12.7	20.1
Grey, private	2.1	25.4	28.3	29.7	12.1
Grey, public access	87.1	42.3	44.9	15.2	29.4
Agricultural		1.4		0.6	18.8
Forest	0.0	2.4		10.5	2.6
Water	3.7	1.9		0.7	1.2

Table 6 summarizes the information from maps D in the case study areas. It encompasses all green areas (from Sentinel-2 maps) within the case study areas. For the old city centre Karl Johan, the green area is 7 ha, i.e. the green share is 0.7 per cent. For the same case study area, Table 5 (Sentinel-2 data) shows that grass and tree land cover sum to 3.6 ha, within “developed” land, the red area. Land use/land cover maps show that there is 2.5 ha grass, that is parks in the map. The difference between the data in Tables 5 and 6 expresses the simplification we make when we use land use/land cover maps and classify areas as built-up or green based on these maps. Then the part of green trees over roads and buildings will not be defined as green. The same is the reason for some deviations in the other case study areas. Agricultural and forest are mostly privately owned, but forest areas are freely accessible to the public, while infield agricultural land is normally not accessible during the growing season, although it is accessible for the public in the winter season.

Table 6 illustrates that a combination of property information and urban green can be of interest, and that different statistical tables may be produced combining the data sources in different ways. The classification of private and public green and grey areas are based on Sentinel-2 maps, for categories agricultural land, trees and grass. However, some of the green areas from Sentinel-2 overlap with agriculture and forestry from the land use/land cover map and are therefore not included. The total amount of private and public green urban areas is lower than the green urban areas in the Sentinel-2 map. Table 6 illustrates the lack of private green space in and near to the city center. However, close to the city center there are parks large green areas being accessible to the public. This type of tables may be produced providing more details of type of buildings and land use as well as ownership.

If we can map the content of green areas and trees in each property by using information from maps and satellites, and with a flexible spatial unit, the overall accuracy of land use statistics would be increased, and we may combine these types of data in different ways in an analysis of the capacity for different ecosystem services.

Another aspect of the combination of data sources is the possibility to achieve a higher quality for time series of changes in land use/land cover and green structure. Such higher quality will be crucial in order to establish ecosystem accounts where different types of change processes may be identified. This may in turn give use the possibility to create algorithms for automatic reclassification of data from land use/land cover maps and Sentinel-2 maps as basis for ecosystem extent accounts.

Most of the accounts proposed in experimental applications of the SEEA EEA so far for land use or land cover have had a span of 10 years in order for changes to become visible and validated. The

ambition of the SEEA Experimental Ecosystem Accounting has been to produce yearly ecosystem accounts once the system is developed and operative. However, the objective of annual accounts may be questioned in contexts where land use change is slow and classification error is high so that annual trends will not be observable with statistical confidence. Presented in the Appendix, Figure A.9 summarizes the information on the urban green areas within the built-up areas, and grey areas (built-up areas) and compares all the case study areas and illustrates the difference between the areas.

If the land cover classification raster map from Sentinel-2 imagery is vectorized and intersected with the Statistics Norway (SSB) land use/land cover map, it makes it possible to produce a more flexible land use/land cover map, allowing the user to aggregate the properties and define their own statistical areas for analysis and reporting. They may use a map definition of areas, adding up the information content for each property. This could easily be done by a selection of information categories that can be combined in a map, as suggested by the results from the case study areas explored in this article. Figure 12 shows how private and public areas are mapped in order to demonstrate the capability of the use of cadastre based data as a statistical unit in the analysis of accessibility to green areas.

Figure 12. Proportion of Sentinel-2 classes visualized using intersection of Sentinel-2 landcover classification and Statistics Norway’s land use/land cover map



