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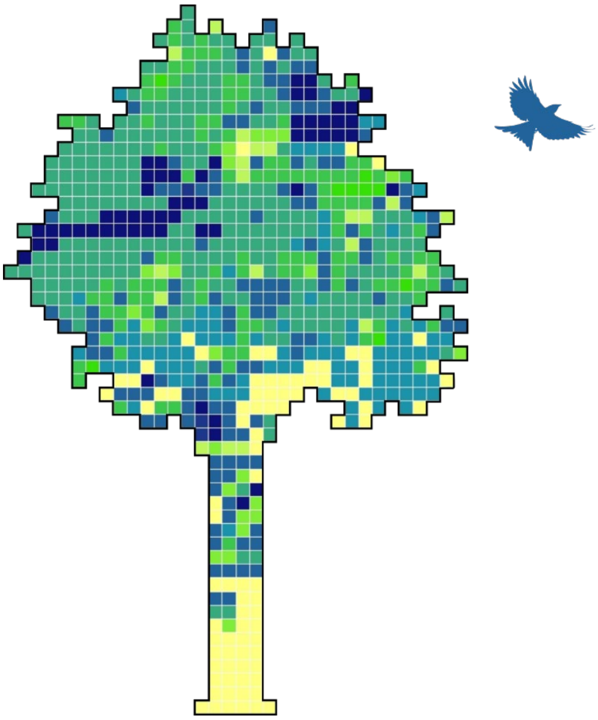
FACULTY OF BIOSCIENCE ENGINEERING



Towards Adaptive and Resilient Bioproductive Space in Flanders

A Spatial and Economic Analysis

Frederik Lerouge

Supervisors:
Prof. Dr. Liesbet Vranken
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Dissertation presented in partial fulfilment of the requirements for the degree of Doctor in Bioscience Engineering

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The coming decades, we face the difficult task to maintain reasonable standards of living and restoring our ecosystems, while adapting to the consequences of global change and other shocks and shifts. One of the crucial challenges will be how to optimize our use of land and space in light of the necessary transitions ahead. This research focusses on the integration of ecosystem services (ES) in spatial planning, in the region of Flanders, Belgium. Flanders is characterized by high degrees of urbanization and fragmentation of open space. At the same time, there is a high demand for the remaining open space to deliver services, from food production, recreation, climate control to water buffering, and many more. Adaptive spatial policy should look at all potential space providing ES. To facilitate this, the term 'Bioproductive space' was coined as *"all forms of land providing functions and services rooted directly or indirectly in primary production processes*". Spatial policy and land management typically put much of their focus on the 'classic' land use categories like agriculture, forests, nature reserves and urban areas. Likewise, the instruments of spatial planning mostly relate to these classical land use categories. As a result, a portion of the bioproductive space has the tendency to stay under the radar of policy and research. Examples are abandoned private lands, roadsides, fallows, horsification, fragmented open spaces in urban areas, or domestic gardens. Major challenges for society, like climate adaptation, transitions to a circular economy or green energy, etc., already interfere with all formal land use categories. Decision makers in land use and spatial planning are in need of appropriate diagnostic tools to estimate trade-offs and synergies between ES, associated with land allocation and land use intensity decisions, over classic sectoral boundaries. This often implies trade-offs between food and biomass production on the one hand, and other non-provisioning ES on the other hand. But in order to do so, one must be able to put all ES to a common denominator. In chapters 2 and 3, the argument is made that monetary valuation of ES can contribute to adaptive land management, by doing just that.

Chapter 2 presents an assessment on the farm scale using an integrated approach that combines spatial and economic analyses. It relies on the ES concept to evaluate land use alternatives. The approach is able to contribute to optimizing land use from the

ecological perspective, but with attention to societal preferences. It allows for benchmarking farm-level land use alternatives by comparing the services that they would deliver under different land allocation scenarios. In essence, this comes down to a choice between combining ES delivery by opting for integrated, multifunctional forms of land use, or rather focussing on the promotion of a single or limited number of ES, aiming to maximize yield. The reality on the terrain is often not unequivocal, and our analysis demonstrates that an optimal land use allocation depends on the landscape context.

In addition to the value of the provisioning services that are delivered, our analysis takes the societal value of a number of regulating and cultural ES into account, many of which are currently treated as externalities by our market system. Even when using conservative estimates, doing so resulted in shifts in preference towards more integrated solutions promoting larger bundles of ES in a landscape. This is particularly the case in landscapes with particular biophysical constraints, like higher degrees of fragmentation, urbanisation, or where baseline agricultural yields are lower. As such, in the context of our research, it can be a viable strategy to opt for land sharing where you can, and land sparing where you have to (e.g. due to regulations). Although, in the absence of said biophysical constraints and at larger scales, it is likely the other way around.

Chapter 3 explicitly builds on the results from Chapter 2, and presents a methodological framework that was developed to explore adaptive management of bioproductive space. As such, this chapter is more about provoking thought and discussion on spatial resilience, rather than presenting specific results. The methodological framework itself, comprises four stages. The first stage is a spatially explicit evaluation of various ecosystem services for different land uses (cf. the analysis in Chapter 2). In a second stage, bio-physical and socio-economic drivers or shocks are introduced that can influence the value society attributes to specific ecosystem services. The third stage of the methodology takes policy priorities into account. In a final stage, the output of the approach is synthesised by ranking the analysis results for different scenarios and policy priority settings. This methodology allows spatial planners to explore and evaluate policy decisions against trade-offs between various land use alternatives, while taking ES into account. This method is applied to the case of Chapter

2 to demonstrate that, from a societal perspective, the optimal strategy can be highly context- and preference-dependent. Besides the potential for supporting policy makers to think about the broader implications of land use changes for community wellbeing, the methodology provides useful feedback for adaptive farm and landscape management.

Chapter 4 focuses on spatial ES analysis for practical applications in spatial planning. In order to make the ES approach operational for planning and management of bioproductive land, it is important to deal with the diversity of services, and the broad range of interactions between ES. In this study, the local ES supply is confronted with the local societal demand in the Flemish Metropolitan Core, a polycentric urban network with a highly fragmented landscape. Trade-offs and synergies between services were evaluated and ES bundles, series of ES that often co-occur in a landscape, were defined by combining spatial analysis techniques with an expert evaluation. This resulted in sensitivity maps that depict where there is a mismatch between local ES supply and demand. These maps were compared with predictions of possible future land use changes according to existing scenarios. Our research indicates that ES in the study area occur in specific patterns associated with social and biophysical structures and processes in the landscape. The sensitivity map delivers a rich and complex image of various emerging spatial interactions. By combining these maps with future land use scenarios, the regions are highlighted where an existing mismatch between local ecosystem service supply and demand bundles might be further exacerbated due to potential future land use changes. From these insights, guide models were drafted to inspire adaptive management of bioproductive space. As such, the research provides a means for practical application of ES in spatial planning.

With this research, it is demonstrated that the ES concept is useful for evaluating different land use alternatives, under changing regimes. A spatially explicit approach is required, taking both the landscape context and various trade-offs and synergies between bundles of ES into account. In a rapidly changing world, we will increasingly be dependent on the services delivered by well-functioning agro- and ecosystems. The concept of bioproductive space contributes to the operationalization of ES concepts in adaptive spatial planning.

In de komende decennia worden we geconfronteerd met de moeilijke taak om een redelijke levensstandaard te verzoenen met een herstel van onze ecosystemen, terwijl we moeten omgaan met de gevolgen van klimaatverandering en andere globale trends. Eén van de cruciale uitdagingen hierbij is hoe we ons landgebruik kunnen optimaliseren, en hierbij de nodige transities toe te laten. Dit onderzoek richt zich op de integratie van het concept van ecosysteemdiensten (eng. *ecosystem services*, ES) in ruimtelijke planning in Vlaanderen. Vlaanderen wordt gekenmerkt door een hoge graad van verstedelijking en versnippering van de open ruimte. Tegelijk is er een hoge druk op de resterende open ruimte om diensten te leveren, van voedselproductie en klimaatregulatie tot de buffering van water, om er slechts enkele te noemen. Een adaptieve ruimtelijk beleid kijkt best naar alle mogelijke ruimte die ES kan leveren. Om dit te faciliteren, wordt hier het begrip 'bioproductieve ruimte' naar voren geschoven, dat gedefinieerd kan worden als "*elke vorm van ruimte die functies en diensten kan leveren die rechtstreeks of onrechtstreeks voortkomen uit primaire productieprocessen*". Ruimtelijk beleid en landbeheer focussen sterk op meer 'klassieke' categorieën van landgebruik, zoals landbouw, bossen, natuurgebieden en stedelijke gebieden. Op dezelfde manier hebben de instrumenten van de ruimtelijke planning doorgaans ook betrekking op deze klassieke landgebruikscategorieën. Hierdoor hebben sommige delen van de bioproductieve ruimte de neiging om onderbelicht te blijven in beleid én onderzoek. Voorbeelden hiervan zijn bermen en overhoeken, braakliggende terreinen, verpaarding in agrarisch gebied, versnipperde open ruimtes in halfstedelijk gebied, of privétuinen. Belangrijke maatschappelijke uitdagingen zoals klimaatadaptatie, transities naar een circulaire economie en hernieuwbare energie, etc., interfereren reeds met alle klassieke vormen van landgebruik. Beleidsmakers in landgebruik en ruimtelijke planning hebben nood aan aangepaste diagnostische instrumenten om de trade-offs en synergieën in te kunnen schatten die zich aandienen bij beslissingen rond landgebruik, en dit over de sectorale grenzen heen. Dit houdt in dat er afwegingen gemaakt moeten worden tussen productiediensten aan de ene kant, en andere, niet-productiediensten aan de andere kant. Om dit elegant te doen, dienen ES op dezelfde noemer gezet te worden. In hoofdstukken

2 en 3 wordt het idee opgeworpen op dat monetaire waardering net dat kan doen, en op die manier als basis kan dienen om afwegingen te maken voor adaptief ruimtegebruik.

In hoofdstuk 2 wordt de levering van ES beoordeeld door middel van een geïntegreerde benadering, waarbij een combinatie gemaakt wordt van ruimtelijke en economische analyses. Dit onderzoek steunt op het ES concept om landgebruiksalternatieven te evalueren. Deze benadering draagt bij tot het optimaliseren van landgebruik vanuit een ecologisch oogpunt, maar met aandacht voor maatschappelijke voorkeuren. De benadering laat toe landgebruiksalternatieven te onderzoeken op bedrijfsniveau door alternatieven te vergelijken op basis van de diensten die ze leveren onder uiteenlopende scenario's van landgebruik. In essentie komt dit neer op een keuze tussen ES combineren door te kiezen voor geïntegreerde, multifunctionele vormen van landgebruik, of veeleer te focussen op het ontwikkelen van één of een beperkt aantal ES, met het oogpunt op opbrengstmaximalisatie. De realiteit op het terrein is doorgaans niet ondubbelzinnig, en onze analyse demonstreert dat een optimaal landgebruik afhangt van de landschappelijke context.

Naast de waarde van de geleverde productiediensten, neemt onze analyse ook de maatschappelijke waarde van een aantal regulerende en culturele diensten mee in rekening, waarvan de meesten beschouwd kunnen worden als economische externaliteiten voor ons marktsysteem. Zelfs met conservatieve inschattingen, resulteerde dit in een verschuiving van de voorkeur richting meer geïntegreerde oplossingen, waarbij grotere bundels van ES in een landschap de voorkeur genoten. Dit is in het bijzonder het geval in landschappen met specifieke biofysische beperkingen, zoals een hogere graad van fragmentatie, verstedelijking, of waar de opbrengsten uit landbouw algemeen lager zijn. In de context van ons onderzoek kan het een te verantwoorden strategie zijn, om te opteren voor verweven wanneer je kan, en te scheiden wanneer je moet (vb. omwille van regulering). Wanneer de hogergenoemde biofysische beperkingen wegvallen echter, is wellicht eerder de omgekeerde redenering van toepassing.

Hoofdstuk 3 bouwt expliciet verder op de resultaten van hoofdstuk 2, en presenteert een methodologisch kader dat ontwikkeld werd om de mogelijkheden rond adaptief beheer van bioproductieve ruimte te verkennen. Het hoofdstuk is veeleer bedoeld om discussie rond ruimtelijke veerkracht te stimuleren en presenteert als dusdanig geen op zich staande resultaten. Het methodologisch kader omvat vier trappen. De eerste trap betreft een ruimtelijk expliciete evaluatie van ES onder uiteenlopende landgebruiksalternatieven (cf. de analyse voorgesteld in hoofdstuk 2). In een tweede trap, worden biofysische en socio-economische drijfveren geïntroduceerd, welke een invloed hebben op de waarde die de maatschappij hecht aan specifieke ES. De derde trap vervolgens, brengt beleidsprioriteiten in rekening. De vierde en laatste trap maakt tenslotte een synthese door de analyseresultaten telkens weer te rangschikken onder de verschillende scenario's van waardering en beleidsvoorkeuren. Dit methodologisch kader laat ruimtelijke planners toe om beleidskeuzes te evalueren tegen afwegingen van verschillende landgebruiksalternatieven, op basis van de te leveren ES. De methodiek wordt hier toegepast op de gevalstudie van hoofdstuk 2 om te demonstreren dat, vanuit een maatschappelijk oogpunt, de optimale strategie erg afhankelijk kan zijn van context en voorkeur. Naast het potentieel om beleidsmakers bewust te maken van de bredere implicaties van veranderingen in landgebruik op maatschappelijk welzijn, biedt de methodologie ook nuttige feedback voor adaptief landbeheer en een adaptieve bedrijfsvoering.

In hoofdstuk 4 wordt een ruimtelijke analyse van ES met vertaalslag naar praktische applicaties voor ruimtelijke planning voorgesteld. Om het ES concept te operationaliseren in planning en beheer van bioproductieve ruimte, is het belangrijk om te kunnen gaan met de veelheid aan verschillende diensten, en de brede waaier aan mogelijke interacties tussen ES. In deze studie is een afweging gemaakt van het plaatselijk aanbod aan ES, met de lokale maatschappelijke vraag naar ES in het Vlaamse metropolitane kerngebied, een polycentrisch stedelijk netwerk met een sterk gefragmenteerd landschap. Trade-offs en synergieën tussen diensten werden geëvalueerd, ES bundels, i.e. combinaties van ES die vaker samen voorkomen in een landschap, werden gedefinieerd door een combinatie van ruimtelijke analyse met expertbeoordeling. Hieruit werden gevoeligheidskaarten ontwikkeld, welke een ruimtelijke mismatch aangeven tussen het aanbod aan en de vraag naar ES. Deze kaarten werden vervolgens vergeleken met toekomstmodellen van landgebruikswijzigingen die ontwikkeld zijn naar gekende scenario's. Het onderzoek wijst uit dat ES in het studiegebied voorkomen in specifieke patronen, die geassocieerd kunnen worden met sociale en biofysische structuren en processen in het landschap. De gevoeligheidskaarten leveren een rijk en complex beeld op van uiteenlopende emergente ruimtelijke interacties. Door een combinatie met toekomstscenario's, wordt eveneens op de kaart waar een bestaande mismatch tussen ES bundels verder onder druk zal komen te staan door mogelijke toekomstige veranderingen in landgebruik. Vanuit deze inzichten, werden gidsmodellen opgesteld die als inspiratie kunnen dienen voor het adaptieve beheer van bioproductieve ruimte. Op die manier levert dit onderzoek een bijdrage aan praktische toepassingen van ES concepten in ruimtelijke planning.

Met dit onderzoek is aangetoond dat het ES concept bruikbaar is voor de evaluatie van verschillende landgebruiksalternatieven, onder veranderende regimes. Een ruimtelijk expliciete benadering is hierbij essentieel, waarbij rekening gehouden moet worden met zowel de landschappelijke context als de verschillende trade-offs en synergieën tussen bundels van ES. In een snel veranderende wereld, zijn we steeds meer afhankelijk van de diensten die geleverd worden door goed functionerende agro- en ecosystemen. Het concept van bioproductieve ruimte levert een bijdrage aan het operationaliseren van ES concepten in een adaptieve ruimtelijke planning.

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List of Abbreviations

BAU	Business-as-usual
CICES	Common International Classification of Ecosystem Services
CSA	Community supported agriculture
ES	Ecosystem Services
EU	European Union
GIS	Geographic information system
IAESSD	Integrated Assessment of Ecosystem Service Supply and Demand
LSU	Livestock units
NARA	NatuurRapport (*eng*. Flemish Nature Report)
NGO	Non-governmental organisation
PES	Payments for Ecosystem Services
PM	Particulate Matter
SES	Social-ecological system
SN	Spatially neutral
SRC	Short rotation coppice
WTP	Willingness to Pay

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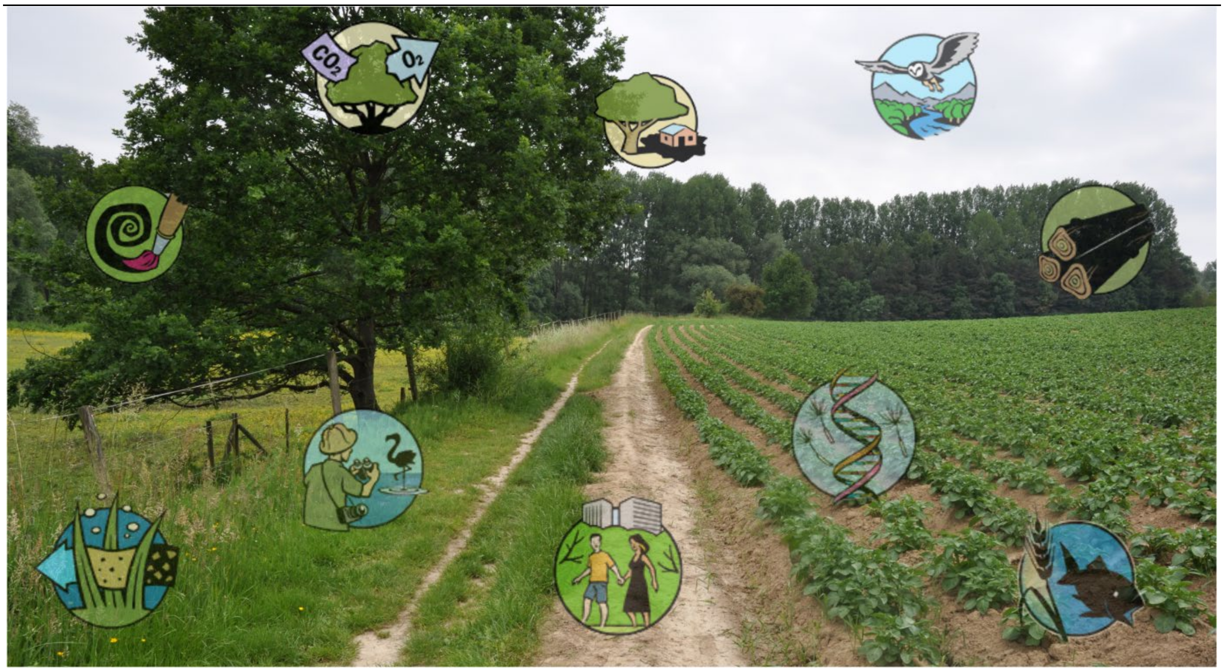
Chapter 1.
General introduction



Icons: Jan Sasse, TEEB

Chapter 1.
General introduction

1 Towards an adaptive and resilient bioproductive space

We do not transcend nature, but are part of it. Human society relies on a myriad of services provided by ecosystems, from food and wood production, water and air purification, soil nutrient cycling, crop pollination, the provision of recreational greenspace and natural beauty, to educational and spiritual values. At the same time, we are at the mercy of nature. The more we encroach upon ecosystems and undermine their structural integrity, the more society feels the need to push these systems to keep on delivering these much needed services. The past century, we have seen biodiversity decline at an increasing rate, altering the functioning of ecosystems (Cardinale et al., 2012). This is not sustainable, and has already drastically affecting human welfare (Crépin et al., 2012; Folke et al., 2004; Scheffer et al., 2001). This problem is exacerbated by climate change. Although it is known for decades that climate change will pose considerable societal challenges in the 21st century, the last decade, awareness on these issues by the general public has been increased drastically. Amongst the effects visible in western Europe are more extreme weather events, resulting in structural droughts and floods. We are in need of more resilient forms of land use to cope with these phenomena, and to allow ecosystems to persistently deliver the services we depend on.

1.1 The concept of Ecosystem Services

1.1.1 A typology of ecosystem services

Ecosystem Services (ES) are generally defined as the benefits provided to humans by ecosystems (Costanza et al., 1997; Millennium Ecosystem Assessment, 2005). While this definition is straightforward, it is too general to be used in operationalizing the concept, and several authors have proposed useful extensions of the concept (Fisher et al., 2009; Haines-Young and Potschin, 2010; Wallace, 2007). Potschin and Haines-Young (2011) and De Groot et al. (2010) rather define ES as the contributions ecosystems make to human well-being, through the benefits they are able to deliver. ES are classifies into provisioning, regulating and cultural ES. The concept has seen several initiatives to develop a useful classification system. In an effort to unify ES classification over other classifications that were and are also in use (see De Groot et al., 2010; Jones-Walters and Mulder, 2009; Millennium Ecosystem Assessment, 2005) in the EU, ES are commonly classified according to the Common International Classification of Ecosystem Services (CICES). CICES is regularly revised and amended, the latest version at the time of writing being v5.1 (Haines-young and Potschin, 2018), and classifies ES into provisioning, regulating, and cultural ES (Haines-young and Potschin, 2018; Haines-Young and Potschin, 2010), which are further subdivided into hierarchical categories of sections, divisions groups to classes. These classes have been refined by Turkelboom et al. (2014) for use in Belgium. Provisioning services include biomass production such as plants and animals for nutrition, materials or energy, but also the provision of genetic materials such as seeds and gametes. Abiotic provisioning services include the provision of drinking water and water for industrial processes. Regulating ES include a.o. flood buffering, pollination, disease and pest control, buffering against human nuisance such as noise and visual disturbances, climate control, regulation of atmospheric composition and conditions, and soil quality regulation. Cultural ES include a.o. greenspace recreation, as well as intellectual, educational and spiritual interactions with nature. ES are predominantly delivered by well-functioning, well-structured and healthy ecosystems (Potschin and Haines-Young, 2011) and have an outspoken spatial component in that different landscapes have a varying ability to provide ES (Burkhard et al., 2009). An overview of the ES classes directly or indirectly addressed in this manuscript, is given in Table 1.

