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Research Article

Facilitating spatially-explicit assessments of ecosystem service delivery to support land use planning

Dirk Vrebos[‡], Jan Staes[‡], Steven Broekx[§], Leo de Nocker[§], Karen Gabriels[|], Martin Hermy[|], Inge Liekens[§], Cedric Marsboom[‡], Sam Ottoy[|,¶], Katrien Van Der Biest[‡], Jos van Orshoven[|], Patrick Meire[‡]

‡ University of Antwerp, Antwerp, Belgium
§ VITO, Flemish Institute for Technological Research, Mol, Belgium
| University of Leuven (KU Leuven), Leuven, Belgium
¶ PXL University College, Diepenbeek, Belgium

Corresponding author: Dirk Vrebos (dirk.vrebos@uantwerpen.be)

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Abstract

Since the early 2000s, there have been substantial efforts to transform the concept of ecosystem services into practice. Spatial assessment tools are being developed to evaluate the impact of spatial planning on a wide range of ecosystem services. However, the actual implementation in decision-making remains limited. To improve implementation, tools that are tailored to local conditions can provide accurate, meaningful information. Instead of a generic and widely-applicable tool, we developed a regional, spatially-explicit tool (ECOPLAN-SE) to analyse the impact of changes in land use on the delivery of 18 ecosystem services in Flanders (Belgium). The tool incorporates ecosystem services relevant to policy-makers and managers and makes use of detailed local data and knowledge. By providing an easy-to-use tool, including the required spatial geodatasets, time investment and the learning curve remain limited for the user. With this tool, constraints to implement ecosystem service assessments in local decision-making are drastically reduced. We believe that region-specific decision support systems, like

ECOPLAN-SE, are indispensable intermediates between the conceptual ecosystem service frameworks and the practical implementation in planning processes.

Keywords

Ecosystem services, decision support system, landscape planning, land use change, spatial analysis

Introduction

The loss and degradation of ecosystems threaten the supply and delivery of a wide range of ecosystem services (ES) across the globe (de Groot et al. 2012). Mapping and modelling of ES is one of the topics within the ES research field that has gained much attention in recent years (Landuyt et al. 2013, Malinga et al. 2015, Palomo et al. 2018, Englund et al. 2017). Spatial data and maps can be very effective tools to communicate complex information accessible to the public and decision-makers (Kandziora et al. 2013). However, maps can also mask the underlying processes and weaknesses and should be used carefully (Hauck et al. 2013). Methods to map ES are increasingly integrated into decision support systems (DSS), making them available to the wider public and decision-makers (Mandle et al. 2016, Sample et al. 2016, Grêt-Regamey et al. 2017b, Grêt-Regamey et al. 2017a).

Both maps and DSS still face many challenges for successful implementation in decision-making (Palomo et al. 2018). In the last few years, a wide range of literature reviews has been published which assess the use of mapping and spatial models and their relevance towards decision-making. (e.g. Vigerstol and Aukema 2011, Martínez-Harms and Balvanera 2012, Bagstad et al. 2013b, Crossman et al. 2013, Nemec and Raudsepp-Hearne 2013, Schägner et al. 2013, Malinga et al. 2015, Andrew et al. 2015, Vorstius and Spray 2015, Englund et al. 2017, Lavorel et al. 2017, Ochoa and Urbina-Cardona 2017). Many of these reviews provide recommendations to improve the different issues, such as relevance, accuracy etc. of ES mapping and spatial tools. Their aim is to make them more successful in guiding policy and management.

To provide reliable outcomes and meaningful recommendations for land use planning, all relevant ES need to be included in ES assessments. However, most of the articles found that regulate ES are most frequently modelled. Cultural ES, on the other hand, are often lacking (Seppelt et al. 2011, Martínez-Harms and Balvanera 2012, Malinga et al. 2015, Grêt-Regamey et al. 2017a), especially in the generalist quantitative models, such as InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), SWAT (Soil and Water Assessment Tool) or ARIES (ARtificial Intelligence for Ecosystem Services) (Ochoa and Urbina-Cardona 2017). Although this issue has been mentioned for some time now, it still remains a recurrent and relevant problem (Grêt-Regamey et al. 2017a). Englund et al. (2017) found that, in individual studies, cultural ES are more often mapped on a landscape level than at large scales, while provisioning and regulating ES are more commonly mapped at larger scales (Crossman et al. 2013). This might imply that the development of regional or local tailor-made assessment models, which reflect the local characteristics of the ES, are the only way to capture all relevant ES into one assessment tool, instead of trying to apply the generalist models.

Despite continuous progress, the ES concept is still far from being firmly anchored in decision-making procedures and planning processes (Albert et al. 2014, Hansen et al. 2015). In much of the scientific literature, the relevance of the gathered information in ES assessments to provide information about decisions is not clarified (Martinez-Harms et al. 2015). Nor is there much research demonstrating how ES information is used in decision-making processes (Posner et al. 2016). However, the available evidence suggests that ES knowledge can support decision-making through different pathways, leading to different strengths in impact, ranging from an increased understanding to actually changing the decision-making (Posner et al. 2016, Ruckelshaus et al. 2015).

To improve implementation, different agencies, advisory boards and others have outlined multiple factors that inhibit the use of ES assessments in decision-making (e.g. Braat 2015, US EPA 2009). These can be divided into two main groups:

1. the failure to link ecosystem changes to outcomes that matter to or are directly valued by people and
2. the use of methods that do not answer relevant policy and management questions and/or are not sufficiently transparent (Olander et al. 2017).

Addressing these recommendations, made by both policy and science, will most often increase the complexity of the DSS. However, gained complexity and accuracy must be weighed against applicability (Bagstad et al. 2013b, Tallis and Polasky 2011). Most tools tend to be too resource-intensive for routine use in public- and private-sector decision-making. Therefore, the accuracy and complexity of research methods must match the needs of the particular decision context (Olander et al. 2017). Simpler models, using local data and models, can result in higher transparency and increase trust amongst users (Smart et al. 2012), providing opportunities for better implementation.