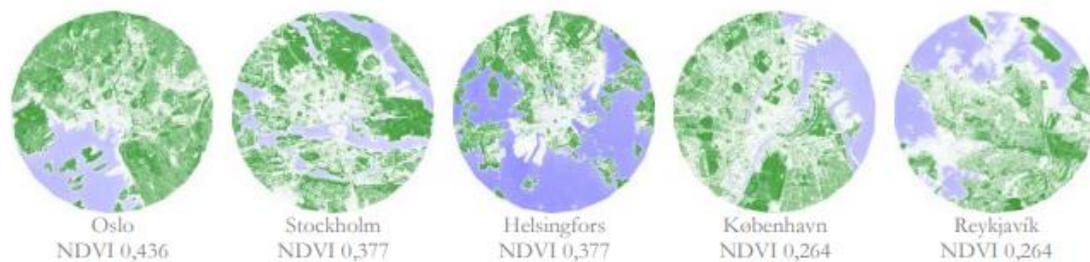
The analysis of urban green areas suggests that combining land use statistics and satellite images gives a richer interpretation of data and that the characteristics of urban ecosystems call for integration of extent and condition accounts.

6.1 Comparison with other studies

In studies of urban ecosystem accounting, it is relevant to include both ecosystems within the city and green areas outside the built-up areas, as both types of green areas have a large value for recreation and providing environmental amenities. Compared to metropolitan areas worldwide, Oslo and the surrounding municipalities, with large forest areas, is a very green region. Oslo was elected the environmental capital in Europe for 2019 (Oslo municipality 2019). Among the Nordic capitals Oslo ranked highest in terms of green areas (Figure 13). The UK National Statistical Office recently produced statistics for urban ecosystem services for all cities in England, where it included some green

areas outside of the built-up areas, relative to the size of the built-up area (EFTEC 2017). The municipality of Oslo did a similar exercise, finding that there was 47% coverage of green areas in the built-up area (Oslo municipality 2017). Our study reports from case study areas, in future work we will explore the comparison with the previous study.

Figure 13. Comparing the capitals of the Nordic countries in terms of green areas available to their citizens. Greenness measured by normalized vegetation index (NDVI)



Source: Oslo municipality (2018) and Gärtner (2017). Reprinted according to license <https://creativecommons.org/licenses/by-sa/4.0/>

7 Conclusions

Urban land use/land cover maps are excellent sources of information about the extent of built-up land and property boundaries, but they do not tell much about vegetation structure. Satellite images provide information on vegetation. Combining information from land use/land cover maps and satellite images represents an integration of extent and conditions accounts that contributes directly to development of the ecosystem accounts structure of the SEEA EEA. This combination of different types of data also contributes to improved and more accurate statistics, as well as to improved measures of ecosystem condition crucial for modelling the capacity for ecosystem services. This is not only a result of overlay techniques, but a result of using knowledge about the information categories, as built-up land can have different degrees of green areas. Using the knowledge about the categories gives basis for interpretation rules, required in order to develop statistics. The exact amount of urban green areas may, however, vary because of seasonal variations and conditions in different years. Statistics on major changes in land use and consequences in terms of loss of green areas will form a basis for an urban ecosystem account.

The results presented in the article, showing a mosaic of urban green, suggest producing land use statistics with a flexible spatial unit that allows users to define different spatial units for different types

of ecosystem services. In particular, spatial units that allow to aggregate across properties, from spatial representation in maps of cadastre data, in order to define statistical units suitable for analysis and reporting on urban green areas. Adding up the information content for each property can easily be done from the available information categories, i.e. land use from land use/land cover maps, vegetation from satellite data, and property boundaries from the cadastre, combined in a map. A fixed spatial unit in ecosystem accounting, as suggested in the SEEA EEA, seems unnecessary, and data should be kept in geo-referenced form to be used in a flexible way, depending on which types of ecosystem services are included in the analysis and the purpose of the analysis. We focus on different ecosystems and ecosystem services, depending on the purpose of the analysis. With different types of data describing ecosystem extent and condition, and modelling, based on the use (supply and demand) of ecosystem services, we can apply the SEEA EEA framework to consider the trade-offs and synergies between ecosystem services, as basis for capacity analysis.

In urban areas an ecosystem extent account based on cadastral units, showing land use and land cover, and adding on information from detailed satellite data in order to grasp the green mosaic structure, offers a large potential for analysis of ecosystem services. Detailed data on vegetation structure are fundamental for assessments of biodiversity and ecosystem services, like potential for pollination, capture of stormwater run-off, and potential for recreation. For many ecosystem services, e.g. pollination and recreation, information on vegetation structure is a necessary, but not sufficient, piece of information for modeling the ecosystem services. Including information on public access to green areas, i.e. public green areas and public access to private green areas, here interpreted as an “ecosystem condition indicator” is necessary for assessing recreation services. In addition, the actual users that benefit from the ecosystem services have to be identified. Ecosystem services such as pollination require modelling of habitat and biodiversity, and recreation require modelling of use of ecosystems for recreation.