The various components of ecosystems are intimately interconnected. Therefore, it makes little sense to single out individual ES. As a result, the ES concept stimulates to think in a more integrated fashion, and across scales. The hierarchical CICES classification facilitates this and allows implementation of the concept by various actors on various spatial scales (Haines-young and Potschin, 2016).

Table 1. Selection of ES (not exhaustive) directly or indirectly relevant to the work in this dissertation (adapted from the classification according to CICES 5.1.).

Section	Division	Group	Class
Provisioning (biotic)	Biomass	*Cultivated terrestrial plants* for nutrition, materials and energy	[…] for nutritional purposes
			Fibres and other materials from […]
			[…] as source of energy
		Reared animals for nutrition, materials or energy	[…] for nutritional purposes
		Wild plants for nutrition, materials or energy	[…] for nutritional purposes Fibres and other materials from […]
	Genetic material from all biota	Genetic material from animals	
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water used as a material (non-drinking purposes)
			Ground (and subsurface) water for drinking
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals
		Mediation of nuisances of anthropogenic origin	Noise attenuation
			Visual screening
	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates
			Hydrological cycle and water flow regulation (Including flood control, and coastal protection)
		Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)
		Pest and disease control	Pest control (including invasive species)
		Regulation of soil quality	Decomposition and fixing processes and their effect on soil quality
		Water conditions	Regulation of the chemical condition of freshwaters by living processes
		Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans
			Regulation of temperature and humidity, including ventilation and transpiration
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions
		Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge
			Characteristics of living systems that are resonant in terms of culture or heritage

1.1.2 Drivers affecting ES delivery

Land use and climate change, as well as biodiversity loss can be identified as principal drivers affecting the delivery of ES (Metzger et al., 2006; Millennium Ecosystem Assessment, 2005; Nelson et al., 2006; Schröter et al., 2005). Given the central role of land use in shaping biophysical structures and hence, the delivery of ES, the ES concept can be used to evaluate land use changes or to support decision making regarding the allocation of land to specific uses, which is central to spatial planning. Rather than evaluating land uses based on unimodal biophysical indicators, the ES concept allows to assess a broad range of potential benefits to humans.

More recently, research efforts have increasingly been focusing on the complex link between biodiversity and ES delivery (Jax and Heink, 2015a; Quijas et al., 2019). Increasing ES delivery and promoting biodiversity are distinct conservation targets that not always go hand in hand. Moreover, the impact of biodiversity loss on global ES delivery is a complex matter altogether. It is important that we look at ES and biodiversity to understand the link between both. The concept of 'biodiversity' encompasses a range of definitions, relating to the number of species, formal, genetic or functional diversity, variability and being different. The essence here is the link between biodiversity and ecosystem functioning: different species occupy different ecological niches, and therefore contribute in different ways to ecosystem functions. In essence, maintaining various ecosystem functions to deliver ES, requires various species to be present in the ecosystem. Gamfeldt and Roger, (2017) argue that, while maintaining single functions or services might require a limited amount of species, the simultaneous delivery of a multitude of ES requires increasingly higher levels of biodiversity. In other words, there is in general a positive relation between biodiversity and the ability to deliver multiple ES.

However, in a number of cases single ES are found to be at odds with biodiversity conservation goals. In forest-based biomass production for energy for example, management aiming to increase biomass harvest generally results in forest biodiversity loss and loss of social functions, due to, amongst others, changing forest characteristics like a local and regional reduction in variation and heterogeneity, and a lack of deadwood (Eyvindson et al., 2018). From these complex interactions between the delivery of single ES or bundles of ES on one hand, and conservation targets on the other hand, the question arises how to spatially combine or reconcile these goals on a landscape scale. With respect to agriculture versus nature conservation, this dilemma is known as the land sharing versus land sparing debate.

1.1.3 To share or not to share?

Land sharing is any land use allocation strategy that combines agricultural production with nature conservation, typically characterized by extensive forms of agriculture interspersed with (semi-)natural elements like hedgerows, forest patched, grass buffers strips, etc (Phalan et al., 2011b; Phalan, 2018). Land sparing strategies on the other hand, strictly segregate land for agricultural production from land for conservation purposes. The idea is that by using particularly fertile lands for intensive food, feed and fibre production, the resulting high yields allow for other lands to be spared, and used for nature conservation. So in a land sparing strategy, agricultural intensification is purposefully done with the intention of restoring natural habitats elsewhere. In that sense, it adds to the Borlaug hypothesis (that states that improvements in agricultural yields enable food supply to increase without further increasing deforestation rates) by putting a clear emphasis on the underlying intention for the intensification (Phalan, 2018). It is obvious that the land-sparing and land sharing strategies represent two ends of a spectrum, and that intermediate strategies exist, depending on the scale on which the sharing or sparing is taking place. Both strategies have the same ethical goal: allow for food production and security while maximizing biodiversity conservation on a global scale. A strength of the framework, is that it evaluates per-species density, and not just overall species richness, in the comparison of sharing versus sparing strategies. While some authors advocate land sparing as a preferred strategy (Phalan et al., 2011a), others (e.g. Tscharntke et al., 2012) argue that in many cases, integrated forms of land use (under the umbrella term of ‘land sharing’) are more effective in meeting societal demands for ES, and less susceptible to undervaluing functional biodiversity. Many empirical studies, in particular those taking biodiversity explicitly into account, are in favor of land sparing strategies (Luskin et al., 2018). However, there are some crucial concerns towards land sparing. One concern is that some externalities are overlooked. For example, intensive agriculture relies heavily on pesticide use, and the long-term impact of pesticides on society (health issues, associated costs) and biodiversity (in particular soil biodiversity) might be underestimated, impacting food security in the long term. Another cause of concern is that while increasing yields goes theoretically hand in hand with more space for wildlife, the reality on the terrain is often very different (Luskin et al., 2018), even if there is an intention to free up land for nature conservation, e.g. because the conservation actions are not enforced. The main argument against land sharing strategies is that there is a limit to how wildlife-friendly agricultural land can be made, and there is a trade-off with yield. This trade-off is in some cases exacerbated by ecosystem disservices like pest species and wildlife damaging crops. Like we pointed out earlier, disservices are often underrated in studies. So the general idea behind the critique is that the more farmland is made wildlife-friendly, the more space is needed to maintain the same level of yield. It must be stressed that in the sharing-sparing debate, reductions and shifts in consumption patterns (e.g. reducing meat consumption), along with (agro)ecological intensification strategies, are also seen as part of the solution.

1.1.4 General strengths and limitations of the ES concept

The ES concept is widely regarded as a successful approach to assess relationships between the natural world and human society, and to draw attention to chronically undervalued contributions of ecosystems to human well-being. While the idea that human society strongly benefits from services delivered by nature, is by no means a new one. The contemporary notion of ES was rooted in the older concept of 'environmental services' as coined in the MIT publication 'Man's impact on the global environment: report of the study of critical environmental problems (SCEP)' (Wilson and Matthews, 1970). The ES concept rapidly gained ground after the keystone publication of Costanza et al. (1997) and Daily, (1997). Since then, ES entered mainstream research and subsequently, policy making (Costanza et al., 2017).

The principal strength of the ES concept is that it is able to underline those contribution by nature to human welfare that are chronically undervalued by society, and more specifically, undervalued by conventional economics (Lele et al., 2013). A key factor contributing to the rapid adoption of the term is that it combines ideas and terminology from the fields of economics and ecology, fields that are often at odds with each other. Yet, with the ES concept, ecologists had a clear framework to underline the economic contributions of ecosystems to society. This included not only direct contributions, like food, fibre or wood, but also indirect contributions. As such, the application of ecosystem service assessment should lead to better decision making.

Also, the ES concept is able to foster trans- and interdisciplinary collaboration and communication between various actors (Hauck et al., 2013; Jax et al., 2013). The ES concept can be considered to be a boundary object, in that it can be interpreted in various ways by different actors (Ainscough et al., 2019; Steger et al., 2018). This is not necessarily considered a weakness, as long as the concept manages to retain a proper integrity (Costanza et al., 2017; Steger et al., 2018). Moreover, one of the main purposes of the concept is to stimulate dialogue and action between actors and communities. Therefore, one of the great strengths of the ES concept lies in the -albeit limited-ambiguity of its definition, making it useful and accessible to actors of various backgrounds (Haines-Young and Potschin, 2014). However, the vagueness of the concept in absence of a clear definition and classification is sometimes perceived as a shortcoming (Ainscough et al., 2019; Hauck et al., 2013). This highlights the relevance of defining solid ES classification systems (Costanza, 2008), and at least a clear definition that upholds within a specific context, jurisdiction or stakeholder group (Jax et al., 2013).

Despite all these strengths, the ES concept also attracted critical remarks and concerns in the two decades it has become mainstream (Costanza et al., 2017; Saarikoski et al., 2018). We can expand on a number of principal fields of critique as identified by Lele et al. (2013) and Schröter et al.,(2014): (1) the lack of clarity in definitions and classifications; (2) underestimating the complexity of the link between ES and ecosystem functioning, including trade-offs and synergies; (3) an anthropocentric focus, at risk of conflicting with biodiversity conservation efforts; (4) the normative character of the concept, with a general emphasis on beneficial services, while neglecting disservices and (5) the use of economic valuation to measure human well-being, risking the commodification of natural values. We will address these fields of critique here, and in the next section, we expand on the practical implications of some of these shortcomings when applying the ES concept in spatial planning.

First It is difficult to clearly categorize 'final ES' from supporting services or ecosystem functions, and if this is not done properly, there is a risk of double counting in ES assessments. Moreover, what constitutes a final service is often context dependent, and any service might produce different benefits to various actors (Haines-young and Potschin, 2016; Hauck et al., 2013). Also, the omission of abiotic services has long been seen as a crucial gap in ES research. Historically, the focus of the ES concept has indeed been predominantly on the biotic contributions of ecosystems, i.e. those rooted in primary production processes. However, the latest CICES classification also allows to include abiotic contributions of ecosystems such as water, mineral substances and geothermal energy.

The second field of critique addresses the discrepancy between the apparent linear simplicity of the ES concept, and the intrinsic complexity of the underlying ecosystems contributing to the services provided (Evans, 2019; Zulian et al., 2018). In many cases, this is exacerbated by policy and decision makers for clear and understandable decision support tools (Ruckelshaus et al., 2015). 'Idealisation' of problems (i.e. reducing their complexity to make them manageable) is widespread in ES research. But it does not necessarily poses problems, as long as ES models are not oversimplified (Hauck et al., 2013), and remain representative for reality and heuristically useful (Evans, 2019). Some shortcomings of ES based research in relation to food security are highlighted by Cruz-Garcia et al. (2016). They found a bias towards the assumption that an increase in crop productivity would automatically lead to increased food security, while aspects of utilization and continuous access to food sources, as well as the effects of co-production, trade-offs and indirect effects are often neglected (Zhou et al., 2019). Some of these issues raised, like the negligence of trade-offs and synergies, are addressed in greater detail in section 1.2.2. Furthermore, the discrepancy between real-world complexity and 'simple' ES models translates in a lack of clarity in the literature about the role of ecosystem functioning and biodiversity in the delivery of ES. As long as ES indicators do not take the underlying ecosystem functioning into account, the importance of (functional) biodiversity is at risk of being underestimated. As highlighted in the previous paragraph, this unclarity is even reflected in the various attempts to classify ES, for example in whether or not to consider supporting ES as proper ES in itself. While this issue exists for a broad range of 'intermediate' or 'supporting' ES, such as nutrient cycling or pollination, it is particularly confusing with respect to the role of biodiversity, which brings us to the third -related- field of critique.

The ES concept is an anthropocentric concept. The very nature of the ES concept implies focus on services that are deemed useful for (specific actors in) society (Jax and Heink, 2015b). As such, the promotion of biodiversity *in se* is in principle not a direct goal of the concept, and conservation efforts based on ES evaluation might counteract efforts based on biodiversity conservation (Schröter et al., 2014). It can be argued for example, that maximizing some specific ES (e.g. crop production) leads to an overall reduction in biodiversity. Or, that increased biodiversity might serve no specific utilitarian purpose (from the anthropogenic perspective), or causes ecosystem disservices like disease and pests. Conserving biodiversity and maintaining rare species in an ecosystem often go hand in hand. This thus raised the question whether rare species contribute significantly to ES delivery. Dee et al. (2019) make the argument that they do, through interspecific interactions, and that ES delivery can in many cases benefit from maintaining rare species. This is because rare species often have particular unique functional traits in ecosystem processes, and that the most critical function in high-diversity ecosystems are often delivered by rare species with low functional redundancy in the system (Mouillot et al., 2013). The insight that biodiversity loss compromises several key components in ES delivery, like nutrient cycling, decomposition of (organic) matter, and the production of organic compounds and biomass, has been scientifically well established (Cardinale et al., 2012). Therefore, in the Millennium Ecosystem Assessment (2005), biodiversity is regarded as an essential -in fact the essential- 'supporting' ES. Nowadays, the tendency is to consider biodiversity as an essential prerequisite for ecosystem functioning, which many authors see as self-evident. In valuation studies, biodiversity is sometimes implicitly included as part of the non-use value of ecosystems. While many scholars recognize that there exists a positive relationship between biodiversity and ES delivery, this relationship is obviously more complicated (Cardinale et al., 2012). It is therefore important to understand the link between biodiversity and ES delivery. For some, mere including biodiversity indicators is not sufficient. (Mouillot et al., 2013) argue that in natural capital accounting, i.e. measuring changes of stock in natural capital, even for efforts based on species and/or ecosystem abundance rather than indirect proxies, one risks to underestimate the contributions of rare species or rare species interactions.

The fourth field of critique addresses a specific bias in ES research. There is an overall focus on beneficial services, while negative services or ecosystem disservices are often neglected (Turkelboom et al., 2014), save for some exceptions (e.g. Zhang et al., 2007). Turkelboom et al. (2014) define ecosystem disservices as the "*functions of ecosystems that are (or are perceived) as negative for human well-being*", and list a number of examples in four categories: (1) species directly affecting human health; (2) species impacting provisioning services; (3) causes of discomfort by nature; and (4) natural disasters. In their effort to draft a local CICES classification for Belgium however, they opted not to include disservices explicitly, since they form part of a single continuum with the 'positive' ES. Moreover, whether a services is regarded as positive or negative lies much in the eye of the beholder.

The final field of critique we want to address here, is the use of economic valuation techniques to measure ES delivery and human well-being. The general idea is to include economic externalities in ES assessments, in order to improve the ecological outcome of private and public projects that have consequences that stretch over time and that entail either an accumulation of capital or the adoption of a government policy. Furthermore, valuation techniques are used to compare various ES on the same scale (Zhou et al., 2019). However, such an economic focus might lead to a more exploitative take on nature-society relations, and ultimately lead to the commodification of nature and systemic negligence of those ecosystem components that have no direct use value (Schröter et al., 2014).

1.2 Exploring the ES concept in spatial planning

1.2.1 General principles

A useful conceptual model to demonstrate how various aspects of ES provision are related to each other, and where they fit into the narrative of ES evaluation for adaptive planning, is the ES cascade (Haines-Young and Potschin, 2010; Potschin and Haines-Young, 2011) (Figure 1). The cascade describes final ES as embedded in the interface between ecological components and social components of a system. These final services are the contributions to human well-being that are the result of supporting or intermediate services, and that deliver certain goods or services. The delivery of final ES is therefore dependent on well-functioning ecosystems, which are in turn reliant on the bio-physical structures and processes in the landscape. For example, wetlands ecosystems form in lowlands, depressions and river valleys, where they provide specific ES like water buffering, denitrification, water purification, etc. The sustained delivery of these services depends on the nature and characteristics of the wetland. On the other hand, all ES delivered represent a benefit -positive or negative- for society, which one can try to quantify or value, sometimes even in monetary terms. Feedback loops exist between all components of the cascade, and this is how needs and preferences of actors in society trickle down and are able to influence decisions made on the management of biophysical structures in the landscape, which in turn affects ecosystem functioning, and hence, the delivery of ES.

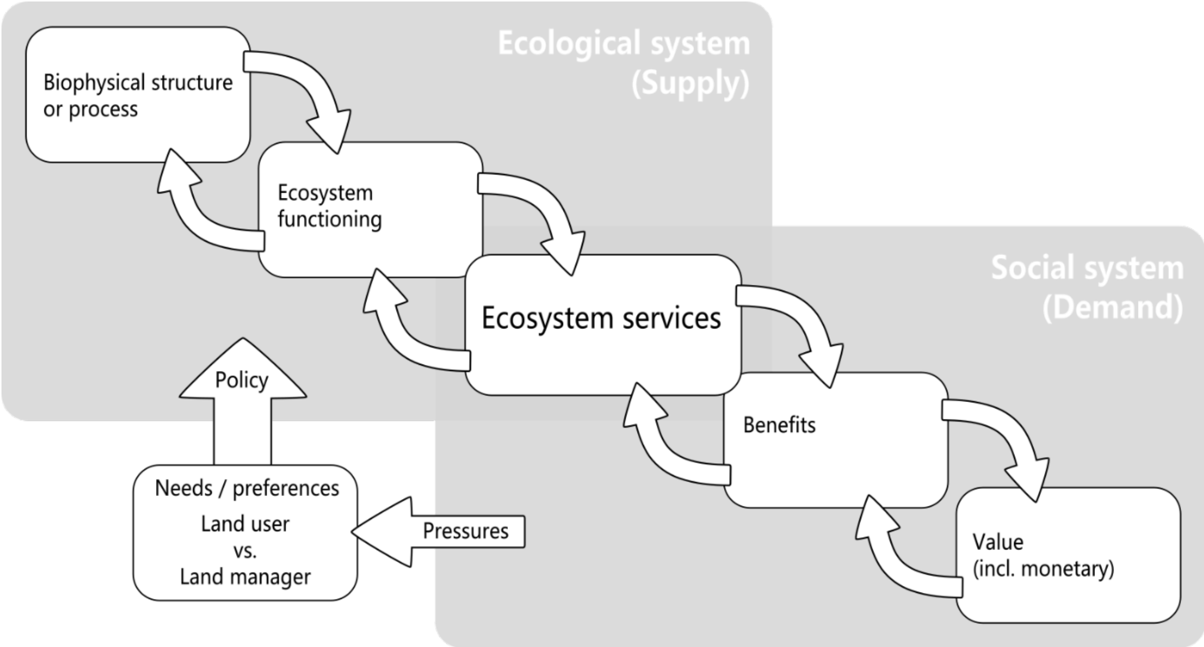


Figure 1. The ES cascade is a useful concept to illustrate how different aspects of a social-ecological system influence each other. Adapted after Potschin and Haines-Young (2011) and Wei et al. (2017).

The ES cascade is complemented by the structure-function-value chain behind the concept of 'landscape services' as proposed by Termorshuizen and Opdam (2009). They argue that a solid knowledge on how changes in landscape structure and functioning are related to the societal values produced by this landscape, is an essential prerequisite for sustainable decentralised landscape planning. It is equally essential to support decision making by producing knowledge and tools that are suited for collaborative decision making on appropriate spatio-temporal scales (de Groot et al., 2010). The landscape scale, although somewhat arbitrary, is often the most appropriate scale for such research efforts (Fisher et al., 2008). It is therefore important to properly integrate the ES concept into spatial planning practices (Baró et al., 2017; Galler et al., 2016; Hansen et al., 2015; McPhearson et al., 2014; Rall et al., 2015; Raudsepp-Hearne et al., 2010). This requires a critical view on the challenges for integrating the ES concept in spatial planning.

1.2.2 Challenges for application of the ES concept in spatial planning

We identify a number of challenges, conceptual and technical in nature, that need to be tackled when incorporating the ES concept in spatial planning practices (Groot et al., 2010; Termorshuizen and Opdam, 2009; Wei et al., 2017).

It can be particularly challenging to define, quantify and value ES while taking spatial aspects into account. In deciding where to introduce and foster ES in the landscape, a spatially explicit approach is required, and a plethora of ecologic and socio-economic aspects needs to be taken into account. A basic ascertainment is that by definition, ES can only be delivered if there are people able to enjoy and value its benefits. While the demand for some ES (e.g. food) can be met by goods and services that are produced elsewhere, the demand for other ES (e.g. recreation) can only be met if the goods and services are produced in the close vicinity of the people who enjoy and benefit them. It is therefore important to complement ES supply information with data on the demand for ES (Burkhard et al., 2012), which Wei et al. (2017) refer to as 'integrated assessment of ES supply and demand' (IAESSD). Also the assessment of ecological aspects of land use planning, benefits from a spatially explicit approach. After all, many ecological processes at the root of ecosystem functioning and thus ES delivery, are dependent on clear spatial aspects like scale, configuration and connectivity. Reciprocally complementary and supplementary ecosystem components need to be properly connected in order to function (Colding, 2007; Ng et al., 2013; Opdam et al., 2006). A straightforward example is the relative location and quality of the ecological connection of pollination-dependent crops to pollinator-friendly habitats (Holzschuh et al., 2012). For some ES, a minimal area is required, whether or not combined with a maximal distance to the end user. An example here would be greenspace recreation as an ES, where there is a minimal demand for (admittedly small) recreational areas close to the residence. This demand often comes together with a demand for larger recreational areas that can be located further away. At the same time also quality and substitutability -the degree to which substitutes for the recreational greenspace exist-are relevant aspects to consider (De Valck et al., 2016). Apart from the fact that both economic and ecological processes act in a spatially explicit way, a number of other reasons can be put forward to focus on a spatially explicit approach. When evaluating trade-offs and synergies between ES in a landscape, spatial heterogeneity and location-specific variations in supply and demand need to be taken into account (Baró et al., 2017; Zulian et al., 2018). From a spatially explicit research approach the insight emerges that ES are never randomly dispersed over a landscape, but occur in patterns.