Ecosystem management decisions are subject to changing attitudes, values and preferences and are dependent on the resources that support it. As a consequence, there cannot be universal fixed rules and methods to ES classification, quantification and valuation. This also implies that there is a need to adapt ES assessment frameworks to the local situation, in collaboration with (institutional) stakeholders. This may appear redundant from an academic perspective, but it can be a crucial process to create ownership of used methods, which increases the political and public support for the ES framework (Volk 2013). Together with the adaptation of the ES framework, ES tools, such as spatial DSS, also need to be geared to the local situation, incorporating relevant local ES, indicators and values.

In the region of Flanders (Belgium), we developed a spatial DSS, ECOPLAN-SE (Planning for Ecosystem Services – Scenario Evaluator), which is specifically designed to the local situation by taking into account data availability, local indicators, local ES demand etc. The aim of the tool is to maximise the relevance of its output towards policy and decision-makers and to increase the possibilities of integrating ES into different decision-making processes. Although the tool itself can only be applied in Flanders, the concept of the tool, its development and implementation is of relevance beyond Flanders as an example on how regional, tailor-made models can increase the implementation of ES in decision-making.

Methodology

Conceptualisation

ECOPLAN-SE was developed to fit the adapted framework as presented in Staes et al. (2010). This framework aims to use ES and functional ecosystems as a cost-efficient and multipurpose strategy to improve environmental quality. From this framework, several ES tools were developed over a 4-year period in close collaboration with stakeholders and potential users. Each of these tools provides different types of information regarding ES delivery within a project area and can be used during the consecutive stages of planning. These include tools for spatial analysis, stakeholder consultation etc.

ECOPLAN-SE is designed as a spatial DSS to assess a wide range of ecosystem functions and services (hereafter referenced as “ecosystem services or ES”) and can be easily used by stakeholders, such as spatial planners. The aim of the tool is to increase the applicability of such a system by addressing several challenges that were raised by local stakeholders during initial consultation (Staes et al. 2010) and which are also mentioned in recent international literature.

- Policy actors need simple, user-friendly tools with a high accuracy and reliability.
- Time investment in an ES assessment should be limited to make application in smaller projects possible.
- Actual ES delivery can be calculated by the integration of both supply and demand, taking into account the flow mechanism between both.
- ES supply is calculated, based on ecosystem properties and functions, instead of using land use/cover proxies.
- Methods to calculate ES delivery are developed through scientific analysis and are well documented.
- Incorporated ES are relevant for regional planning and the DSS provides ES indicators that can be used for better informed decision-making.

ECOPLAN-SE is specifically designed for planning processes in the countryside and the fringes of cities and is less accurate in heavily urbanised areas. The tool is meant to signify the importance of ES and to improve their delivery during spatial planning processes as pressure from urbanisation, industrialisation and intensive agriculture remains high. To make the tool also applicable in urban areas, additional data and functionalities will have to be integrated. Throughout the development process, stakeholders were systematically consulted twice a year to evaluate the applicability and design of the tool, as well as the outputs (ES and indicators). ECOPLAN-SE is designed to be used in the early stages of the planning process. Information on the current state of ES delivery, supply and demand can be valuable in the early stages of decision-making, where decision-makers identify and understand problems and change their understanding (Posner et al. 2016). To this end, the tool can be used to assess the current delivery of the ES by taking both supply and demand into account through different flow mechanisms. However, it can also be used in subsequent stages of the planning process, where alternative plans are assessed. This information can be used to engage with stakeholders and residents. In later stages, different planning scenarios can be evaluated, based on their impact on ES delivery.

Regional implementation

The tool was developed for the Flemish Region (Flanders), which is one of the three regions of Belgium. This region of 13,522 km² or 44% of the Belgian territory has a high population density (445 inhabitants/km) and one of the densest traffic networks in the world (Lammar and Hens 2005). Urban sprawl is estimated to consume about 25% of the Flemish territory and irrevocably continues to threaten the remaining open space (Poelmans and Van Rompaey 2009, De Decker 2011). The rural matrix is spatially heterogeneous, with agriculture (46%), forests (11%) and protected nature (7%) as the most dominant land cover types. As a result of external pressures, more intense use andincreasing competition for land (Kerselaers et al. 2013), more and more emphasis is placed on multi-functional land use.

Plugin structure and geodataset

ECOPLAN-SE is provided to the user as an open-source, QGIS plug-in. The plug-in encompasses both a range of modules that can be accessed through a dropdown menu in the QGIS menu bar (Fig. 1), as well as a geodataset containing all required datasets. The modules allow the user to preprocess the datasets, develop scenarios, calculate the different ES and evaluate the results using different communication formats (Fig. 2). The QGIS plug-in interacts with the geodataset on different levels during data preprocessing and calculation of the ES (Fig. 3).

The geodataset contains raster maps with a 5 m resolution covering the entire region of Flanders and is structured into a general and an ES-specific part. The general part contains the most important datasets, which are used in many of the ecosystem service calculations: land cover and land use, soil texture, ground water depth and population densities. Land cover and land use are divided into two maps to make a better distinction between land cover (e.g. grassland or forest) and function (e.g. grazed grassland and hayfield). An overview of the land cover and land use classification is given in Suppl. material 1. Additionally, the ES specific part of the geodataset contains ES specific maps which give local ES demand, such as the current fine particulate matter concentration (PM10) map. This map gives the demand for air quality improvement to calculate the ecosystem service “Air quality regulation”. It also provides maps which describe ES supply, such as the location of hiking trails, which is part of the supply to assess the “Recreation” service. An overview of these maps is given in Suppl. material 2. All maps are based on official maps developed by or for Flemish institutes and agencies. The European Directive “INSPIRE” (2007/2/EG) is well implemented in the Flemish Region and enabled an abundance of maps and datasets to be freely available to the public and the scientific community. To reduce calculation time for some ES modules, the required datasets were combined and the derived map is made available within the tool. For example, to calculate “Erosion prevention” the LS-factor map is provided within the tool, instead of the digital elevation map that is needed to calculate this map. In these cases, calculation methods are described within the manual. As a result, all used information is traceable and known by the potential users.