In future research and statistical development of urban ecosystem accounting, it may be explored how new types of land use statistics can be generated by using new methods and new types of data. Big data, e.g. the nation-wide data base for real estate transactions (www.finn.no), and data from social media, represent new types of data sources that may form the basis for new official statistics. Urban green areas are small and under development pressure. Proximity to green areas is an important driver of local variation in residential prices. The hedonic pricing method uses the price of properties and proximity to green areas. This illustrates the importance of using the cadastre unit as a basic unit, particularly in urban areas (Office for National Statistics ONS 2019b). Combination of data sources

may be problematic in terms of the data security for individuals and firms. However, this type of information should be made publicly accessible through being published as official statistics by the national statistical offices, where data and confidentiality is protected by law.

The suggested methods for urban ecosystem accounting may have important applications in urban planning processes, as knowledge base for trade-off between retaining the green areas of the city and its adjacent regions, in order to protect ecosystems, biodiversity, and environmental amenities, while responding to climate mitigation objectives calling for large-scale densification of residential areas. In current policy debates on urban densification it has been questioned if there has been too much focus on climate policy as driver of densification of urban areas and around public transportation nodes, and too little focus on qualities that are lost as consequence of concentrated urban development, both with regard to biodiversity of urban green areas, potential areas for recreation, availability of sunlight and view in new residential developments, and socio-economic considerations (Plathe 2018). Our analysis suggests an approach for enhancing the knowledge base for the trade-offs between protecting urban green areas and the concentrated urban densification motivated by climate policy and contribute to highlight several aspects of sustainable development of urban areas.

An important conclusion is, however, that combination of data sources will provide national statistics more relevant for the analysis of urban green areas in the context of ecosystem accounting. Some basic steps have been made towards urban ecosystem accounting, by including vegetation structure observed using satellite data, and information on public access to green areas. Other types of information will also be needed to assess the urban ecosystem services, as basis for land use planning and informing policy. The results of our analysis contribute to enhance the knowledge base for the complex policy trade-offs between protecting urban green and concentrated urban densification motivated by climate mitigation objectives. Thus, the analysis highlights several aspects of trade-offs and synergies in sustainable development of urban areas, by taking into account the conservation of biodiversity and the environmental amenities for city dwellers.

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Appendix: Case study area 2: Akersveien, Oslo

A short distance outside of the city center of Oslo, the urban area Akersveien is located to the northeast. The oldest church in Oslo and a large cemetery are located in this area. Akersveien is the oldest road in the city, leading from the oldest church down to Akershus Fortress. To the east, is a gentrified area which is among the most attractive areas for young people to live. This area represents the green areas to the east in map D (Figure A.2).

Comparing the two maps A and C (Figure A.2), the large green area to the west represents the large cemetery, dominated by tall trees, with lawns and tomb-stones between. The river running through this area, the main river in Oslo, has been rehabilitated from pollution, and the river banks are rehabilitated with trees and vegetation and a trail. The vegetation along the river clearly appears on the Sentinel-2 landcover map and dominates the visual impression of a blue-green structure, i.e. combination of water and vegetation. Water is not always correctly identified in the Sentinel-2 map, while on the land use/land cover map the river itself mostly appears as a blue structure, without the adjacent green structure. Accordingly, combining the two types of data completes the picture and give complementary information about environmental qualities.

The land use/land cover map A (Figure A. 2) identifies a large agricultural area, in the middle of the map, that is an “allotment garden”, i.e. an area where residents of the nearby apartment buildings can rent a plot of land and grow flowers, berries and vegetables. This area is identified as a mix of grass, agricultural land and tree cover in the satellite map. Furthermore, the land use classification according to Sentinel-2 data identified some agricultural areas in the cemetery, an obvious misclassification of grass as agricultural land.