Some ES often coincide in a landscape, while other ES behave antagonistically, and tend to rule each other out. For example, erosion control and carbon storage in biomass show a strong spatial association, since similar ecosystems are responsible for the delivery of both these ES. Flood control and water infiltration to deep aquifers on the other hand, rarely go hand in hand, and are delivered by different landscape components. Also within a landscape units, trade-offs might occur. Schwaiger et al., (2019) for example, demonstrate a trade-off between wood production and groundwater recharge in German forests. In agricultural landscapes, trade-offs exist between food production, regulating services and biodiversity (Holt et al., 2016). From these observations, we can conclude that it is often more relevant to assess bundles of ES, rather than individual ES (Baró et al., 2017; Haines-Young et al., 2012; Raudsepp-Hearne et al., 2010; Turner et al., 2014; van der Biest et al., 2014). The global aim of an IAESSD should be to translate deficits in ES supply towards adapted solutions at a spatio-temporal resolution that is useful for policy makers and land managers. A growing body of literature deals with the challenges associated with spatially explicit approaches, and our research adds to this in a number of ways.

Next, there is the challenge to combine ecological with economic approaches. An economic approach in ES valuation is particularly useful to operationalize ES concept in planning policy (Fisher et al., 2008), not in the least because it allows local actors to decide on the societal values of ES in a given landscape context (Galler et al., 2016; Termorshuizen and Opdam, 2009). This also follows logically from the ES cascade concept. Economic theory encompasses a number of methods to evaluate the needs and preferences of both the land user and the land manager, some of which include monetary valuation techniques. It should be noted that, although an economic approach often comprises monetary valuation, for this research we use the term in a broader sense. An economic approach also lends itself to compare ES supply versus demand, which is an essential part of any spatially explicit evaluation of land use regimes. We agree with Wei et al. (2017), who argue that in IAESSD studies, the reciprocal relations between the social-ecological and economic parts of a system can only be evaluated when taking into account both the supply of ES by ecosystems, as well as the demand for ES by society.

At the same time, an economic approach is not without its risks and caveats (Galler et al., 2016). Applied in a strict sense, an economic approach is at the risk of falling short to including the complexity of ecosystems into the equation (Gómez-Baggethun and Muradian, 2015). The ES concept in itself comprises an outspoken anthropocentric view on nature. The concept was originally conceived as complementary to other fundamental ethical and scientific arguments pro nature conservation (Costanza et al., 1997; Millennium Ecosystem Assessment, 2005). Yet, it still tends to shift the focus away from the intrinsic 'conservation' value of nature, towards a more utilitarian view (Opdam et al., 2015). The ES cascade of Potschin and Haines-Young (2011) firmly roots ES delivery as a function of underlying structures, processes and functions. In this way, the intrinsic conservation value of nature is brought back in the equation. This underlines the importance of taking (functional) biodiversity into account when evaluating potential ES supply (Groot et al., 2010; Verheyen et al., 2014), as the link between both is still poorly understood (Pires et al., 2018). However, an economic valuation approach does sometime implicitly include biodiversity, as part of the non-use value of ecosystems, i.e. the value that is not accessible to people. As we stated earlier in Section 1.1.4 , biodiversity is regarded as an essential -in the essential- 'supporting ES'.

1.3 The need for adaptive planning practices

An important concern to policy makers in spatial planning is how to ensure the provision of optimal bundles of ES, even under various societal changes, shocks and regime shifts, e.g. due to driving forces like global change, market shifts, natural disasters or geopolitical developments. Regime shifts can be defined as substantial reorganisations within a social-ecological system affecting structure, functioning and internal feedback loops (Crépin et al., 2012; Walker et al., 2004). They pose a significant challenge in contemporary land management, because they are often difficult to predict, but can lead to significant and persistent changes in ES delivery (Crépin et al., 2012). Land management is best organized in ways that allow to adequately (and proactively) react to regime changes, by optimizing land use in ways that simultaneously meet the demand for services (Zell and Hubbart, 2013), while keeping the underlying ecosystems responsible for providing them in good condition (Muys, 2013). With any transition of a social-ecological system from one state into another, we can consider the implication in terms of ES delivery. A transition can affect the ES delivery itself, i.e. an expected increase or decrease can be modelled or estimated. However, it might also affect the societal value attributed to ES, in particular when the ES becomes either very scarce or overly abundant (Fisher et al., 2008).

Changing regimes force us to rethink our use of the land we have available to provide us with the goods and services we need. While the demand on open space to deliver a multitude of services is increasing, the aforementioned drivers are often undermining these services. Retaining some degree of (potential) self-sufficiency to meet the local societal demands for ES is a major component to build a resilient society (Baró et al., 2017; Malucelli et al., 2014; McPhearson et al., 2014). A truly resilient society can be affected by crisis, but not to a debilitating extent. Instead, a resilient society is not so much impeded by crisis, but rather responds by using the opportunity to redevelop and reorganize into an adapted form (Folke et al., 2005). In other words, the system responds to crisis by transforming into forms that are adapted to the new regime.

In order to achieve adaptive planning, there is the need to investigate how interventions and actions can transform the structure-function-value chain of the ES cascade, so that societal benefits are maximized under different regimes. Local actors and decision makers are to collaborate to foster ES while taking into account the ecology and spatial context of a specific landscape. Adaptive land management is largely decentralized, working through bottom-up initiatives rather than according to a top-down set of rules (Termorshuizen et al., 2007). Local actors need tailor-made solutions to make informed decisions. This involves translating complex system properties to tools, metrics and principles that transparent, and usable on the local level.

1.4 Bioproductive space as a research concepts for integrating ES in adaptive planning practices

Striving towards adaptive planning forces us to rethink how we perceive the meaning and potential of available spaces. A strict sectoral view on open space often impedes innovative thought processes on adaptive land management. Spatial policy and land management typically put much of their focus on the 'classic' land use categories like agriculture, forestry and urban areas. Likewise, instruments of spatial policy mostly relate to these classical land use categories. Another example is the core concept of 'open space' in spatial planning, which does not include some particular greenspaces. As an overall result, a portion of the greenspace has the tendency to stay under the radar of policy and research. Examples are abandoned private lands, roadsides, 'tare land' (*sensu* Bomans et al., 2010a) or domestic gardens. In a diffuse urbanised landscape like Flanders', domestic gardens constitute a significant portion of the total bioproductive land area (Bomans et al., 2011; Dewaelheyns et al., 2014). Many actors involved in rethinking how ES can be provided on a landscape level, already develop production systems that cross the classic sectoral boundaries in some way or another, or can be seen as hybrids or combinations of classic forms of land use. Examples are agroforestry, i.e. forms of land use where trees are combined with agriculture or livestock production, community supported agriculture (CSA) and urban agriculture, or eco- and agritourism.

For the research presented in this thesis, we therefore chose to complement the sectoral view on open space for a more holistic approach to evaluate the resilience of ES supply, for which we coined the term 'bioproductive land' or 'bioproductive space'.

Bioproductive land encompasses all forms of land providing functions and services directly or indirectly rooted in primary production processes (Lerouge et al., 2015).

It is essentially all space providing societal benefits from the supply of ES. This is not limited to provisioning services like food, fibre, wood or other materials, but includes a wide range of functions and services.

The term bioproductive land aids decision makers to apply a 'back-to-basics' reasoning when it comes to land management. Bioproductive land is resilient when it is able to continue delivering ES under changing conditions (Zell and Hubbart, 2013). As such, we arrive at a functional definition for spatial resilience.

Spatial resilience is the capacity of social-ecological systems to buffer spatially-bound functions and services against internal and external shocks, by means of adaptive forms of bioproductive land management (Lerouge et al., 2015).

Translating complex problems into practical tools and methods that can support decision processes and involve various actors in the field, requires a transdisciplinary (i.e., involving actors from distinct disciplinary backgrounds) and interdisciplinary (i.e., combining knowledge and techniques from distinct academic disciplines) approach (Brink et al., 2018; Termorshuizen et al., 2007). For the research presented here, we used a special mixed methods approach, combining qualitative, quantitative and participatory methods. Most of the research was done in the framework of the Flemish Support Center on Space.

As such, the focus of this research lies on the region of Flanders, Belgium. Many of the results and insights however, can be applied to other complex cultural landscapes. In any such landscape, the pressure on the remaining unsealed space is increasing (Turkelboom et al., 2014). This leads to an increasing polarization between land used by different sectors and their respective actors (Kerselaers et al., 2013). Strong sectoral claims on the remaining available land are part of a logic, albeit often overly defensive, response. In many cases this results in ineffective forms of land management, where opportunities to create added value from spatial complementarities and supplementarities that can be found in more integrated forms of land use (Colding, 2007), are underrated or neglected (Tscharntke et al., 2012). We argue that thinking in extremes rarely contributes to finding solutions for intrinsically complex problems. As such, classic sectoral divisions of land use fall short of fostering the innovative solutions that are much needed in contemporary land management.

2 Research aim and objectives

The principal objective of the thesis is to contribute to the efforts of optimizing land use to advance ES delivery in order to meet the societal demand. The central research question is:

RQ1: "Can the ES concept support decision makers in land use optimization problems for adaptive planning?"

This requires the integration of ES concepts in resilient and sustainable spatial planning. For this, we need a better understanding of how ES concepts can be operationalized for spatial planners and land managers, and how this approach can contribute to optimizing land use for the delivery of services.

The specific objectives of this thesis are to analyze and explore:
The influence of local context and constraints on land use allocation decisions by assessing land management choices in function of ES delivery, and how this can bring nuance in the land sharing vs. sparing debate.

RQ2: "How does a more integrated approach to land use evaluation, taking more ES into account, affect the decisions made for optimal land use allocation?"

How the optimality of land use allocations can be influenced by future scenarios and changing policy preferences, and how to go about measuring this in terms of resilience.

RQ3: "Can an indicator be developed capturing the performance or resilience of land use allocation strategies under changing societal or policy preferences?"

How to capture the heterogeneity and spatial mismatch between ES supply and demand, and use this information to highlight priorities for adaptive land management.

RQ4: "Can the ES concept be applied to identify region-specific priorities for adaptive land management?"

A large part of the research involves the valuation of ES delivery under different scenarios, and using this information to determine policy priorities. Therefore, the research is somewhat related to social cost benefit analysis. However, where the latter also explicitly takes cultural and social dimension of space into account, our analysis puts the emphasis on the environmental (dis)benefits of land use and land allocations. Cultural and social aspects are only indirectly taken into account, where they are implicitly included in the non-marketable ES that are used in the assessment.

3 Outline of the dissertation

Land use is the resultant of decisions made on various spatio-temporal scales. From micro-decisions by individual parcel owners, over larger scale city planning efforts, to reforms in international policy: the way a landscape or territory will be able to deliver functions and services to society is affected by decision making on all these levels. While it can be very useful to focus on a particular spatial scale to solve particular issues, it is also crucial to look at decision making across spatial scales. This dissertation highlights some crucial aspects of incorporating the ES concept into spatial planning, from the parcel level to the regional scale, and back. On all these spatial scales, decision makers are facing trade-offs and synergies between functions and services delivered by bioproductive land. In order to be able to compare and aggregate ES, we put them to a common denominator using monetary valuation.

In Chapter 2, we use this technique to explore potential ES delivery on a small scale, by analyzing possible land use scenarios for a case farm in Flanders. This particular case farm was selected because of a number of reasons. The farmer combines meat production with agritourism and nature management in innovative ways, providing an excellent baseline scenario of innovative multifunctional land use, upon which we could develop alternative scenarios. The ES indices, used to evaluate potential land use scenarios, are developed based on more 'classic' forms of agriculture. Therefore, it makes sense for a detailed case study to focus on an innovative farm, rather than a classical one, since it's very hard to imagine, let alone calculate, ES delivery under innovative scenarios. Another important reason was the high level of trust and willingness to collaborate. Part of the research included a thorough analysis of the farm registers and cash flow, which can be rather sensitive information, not easily shared. We combine this information with an indicator-based approach to evaluate potential ES delivery under a number of land use scenarios. In addition to the provisioning services, we include a selection of regulating and cultural ES in the analysis. The importance of landscape context is stressed, and we try to bring nuance in the land sharing versus land sparing debate.

Chapter 3 builds on the results of Chapter 2 by designing a thought-provoking methodological framework, subjecting the land use evaluation to an number a number of future scenarios, under different policy preferences. We suggest an approach to evaluate strategies under various scenarios of context and preferences, and develop an indicator summarizing performance of said land use alternatives under various scenarios. As such, the framework might contribute to efforts developing decision tools for resilient planning.

Chapter 4 shifts the focus to the regional scale, with a spatially explicit evaluation of trade-offs and synergies between bundles of ES supply and demand. Here, our findings illustrate the relations between spatial heterogeneity in the mismatch between local supply and demand of ES. The results can contribute in many ways to defining region-specific priorities for adaptable management of bioproductive land. They could, for example, inspire specific policy scenarios in the analytical framework of Chapter 3. In collaboration with a planner, the insights from the analysis were translated into region-specific guide models. Although the guide models are not part of this dissertation, an example was included in Chapter 0.

Finally, a concluding chapter summarizes the main research findings and highlights strengths and limitations of the research. We widen the scope for future research, and discusses policy implications and recommendations, before reflecting on practical applications of the ES concept in adaptive planning and management of bioproductive land.

Chapter 2.
Revisiting production and ecosystem services on the farm scale for evaluating land use alternatives

Chapter 2.[1]

Revisiting production and ecosystem services on the farm scale for evaluating land use alternatives

1 Introduction

Population pressure results in an increasing demand for food and bio-energy products and hence also in an increasing demand for agricultural land (Meyfroidt et al., 2013; Tscharntke et al., 2012). This demand is in competition with the additional demand for land for residential, conservation, forestry, recreational, and other purposes (Zasada, 2011). With land as an increasingly scarce resource, spatial planners seek to balance land use allocation among competing stakeholders. This has led to a polarization in land use policies between demands for expanding urbanized fabric and the remaining open space used for agriculture, whilst natural areas are largely pushed back to relatively small and fragmented relics. Spatial planning has mainly focused on allocation of land to space demanding sectors and minimizing spatial conflicts, further contributing to a sectoral polarization. This approach falls short in considering present-day demands for multifunctionality, sustainability, ecosystem services, resilience and adaptive governance. While an integrative and spatially explicit approach to land allocation is highly needed, it is largely missing (Bomans et al., 2010b; Termorshuizen and Opdam, 2009). Particularly in strongly urbanized regions, the relation between the availability and use of space, and the potential services this space is able to provide to society, needs to be explored further. Increasing service delivery per unit of space can allow a decreasing spatial requirement for delivering this service, and hence, freeing space for other services. Fragmented peri-urban landscapes in particular, where interfaces between different forms of land use and associated actors are plenty, are in need of innovative concepts for land use allocation. Meanwhile, concepts of multifunctionality and ecosystem services (ES) already bridge the distinction between classical sectors like agriculture, nature and forestry. In the light of food and biomass production, the

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principal challenge is to simultaneously assess and maximize production as well as the other ES provided by open space (Balmford et al., 2012) which inevitably implies trade-offs.

The concept of ES, which was popularized by the Millennium Ecosystem Assessment in the early 2000s (Millennium Ecosystem Assessment, 2005), has proven to be useful in supporting resource management decisions (Wainger et al., 2010). ES are defined as the benefits of ecosystems to human beings and are categorized in provisioning services such as food, biomass and water production, regulatory services such as carbon sequestration and air and water purification, and cultural services such as recreational and aesthetic experiences (Haines-Young and Potschin, 2010). Meanwhile, the EU called its member states to assess and map the state of ES within their territory in the framework of the Biodiversity Strategy 2020. This development will provide opportunities to incorporate ES into decision making. Nonetheless, application of the ES concept to real-life land management decisions is a major challenge (Crossman et al., 2013) and there is a continuing need to evaluate the available tools against existing cases (Dale and Polasky, 2007). Nevertheless, there is a growing awareness that agricultural systems also provide other services besides food and biomass production. Examples are cultural services such as recreation and landscape amenity, as well as regulating services such as flow regulation and pest control (Haines-Young and Potschin, 2010; Zasada, 2011). A conceptual framework as proposed by (Foley et al., 2005) argues how agro-ecological cropland management might support a larger portfolio of ES than production-oriented cropland. These ES need to be recognized (Daniel, 2008; Swinton et al., 2007). Moving away from a predominantly 'production-oriented' view on the landscape will aid policy makers and other stakeholders to recognize opportunities and innovations within and across landscapes.

Many of the services delivered by agricultural systems are non-marketable, so free markets fail to provide sufficient incentives for delivering these services. A dominant production logic may push provisioning agricultural systems towards a state that is sub-optimal from a societal point of view because several non-provisioning services are not rewarded in the market. On the other hand, semi-natural lands are also able to contribute to the food and biomass supply, while they simultaneously maintain the capacity to deliver a wider array of essential non-provisioning services (Foley et al., 2005). Hence, there is a need to evaluate land use scenarios with respect to the provisioning services, as well as the non-provisioning services that they deliver (Bernués et al., 2011; Swinton et al., 2007).

In order to develop an integrated approach to assess land use at the farm scale from the societal perspective, we look into the societal benefits delivered through different land use strategies for a case farm in the region of Flanders, Belgium. Flanders is essentially a peri-urban region with high population pressure. Some challenges and lock-ins for spatial planning can be identified when developing integrative approaches to land allocation in this region. First, the use of space in Flanders is intrinsically multifunctional, while spatial planning policies are largely monotypic in nature (Kerselaers et al., 2013), with for agriculture, a clear focus on productive functions (Leinfelder, 2007). Current spatial planning frameworks have difficulties facilitating multifunctional land use strategies. Second, a high spatial fragmentation leads to scale dissociations of spaces from policy, as the role and potential of many small fragments are systematically underrated. Also, there is little knowledge about the privatization (e.g. use of agricultural land in residential gardens) and domestication (e.g. use of agricultural land for hobby activities) of land use types (Dewaelheyns et al., 2014; Gulinck et al., 2013). This results in an additional dissociation of spaces from policy. A fourth dissociation stems from the discrepancy between a relatively static policy framework and a dynamic reality shaped by climate change, biodiversity loss, species' adaptation, market change, change of norms and preferences, a.o. As such the case of Flanders is representative for many other peri-urban regions that experience high urbanization pressures and face similar dissociations of spaces from policy.

We use an integrative and transdisciplinary approach to evaluate potential land use alternatives. We used a thorough indicator-based approach, applied to a case farm. For this case farm, representing a limited stock of land, we benchmark land use alternatives by comparing the services they would deliver. This sets the foundation for a policy supporting approach to evaluate spatial productivity under various land use and land management rationales.

2 Approach of the study

To develop an integrative regional approach to evaluate land use strategies for open spaces, the concept of *bioproductive land* is introduced. ‘Bioproductive land’ is defined as the area providing services through primary production processes (See Chapter 1, Section 1.4). It includes semi-natural as well as agricultural ecosystems. This bioproductive land is key in delivering ES in a landscape. By also incorporating non-provisioning ES, we acknowledge both the importance of production, while other essential sustainability concepts are not neglected. Hence, we emphasize that ‘bioproductive land’ encompasses more than the notion of ‘bioproductive capacity’ in ecological footprint calculations. While both terms relate to primary production, the latter term refers to the fraction specifically required for human consumption in the material sense and waste product absorption. In contrast, bioproductive land provides a multitude of provisioning, cultural, regulating and maintenance services. As such we are able to consider different sectors and land-use categories, which in turn allows us to take into account ‘hidden’ land uses. A first form of ‘hidden’ land use would be due to underrated transformations, i.e. land use changes that are not or insufficiently picked up by monitoring and feedback systems (Bomans et al., 2010b, 2009; Verhoeve et al., 2015). Our case is an example of farm diversification and recreational use of semi-natural land, which can be seen as underrated transformations. The selected case farm is also ‘hidden’ in the sense that much of the area used for production is not situated within the statutory demarcated agricultural space. A second form of ‘hidden’ land use is the amount and use of *tare land*, i.e. those parts of the agricultural landscape not directly supporting crops (Bomans et al., 2010a). We also take tare land into account since they provide ES. We use an indicator based assessment to take ES into account. This allows for identifying differences in societal benefits between land use alternatives. These benefits can either be marketable or, alternatively, be regarded as externalities. Adaptive management of bioproductive land aims amongst other at internalizing positive externalities. Adaptive governance can both aim to facilitate internalizing such externalities, as well as compensating for those externalities that are difficult to internalize, e.g. through subsidies, payments for ES (PES), tax reductions, or other means.

To assess land use alternatives we assess the output of several ES per unit of bioproductive land. This corresponds to agricultural land productivity measures but we take into account the value of non-provisioning ES instead of considering only agricultural output, and we look at all bioproductive land instead of only considering the agricultural land. By assessing agricultural output, which is traded on the market, as well as other valuable services for the society but which are mostly not traded on the market, we are assessing the optimality of land use scenarios from a societal point of view rather than from a private or farmer's point of view. Depending on the availability of data and aggregation techniques, this allows to take potential externalities into account in evaluating land use alternatives.