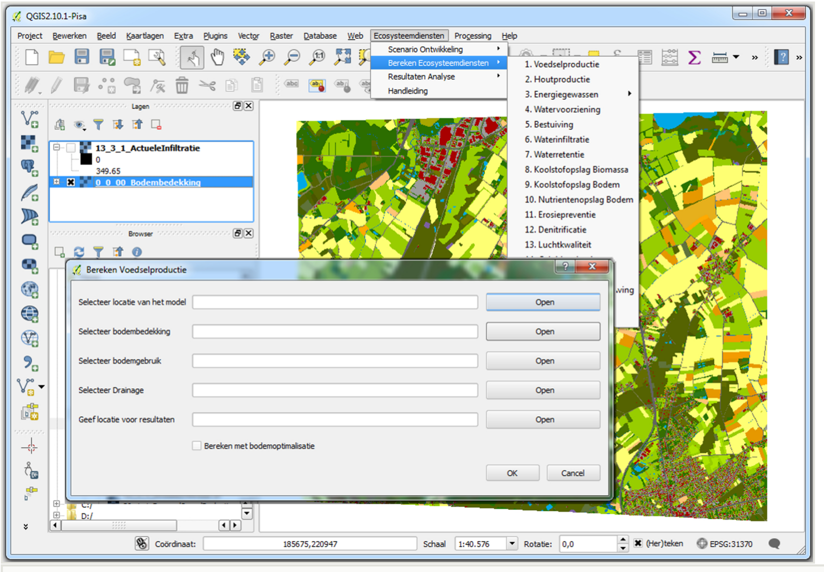

Figure 1.

Screenshot of the ECOPLAN-SE plugin in QGIS. A menu "Ecosysteemdiensten" (= ecosystem services) is provided in the menu bar which gives access to the different modules. After selecting one of these modules, a simple window is given requesting the required datasets.

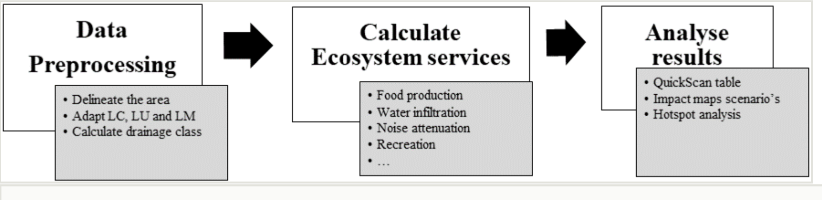

Figure 2.

Overview of the three main steps that need to be taken during an ES evaluation.

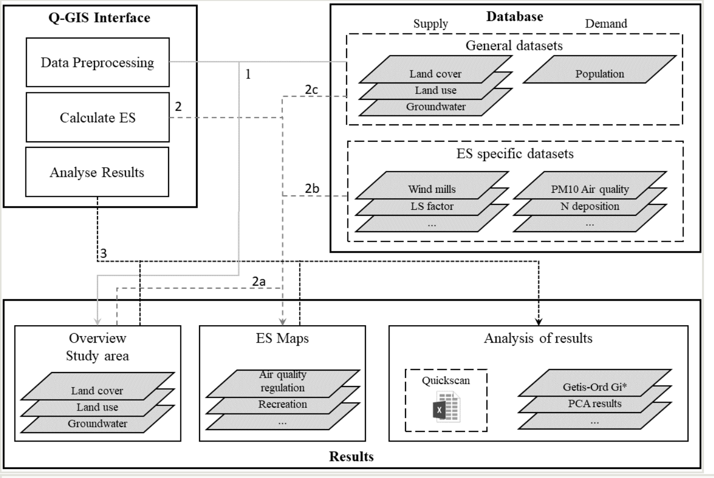

Figure 3.

General overview of the various data processing stages and functionalities that the ECOPLAN-SE features.

1. During data preprocessing, data from the general geodataset are extracted at study area level. Datasets can be adjusted to develop LC and LU scenarios using available modules.
2. ES are calculated using the data on (a) study area level. (b) Additional, ES specific data can be incorporated from the geodataset when needed, including both demand and supply-related files. (c) When flows are taken into account, the plug-in will automatically increase the area that is evaluated to also include the relevant areas outside of the study area.
3. ES maps are processed to obtain comprehensible, aggregated results in tables and hot-spot and bundle maps.

As the geodataset only contains freely-available datasets, both plug-in and geodataset can be provided free of charge. Since the plug-in is developed for an open-source software programme, initial investment costs are low and the tool can also be used by agencies or stakeholders with limited budgets.

Data preprocessing

Before the ES can be calculated, data from the main geodataset needs to be extracted on the level of the study site. This restricts the calculations to the relevant area, thereby minimising calculation time. A calculation of all ES for the whole of Flanders would take at least a week on a high performance desktop computer, making it impractical. It also provides the user with datasets on the correct scale to be shared with others. A module provided in ECOPLAN-SE automates this process using a shapefile, delineating the area.

Probably one of the most time-consuming processes in an ecosystem service assessment is the development of land use/land cover (LU/LC) change scenarios. To assist the user, ECOPLAN-SE contains a module, 'Adaptation of land cover and land use', to easily adapt the land cover and use maps provided in the geodataset. This functionality can be used to develop a potential scenario, but also to update the land cover and land use maps to better represent the current local situation.

Ecosystem service calculation

The ECOPLAN-SE tool can quantify and/or monetise the delivery of eighteen different ES (Table 1) in a spatially-explicit manner. These encompass four provisioning services, eleven supporting and regulating functions and services and three cultural services. The methods used in the tool are almost all specifically developed for the region of Flanders, using local datasets and model results. Many of these methods were developed in previous studies such as Broekx et al. (2013) and Staes et al. (2017) making use of existing studies or specific data analysis. More recent statistical analyses have also been incorporated (e.g. Ottoy et al. (2017b) and De Valck et al. (2017)) (Table 1). All methods were developed in collaboration with public institutions and stakeholder groups to increase their informative value. Where needed, the different ES modules were connected with each other as in Staes et al. (2017). Afterwards, these methods were also reviewed by experts in their respective research fields. Biodiversity is not incorporated as an individual ecosystem service, but it is taken into account in the relevant ES, such as pollination.