Figure A.1. Akersveien, Oslo. Comparing the information content of the map of land use/land cover and the map of Sentinel-2 satellite data

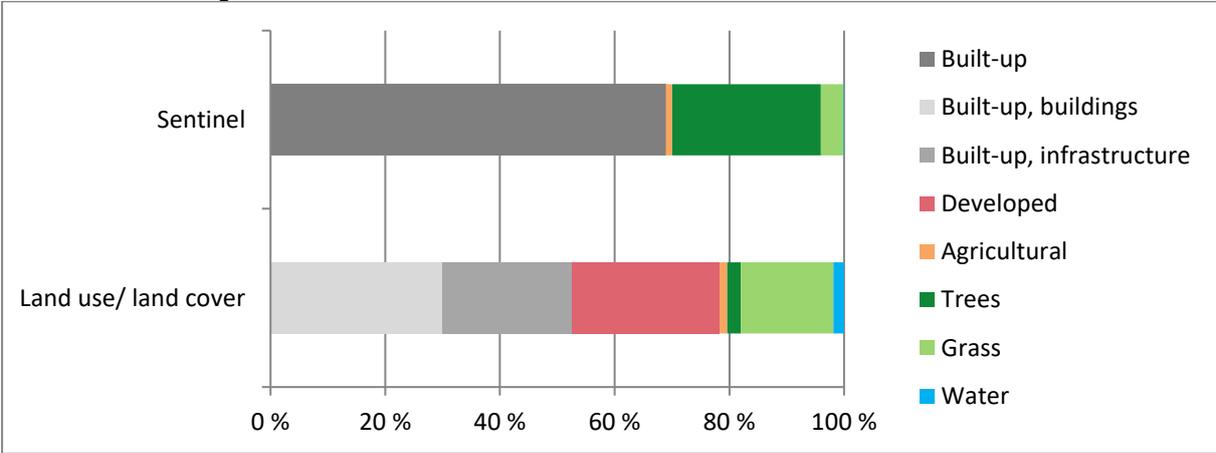


Figure A.1 illustrates the differences in information content between the map of land use/land cover and the map of Sentinel-2 satellite data. The Sentinel-2 data give much higher value for the green share in this case study area as compared to the land use/land cover map by Statistics Norway. Along the river, the riparian forest canopy covering the water course is a characteristic of good ecological condition and an important aspect of the extent account. Obviously, the agricultural area, which in fact is grass area in the cemetery, is misclassified. We could combine agriculture and grass into a single class because in an urban environment, the area that is actually agriculture is insignificant. Outside the urban areas, we can use the boundaries of agricultural areas to reclassify the crops.

Close to the city center of Oslo public green areas still dominate, and even some private areas may be accessible to the public, e.g. lawns outside apartment buildings. As the cadastral system contains all information about owners, and an address-system that keeps tracks of which persons are actually living in each apartment, substantial statistics may be produced concerning access to green areas for residents living in this area.