3 Case Farm Description

The case farm is an organic farm that was established in 2001 on the land of a former conventional dairy farm. It covers about 112 hectares in 2013. Most of this area is located within nature reserves called 'Dassenaarde-Groot Asdonk' and 'Webbekoms broek'. The farm is located at 51°00'47"N; 5°02'41"E, in two subcatchments of the Demer river. The catchments suffer from relatively poor water quality, mainly due to a contamination with a.o. heavy metals and chlorides (VMM, 2014). Aquatic vegetation is largely absent in the main tributaries. Hence, flooding events pose a contamination risk, which needs to be taken into account when evaluating possible land use alternatives for some parcels.

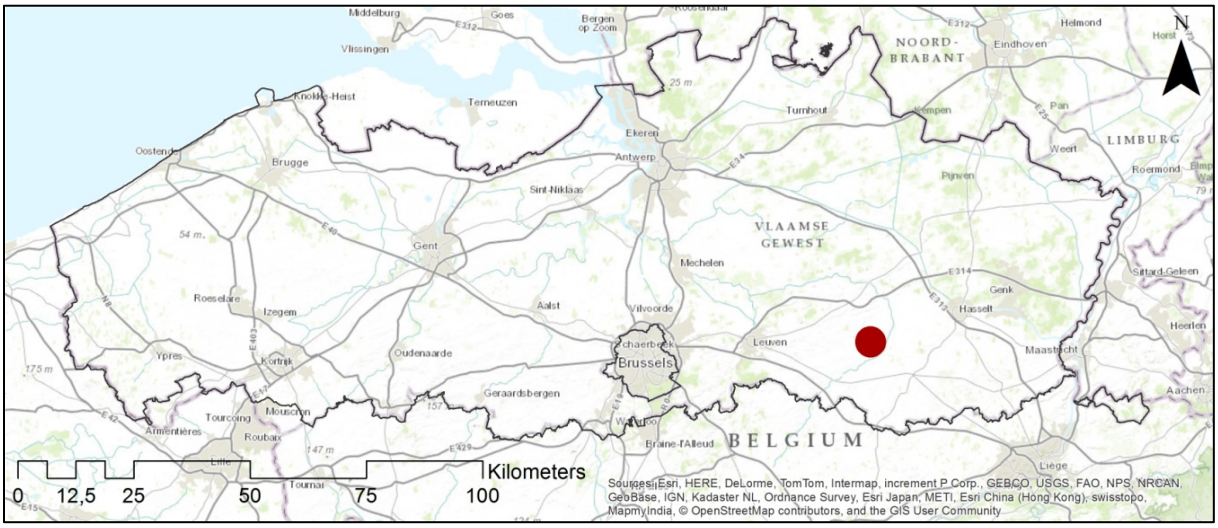


Figure 2. Location of the case farm in Flanders.

In an ongoing effort to counteract atmospheric nitrogen deposition (Stevens et al., 2011), semi-natural grassland management in Flanders has to deplete nutrient stocks (Oelmann et al., 2009). Consequently, semi-natural grassland management typically produces biomass waste streams from mowing and haymaking. In general, grass from semi-natural grasslands is less suited for conventional livestock breeds, both in terms of digestion and nutritional intake. Therefore, ecological farms typically resort to more sturdy and self-reliant livestock breeds (Bedoin and Kristensen, 2013). The case farm uses the rustic cattle breed '*Kempisch Roodbont*' and the rustic sheep breed '*Ardense Voskop*' (Figure 3). Both are able to digest low-quality feeds and convert it to high-quality animal protein (i.e. dairy products and meat). Both breeds are threatened by extinction so that preserving their genetic resources can be considered as an additional provisioning service delivered by the farm system, internalized by means of live sales.

Figure 3. The case farm is highly diversified, offering a range of 'products', from organic meat to agritourism (pictures by K. Sannen).

4 Methodology

4.1 Data compilation

The case farm parcels were mapped in ArcGIS 10.1. Land use was based on the farms register and the Biological Valuation Map (AGIV, 2010), updated using aerial imagery (Aerodata International Surveys, 2007) combined with verification in the terrain (early 2013). The Biological Valuation Map is a spatially explicit dataset containing a categorical ecological valuation of the land cover, as well as detailed information on the vegetation types on a sub-parcel level. The following data were added to the parcel dataset: production data (grazing and cutting) compiled from the farm register, soil texture and moisture data (AGIV, 2006), the Habitat map v5.2 expliciting the occurrence of habitats falling under the EU Habitat Directive (INBO, 2010), flood risk zones (VMM, 2006), and presence of woody vegetation such as hedgerows, isolated trees and orchards based on a map of green components in the landscape, i.e. the 'Groenkaart' (ANB, 2013, 2010). Livestock and feed production figures were attributed to the respective parcels by a parcel-by-parcel breakdown of the livestock movement and mowing registers (Figure 4, Figure 5).

4.2 Aggregation of ES delivered by bioproductive land

In order to evaluate the relative performance of land use scenarios in providing ES, a selection of ES is aggregated. For this study, we used monetary valuation as an aggregation tool. Differences in provision of ES among different land use alternatives were estimated using the "Ecosystem Service Valuation Tool" developed by VITO (Broekx et al., 2013b; Liekens et al., 2013). The land use alternatives include a reference scenario based on the actual land use, and some more conventional land use scenarios. They are described in detail in Section 4.3. Liekens et al., (2013) provide a key to translate the detailed land cover categories of the Biological Valuation Map into useful input for the Ecosystem Service Valuation Tool. In order to take local variations into account, the farm was divided in five spatially distinct clusters, and each of these clusters was evaluated separately. The evaluation of cultural services was done for the case farm as a whole. The valuation tool provides a lower and upper estimate for the value of the considered ES, based on the 25 and 75 percentile values of the calculated values, and the comparison is based on the minimal estimates to avoid potential overestimation of the positive externalities.

The crops and livestock values as well as wood production value under the *Reference* scenario were quantitatively estimated based on accountancy data of the farm case and interviews with the case farm manager. For the other land use scenarios, these estimations are based on average Flemish farm income registrations over various sectors, combined with crop registration and soil suitability data.

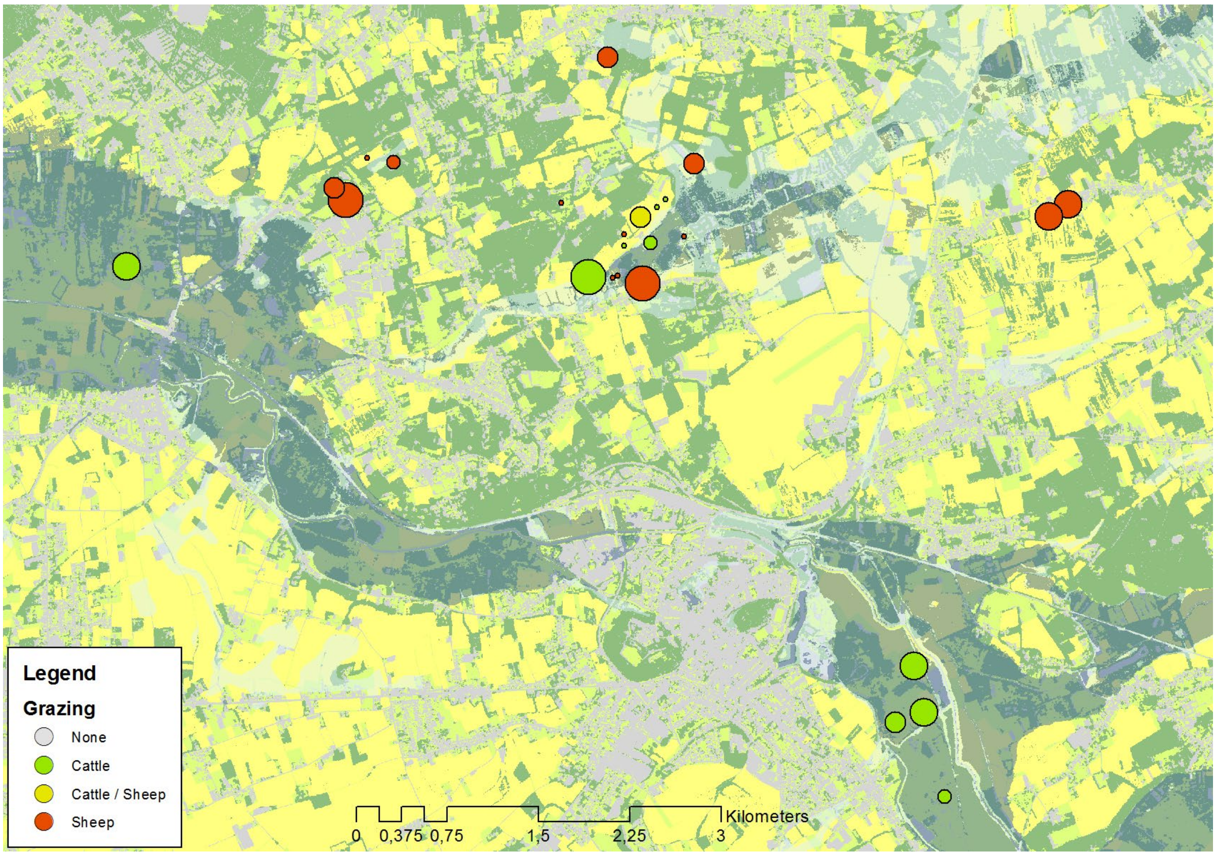


Figure 4. Map of the farm parcel locations. Point size is proportional to relative grazing intensity

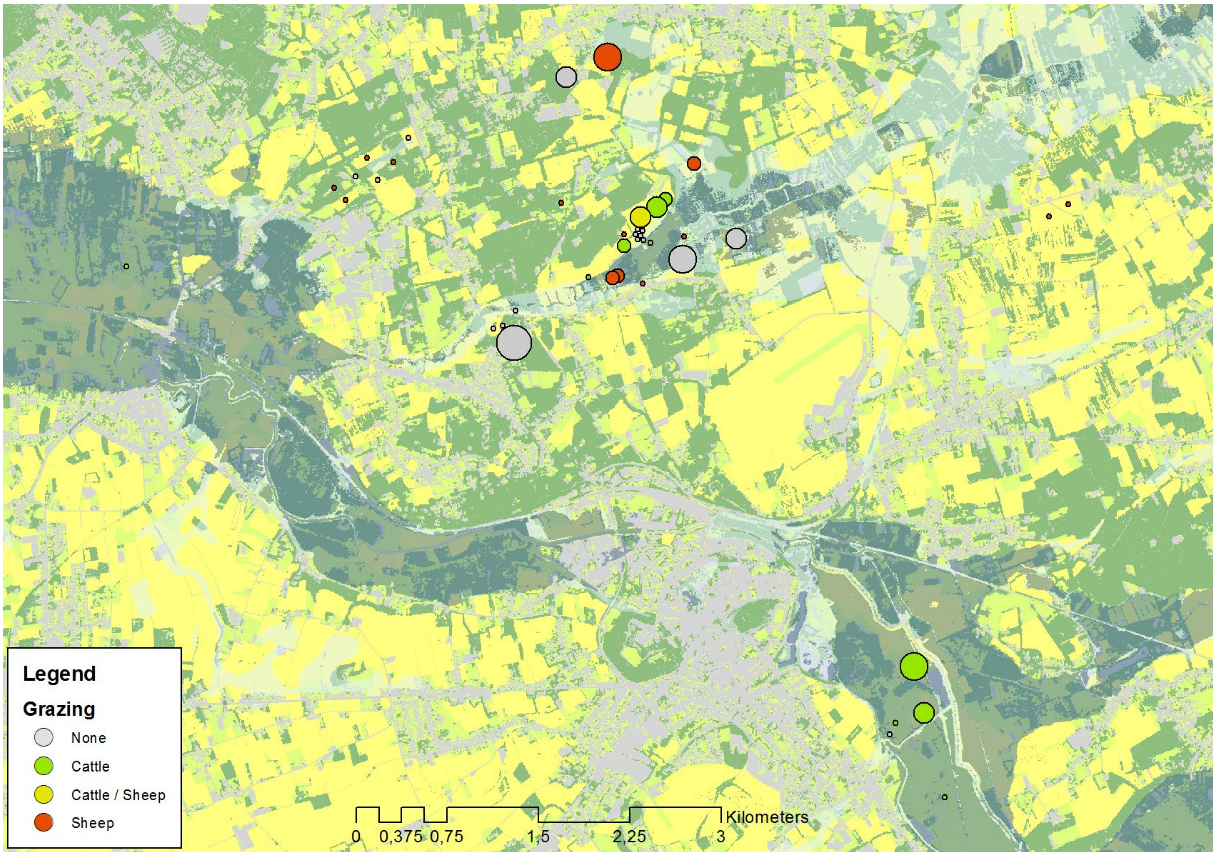


Figure 5. Map of the case farm parcel locations. Point size is proportional to the relative mowing intensity.

Calculation of feed production values cannot be done based on market prices since most feed is cultivated and used on the farm itself. Instead, gross livestock revenues are distributed over the area used for feed production (Liekens et al., 2013). Quantitative assessment and valuation of wood production is done by multiplying the area under forest cover with matched productivity figures (Jansen et al., 1996), related to the type of forest and the typology of the physical system. The results are multiplied with a harvest factor (%), the percentage wood actually harvested in relation to the maximal potential harvest, to estimate the effective wood production. Valuation is done by multiplying this estimate by the market price for standing timber.

For the regulating services, fine particle filtration ('air quality'), carbon sequestration in soil and biomass, and N and P sequestration in soil were evaluated. Subsidies are not taken into account in the aggregation. The air quality estimations in kg/year are based on figures by Oosterbaan et al. 2006. Valuation is done by multiplying these estimates by a generic avoided medical cost otherwise caused by fine particulate matter (PM10) of 54 €/kg PM_{10}, derived from De Nocker et al. 2010. For soil carbon storage the regression model by Meersmans et al. 2008 is applied, estimating maximal potential carbon stocks taking soil texture class, water tables and land use into account. Valuation is based on marginal reduction costs for N and P (Broekx et al., 2009), and estimated avoided cost of carbon reduction, according to De Nocker et al. 2010.

The valuation function applied in the tool to calculate cultural services was obtained using a stated preference method (willingness to pay, WTP) (Hoyos, 2010). This value function can be applied for the loss or gain of natural areas and combines the values for recreation, amenity and education. The methodology calculates the number of households within a 50 km radius, i.e. where the value function is larger than zero. This number is multiplied with a mean WTP based on the type of ecosystem, species richness, accessibility, surrounding land use, size and distance to the household using a distance decay function (Broekx et al., 2013b). A similar approach was used by Costanza et al. (1997) to estimate the value of world ES.

4.3 Land use alternatives for crop and livestock production

To evaluate land use configurations and practices, we considered different scenarios to determine the output of selected ES for the case study area. The existing extensive farm model is used as the baseline scenario, referred to as the *Reference* scenario in the remainder of the paper. On the same land, we assume three additional normative land use scenarios, which we call *IntensiveMIN*, *IntensiveMAX* and *IntensiveSRC*.

The *Reference* scenario describes the case study area as it is currently cultivated by a farm that combines ecological meat production and livestock breeding with nature management and ecotourism. Cultivated grasslands are combined with semi-natural grasslands, but the share of semi-natural grasslands is relatively high and the livestock production is very extensive. This results in a high nature conservation potential. The other side of the coin is a penalty in terms of animal growth and carcass quality (Bedoin and Kristensen, 2013; Fraser et al., 2009). In addition, the spatial footprint of livestock rearing is relatively high.

The *IntensiveMIN* scenario is designed as a realistic intensive livestock production using the same land as the case farm. It assumes conventional livestock production, and local biophysical constraints are taken into account. Using a spatial overlay with the flood risk zone dataset in a GIS environment, frequently inundated parcels and zones showing high inundation risks were excluded for intensive livestock production. A similar approach was used to identify and exclude parcels with species communities subject to the EU Habitat Directive. For reasons of comparison and in order to minimize dependency on off-farm land, we assumed a largely autonomous production, i.e. the *IntensiveMIN* farm meets its own feed requirements from own production within the analyzed area. The required ratio of land for grazing to land for feed production could be derived from figures from the agriculture monitoring network of the Flemish Department of Agriculture and Fisheries (Gavilan et al., 2012; Raes et al., 2011). In 2010, an average specialized livestock farm had 81.51 livestock units (LSU) on 30.47 hectares of grassland and an additional 35.48 hectares of feed production. Therefore, the *IntensiveMIN* alternative assume a spatial ratio between grassland and feed production of 0.86.

Within the case area several parcels are unsuited for intensive grazing. The 'Bekkevoortse beemden' (BVB) mainly consist of wet, semi-natural grasslands and reedbeds. Frequent inundations make most of the parcels unsuited for intensive grazing or feed production. The cluster 'Bolhuis' (BH) comprises the farm building, stables and associated infrastructure, as well as all surrounding parcels, mainly semi-natural grasslands with high levels of biodiversity. All grasslands that are not frequently flooded can potentially be used for intensive livestock rearing, either as grazing lands or for feed production. The cluster 'Catselt' (CT) consists mainly of biologically very valuable land dune ecosystems dominated by very nutrient-poor grass- and heathlands, which are grazed by sheep in the *Reference* scenario. Based on the previously stated criteria, less than half of this cluster could be converted to intensive grazing lands. The cluster 'Webbekoms Broek' (WB) is a protected natural area, mainly wet grasslands and wetlands under extensive grazing. Intensive grazing would be the principal intensive land cover for this cluster. The cluster 'Zwarte beek' (ZB) is located upstream in the Winterbeek-Ossebeek subcatchment and consists of species rich grazing lands. Intensive grasslands and feed production are realistic land use alternatives.

In the *IntensiveMAX* scenario, we formulate a corner solution where all land of the case study area is taken into intensive production, irrespective of biophysical constraints that would make some lands unsuitable for intensive livestock production. As such this scenario would be difficult to establish within the spatial footprint of our case farm, but it provides an estimate of the differential output of ES of an unrestrained intensive livestock enterprise within the same catchments. The scenario assumes the removal of all small landscape elements such as hedgerows and isolated trees. Also, and in line with the *IntensiveMIN* scenario, maximal autonomy and a grassland over feed production spatial ratio of 0.86 is maintained.

Finally, the *IntensiveSRC* scenario explores the application of short rotation coppice (SRC) (willow and poplar) for biomass production in the most humid parcels. The cultivation of SRC can be seen as a relevant alternative strategy to increase the provisioning services delivered by the most humid parcels in this farming system. To select parcels for SRC production, a spatial overlay with the flooding risk zones was used and a total of 12.7 ha was selected. Willow (*Salix* spp.) was assumed for the parcels that effectively inundate, otherwise, poplar (*Populus* spp.) was assumed. All small landscape elements (single trees, hedgerows) and forest cover on land dunes remain in place. On the other parcels, livestock production remains as in the *Reference* scenario.

The land use distribution for each of these scenarios is provided in Table 2.

Table 2. Land use (in ha) for each cluster under different scenarios (see text for acronyms)

	Land Clusters					
	BH	CT	BVB	ZB	WB	**Total**
Reference						
Urban land	0.5	0.1	0.0	0.0	0.0	**0.6**
Agriculture and pastures	9.2	0.1	0.0	0.2	0.4	**9.9**
Rivers and ponds	0.1	<0.1	<0.1	0.0	<0.1	**0.1**
Wetlands	<0.1	0.0	0.9	0.0	1.3	**2.2**
Heath and land dunes	1.4	6.0	0.0	0.0	0.0	**7.4**
Forests and shrubs	3.0	6.1	0.0	<0.1	6.7	**15.8**
Semi-natural grasslands	35.6	9.3	4.9	4.5	22.0	**76.3**
IntensiveMIN						
Urban land	0.5	0.1	0.0	0.0	0.0	**0.6**
Agriculture and pastures	21.4	5.4	0.0	4.7	0.4	**31.9**
Rivers and ponds	0.0	0.0	<0.1	0.0	<0.1	**<0.1**
Wetlands	0.0	0.0	0.9	0.0	1.3	**2.2**
Heath and land dunes	1.4	6.0	0.0	0.0	0.0	**7.4**
Forests and shrubs	2.8	6.1	0.0	0.0	6.7	**15.6**
Semi-natural grasslands	23.7	4.0	4.9	0.0	22.0	**54.6**
IntensiveMAX						
Urban land	0.5	0.1	0.0	0.0	0.0	**0.6**
Agriculture and pastures	44.0	9.4	5.8	4.7	9.6	**73.5**
Rivers and ponds	0.0	0.0	0.0	0.0	0.0	**0.0**
Wetlands	0.0	0.0	0.0	0.0	1.3	**1.3**
Heath and land dunes	1.4	6.0	0.0	0.0	0.0	**7.4**
Forests and shrubs	2.8	6.1	0.0	0.0	6.7	**15.6**
Semi-natural grasslands	1.1	0.0	0.0	0.0	12.8	**13.9**
IntensiveSRC						
Urban land	0.5	0.1	0.0	0.0	0.0	**0.6**
Agriculture and pastures	9.2	0.1	0.0	0.2	0.4	**9.9**
Rivers and ponds	0.1	0.0	0.0	0.0	0.0	**0.1**
Wetlands	0.0	0.0	0.9	0.0	1.3	**2.2**
Heath and land dunes	1.4	6.0	0.0	0.0	0.0	**7.4**
Forests and shrubs	13.3	6.1	2.4	0.0	6.7	**28.5**
Semi-natural grasslands	25.3	9.3	2.5	4.5	22.0	**63.6**

5 Results

For livestock production, the valuation tool estimates a mean yearly added value of € 6 971 (min: € 5 480, max: € 8 460) under the reference scenario. However, nutrient-poor semi-natural grasslands are considered unsuitable for livestock production in the valuation tool's methodology. As such, this tool only takes into account parcels with intensive grasslands. Since sturdy and self-reliant livestock breeds enables the case farm to use most semi-natural grasslands for production, we derived the estimates for the *Reference* scenario from accountancy data. Concerning livestock productivity on semi-natural grasslands, research by Pelve et al. (2012) indicates that live weight gain of about 400 to 500 g/day is feasible using adapted breeds. While weight gain figures reported in literature surpass 1 000 g/day for meat production breeds like *Limousin*, they only range between 260 g/day and 650 g/day for *Galloway* (Bedoin and Kristensen, 2013; Fraser et al., 2013), a breed typically used in nature management practices in Flanders. With an estimated live weight gain of about 800 g/day, the *Kempisch Roodbont*, which is used on the case farm, performs relatively well. *Kempisch Roodbont* has the added advantage of being suited for both milk and meat production, contrary to *Limousin*. According to the accountancy data of the case farm, a value for livestock production of 27 000 euro is used for the *Reference* scenario. About 55% or 15 000 euro of this output stems from meat production, while the remaining 45% or 12 000 euro results from rustic breed sales. Since the tool's calculation of provisioning services is based on a representative sample of Flemish farms, which thus includes mainly intensive, non-organic farms, it can be used for the calculation of provisioning services under the intensive scenarios.