Table 1.

Overview of studies and publications used to develop the different calculation methods. For each method the origin, type and reference of the studies is given.

	Ecosystem service	**Type**	**Location study**	**Type of study**	**References**
1	Food production	Provisioning	Flanders	Expert report	Bollen (2012), D'Hooghe (2012), Van Broekhoven et al. (2012)
2	Wood production	Provisioning	Flanders	Peer-reviewed article	Dalemans et al. (2015)
3	Energy crops	Provisioning			
	Agriculture		Flanders	Expert report	Van Kerckvoorde and Van Reeth (2014)
	Forestry		Flanders	Expert report	Van Kerckvoorde and Van Reeth (2014)
	Nature management		Flanders	Peer-reviewed article	Van Meerbeek (2015), Van Meerbeek et al. (2014)
4	Water provisioning	Provisioning	Flanders	ECOPLAN-SE specific	no references
5	Pollination	Supporting	International/ Flanders	Report	Van Gossum et al. (2014)
6	Water infiltration	Supporting	Flanders	Peer-reviewed article	Batelaan et al. (2007)
7	Water retention	Supporting	Flanders	ECOPLAN-SE specific	no references

	Ecosystem service	Type	Location study	Type of study	References
8	Carbon in biomass	Regulating	Flanders	Peer-reviewed article + report	De Nocker et al. (2010), Dalemans et al. (2015)
9	Carbon in the soil	Regulating	Flanders	Peer-reviewed article	Ottoy et al. (2015), Ottoy et al. (2017b), Ottoy et al. (2016), Ottoy et al. (2017a)
10	Nutrient storage in the soil	Supporting	International/ Flanders	Peer-reviewed article	Duvigneaud et al. (1971), Froment et al. (1971), MacLean and Wein (1977), Cole and Rapp (1981), Nys et al. (1983), Ponette et al. (2001), Andre and Ponette (2003), Hytönen and Saarsalmi (2009), Uri et al. (2003)
11	Erosion prevention	Regulating	International/ Flanders	Peer-reviewed article	Desmet and Govers (1996), Notebaert et al. (2006)
12	Nitrogen removal	Regulating	International	Peer-reviewed article	Seitzinger et al. (2006)
13	Air quality regulation	Regulating	The Netherlands	Expert report	Oosterbaan and Kiers 2011, Oosterbaan et al. 2006
14	Noise attenuation	Regulating	Flanders	PhD dissertations	Huisman (1990)
15	Cooling effects from green-infrastructure	Regulating	The Netherlands	Peer-reviewed article	van Hove et al. (2015)
16	Recreation	Cultural	Flanders	Peer-reviewed article	De Valck et al. (2017)
17	Added value to houses due to a green environment	Cultural	International applied to Flanders	Peer-reviewed article	Brander and Koetse (2011)
18	Health effects of nature	Cultural	The Netherlands/ Flanders	Peer-reviewed article	Maas et al. (2008), Stassen et al. (2008)

As stated in Staes et al. (2017), dependencies amongst processes, functions and services are integrated in the calculation methods. As such, trade-offs and synergies between ES can be evaluated. Quantification and valuation methods were mostly based on local knowledge and datasets available for Flanders. Unlike many other tools (Bagstad et al. 2013a, Ochoa and Urbina-Cardona 2017), most of the methods are based on empirical models, of which many were validated in individual studies and published in peer-reviewed papers. This allowed the development of reliable methods that are tailored for the Flemish region and prevents knowledge loss due to conversion between regional and international classifications (e.g. soil types or land cover classification).

Valuation methods were based on the most suitable methods and data available. The valuation is partly based on market values (food production, wood production, replacement costs, avoided health costs), revealed preference methods (travel cost method for recreation and tourism) and – to a lesser extent – on stated preference methods (valuation of health effects). Overestimations, biased assumptions and double counting were avoided throughout the study by assessing each of the calculations and the potential inter-relationships between the different ES modules.

For almost all ES, except “pollination”, “water retention” and “cooling effects from green infrastructure”, the yearly mean delivery of the service is calculated as an output unit. To assess the delivery, both supply and demand are incorporated in the calculation and connected to each other through different ES flow mechanisms. For example, to assess water provisioning, the amount of rainfall that infiltrates into the ground (= supply) is evaluated in comparison with nearby located water abstractions from phreatic ground water layers (= demand). By taking this demand into account, which can vary across Flanders, a detailed evaluation of the delivery of the different ES can be made. The user can assess the effect of LC and LU changes on demand, supply and delivery for ES as well as compare the differences between case-studies or sub-areas.

Where needed, demand and supply are spatially separated from each other. When relevant, this spatial differentiation is taken into account during the calculation, connecting demand and supply through various flow mechanisms (Table 2). As the geodataset of ECOPLAN-SE is available for the entire Flemish region, the tool can also take ES demands and supplies into account that are located outside of the study area. For example, the module for “noise attenuation” will take nearby roads and railways into account even when they are located outside the study area. Similarly, high population densities from nearby cities will affect the value of the study area for “recreation” or “health effects of nature”. However, the tool cannot directly take into account cross-boundary effects with other Belgian regions or neighbouring countries or impacts from changes in international trade. However, the market prices which are used in the tool can be changed manually to simulate potential increases or decreases in value.

Table 2.

Overview of the ES incorporated in the plugin, the maps which are created for each ES and the units associated with each map. Only one service is assessed qualitatively, all others incorporate quantitative and/or monetary calculation methods. For ES in which the flows are dynamically incorporated, both ES demand and supply are spatially compared to each other. For most of the ES, a yearly mean delivery can be calculated.