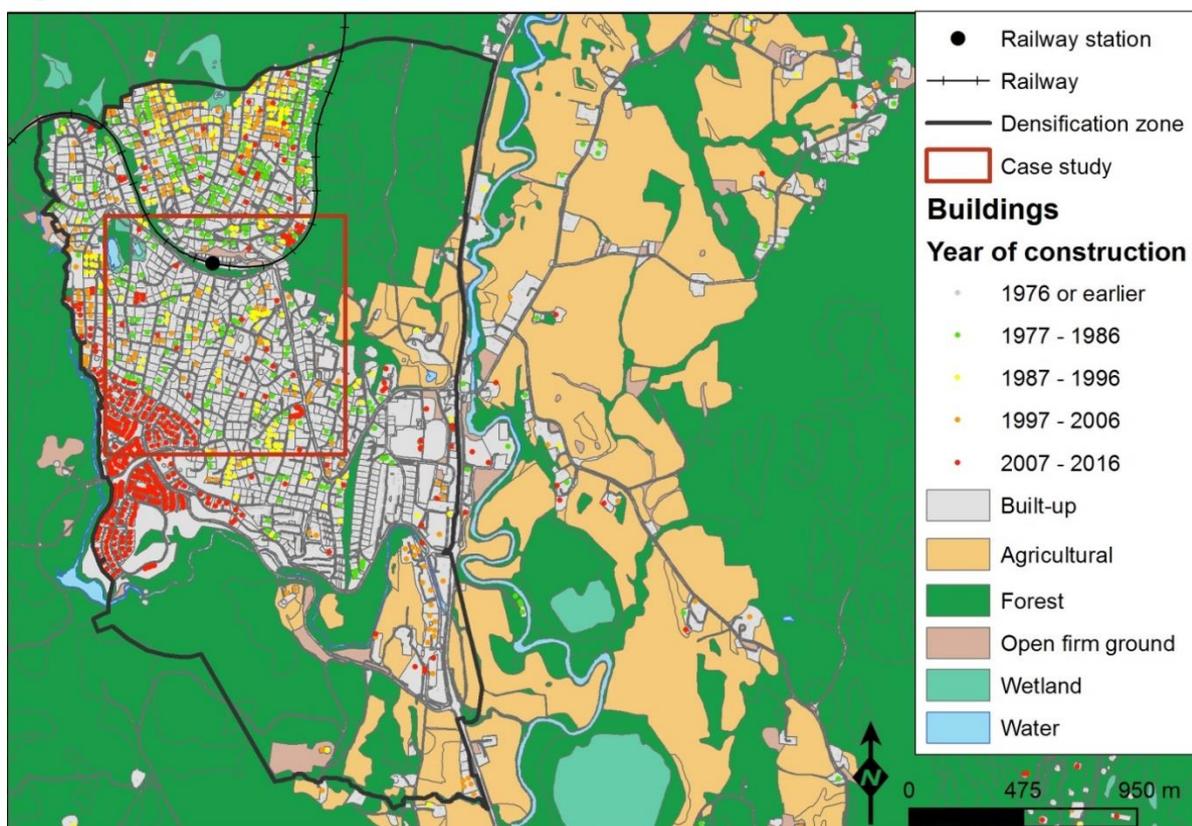
Figure A.2. Case study area: Akersveien, Oslo



Case study area 4: Nittedal

Nittedal municipality, northeast of Oslo, is a typical agricultural area and commuter community for people employed in Oslo. The distance to Oslo is short, and previously housing prices were reasonable as compared to Oslo. Today Nittedal is in a process of rapid rural-urban transformation, as it is suggested to densify the central area of the municipality, which earlier was consisting of many rural areas. The area for densification is quite large and also contains some valuable farm land in the southern part (Figure A.3). The most actual area for expansion is probably the forested area in the north closest to the railway station, although the growth in urban development in the last ten years has been in the southern part of the municipality.

Figure A.3. Densification area in the centre of Nittedal



Densification in Nittedal has been considerable during the last twenty years. The main new development has, however, been in the south western part of the municipality, at the area of a previous industrial site, as well as a large development on forest land. A large number of houses have been built in new residential areas with a high density of buildings.

The land use/land cover map A (Figure A.5) in this case study area provides more information about infrastructure, i.e. the settlement pattern, roads and rivers are clearly indicated. In map C the road map (orthophoto) has been left out, hence there are some additional features that can be identified from the Sentinel-2 data (map C) that clearly shows that the private green dominates the green structure in this case study area. Some water in the Sentinel-2 map has been classified as trees. If this is riparian tree canopy, it is an important ecosystem condition indicator rather than a misclassification.

Figure A.4. Nittedal. Comparing the information content of the map of land use/land cover and the map of Sentinel-2 satellite data