In terms of crop and livestock output, the *IntensiveMIN and IntensiveMAX* scenarios perform better than the *Reference* scenario, while the production value of the *IntensiveSRC* scenario is lower (table 2). The differences are much less obvious for the value of wood production, for which *IntensiveSRC* performs slightly better than the *Reference*.

For most regulating services that were taken into account, the *Reference* scenario is preferred over *IntensiveMIN* and *IntensiveMAX*, and is on par with *IntensiveSRC*. The exception here is the service 'air quality', for which *IntensiveSRC* is the best performer. The differences in terms of fine particle filtration (air quality) can be attributed to the presence of small landscape elements in the *Reference* scenario, and of coppice in the *IntensiveSRC* scenario. Differences are negligible for carbon storage services in biomass.

The value of the cultural services is highly dependent on the aesthetic value of the local landscape and is much higher under the *Reference* scenario than under the *IntensiveMIN* and *IntensiveMAX* scenarios. The WTP for cultural services is depending amongst others on the number of households living within a certain radius and on the site area. Although relative WTP/ha is higher for smaller sites, the WTP per ha quickly decreases when households are living farther away from the site. This is in particular the case for smaller parcels that are remotely located so that the WTP drops to zero very fast. As such, for remote sites the site area has a strong positive impact on the valuation of the cultural benefits in the methodology used. The fact that the case farm consists of several clusters that are all managed ecologically and all deliver cultural services, and is still relatively close to urban areas, has thus a strong positive impact on the cultural services provided under the *Reference* scenario.

Table 3 and Figure 6 compare the relative monetary value of ES delivered under the *Reference* scenario with these delivered by the other scenarios. The vertical line in the graph marks the *Reference* land use. Positive values in this table are situated to the right of this line and indicate that the alternative land use performs better that the *Reference* land use for that particular ES. The largest differences between the land use alternatives are in crop & livestock production, air quality, and cultural services. Table 3 and Figure 6 illustrate that the potential societal benefits (in terms of selected ES) provided by bioproductive land of the case study is considerably higher in the *Reference* scenario than in the *IntensiveMIN,* but the difference between both is less obvious for the *IntensiveMAX* scenario. Of course one should take into consideration that *IntensiveMAX* is a corner solution that neglects biophysical constraints.

Table 3. Aggregated differences in ES delivery between respective intensive scenarios and the *Reference*, based on conservative estimates. A negative value indicates the respective land use alternative performs worse than the *Reference* scenario, a positive value indicates it performs better.

Ecosystem service	IntensiveMIN - Reference	IntensiveMAX - Reference	IntensiveSRC - Reference
Crop & livestock	20 200	65 900	-8 900
Wood	300	500	3 300
Air quality	-7 300	-17 450	17 800
C storage in soil	-100	-5 300	500
C storage in biomass	-200	-850	0
N storage in soil	-4 000	-8 850	0
P storage in soil	-4 250	-9 450	0
Cultural services	-9 250	-23 750	2 600
Total (€)	**-4 600**	**750**	**15 300**

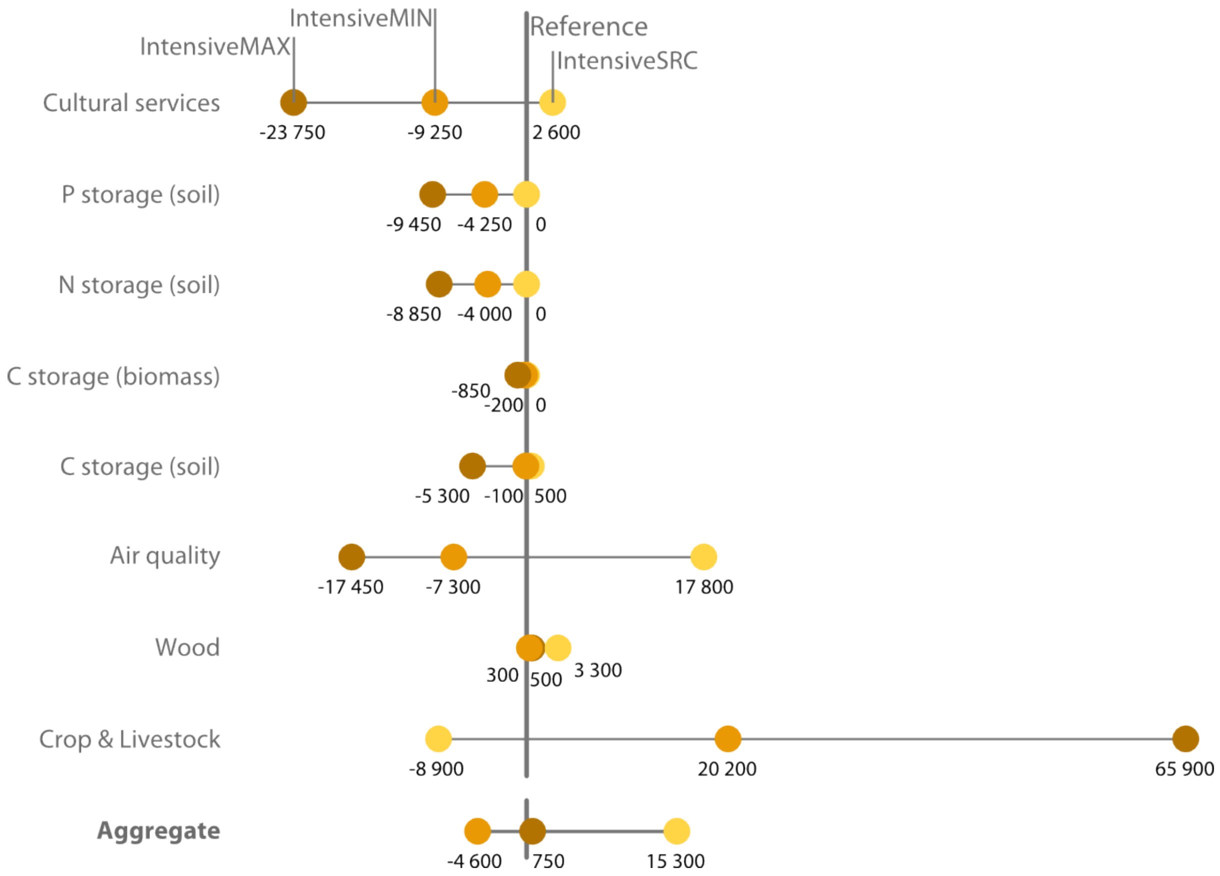


Figure 6. Relative differences in valued ecosystem service provision between the *Reference* scenario and the intensive scenarios. The central axis represents the *Reference* scenario. Alternatives performing better for a given ecosystem service are positioned to the right of this line, and alternatives performing worse are positioned to the left.

Next, we compare land use scenarios by aggregating ES at 3 levels (Figure 7): (1) aggregation of only provisioning services; (2) aggregation of provisioning and regulating services, and (3) aggregation of all selected ecosystem services.

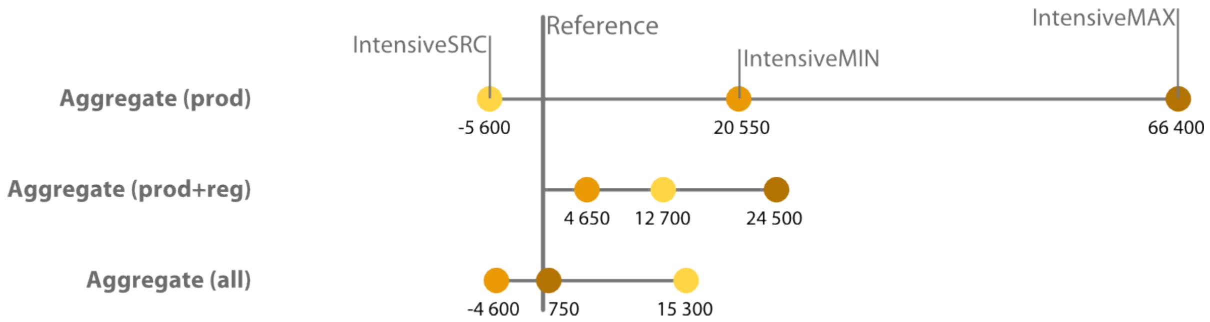


Figure 7. Comparison of aggregation based on (1) only provisioning services, (2) provisioning and regulating services, and (3) all selected ecosystem services (provisioning, regulating and cultural).

The success of the *Reference* scenario relative to the *IntensiveMin* scenario relies in the successful adaptation of its production to biophysical constraints, to the benefit of both the natural environment and the recreationists. The ecological farm adapts to its environmental constraints by using specific livestock breeds. While traditional cattle grazing preferably takes place on grasslands that are less subjected to inundation, the rustic cattle breed does allow for limited grazing management on parcels that are effectively sensitive to flooding. As such, the farm realizes livestock output on natural flooding plains and thus acts as a buffer zone for water retention and reduces flooding risks in the downstream city of Diest. However, parcels with tree cover and small landscape elements are less suited for cattle breeding. This is not the case for the sheep breeds used (Figure 8).

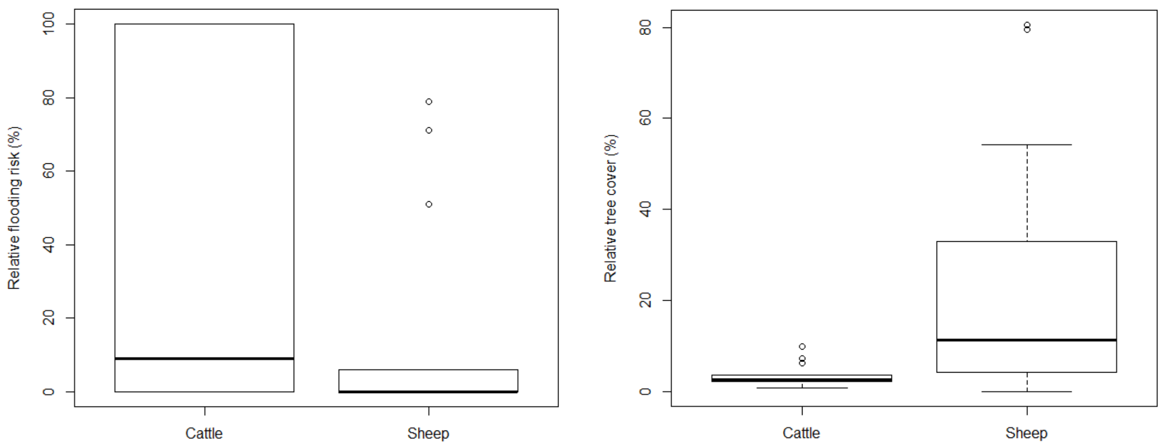


Figure 8. The use of cattle and sheep in an adaptive farming strategy: in relation to the flooding risk (left), and in relation to tree cover (right).

Sheep provide grazing management on those parcels that inundate significantly less frequent (Wilcoxon W=130, $p<0.05$), but contain significantly more trees (Wilcoxon

W=43, p<0.05). By using rustic cattle and sheep breeds on semi-natural grasslands and heathlands, the case farm reduces the biomass waste streams from these natural grasslands and contributes to reaching biodiversity targets.

6 Discussion

Our results illustrate that optimal land use from a societal perspective depends on local biophysical constraints and the spatial and socio-economic context, and point out the importance of internalizing positive externalities. When land use scenarios are assessed by aggregating only provisioning services, the *IntensiveMAX* and *IntensiveMIN* would be preferred over the *Reference*, which in turn would be preferred over *IntensiveSRC*. This corresponds to an exclusively production-oriented rationale.

However, taking regulating and cultural services into account shifts the preference towards more unconventional land use alternatives. The case farm which is using its land extensively and largely relies on semi-natural grasslands, is able to provide societal benefits that are higher than these provided under more conventional approaches (i.e. the *IntensiveMin*), while serving the local biodiversity targets. The *IntensiveSRC* scenario performs relatively well, also in comparison with the *Reference* land use. Possible limiting factors for this development path can be economical, logistic, cultural, or related to legislation, e.g. conflicts with nature development targets. Future research is needed to reveal which, if any, factors are the most limiting. However, if biophysical constraints are less restricting, a situation corresponding to the *IntensiveMAX* scenario, the differences in delivering non-provisioning societal benefits decrease, making it harder for an organic farming system to outperform more intensive systems, even when multiple ecosystem services are taken into account. Hence, local biophysical constraints highly determine whether an organic farming system will outperform more intensive farming systems.

According to the valuation method used, the value of cultural services depends on both local population densities and area. Small sites are only valued by those living close by, while the cultural benefits of large and well connected sites are also valued by people living further away. As such, in a different spatial and socio-economic context (e.g.

smaller sites that are not connected or lower population densities), the outcome of the evaluation of optimal land use strategies could be very different. For the calculation of the ecosystem services, the study applies the "Ecosystem Service Valuation Tool" developed by VITO, which aims at being commonly used in various decision making processes in Flanders. This tool applies benefit transfer functions to estimate the value of the ES delivered by the considered bioproductive land. Benefit functions are based on several other studies and easy to use. As such, benefit transfer has some advantages and is widely used (Costanza et al., 1997). However, it typically fails to consider the specific characteristics of study area of interest. This became clear when we calculated the value of crop and livestock production under the *Reference* scenario with the valuation tool and compared that estimate with the on-site production data. The tool underestimated the actual production value by the organic farm because high-diversity semi-natural grasslands are not properly considered as sites suitable for livestock production. However, the case farm does manage to use these grasslands and to sell its meat to local customers by organizing periodical sales in collaboration with other producers of regional products[2]. As such, while the tool lends itself well for estimated conventional livestock farming production, decision making based on it can be biased against organic land use alternatives. This stresses the need to highlight the potential of agro-ecological innovations and take them into account in spatial planning processes. Key innovations in our case are the use of adapted rustic breeds, paired with efforts to close nutrient cycles within the production system. Further, the added value of agro-ecological innovations that rely on land use complementarities, such as buffer strips or agroforestry, are not yet included in the methodology, while it is an important lever for spatial planning to work with.

The objective of the research is not to provide an absolute valuation of the ES delivered, but rather a relative positioning of potential land use alternatives that might emerge in the considered subcatchments. Obviously, some assumptions needed to be made in drafting the intensive scenarios. The extensive farming model co-evolves in response to very common nature management strategies in developed regions such as

[2] Meat from rustic breed is often not suited for conventional meat markets and requires 'alternative' markets with different quality criteria (e.g. sustainable, good taste, local, …) (Bedoin and Kristensen, 2013).

Flanders, where ecosystems are dealing with excess nutrient loads. Through combined grazing and cutting management, nutrients are removed from the system and floristic diversity is able to increase. This grazing and cutting management should at minimum compensate for the nutrient influx through dry and wet deposition, but from a floristic diversity perspective, it is desirable for the system to progressively become more nutrient poor.

On-farm diversification is aiming to validate this biodiversity, e.g. by engaging in ecotourism, but also subsidies and payments for ES that partially enable to internalize positive externalities. While the *Reference* scenario is able to outperform the *IntensiveMIN* farming strategy, and is almost on par with the *IntensiveMAX* corner solution when taking a wider range of ES into account, the increasingly limited income for farmers remains a cause of concern. The case farm is partially dependent on additional government subsidies and this adds to its vulnerability.

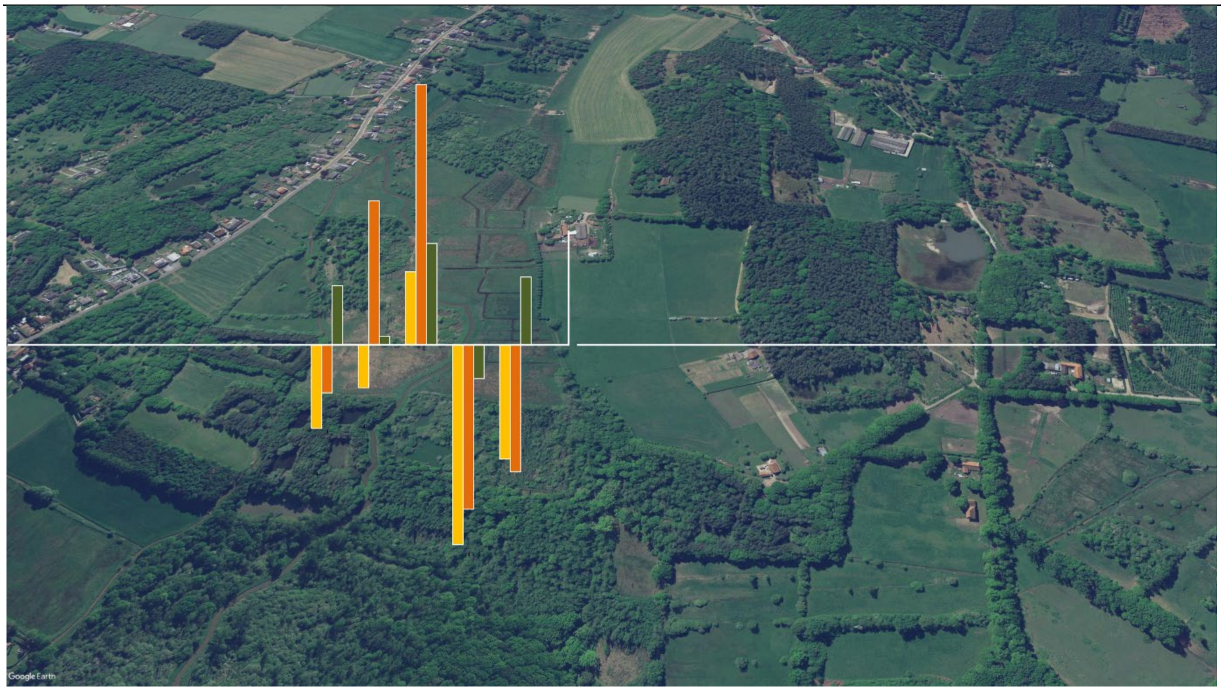
Some functions and services provided under the *Reference* scenario are underestimated. First, the case farm manages to valorize the biodiversity in its surrounding through ecotourism. Revenues from ecotourism are not included in the valuation of the land use scenarios. Second, as agricultural research faces a lock-in that favors innovations in the field of genetic engineering and risks locking out agro-ecological innovations (Vanloqueren and Baret, 2009, 2008), this case illustrates the potential of using selected rare breeds and generates positive externalities through the conservation of genetic resources. Third, several parcels managed by the case farm inundate regularly, contributing to the flooding risk reduction for a nearby provincial town. This flood protection service delivered by the case farm is also not yet taken into account.

7 Conclusion

Like many urbanized regions, Flanders is characterized by a high degree of polarization between expanding urbanized tissue and the remaining open space used for agriculture, with natural areas largely pushed back to relatively small and fragmented relics. As pressure on remaining open spaces increases, more actors adopt a conservational attitude of safeguarding a spatial niche from claims of other sectors. However, there is growing awareness that one spatial niche can provide services that are beneficial to several sectors. Not surprisingly, efforts to reconcile food production with ecosystem rehabilitation in Flanders have therefore mainly been focusing on land sharing strategies. While nature organizations are increasingly willing to cooperate with livestock farmers, many farmers show little interest in managing nutrient-poor or wet grasslands. In addition, some land sharing strategies, in particular agri-environmental schemes, are not achieving the expected results (Balmford et al., 2012; Kleijn et al., 2011, 2001; Pe'er et al., 2014). This makes it difficult for land planners to assess whether a land sharing or sparing policy is preferable. An assessment and valuation of all ES provided by bioproductive land can be used as a framework to assess land use strategies. ES can help to make the services provided by different land uses more easy to understand and more comprehensive. Breaking down the potential societal benefits provided by different land uses into a number of different ecosystem services, provides opportunities for policy makers to design well-informed and targeted policies, e.g. by defining local targets for specific ecosystem services.

In our study we apply an integrative and transdisciplinary approach to evaluate land use of a case farm and compare it with alternative land use scenarios. The results demonstrate that the agro-ecological land use strategy of this farm may or may not be preferred over more conventional land use strategies, depending on the services are taken into account, the biophysical constraints and the socio-economic context. The results demonstrate the potential of the agro-ecological land use to provide higher levels of societal benefits (i.e. output of ES) in regions with both 'inferior' and high quality land and with high population densities. However, if there are no biophysical constraints, if the potential area for extensive land management is small and/or not connected, or if the population density is low, the intensive land use strategies might outperform agro-ecological land use strategies. A local demand for ES can thus be addressed by a multitude of different farming models (Firbank et al., 2012). The analysis illustrates that the optimal land use strategy is likely to be context and scale-dependent and that the concept of ES can be very useful in designing optimal land policies.