	Ecosystem service	Qualitative	Quantitative	Valuation	Flows	Output maps	Unit
1	Food production			X		Yearly added value of agricultural activities	€/ha/year
2	Wood production		X			Yearly added harvestable wood volume	m³/ha/year
				X		Yearly monetary value of harvestable volume	€/ha/year
3	Energy crops						
	Agriculture		X			Yearly energy benefits LHV	Gj/ha/year

	Ecosystem service	Qualitative	Quantitative	Valuation	Flows	Output maps	Unit
				X		Yearly added value of agricultural activities	€/ha/year
	Forestry		X			Yearly energy benefits LHV	Gj/ha/year
	Nature management		X			Yearly energy benefits LHV	Gj/ha/year
4	Water provisioning		X	X	X	Yearly extracted volume from phreatic groundwater	m³/ha/year
5	Pollination	X			X	Qualitative indicator of pollination availability	Qualitative indicator
6	Water infiltration		X			Yearly infiltration volume	m³/ha/year
7	Water retention		X			Seasonal retention	m³/ha
						Permanent retention	m³/ha
8	Carbon in biomass		X	X		Yearly carbon sequestration in forests	tonne C/ha/ year
9	Carbon in the soil		X	X		Total carbon storage in soils	tonne C/ha
10	Nutrient storage in the soil		X			Total nitrogen storage in soils	tonne N/ha
						Total phosphorus storage in soils	tonne P/ha
12	Nitrogen removal		X	X	X	Yearly denitrification in soils	kg/ha/year
11	Erosion prevention		X			Yearly avoided erosion	tonne/ha/ year
13	Air quality regulation		X	X		Yearly deposition of PM10 on vegetation	kg/ha/year
14	Noise attenuation		X	X	X	Yearly added value to houses	€/year
15	Cooling effects from green infrastructure		X		X	Avoided temperature rise	°C
16	Recreation		X	X	X	Number of recreationists	# visits/ha
17	Added value to houses due to a green environment			X	X	Yearly added value to houses	€/ha/year
18	Health effects of nature			X	X	Received health benefits	DALY/ha

For each of the ES, at least one map is given as a result to show the spatial differentiation in ES delivery throughout the study area. Depending on the ES, this can be a quantification or monetisation of the function or service. When there is a non-linear relationship between

ES quantity and value, both maps are given. For example, quantification (m³/ha/year) and monetisation (€/ha/year) of wood production differ due to the differentiation in market prices between tree species. Poplar trees can provide large quantities of wood, but their value is relatively low compared to oak or beech. When quantification is possible and monetary values are a fixed value, monetisation is done during the aggregation of the results in the co-supplied excel file.

An overview of the different calculation methods and the relevant literature is given in Suppl. material 3.

Types of ECOPLAN-SE output

ECOPLAN-SE provides a couple of modules to evaluate and compare ES and land use scenarios. Their outputs are useful to interpret results that can help a project team to analyse and communicate the changes in ecosystem service delivery.

1. Tables and figures

The main module used to analyse the results of an ES assessment is called a “Quickscan”. It aggregates the results for the site and allows for an easy comparison of the impacts on the level of the study area and its subzones. Using an excel-file, changes in land use and ES delivery are aggregated into totals and mean values per hectare. Where needed, a further monetisation is given. The results are also automatically presented in graphs that can be directly used in reports or presentations. Ecosystem service assessments are often difficult to interpret, as reference values are not straight-forward. Therefore, the excel-file provides different options to provide context to the results:

- The excel-file can contain the results of many study-areas and/or scenarios. Differences in ES delivery between two cases or scenarios are presented in tables and graphs.
- An excel-file is provided with values of current ES delivery at different administrative levels in Flanders: municipalities, provinces, ecoregions etc. This allows the user to compare the study site results with its surroundings.
- When possible, values are also translated into indicators that are more easy to communicate. For example, the amount of PM10 captured by vegetation under “Air quality regulation” is a rather abstract value for most people. By converting this value into the number of cars that would emit the same amount of PM10 on a yearly basis, the value becomes more tangible. These indicators can be used to illustrate the importance of an ES towards the broader public.

2. Map comparison

This batch-process calculates differences between two scenarios for all ES maps available. These maps can help to find changes in ES delivery throughout the study area and highlight areas that are positively or negatively affected by the scenario developments.

3. Hot-spots and bundles.

The plug-in also provides a set of modules to evaluate the spatial patterns, both for individual ES, as well as for bundles of ES.

- Two modules, Top Richest Cell and Gettis-Ord Gi*, are provided to calculate hot-spots and cold-spots for individual ES (Eigenbrod et al. 2010, Timilsina et al. 2013, Schröter and Remme 2016).
- To map bundles of ES within the research area, a PCA redundancy analysis was developed (Marsboom et al. 2018). This PCA method can reveal multifunctionality between ES and map areas which are performant in delivering a multitude of ES. The module provides PCA graphs, ES-bundle maps and an integrated RGB-visualisation. These results are objective and factual outputs of a statistical analysis that can be used for communication and discussion with stakeholders.

By applying these modules on the ES result maps, the user can gain more information regarding the importance of specific areas for ES delivery and the co-occurrence of ES.

Example of model application

Throughout the development of ECOPLAN-SE, the ES-models and design of the tool were tested and evaluated through their application on several case-studies within Flanders. One of these case-studies is ‘De Cirkel’, located in the east of Flanders in the municipality Borgloon (50.8395°N, 5.3863°E). It encompasses a land consolidation project which is combined with a nature restoration project.

Within the project area, 317 ha of commercial forests and agricultural land will be converted and restored to mainly wetlands and natural grasslands. The zones with land use conversion are scattered throughout the study area and mainly located in riparian zones along the various streams. Some of the agricultural fields are converted to traditional high stem orchards to emphasise the historical character of the area. To further increase the recreational potential of the area, additional walking trails are put in place.

Many nature restoration projects are rife with criticism, especially when they claim agricultural land. Evaluating and communicating the additional benefits, as a consequence of nature restoration, are primordial to increase local public support for such plans. To evaluate the effects of these actions, ecosystem service delivery was calculated for both the current situation, as well as the future development scenario. The economic effects of the land consolidation project itself were not assessed.