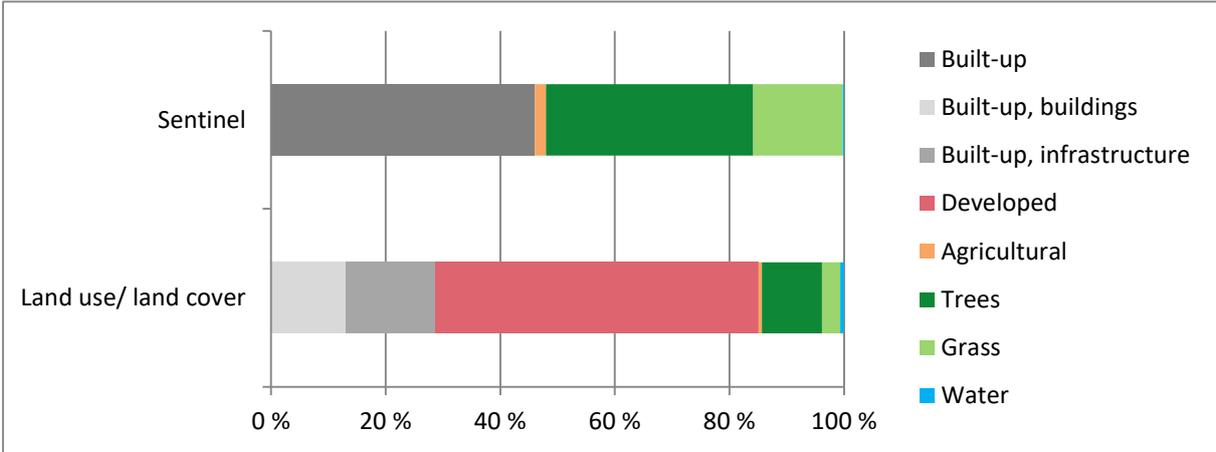
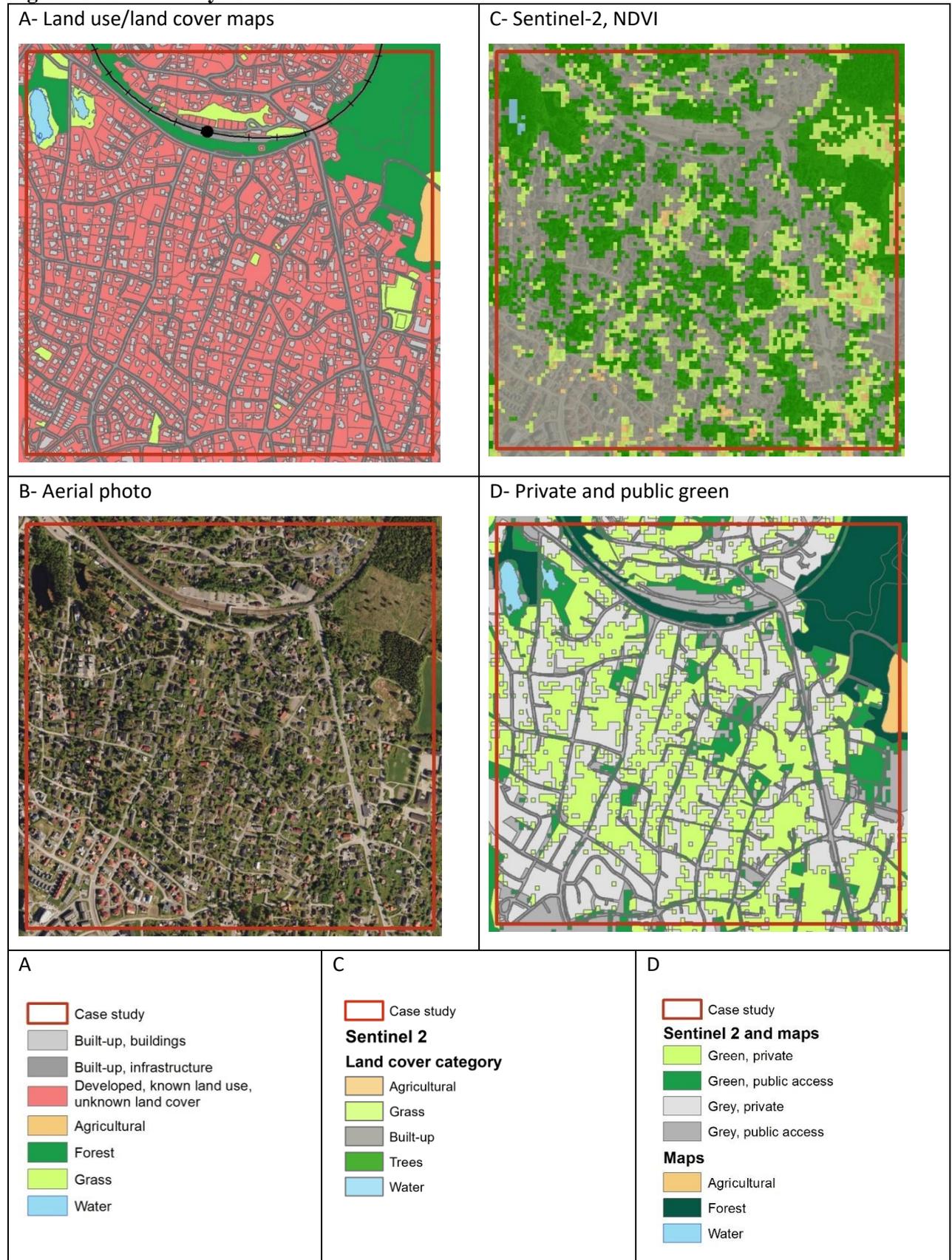