Chapter 3.
Valuing ecosystem services to explore scenarios for adaptive spatial planning



Chapter 3.[3]

Valuing ecosystem services to explore scenarios for adaptive spatial planning

1 Introduction

1.1 Ecosystem services, land use change and spatial planning

Land is becoming an increasingly scarce resource, because of increasing population pressure and associated urbanization, coupled with the increasing demand for food and (bio)energy products (Meyfroidt et al., 2013; Tscharntke et al., 2012). This relative scarceness becomes more apparent with progressing insights that productive space worldwide delivers many functions and services (Lambin, 2012), expressed by a.o. the concept of ecosystem services (ES) (Millennium Ecosystem Assessment, 2005). Meanwhile, injudicious use of remaining space puts constraints on its provision of ecosystem services (Stoate et al., 2009). Like many urbanized regions in the world, urbanization in Flanders, the northern part of Belgium, leads to an increasing competition for the remaining open space (Kerselaers et al., 2013). This puts additional constraints to the delivery of ecosystem services by inhibiting more integrated, multifunctional forms of land use. This is particularly the case for the agricultural sector, which traditionally shows a clear emphasis on maximizing provisioning ES, often at the expense of other services (Leinfelder, 2007).

The ecosystem service concept shows great potential to contribute to an adaptive spatial planning paradigm, combining robustness to develop ecosystem functions and services with flexibility to find new development paths to answer challenges (van Buuren et al., 2013). However, it is not yet a mainstream practice in spatial decision making. Adaptive planning assumes that complex processes are characterized by a large degree of uncertainty. Dealing with this requires room for experiment, monitoring and learning. While ES modelling tools are able to facilitate the practical application of ES

[3] Adapted from: Lerouge, F., Gulinck, H., Vranken, L., 2017. Valuing ecosystem services to explore scenarios for adaptive spatial planning. Ecol. Indic. 81, 30–40. https://doi.org/10.1016/j.ecolind.2017.05.018

in planning practices (Ruckelshaus et al., 2015), it remains a challenge to overcome static frameworks when it comes to foster adaptive planning and land management.

A promising approach is to combine (spatially explicit) quantification of ES with valuation techniques. A notable example on a larger scale is InVEST[4] (Integrated Valuation of Environmental Services and Tradeoffs), a collection of open source models for mapping and valuing ES (Sharp et al., 2015). At the very least, ES based decision tools should allow for the estimation of changes in ES delivery caused by land use and management changes (Bateman et al., 2014; Ruckelshaus et al., 2015). Furthermore, in the framework of the UK National Ecosystem Assessment, Bateman et al., 2014 emphasise the need to consider a broader ranges of both policy options and ecosystem services, while taking uncertainties in the valuation of the latter into account.

Here, we add to this by developing a framework that allows for exploring the performance of alternative land use options under various scenarios of shifting values attributed to ES. The framework presented here is developed to support decision makers to consider and integrate ecosystem services in land planning and management. In this paper, we explore a couple of land use alternatives that can be described as being active land management choices (e.g. choosing for organic or conventional production), but in practice, the analytical pathway can also be applied to modelled land use outcomes (e.g. under climate change). With respect to land use modelling, the approach recently published by Bateman et al. (2016) could prove to be complementary to our approach.

A practical application of ES in spatial planning is to evaluate land use alternatives over a whole range of ES. This should allow to choose for land use development pathways aiming at maximising the supply of ES. It is generally assumed that this results in more environmentally sustainable decision making. The added value of the ES concept is to come loose from a strict productivistic apprach, inspiring decision makers to take regulating and cultural ES into account as well.

The aim of this paper is to propose a conceptual framework to support scenario planning and foster adaptive decision making related to bioproductive space, with particular attention to food systems. We define 'bioproductive space' as all space providing ecosystem services through primary production processes in both (semi-

[4] available on www.naturalcapitalproject.org/invest

)natural and agricultural ecosystems (See Chapter 1, Section 1.4). These ecosystem services include food and biomass production, as well as regulating (e.g. climate regulation, pollination) and cultural (e.g. recreation, landscape amenity) services (Haines-Young and Potschin, 2010).

The framework is based on an appraisal of the ecosystem services provided by bioproductive space, irrespective of sectoral boundaries. This implies that agricultural areas can not only be seen as spaces for the production of food, fuel and fiber, but that associated non-provisioning ecosystem services are also to be recognized. On the other hand, there is potential for food and biomass production outside of the statutory agricultural area, for example on road verges, in natural areas and in residential gardens.

1.2 Drivers affecting food production systems in Flanders

Adaptation is meaningful only when described relative to a specific driver (Carpenter et al., 2001). Drivers generate shifts (slow) or shocks (fast), and can be of bio-physical or socio-economic nature (Figure 9). A driver can cause a directional change to the social-ecological system. This in turn, influences the way land is used by that system. Examples of slow shifts are land speculation and privatisation, or ageing of the farmer population leading to farm size increase and the emergence of non-agricultural land use on farmland. Examples of faster shocks are exteme weather events, market price fluctuations or international conflicts.

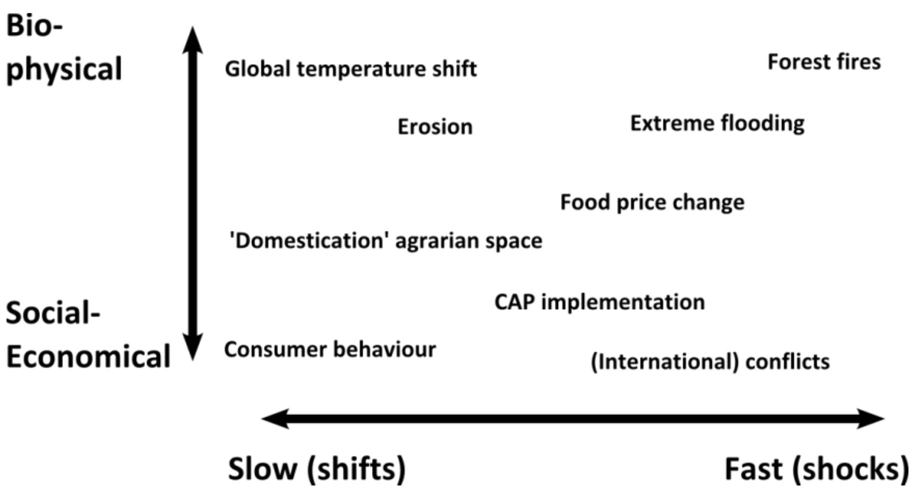


Figure 9. Drivers that affect the food production system in Flanders, ordered according to their nature (from bio-physical to social-economical) and the speed upon which they act.

As part of the Millennium Ecosystem Assessment (2005), Nelson et al. (2006) provide an overview of relevant direct and indirect drivers for global ecosystem change. Direct drivers cited are climate variability and change, drivers related to exploitation, land conversions, and biological invasions and diseases. Indirect drives cited are demographics, economics, socio-politics, science and technology, and culture and religion. For Flanders, conversion of land from agricultural use into other uses is a relevant driver that is easily overlooked, because the total area of statutory agricultural land remained relatively constant during the last decades. Nonetheless, recent research points out that an estimated 10% to 13% of the agricultural land is used for non-agricultural purposes (Danckaert, 2013; Verhoeve et al., 2015). Land 'horsification', i.e. use for recreational horsekeeping is part of this driver (Bomans et al., 2010b), as well as competition for hobby animal feed production (Van Gossum et al., 2014). These trends decrease the availability of land for agriculture both directly, by occupying land, and indirectly, e.g. by increasing land prices. This might limit the spatial adaptive capacity of the agricultural sector.

Also exploitation is considered a major driver in Flanders, with soil degradation, compaction and potential water shortage as major aspects (Van Gossum et al., 2014). Similarly, climate variability and change is an important driver. Although several benefits can be associated with climate change for Flemish food production, for most crop and livestock production systems a net productivity loss is expected, even when measures for adaptation are taken into account (Gobin et al., 2008). However, the relative productivity loss is expected to be less for agro-ecological production models, characterized by higher intrinsic tolerance levels to stress (Ulanowicz et al., 2009).

2 Study area and methods

2.1 Methodological framework for evaluating land use alternatives under changing societal preferences

In Figure 10 we present the methodological framework in the form of a toolkit. For the purpose of clarity, we subdivided this framework in 4 distinct stages. On the input side is a spatially explicit analysis of the biophysical system and actual land use, as well as possible land use alternatives. This analysis should be sufficiently detailed to assess the delivery of ES by the land use alternatives. Since the EU calls its member states to map ES in the framework of Action 5 of the EU Biodiversity Strategy to 2020, there is an important momentum to use such spatially explicit datasets for land use evaluation.

In *Stage 1*, the differences in ecosystem services delivered by these alternatives in comparison to the actual land use are quantified and valued. This evaluation should be quantitiative and allow for aggregation of the ES, i.e. that different ecosystem services can be combined and compared. For this purpose, we use monetary valuation (in EUR). The differences in ecosystem service delivery are calculated between a baseline land use, in this case the actual land use, and a land use alternative. This can be seen as a basic outcome. In the following Stages, we tweak several methodological aspects and assumptions that we relied upon to reach this outcome. Each time we choose an array of simple tweaks, exploring the sensitivity of the approach for changes at that particular stage. We also give a practical interpretation for each stage, ranging from driver scenarios (stage 2), policy priorities (stage 3), and weighted aggregation (stage 4).

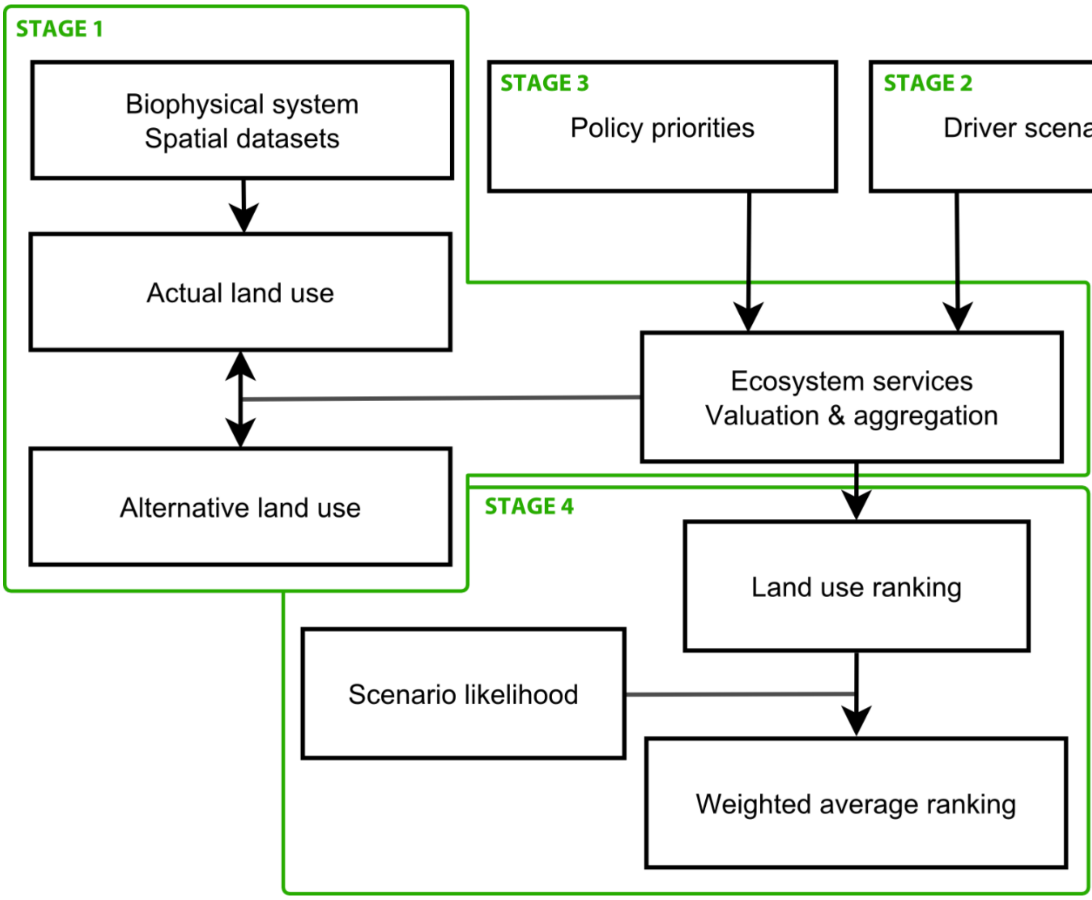


Figure 10. The structure of the toolkit.

In *Stage 2*, the assigned values are recalculated for different driver scenarios. Biophysical and socio-economic shocks can influence the societal demand for specific ecosystem services. Examples are changing demand for local or organic food products, for recreational space, or for regulating services, such as water storage or fine particle filtration. Changes in demand and supply will typically affect the value of a good or service. Some of these variations are essetially driven by society, e.g. changed bioenergy demand or more restrictive air quality targets. Other variations are rather induced by biophysical factors, like increased need for buffering of extreme weather events. To allow these drivers to be taken into account, a factor reflecting a change in demand and associated valuation is introduced in the valuation step for each ecosystem service. While the biophysical output of different land use alternatives may not change, the value attached to the output may change due to changing societal demand for the services delivered.

Stage 3 allows for assigning weights to individual ecosystem services. Spatial planners may decide to attach higher importance to certain ecosystem services. This can for example be done to prioritise specific ES for the area under consideration, or to take into account that there is a minimum quantity of ecosystem structure and process required to maintain a well-functioning ecosystem capable of supplying services. Below such a threshold, the social-ecological system (SES) might collapse and the economic value below this safe minimum standard drops to zero or becomes negative. Uncertainties on the exact value of this threshold, might also stimulate prioritisation of ES (precautionary principle). If one fears that the ecosystem state is approaching a minimum standard of functioning, one might attach more importance to the associated ecosystem services in order to conserve the ecosystem structure and functions. But also end users attach different levels of importance to ES (Casado-Arzuaga et al., 2013). Alternatively, weight factors can also be a means to explore the influence of various policy priorities. For example, one can increase the weight of regulating services in the case of a landscape where buffering against disturbances is of great importance. Or, where climate neutrality is a priority, the importance attached to carbon sequestration in soil and biomass can be increased. These examples illustrate the potential of the proposed framework for spatially explicit evaluations.

Stage 4 provides the means to aggregate the information in a useful way. Adding drivers and policy priorities quickly leads to a large output matrix, making the output difficult to grasp. In terms of adaptive governance, we are mainly interested in identifying these land use alternatives that provide, on average, the highest value of ecosystem services under various potential scenarios. Calculating rankings provides an elegant way to extract this information from this large output matrix. Therefore, all land use alternatives are ranked relative to the baseline land use, and for each land use alternative, the weighted mean rank is calculated. This means that, if a land use alternative is consistently preferred over the others in different driver scenarios, it will have a high mean ranking (i.e. the mean ranking approaches 1) and the standard deviation of this land use alternative will be low. A high mean ranking (low ranking number) is thus indicative for a high relative preference for the alternative. A low standard deviation in turn, indicates a high ranking consistency of the alternative, in the light of the driver scenarios, and in comparison with the other alternatives. This ranking will change if the policy priorties change, because the aggregate values of the ecosystems services delivered by each land use alternative also change. The ranking may also change if it is considered that some future scenarios of drivers and shocks are more likely than others. In the latter case, the different scenarios get a unequal weight, e.g. proportional to their likelihood to occur, when calculating the average ranking of the land use alternatives.

The toolkit allows spatial planners to explore trade-offs between various land use alternatives, taking ecosystem services into account. It is applied to a case to demonstrate its use for scenario planning.

2.2 Application to a case of extensive meat production in Flanders

The case is an unconventional livestock farming in Flanders, aiming at reconciling organic meat production with nature management. This agro-ecological production strategy aims to close cycles as much as possible , and to adapt to both the local biophysical conditions and biodiversity targets. Due to the high background deposition of nutrients, the extraction of nutrients is an important aspect of ecological grassland management (Oelmann et al., 2009; Stevens et al., 2011). Because of this, nature management in Flanders generates a biomass waste stream. This waste stream is spatially and temporally spread, making adequate removal and processing a challenge. An outline of the production system is given in Figure 11, and a map showing the location of the case farm in Flanders is given in Figure 12.

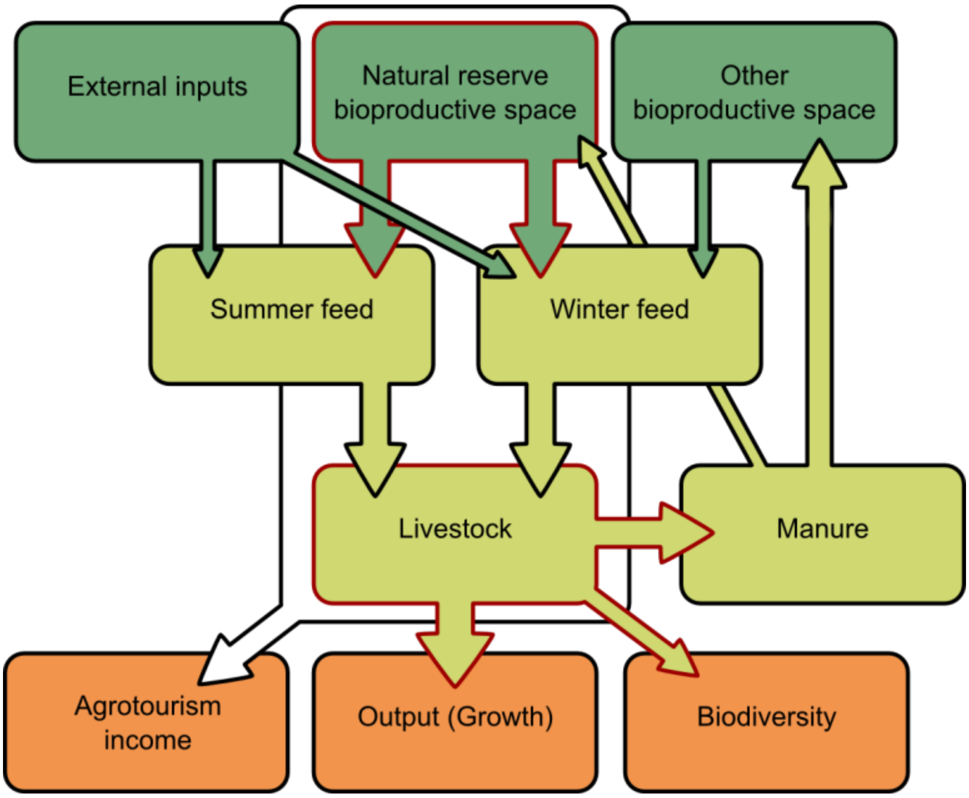


Figure 11. The livestock production system of the case farm is largely based on feed from a natural reserve.

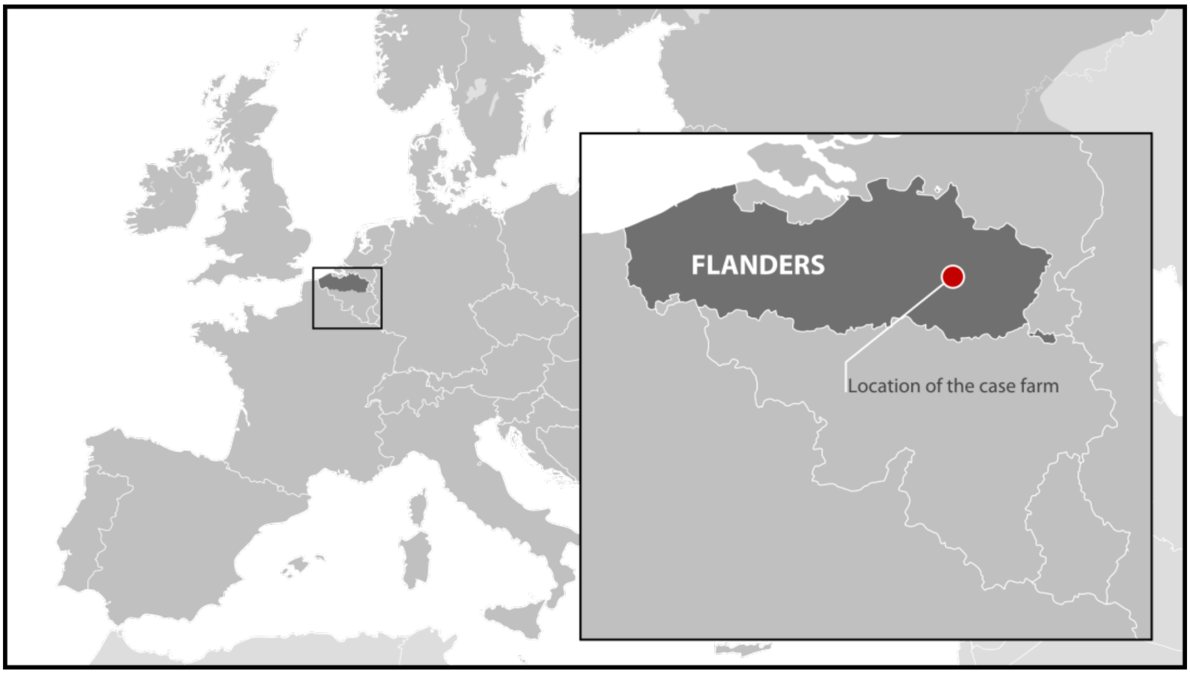


Figure 12. The case farm is located in the eastern part of the region of Flanders, Belgium.