In a first step, both the current situation and the future scenario, which was developed by the Flemish Land Agency, were integrated in the land cover and land use maps required for ECOPLAN-SE, using the 'Adaptation of land cover and land use' module (Fig. 4). After the realisation of the project, there will be an increase in grasslands (+15.14ha) and orchards (+32.76ha) and a large decrease in arable land (-42.32ha). Although the forest area will remain mostly the same (+2.55ha), conversion from commercial poplar stands to more natural mixed forests is planned.

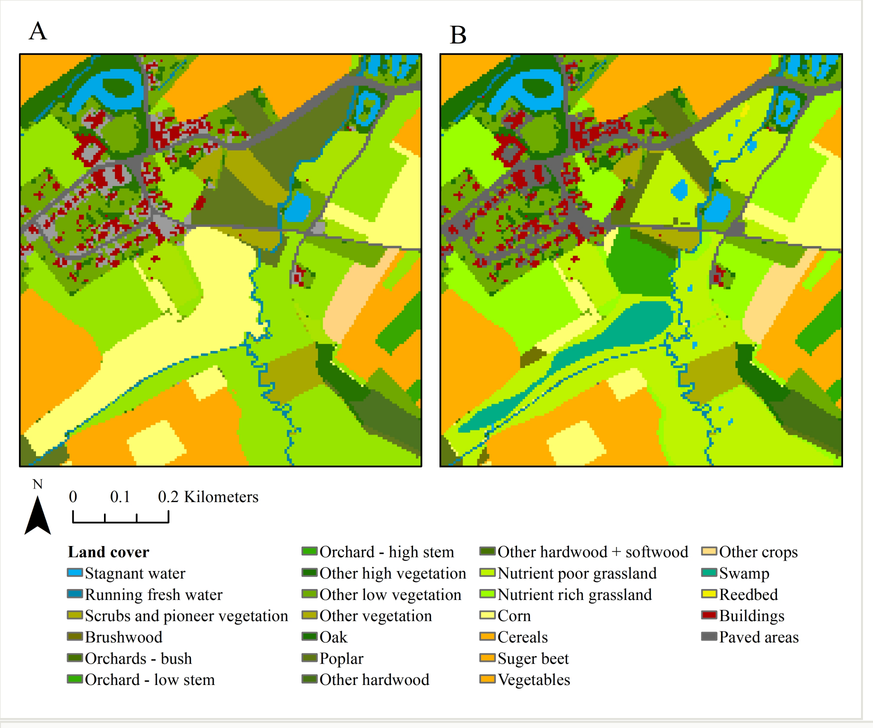

Figure 4.

Detail of the land cover map for both the current situation (A) and future situation (B). Intensive agricultural land, croplands and nutrient rich grasslands, are replaced by nutrient poor grasslands and wetlands.

Both sets of input maps were used to calculate the delivery of all eighteen ES. For each of the ES, at least one map was generated which illustrates the spatial differentiation in delivery throughout the project area (Fig. 5). Although these maps can be informative towards the project team, it is difficult and time-consuming to compare the scenarios. To this end, the "Quickscan" module was used to aggregate the results and provide meaningful data in comprehensive tables and figures. Both current and future land use provide a wide range of ES. Of the assessed ES, only a few are not delivered due to a lack of local demand. These encompass “energy crops”, “noise attenuation” and “cooling effects from green infrastructure”.

All other ES are delivered to some extent by the areas within the project both before and after the nature restoration project (Table 3). As trade-offs are always present between the different ES, the delivery of some of the ES increases after the project implementation, while other decrease (Table 4). All ES, deemed important by the project team, recreation, pollination and erosion prevention, will increase after project implementation. As expected, food production is negatively impacted by the project, but this effect is compensated by the land consolidation project that is associated with the nature restoration project.

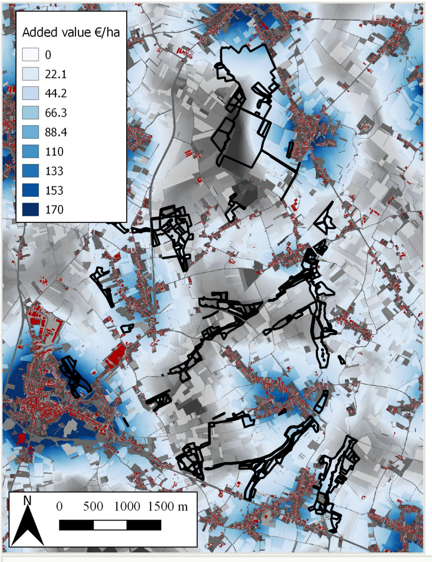

Figure 5.

Example of a map "Added value to houses due to a green environment" calculated by ECOPLAN-SE. The added value ranges between 0 and 170 €/ha/year. The project areas are delineated by black lines. Some areas within the project area do not generate value for this service.

Table 3.

Overview table of the ecosystem service delivery after nature restoration as provided by ECOPLAN-SE. For each of the ES or functions, quantities and if possible economic values are given. When there is a high uncertainty in the results, low and high estimates are given. Mean values per ha non-urban area are also made available within the table.

		Quantification		Monetisation (1000 €/year)		€ / ha non-urban area by year	
	Ecosystem function/service	**Value**	**Unit**	**Low estimate**	**High estimate**	**Low estimate**	**High estimate**
Producing	Food production	88.85	k€ added value by year	88.85		280.90	
	Wood production	459.93	m³ harvested wood	15.98		50.53	
	Energy crops - agriculture	0.00	Gj Low Heat value	0		0.00	
	Energy crops - forestry	0.00	Gj Low Heat value	no data available			
	Energy crops - nature management	0.00	Gj Low Heat value	no data available			
	Water provisioning	122.91	1000 m³ water	9.22	24.58	29.15	77.72