Figure A.4 illustrates the differences in information content between the map of land use/land cover and the map of Sentinel-2 satellite data. The statistics show more detailed information from the land use/land cover map as compared to the Sentinel-2 map. Combining with data from Sentinel-2, the developed land, i.e. the red area, with known land use and unknown land cover, can be divided into grass, trees, and open bare ground (driveways and parking lots). Supplementary cadastre information can be included to decide whether the green areas are private or public.

The land use/land cover statistics display some grass-fields as well in some limited plots, not being agricultural areas, accordingly this will have to be sports-fields or park-land. This can be decided upon in the more detailed classification of land use.

Figure A.5. Case study area: Nittedal

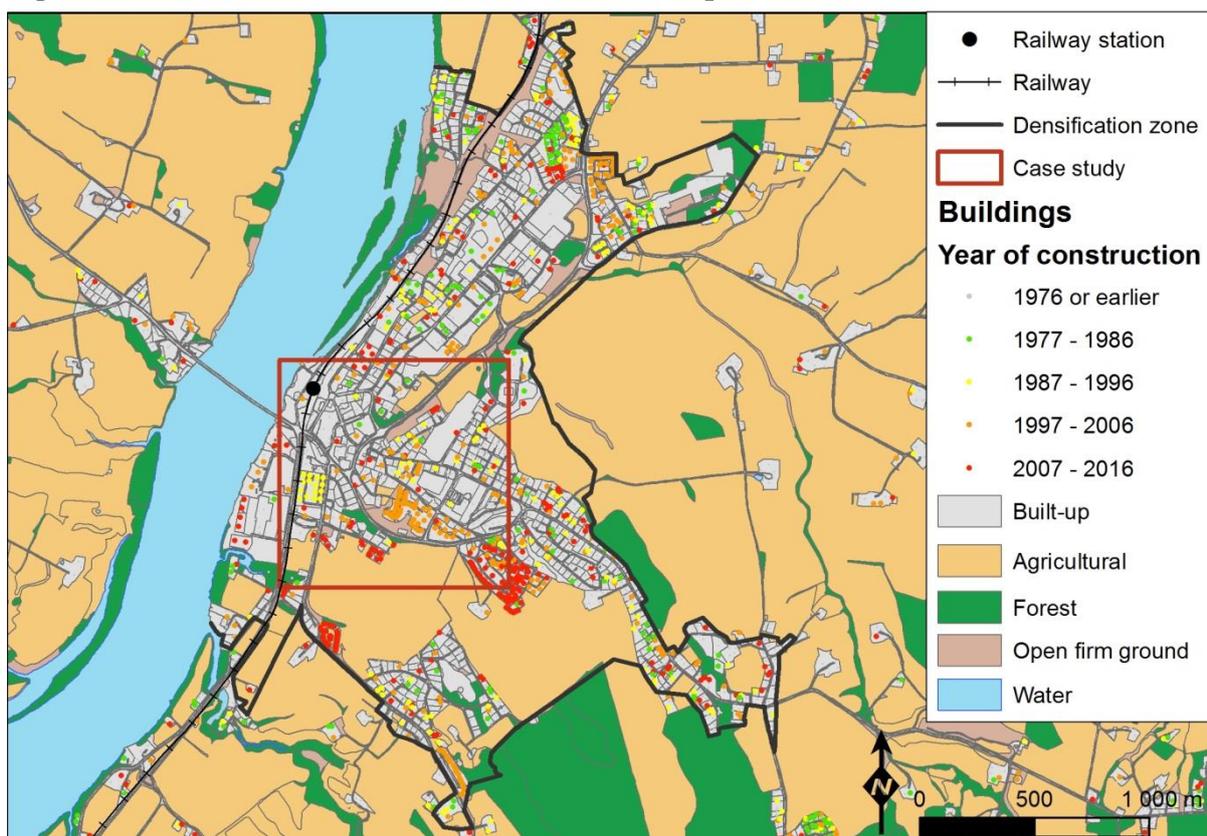


Case study area 5: Årnes in Nes municipality

Årnes is located quite far from the labour market of Oslo. However, there is still a fair amount of commuting, and hence new houses are being built in the central area close to the railway. Some of the new developments seem to be on prime agricultural land (Figure A.6 and Figure A.8, map B), which is surprising, due to policy focus on protection of high-quality agricultural land. Some minor multi-story apartment blocks have been built on the river bank, with good views and good availability of sunlight. The buyers of these houses are most local residents selling their large houses and moving into flats as they still want to live in the municipality.