The bioproductive space used comprises 44 parcels covering about 113 ha in total. Since most of the biomass is of inferior quality, the farm relies on relatively rare local breeds which are able to digest the low-quality feed from extensive grasslands within the natural reserve. This low-quality feed forms the mayor component of the animals' diet, either by directly grazing the parcels, or cutting the grasslands for feed production. In addition, a number of parcels with a more intensive grass-clover cultivation are strategically included in the farm's bioproductive space. The purpose of these parcels is twofold: (1) adding a nutritious share the animals' diets, and (2) providing space to spread manure. In doing so, the farm effectively extracts nutrients out of the natural reserve. Through both on-farm diversification and collaboration with other farms, the farmer is able to adapt to the specific requirements of the nature management plans. In the analysis we compare this agro-ecological farming strategy with a number of more conventional alternatives.

2.3 Stage 1: Spatial explicit ecosystem service evaluation

All parcels of the case farm were digitized in a GIS (ArcGIS 10.1) and attributes like land use, production, grazing and mowing intensity were added from the farm registry. The land use was verified using aerial imagery (Aerodata International Surveys, 2007) combined with fieldwork (early 2013). Using spatial overlays, additional data was attributed to the parcels: the Biological Valuation Map (AGIV, 2010); soil texture and moisture data (AGIV, 2006); the Habitat map v5.2 indicating habitats of the EU Habitat Directive (INBO, 2010); flooding risk zones (VMM, 2006); and prevalence of woody vegetation based on the 'Groenkaart' (ANB, 2013, 2010).

The actual land use was used as the *Reference* scenario. On a parcel by parcel basis and in collaboration with the farmer, 'what if' land use alternatives were formulated corresponding to different farm management choices: *IntensiveMIN* is a land use alternative that corresponds to a conventional livestock farming within the limits posed by the biophysical system. *IntensiveMAX* is a corner solution corresponding to maximal intensive livestock farming, ignoring local biophysical constraints. *IntensiveSRC* is a land use alternative that represents a mixed farming for livestock and woody biomass production. It assumes short rotation coppice on the most humid parcels near the farm.

We subsequently compared the capacity of actual land use to supply ecosystem services with the capacity of each of these alternatives. Monetary valuation is used to allow for comparison and aggregation of the different ecosystem services. We used the methodology developed by Broekx et al. (2013), which is available in an online tool 'Nature Value Explorer'. This tool values differences in ecosystem services delivery between land use alternatives. Detailed estimations on provisioning services were derived from the farm registers. Using grazing and cutting registers, we performed a by-parcel estimation of the contribution to these provisioning services.

As such this analysis, described in detail in Lerouge et al. (2016), yields differential estimates for the land use alternatives for a number of ecosystem services, namely crop & livestock production, woody biomass production, fine particle filtration (PM10), carbon sequestration in soil and biomass, nitrogen and phosphorous sequestration in soil, and cultural services using a stated preference method. Lower and upper estimates for the differential values are provided. To avoid overestimating the differential ecosystem services, we worked with the lower estimates.

2.4 Stage 2: formulating driver and shock scenarios

For demonstrative purposes, four shock scenarios were formulated, including a baseline scenario for comparison. The baseline scenario assumes no changes in the demand for and hence valuation of ecosystem services, and can be used as a reference to evaluate the influence of the other driver scenarios. Two scenarios were included to explore the effect of an increasing valuation of food produce: *FoodValueGlobal*, assuming a general increase of food valuation to the level of 150% of the original value, and *FoodValueOrg*, assuming this value increase only to apply to organic food products. This last driver scenario corresponds for example with the emergence of a local market for organic produce, offering higher prices to the farmers involved. The *RecValue* scenario assumes a similar valuation increase for the recreation value of green open space. Such a scenario is likely to occur in any peri-urban context where a population increase is associated with a net decrease of open space available for outdoor recreation.

Each driver or shock scenario results in change in the valuation of a particular ecosystem service. For every driver scenario the relative value of ecosystem services supplied under different land use alternatives was calculated.

2.5 Stage 3: Policy priorities

The aggregated value for the ecosystem services supplied by different land use alternatives was initially calculated as the unweighted sum of the value of individual ecosystem services. However, depending on the context policy makers might want to assign a larger weight to specific ecosystem services. We illustrate this by means of a simple demonstrative exercise using an arbitrary weighting matrix (Table 4).

Table 4. Weights assigned to individual ecosystem services during aggregation to explore the impact of policy priorities

Ecosystem service	Equal weight	More weight attached to…				
		Regulating services	Provisioning services	Cultural services	Carbon sequestration	Bioenergy production
Cultural services	1	0.8	0.8	1.7	0.7	0.6
P storage (soil)	1	1.12	0.8	0.9	0.7	0.6
N storage (soil)	1	1.12	0.8	0.9	0.7	0.6
C storage (biomass)	1	1.12	0.8	0.9	1.9	1.4
C storage (soil)	1	1.12	0.8	0.9	1.9	1.4
Air quality	1	1.12	0.8	0.9	0.7	1.4
Wood	1	0.8	1.6	0.9	0.7	1.4
Crop & Livestock	1	0.8	1.6	0.9	0.7	0.6

Once again, a baseline is included in which all ecosystem services are weighted equally, to allow for comparison between weighted and non-weighted analysis. Defining regionally variable priorities for ecosystem services is essential for spatial planning applications. For example one can decide to emphasise buffering and regulating services in upstream water catchments, or provisioning services on particularly fertile soils in an effort to promote efficient land use.

2.6 Stage 4: Ranking

The aggregated values are calculated for five policy priorities, over five driver scenarios, for the reference and 4 land use alternatives. This yields an output matrix of 5x5x4 comparison results indicating in Euros whether the land use alternative in its respective context represents societal benefits (positive balance) or costs (negative balance).

For each of the driver scenario, land use alternatives were ranked based on the amount of aggregated ecosystem services that they supplied. For this particular case this means we end up with a table ranking the land use alternatives from 1 to 4 in order of preference, for each driver scenario. Next, the mean rank was calculated for each land use alternatives, and weighted according to the likelihood that a scenario occurs. In addition, four different sets of likelihood figures for these scenarios are formulated, again by means of a demonstrative exercise.

A. 'equal': assuming all of the scenarios are equally likely to occur, i.e. no weighting is applied in calculating the mean ranking;
B. 'organic': assuming scenarios in which demand for and hence valuation of organic food increases, are relatively more likely to occur. A larger weight is attributed to the *FoodValueOrg* and *FoodValueGlobal* drivers, as well as to the baseline scenario ;
C. 'conventional': similar to the previous, but assuming scenarios in which the valuation of more conventional produce increases, are more likely to occur;
D. 'recreation', assuming increasing demand for recreational services due to population pressure and increased urbanisation.

These will be used as weighting factors in calculating the mean ranking in stage 4.

Table 5. Overview of scenarios and the likelihood distributions used for the demonstration

Scenario	Description	Likelihood			
		A	B	C	D
Baseline	Original comparison for reference.	0.2	0.31	0.14	0.08
FoodValueGlobal	Increased valuation of food (150%)	0.2	0.21	0.34	0.08
FoodValueConv	Increased valuation of conventional food (150%), status quo for organic food	0.2	0.06	0.24	0.08
FoodValueOrg	Increased valuation of organic food (150%), status quo for conventional food	0.2	0.26	0.09	0.23
RecValue	Increased valuation of recreational services (150%)	0.2	0.16	0.19	0.53

3 Results and discussion

3.1 *Stage 1: Spatial explicit ecosystem service evaluation*

In presenting the results, the actual land use (*Reference*) is used as a reference for benchmarking the other alternatives (Figure 13). These results are essentially the same as in the companion paper (Frederik Lerouge et al., 2016), except for small differences regarding the provisioning services, which were recalculated using more recent farm registry data. As expected, the conventional production-oriented scenarios *IntensiveMIN* and *IntensiveMAX* perform better for provisioning services, but less good for nearly all other ecosystem services evaluated. The *IntensiveSRC* scenario performs relatively well in the analysis, offsetting losses of provisioning services by increased fine particle filtration and cultural services. The aggregated estimates position the actual scenario as delivering more societal benefits than the more intensive farming models, but less than a model including woody biomass production.

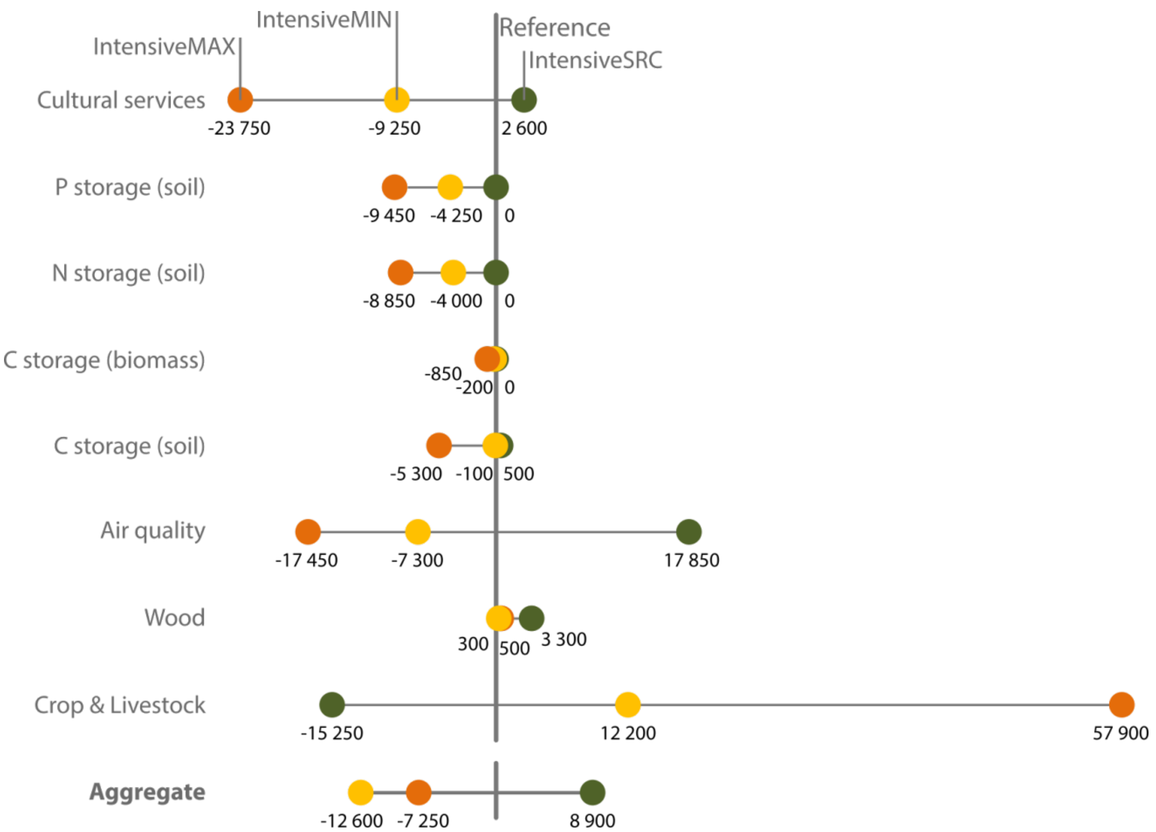


Figure 13. The evaluation of ecosystem services indicates relative societal benefits (expressed in EUR/year) provided by the studied land use alternatives (baseline scenario, no weighting applied), values are compared with the reference land use, being the current extensive land use

The fine particle filtration ('air quality') in particular contributes to the overall positive assessment of the *IntensiveSRC* land use alternative. Fine particle filtration however, is a positive externality that is difficult to internalize in a production system. Moreover, the productivity for woody biomass in the case area is relatively low, and short rotation coppice is largely in contradiction with local biodiversity targets. All these factors partially explaining why this land use is not adopted by the case farm. We have to point out that the assessment of ecosystem services is at this stage relatively rough, in particular with respect to cultural services. Moreover for the *IntensiveSRC* alternative, the ecosystem service estimations are based on a young monoculture of either willow or poplar species as a proxy for short rotation coppice. A short rotation coppice stand is visually less appealing compared to a young forest stand on which the valuation tool is based, therefore the result for cultural benefits is likely to be an overestimation.

The results of the comparisons in this stage will improve considerably as scientific work on the quantitative assessment and valuation of ecosystem services advances. The analysis presented in this paper is predominantly based on a Flemish evaluation framework, the Nature Value Explorer (v2, Broekx et al. 2013, available on www.natuurwaardeverkenner.be) that is also accessible to policy makers and spatial planners and is continuously in development. The development of this valuation tool explicitly takes into account the trade-off between sophistication and ease of use. Recent efforts of EU member states to map ES open new opportunities to include the ES concept in spatial planning and land management. A spatially explicit approach has the advantage that spatial variations in ecosystem services valuation can be taken into account. An example is a higher recreational value attributed to open space in more densely populated areas, or where substitues are rare.

While an assessment of the accuracy of the tool is beyond the scope of this research, a number of shortcomings at this stage could be identified. Mainly for regulating and cultural services, spatially explicit land use complementarities are insufficiently taken into account. This makes evaluating land use configuration alternatives impossible, while they might constitute a major opportunity to improve the overall societal benefits generated by a land use system, in particular in a highly used, peri-urban landscape

(Colding, 2007). Another challenge for valuation tools lies in the importance to take social-ecological innovations into account, many of which rely on spatial complementarities. For the case farm studied in this research, the principal social-ecological innovation is the explicit association between the traditionally segregated sectors of farming and nature management. Also, a number of ecosystem services are not yet included in the valuation tool. Adding additional ecosystem services to the assessment has the potential benefit to incorporate more of the positive and negative externalities, but at the risk of increased double counting (Loomis et al., 2000; Ninan and Inoue, 2013).

3.2 Stage 2: Driver scenarios

In Figure 14, we illustrate the amount of ecosystem services supplied under different land use alternatives for different driver scenarios, i.e. for different changes in the changes in demand for and hence valuation of ecosystem services. Initially, we simply aggregated all individual ecosystem services, i.e. equal importance was attached to each of them. These results demonstrate how certain drivers or shocks cause thresholds to be crossed, whenever land use alternatives switch position relative to the *Reference* alternative or to each other. A general increase in the demand for food and in the food value as simulated by the *FoodValueGlobal* scenario, generates a relative increased preference for conventional intensive land use alternatives. When the value increase is constricted to conventional produce, the extensive land use scenario becomes the least preferred. In contrast, a selective increase in the demand for and value of organic produce, which could for example be caused by the emergence of a market for locally produced organic food, has the opposite effect. Increasing demand for open recreational space might contribute to the emergence of extensive production systems, as illustrated by the *RecValue* scenario.

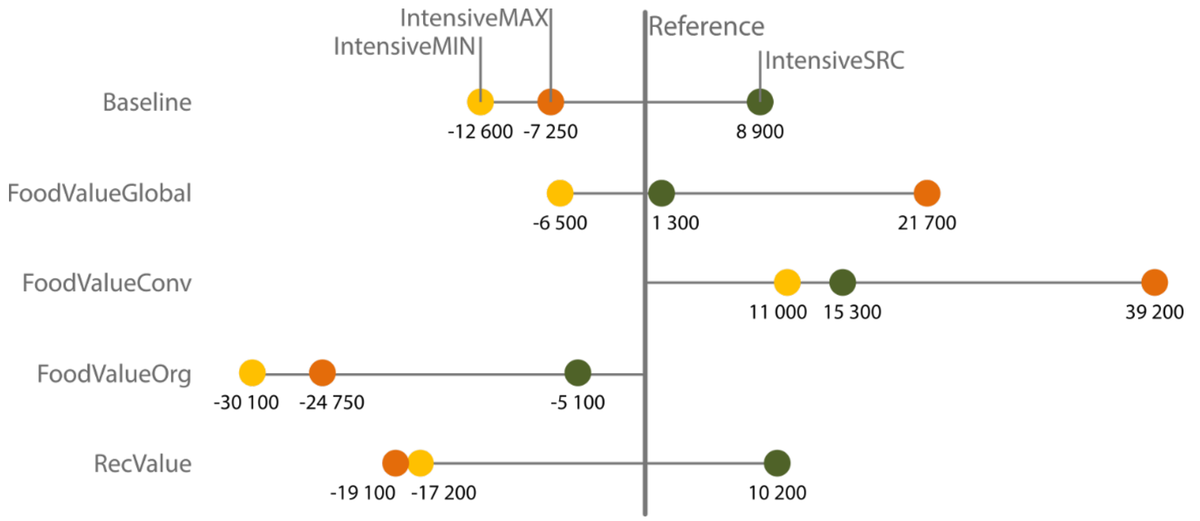


Figure 14. Aggregated monetary values of ES (in terms of EUR/year) for each of the driver scenarios, values are compared with the reference land use, being the current extensive land use.

For this demonstration, we assumed all defined scenarios are equally likely to occur and we assumed that individual ecosystem services are simply aggregated (i.e. without attaching more importance to one of the ecosystem services).

3.3 Stage 3: Applying policy priority settings

Figure 15 illustrates how thresholds might be crossed when policy priorities are incorporated into the calculation. This is of particular interest in spatial planning when the policy priorities are formulated in a spatially explicit way, or rooted in spatial analysis. For example, a community deciding to strive for carbon neutrality might increase the weight of carbon sequestration in the toolkit. The spatial focus can be more selective, for example in an analysis where water buffering capacity is weighted more in catchments that are upstream of problematic flooding areas. Ideally, the user will incorporate such spatial heterogeneity in the first stage, during assessment and valuation of the ecosystem services.

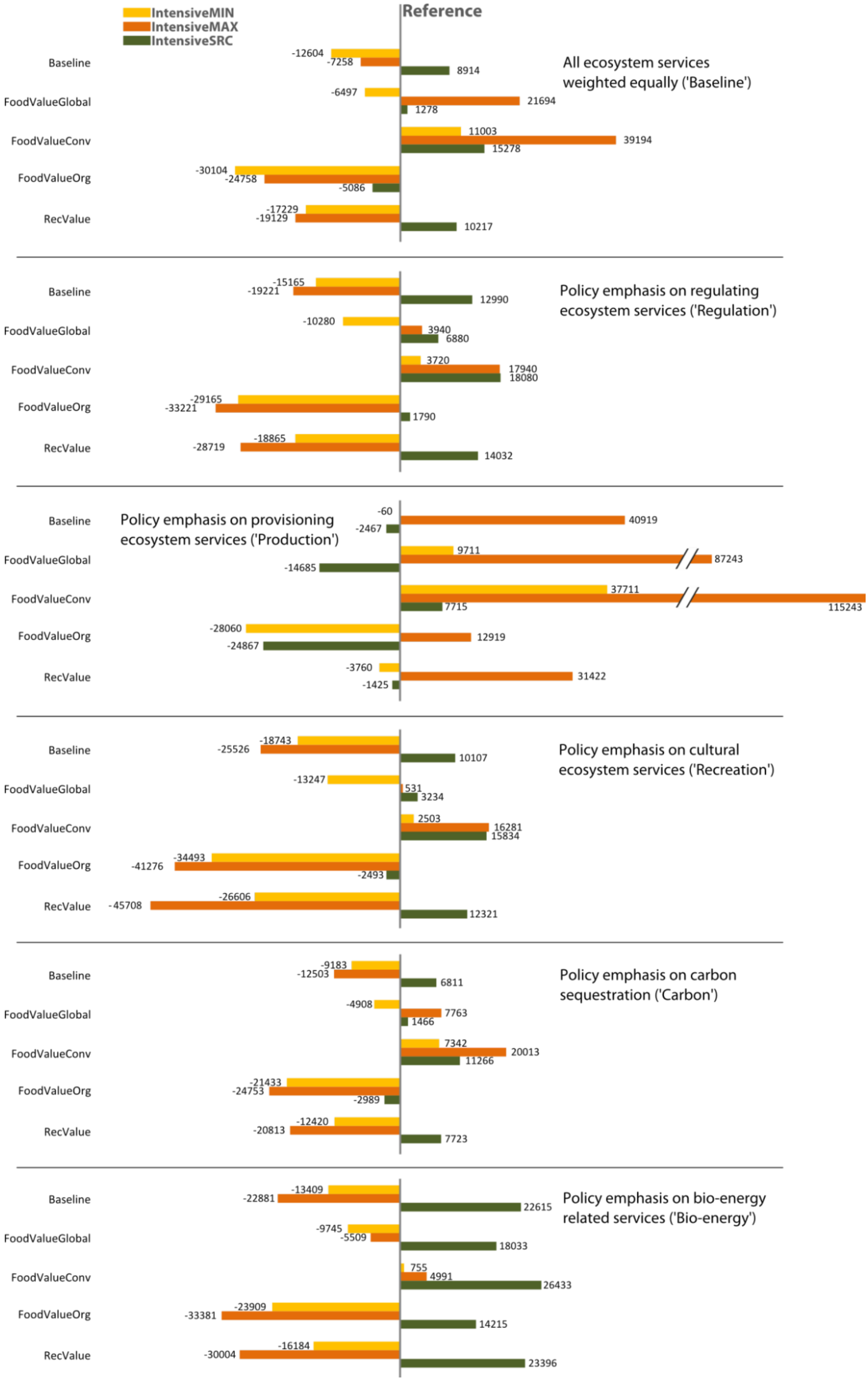


Figure 15. Aggregated monetary values of ES (in terms of EUR/year) for each of the driver scenarios and for different policy priorities, values are compared with the reference land use, being the current extensive land use.

If more importance is attached to food production, then the *IntensiveMAX* land use alternative is performing best. When interpreting the results, one should however bear in mind that the *IntensiveMAX* land use alternative is a corner solution that does not take local biophysical constraints into account. The more importance one attaches to cultural services, the less well the *IntensiveMIN* and *IntensiveMAX* land use alternatives are performing. More focus on bio-energy production or on the supply of regulating services increases the performance of *IntensiveSRC* land use alternative.