		Quantification		Monetisation (1000 €/year)		€ / ha non-urban area by year	
	Ecosystem function/service	**Value**	**Unit**	**Low estimate**	**High estimate**	**Low estimate**	**High estimate**
Supporting and regulating	Pollination	0.44	Mean indicator value by ha	supporting function			
	Water infiltration	521.51	1000 m³ infiltration capacity	supporting function			
	Water retention	519.56	1000 m³ water retention capacity	supporting function			
	Carbon in biomass	243.51	tonne C opslag biomass by year	53.57		169.37	
	Carbon in soil	62151.10	tonne C stock	136.73		432.29	
	Nitrogen in soil	3575.74	tonne N stock	supporting function			
	Phosphorus in soil	238.38	tonne P stock	supporting function			
	Nitrogen removal	175.33	kg N removal	0.88	12.97	2.77	41.02
	Erosion prevention	9504.38	tonne soil	no data available			
	Air quality regulation	3.23	tonne PM removed	184.14		582.18	
	Noise attenuation	0.00	number of houses	0.00	0.00	0.00	0.00
	Cooling effects from green infrastructure	0.00	decrease °C / ha non-urban	no data available			
Cultural	Recreation	46.41	1000 visitors each year	139.23	417.69	440.19	1320.57
	Added value to houses due to a green environment	0.57	1000 inhabitants within 100 m	9.38		29.66	
	Health effects of nature	7.92	1000 inhabitants within 1 km	1431.61		4526.14	
Total value				2069.59	2375.52	6543.19	7510.39

Table 4.

Changes in ecosystem service delivery between the current situation and future scenario for both quantification methods, as well as monetisation.

	Ecosystem function/service	**Quantification**	**Valuation**		
			Low	**High**	**Mean**
Producing	Food production	-52.56	-52.56		-52.56
	Wood production	-2.35	8.23		8.23

	Ecosystem function/service	Quantification	Valuation		
			Low	High	Mean
	Energy crops - agriculture	0.00	0.00	0.00	0.00
	Energy crops - forestry	0.00	no data available		
	Energy crops - nature management	0.00	no data available		
	Water provisioning	-0.02	-0.02	-0.02	-0.02
Supporting and regulating	Pollination	1064.33	supporting function		
	Water infiltration	-0.02	supporting function		
	Water retention	0.00	supporting function		
	Carbon in biomass	13.83	13.83		13.83
	Carbon in soil	4.97	4.97		4.97
	Nitrogen in soil	-6.49	supporting function		
	Phosphorus in soil	-6.49	supporting function		
	Nitrogen removal	-6.32	-6.32	-6.32	-6.32
	Erosion prevention	9.79	no data available		
	Air quality regulation	6.23	6.23		6.23
	Noise attenuation	0.00	0.00	0.00	0.00
	Cooling effects from green infrastructure	0.00	no data available		
Cultural	Recreation	2.12	2.12	2.12	2.12
	Added value to houses due to a green environment	0.00	14.05		14.05
	Health effects of nature	0.00	-0.02		-0.02
Total			-3.26	-2.66	-2.96

For some ES, the effect can be less straightforward. For example, the volume of harvested wood decreases slightly, while its monetary value increases. This is due to a conversion to tree species with a slower annual growth, but with a substantially higher economic end-value. Although the forest areas will be managed as nature areas, we assume that, at the end of their life-time, trees will still be harvested. Both changes in supply and demand can affect the ES delivery. The decrease in nitrogen removal, for example, is not due to a decrease in denitrification capacity, but because of less nutrient application on the former agricultural field. The total economic value within the project area decreases slightly, compared to the current situation. Since not all important ES are monetised, this value should be handled with care and was considered to be less informative by the project team.

Some of the values provided in Table 2 were also converted to more intuitive indicators. For example, the conversion and increase in woodland provides an additional CO_2 sequestration of 13.83 tonnes C/year. This value in itself is difficult to interpret for local residents and stakeholders. However, this value is comparable to the annual CO_2 emission of 2113 Flemish inhabitants (VMM 2017), which is easier to communicate to the public.

Discussion

ECOPLAN-SE was developed as a region-specific assessment tool, using regional datasets and studies to develop the different ES modules. This DSS is ready to use and can be easily applied across Flanders in many different assessments as both the methods, as well as the geodataset with the input maps, are readily available. This significantly lowers barriers to implementation and makes the option of an ES assessment available to many spatial planning processes, which would otherwise miss the resources to perform one. At the moment, ECOPLAN-SE can be applied ad-hoc by interested project managers, as it is not yet implemented in the different policy decision processes. In this way, however, the relevance of ES can be demonstrated and the further institutionalisation of ES advocated.

The development of region-specific quantification and valuation methods requires significant investments. However, such investments result in methods that have a high accuracy and legitimacy. It also allows the provision of more relevant information, expressed in units that relate to local policy and management objectives.

The interdisciplinary interaction amongst researchers from different fields (ecology, sociology, economics etc.) allowed us to explore each ecosystem service from different points of view and provided an opportunity to identify gaps in knowledge and scientific research priorities with an applied goal.

All necessary input data is compiled into an associated geodataset. Users have the benefit that they do not have to invest time themselves to gather the required datasets and align their spatial projections, resolution and classifications or units. At the same time, the content, accuracy and provenance of the datasets are generally well understood by the users. Most of the datasets and their metadata are presented at the geographic information data portal of the regional government (www.geopunt.be) or at the project website (www.ecosysteemdiensten.be). Interpretation and classification of local datasets to align with international classification systems, implemented in general models, can lead to significant information losses which reduce the reliability of the outcomes. Understanding the quantification and monetisation methods and how to interpret the results still require time.

The interpretation of ecosystem service maps and modelling results is often time-consuming and can seriously hamper the implementation of ES tools. By providing different tools to aggregate and evaluate the ES results, the user can be guided during the interpretation of the results, making the tool more applicable. As a result, the overall time investment is significantly lower compared to general international tools, such as Invest. An analysis of the current situation and a simple scenario at local scale with ECOPLAN-SE can be done in one or two working days. Although other models exist which can perform fast ES analysis, they have less spatial accuracy.