The densification area contains quite large parcels of agricultural land, and accordingly a policy of using this area for low density housing development will probably not be acceptable. Furthermore, the politicians want to allow new settlements in other small centers in the municipality in order to keep schools and the existing settlement pattern.

Figure A.6. Årnes. Densification zone and recent development



Map A, B, C, D (Figure A.8) show that Årnes is an old industrial town based on agriculture and forestry. Some of the city structure represents the old factory areas. Thus the lack of green in the old

part of the town is noteworthy. Worth noticing is as well the amount of green in the residential areas, with a dominance of private green areas, but with large blocks of public greens along some of the roads (Map D).

Figure A.7. Årnes. Comparing the information content of the map of land use/land cover and the map of Sentinel-2 satellite data

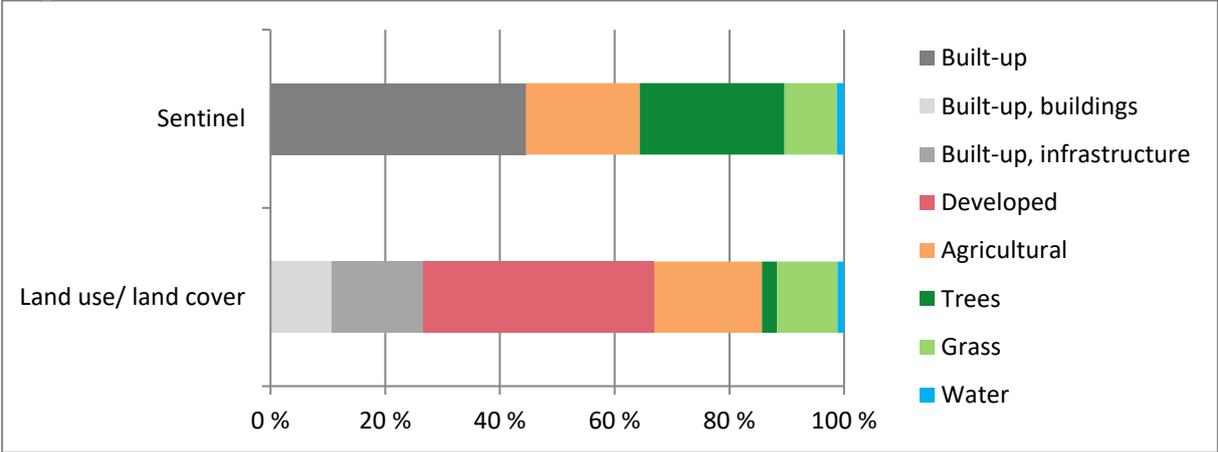


Figure A.7 illustrates the differences in information content between the map of land use/land cover and the map of Sentinel-2 satellite data. The statistics show more detailed information from the land use/land cover map as compared to the Sentinel-2 map. Both sources of information show the large agricultural areas in this rural community.

Figure A.8. Case study area: Årnes



Figure A.9. Distribution of green and grey areas, from Sentinel-2, within red areas (known land use, unknown land cover) of the land use/land cover map. Comparison of case study areas