Instead of a generic and widely-applicable tool, ECOPLAN-SE is tailor-made for a specific region. In our experience, locally-developed tools are needed to bridge the gap between scientific research and implementation in developed countries. ES assessment tools need to take into account and be adapted, to the political and organisational aspects of decision-making (Laurans and Mermet 2014). If we want a broad implementation of ES within local policy, we need to move away from voluntary, ad hoc assessments and towards the integration within administrative and legal procedures. In order to make this possible, assessment tools need to align their output with guidelines and procedures. In general, global applicable tools are disbefitting, as ownership and development are independent from the authorities that impose these processes. Locally-developed tools and models can, however, be designed to calculate data and indicators that are aligned to the legal process and local circumstances.

Regionally specific tools and models should be developed in close collaboration with policy-makers and other stakeholders. This co-development increases the applicability of the tool and creates a sense of co-ownership and stakeholder trust, increasing support for the implementation of these tools. Evidently, the investments and efforts that are needed for the development need to be balanced with the added value of the tool. However, over time, significant savings can be made by averting re-occurring costs for data collection and the adaptations that are required to run generic tools.

ECOPLAN-SE provides a broad range of tools for quantifying ES, including several health-related and cultural ES, which are often lacking in other DSS. The importance of integrating health-related and cultural ES cannot be understated, as they are often determining factors for decision-making. However, correct representation of these cultural ES can only be done by developing local models that correctly represent the cultural perception of the area. The provisioning and regulating service calculations can also be made more accurate, as they can be adapted to the local ecological context.

Despite the broad range of ES in the tool, not all ES and functionalities are equally relevant to the context of a particular study site or project. To avoid unnecessary calculations, a selection can be made of the relevant ES before assessing the study area. In the case of De Cirkel, all ES were calculated, but some were considered to be more important to the project. All of the "essential" ES improved in delivery under the proposed scenario. As such, the analysis confirmed the project goals and provided the project team with accurate data and indicators that can be used in communication to stakeholders and higher authorities. However, not all proposed actions and measures that are planned for "De Cirkel" could be assessed with ECOLAN-SE, either due to a lack of data or because of limitations of ECOPLAN-SE. Besides land conversion, the nature restoration project also foresees rewetting of certain areas. This increase in the groundwater table will impact several of the ES available in the tool. As no hydrological study was available, it was impossible to include the future groundwater table.

Resolution and scale are important factors that determine the applicability of spatial ecosystem assessment tools and maps (Zhao and Sander 2018, Malinga et al. 2015). Although ECOPLAN-SE has a 5 m-resolution, this still limits the types of land use and land cover conversions that can be assessed. Especially linear elements, such as hedges and ditches, are difficult to integrate in the current version of the tool. As such, not all planned nature restoration actions could be accessed within De Cirkel. Especially the planting of hedges, which restores important historical elements within the landscape of De Cirkel, could not be evaluated. Future improvements should allow better integration of these structures, as they are considered important factors within multi-functional landscapes where “land sharing” predominates. ECOPLAN-SE is very effective in calculating ES for areas of the size of +20 ha. On a smaller scale, the information provided by ECOPLAN-SE is less informative.

Although ECOPLAN-SE provides a total monetary value for an area, this value should be handled with care, primarily because not all ES can be quantified in such a way. For example, erosion prevention can be relevant in certain areas, but the tool is currently not able to monetise its importance. By only recognising the total monetary value, important positive effects can be overlooked.

An evaluation of ES is not a full cost-benefit analysis. Projects, such as De Cirkel, also target other goals, often with specific economic benefits (e.g. agronomic scale and logistics). Nature restoration and compensation are only one aspect of much broader land use re-organisation plans. Assessing these other economic or social benefits requires other tools. Nevertheless, ecosystem service assessments can offer valuable contributions to land use planners, as they can reveal gains and/or losses of less obvious societal aspects that we call ES. Tools such as ECOPLAN-SE lower the barrier for implementation. The open-source nature of the tool and the integrated geodataset drastically reduces financial cost and workload of performing an ES assessment. In contrast, generic tools require a high effort in data collection and preparation, which impedes the implementation of such assessments. By integrating ecosystem service assessments into other existing planning processes, a more complete understanding of gains and losses can be made.

ECOPLAN-SE was developed specifically for Flanders and tested on a set of project areas with a variety of underlying planning processes. Further tailoring the tool to specific types of planning processes, such as land consolidation projects, environmental impact assessments, nature restoration projects etc. is needed to increase its informative value for the different planning processes.

Both validation and uncertainty are often mentioned in scientific literature as important aspects to be taken into account in ES assessments (Hamel and Bryant 2017, Ochoa and Urbina-Cardona 2017). Nevertheless, both are lacking in most spatial DSS. At the moment, ECOPLAN-SE does not incorporate methods to validate the results with field data nor can it perform uncertainty analysis. At the moment, ECOPLAN-SE can only assess changes in land cover, land use and groundwater changes. Future improvements will allow for the assessment of specific management practices for forestry (e.g. long or short rotation), agriculture (e.g. tillage – non-tillage) and nature conservation (e.g. mowing or grazing of grasslands).

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Supplementary materials

Suppl. material 1: Land cover and land use classifications doi

Authors: Vrebos Dirk, Staes Jan, Broexkx Steven, De Nocker Leo, Gabriels Karen, Hermy Martin, Liekens Inge, Marsboom Cedric, Ottoy Sam, Van der Biest Katrien, van Orshoven Jos & Meire Patrick.
Data type: Classification system
Brief description: Overview of the land cover and land use classifications used in the ECOPLAN-SE tool.
Download file (19.77 kb)

Suppl. material 2: Overview ES specific datasets. doi

Authors: Vrebos Dirk, Staes Jan, Broexkx Steven, De Nocker Leo, Gabriels Karen, Hermy Martin, Liekens Inge, Marsboom Cedric, Ottoy Sam, Van der Biest Katrien, van Orshoven Jos & Meire Patrick.
Data type: Table
Download file (15.01 kb)

Suppl. material 3: Calculation methods of the ecosystem services doi

Authors: Vrebos Dirk, Staes Jan, Broexkx Steven, De Nocker Leo, Gabriels Karen, Hermy Martin, Liekens Inge, Marsboom Cedric, Ottoy Sam, Van der Biest Katrien, van Orshoven Jos & Meire Patrick.
Data type: descriptive word document
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