3.4 Stage 4: ranking land use alternatives

Ranking the land use alternatives is an elegant way to summarize the results from the scenario analysis taking policy priorities into account. Changes in ranking of land use alternatives due to different likelihood of future scenarios or due to different policy priorities are of particular interest. When a ranking is consistent, e.g. when one land use alternative is systematically higher, combined with a low variation of the mean ranking, the land use preference can be said to be resilient. It is useful to explore how the ranking of specific land use alternatives changes when one considers a specific future scenario more likely than another, or when one attaches more importance to specific ecosystem services.

For the demonstrative evaluation of the case farm, both the *IntensiveSRC* and *IntensiveMIN* mean scenario rankings are relatively consistent. Even for varying likelihood of future scenarios, they generally rank as the most and least preferred land use alternative, respectively. This in contrast to *Reference* and *IntensiveMAX*, showing more variability in their respective ranking.

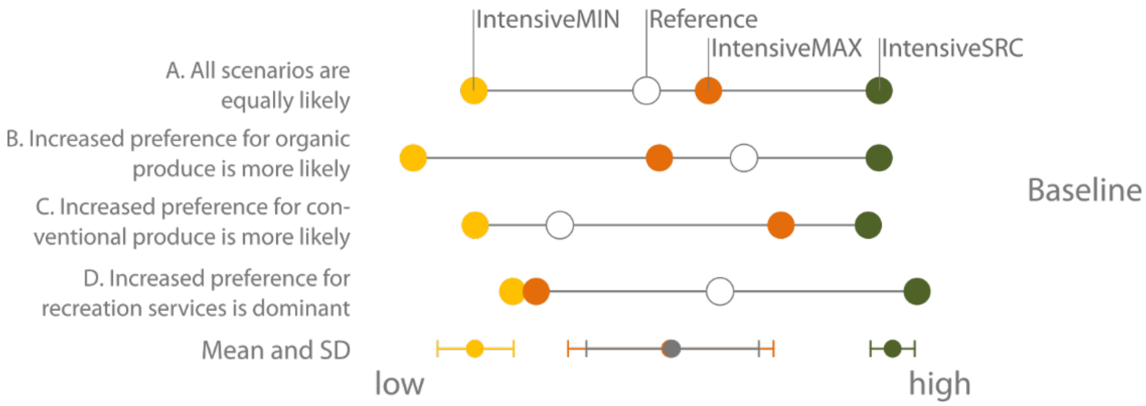


Figure 16. Ranking of land use alternatives with no specific policy priorities formulated ('baseline').

If policy emphasizes regulating services, the extensive land use alternative (i.e. the reference) is systematically ranked second, while the *IntensiveSRC* alternative would be consistently preferred.

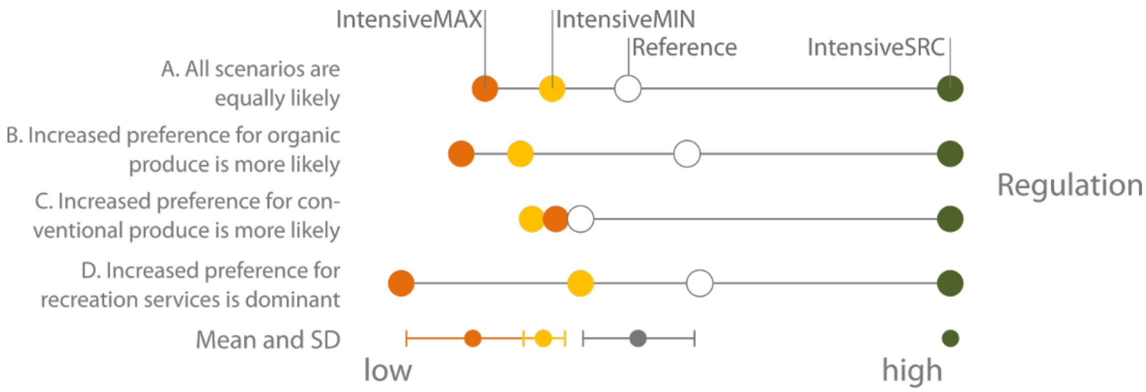


Figure 17. Ranking of land use alternatives with policy priority for regulating ecosystem services.

Where policy emphasizes provisioning services, the ranking shifts and the *IntensiveSRC* alternative becomes the least preferred. Notably, even under these priority settings, the *Reference* alternative is preferred over the *IntensiveMIN* alternative.

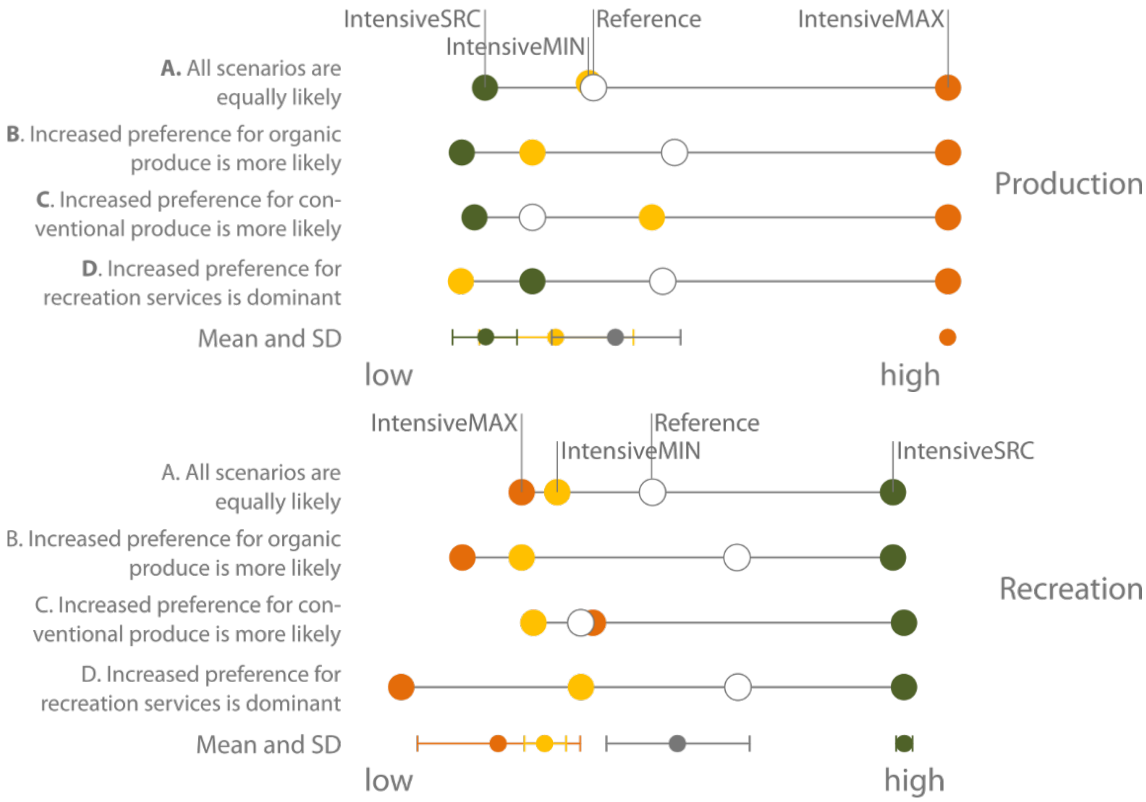


Figure 18. Ranking of land use alternatives with policy priority for provisioning and cultural ecosystem services.

Emphasizing cultural benefits increases the consistency of the *Reference* alternative slightly. Here too, if one assumes an increased demand for organic produce rather than an increased demand for conventional food, the *Reference* alternative outperforms the *IntensiveMIN* and *IntensiveMAX* scenario. However, if one assumes an increased demand for conventional food more likely, then the *Reference* alternative is ranked third after *IntensiveMAX* alternative. However, one should take into account that the *IntensiveMAX* scenario is a corner solution that does not take the local biophysical conditions into account.

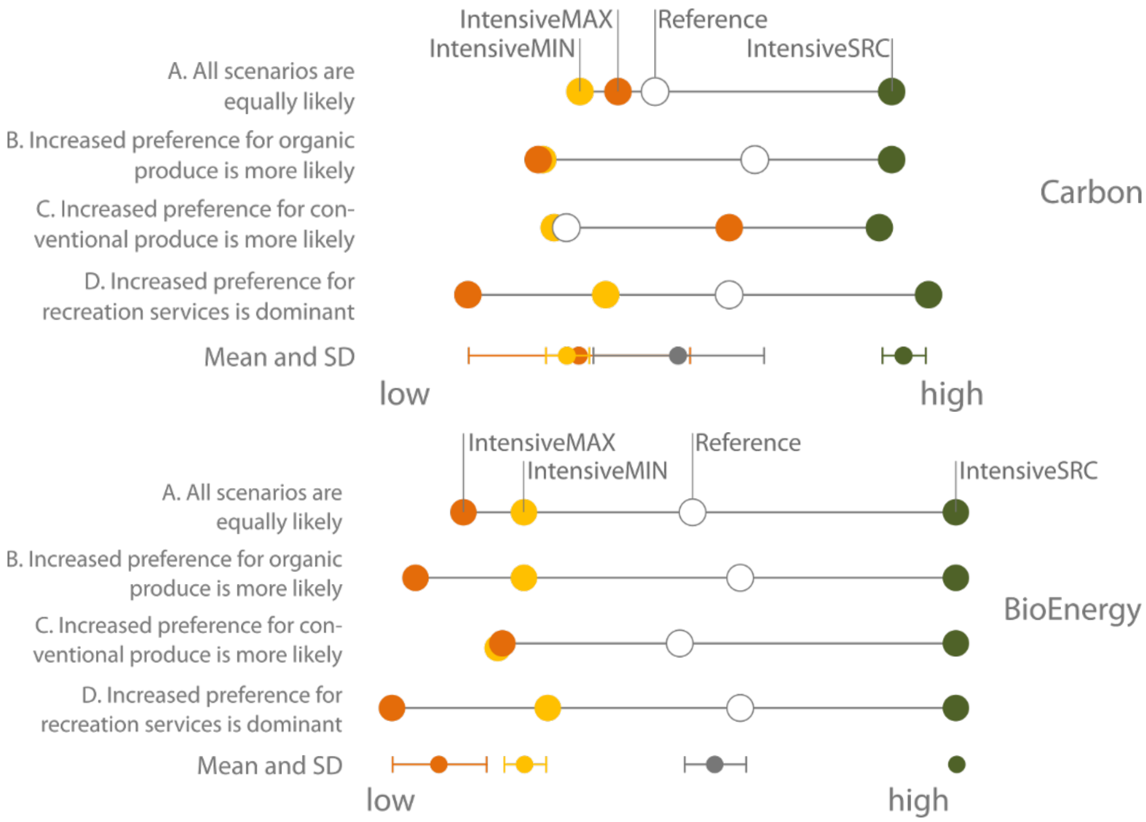


Figure 19. Ranking of land use alternatives with policy priority for carbon storage and bio-energy production.

The impact of a policy towards carbon sequestration on the ranking is limited. This is not the case for the policy priority setting towards bio energy, which not surprisingly pushes the intensive production alternatives to the end of the ranking.

Although these summarizing rankings provide a clear and simple way of interpreting the scenario evaluation, they do not contain all information and should be interpreted with care. For each scenario – policy priority combination of interest, it is recommended to look at the rankings of the individual scenarios. As such, we see the aggregated ranking output at this phase as a useful way of exploring the results of the toolkit. However, comparison of the ranking value with the consistency and standard deviation of the ranking can be used as an indication for the relative spatial resilience of the land use scenario in question.

4 General discussion & conclusions

As ex ante evaluation of ecosystem services performance under land use changes becomes more common, one should consider the possible caveats and strengths of these evaluations. We propose an analytical workflow to explore the behaviour of such evaluations under changing policy priorities and future development scenarios. This research aims at developing a toolkit for planners to incorporate ecosystem services in the decision making process. The conceptual toolkit was demonstrated using an actual case farm, applying a variety of illustrative scenarios. Besides the potential for supporting policy makers, the toolkit provides useful feedback for adaptive management of other stakeholders. For the example of the case farm, including more standing woody biomass in the production model is highlighted as a potential means towards increasing the total societal benefits delivered by the farm.

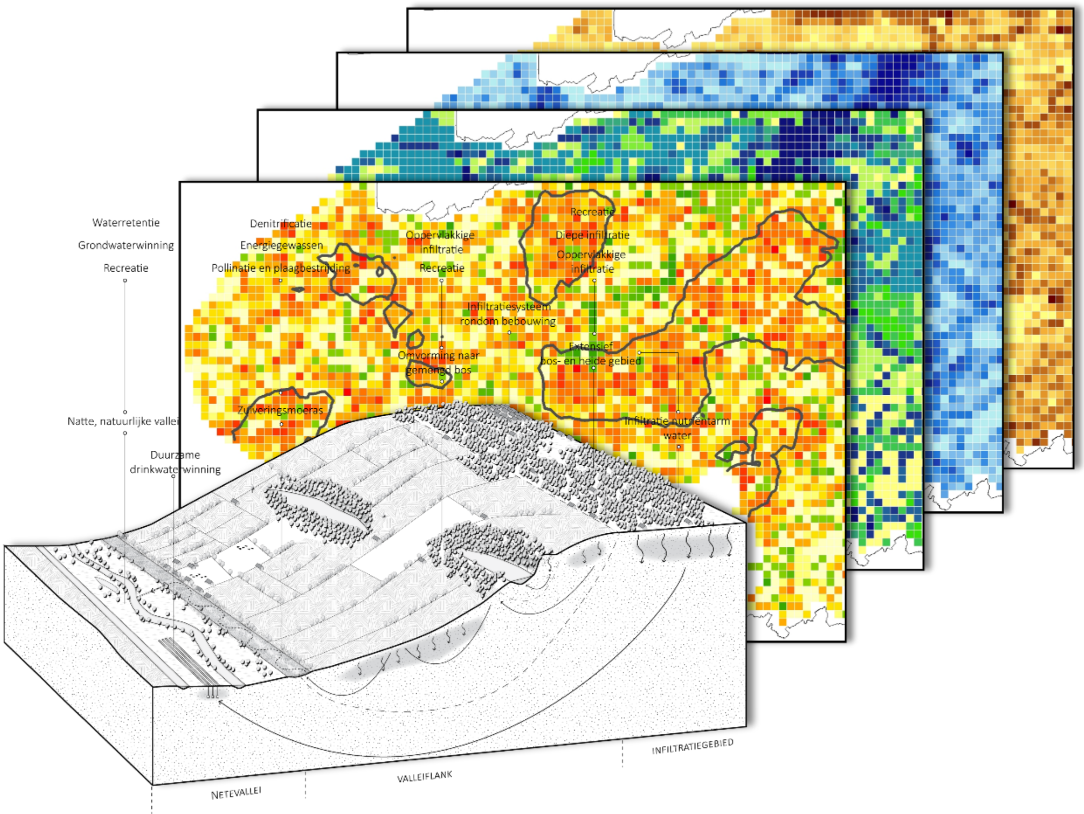
We see a number of potential applications for the proposed analytical workflow. First and foremost, it can contribute to regional spatial planning and land use optimisation. By allowing to explore the effect of multiple future scenarios, it can contribute to adaptive governance approaches, e.g. by allowing scenario planning exercises and provoking discussion. The results in our demonstrative case study seems to be relatively sensitive for changes in how conventional food production is valued and/or prioritized relative to organic production or regulating ES. As techniques for quantifying and valuing ecosystem services evolve and get more refined, the approach can contribute to 'payments for ecosystem services' (PES) schemes (Ruckelshaus et al., 2015).

Despite this potential, we also recognize a number of potential caveats to this approach. The analytical framework draws heavily on monetary valuation of ES, with associated advantages and drawbacks. The rationale for using monetary valuation is twofold: it allows for comparison of a diverse range of ecosystem services. But more importantly, it allows for comparisons with economic indicators. However, the approach does not aim at calculating absolute values for ES, nor at commodification of ES. The use of output figures without proper interpretation of the underlying assumpions might lead to wrong conclusions. Also, the quality of the output is directly dependent on the quality of the input and applied models. Dealing with uncertainties in both ES quantification and ES valuation is vital to improve decision making (Johnson et al., 2012). Even though simplifying complex social-ecological processes intuitively goes against the ambitions of interdisciplinary scientists, tools need to be sufficiently simple to be used in decision processes (Ruckelshaus et al., 2015). Therefore, responsible simplification, at least of the tool's output, is necessary. The means and ends of the tool should be adequatly communicated, including caveats against improper applications (Johnson et al., 2012). Although relative ranking of land use alternatives is a useful form of output for decision makers (Ruckelshaus et al., 2015), interpretation of the ranking results should always be coupled with in depth study of the underlying assumptions by the tool. Application in the field should be preceded by more in-depth modeling in order to validate the results from the explorative comparison. In that phase, oversimplification should be avoided.

The framework can also provide insights in some resilience aspects of the land use system in question. In analogy with Zell & Hubbart (2013), we could argue that bioproductive space is resilient if it continues in delivering similar levels of ecosystem services under changing conditions. As such, we define spatial resilience as "the capacity of social-ecological systems to buffer space-bound functions and services against internal and external shocks, by using adaptive forms of land use and configuration". The more a land use system remains capable to deliver services to human well-being, despite socio-economic or biophysical factors affecting their demand and value, the more resilient it is to these factors.

Social-ecological resilience recognizes the intrinsic complexity, uncertain and dynamic character of SES (Carpenter and Folke, 2006; Folke, 2006), and moves away from a linear cause-consequence reasoning (Kinzig et al., 2006). The framework presented contributes to this by allowing to explore and elegantly compare numerous scenarios for land use systems under various shocks and shift scenarios.

Chapter 4.
Mapping the spatial mismatch between local ecosystem service supply and demand



Chapter 4.

Mapping the spatial mismatch between local ecosystem service supply and demand

1 Introduction

A proper integration of the ecosystem service (ES) concept in planning practices is a promising yet challenging pathway towards sustainable and resilient regional and local planning (Galler et al., 2016; McPhearson et al., 2014; Nin et al., 2016). An obvious starting point for this is properly defining environmental conditions and associated ES on a landscape scale, based on underlying biophysical structures and processes (Verhoestraete and Meire, 2009). One needs to deal with the number and diversity of various ES, and the broad range of interactions between ES (Maestre Andrés et al., 2012; Willemen et al., 2010). Various trade-offs and synergies occur between different ES in a landscape (Castro et al., 2014; Jacobs et al., 2014), often forcing decision makers to make difficult choices (Turkelboom et al., 2018). Despite often being assessed individually, ES cannot be treated separately from each other. Therefore, ES are increasingly described as being part of specific ES bundles, series of ES that often co-occur in a landscape (Hauck et al., 2013; Raudsepp-Hearne et al., 2010). In addition, ES assessments should aim to integrate aspects of supply and demand (Wei et al., 2017). As such, regions can be classified based on the prevalence of specific –wanted or unwanted– ES bundles (Raudsepp-Hearne et al., 2010), or based on the relation between local ES supply and demand (Burkhard et al., 2012; Schulp et al., 2014). Spatial modelling of ES can be a useful tool for this and can help to mainstream ES into policy-making. Operationalization of ES maps suffers from problems linked to the terminology used and the knowledge base that supports the models of ES supply and demand (Zulian et al., 2018). This resulted in a large variety in mapping methods (Harrison et al., 2018) which makes it hard to integrate them into planning and policy process (Hansen et al., 2015; Kabisch, 2015; Rall et al., 2015).

This paper illustrates how one can arrive at a classification of regions based on the spatial (mis-)match of ES bundles, and as such it provides a meaningful foundation for practical applications of the ES concept in spatial planning. This study thus presents an integrated assessment of ES supply and demand (IAESSD, sensu (Wei et al., 2017)). The central metropolitan area in Flanders, Belgium, serves as a case study area. It has a polycentric structure with a highly fragmented landscape and therefore stands as an example for a diffuse urban network. Because of its high population densities -also outside of the urban cores- we can expect a strong demand for local ES (Tammi et al., 2017). This makes spatial match-making between supply and demand a crucial exercise in spatial planning and governance.

In addition, under the impulse of the EU 2020 Biodiversity Strategy which aims to halt the loss of biodiversity and associated ES, member states have made serious efforts to map and quantify the delivery of ES on their territory. In Flanders, the northern region of Belgium, ES mapping has been integrated in the 2014 Nature Report (NARA14). With these efforts, new possibilities emerged for the integration of the ES concept in spatial planning.

For this research, we define local trade-offs and synergies between individual ES based on a selection of spatially explicit ES assessments for Flanders from NARA14, and translate them to logical ES bundles which were mapped for the metropolitan area of Flanders. Through expert evaluations, we estimated the spatial match and mismatch between these ES bundles, to produce a supply-demand mismatch map. We also assessed whether the areas that are showing a supply/demand mismatch today, will be put under additional stress in the future. If so, such areas require specific governance. To explore this potential issue and identify such areas, we compared the supply/demand mismatch maps to selected existing future land use change scenarios. This allows to identify (future) problem areas, i.e. areas where an existing mismatch between ES supply and demand will likely be further exacerbated.

2 Materials and methods

2.1 Study Area and conceptual framework

Flanders is characterized by a high degree of diffuse urbanisation. In particular in the central region of Flanders, between the cities of Brussels, Gent, Antwerp and Leuven, small historical centres are fused by patterns of urbanisation, to form one larger metropolitan area (Albrechts et al., 2003), the so-called ‘Flemish Metropolitan Core’ or ‘Flemish diamond’. This area can be described as a typical example of an urban network: a polycentric structure with a highly fragmented landscape. In between the urbanised axes of this network, agriculture acts as the main carrier of the remaining open space (Gellynck et al., 2007). However, ongoing transformation processes towards higher population densities and urbanisation put the remaining open space, and the ES delivered there, under pressure. At the same time the local need for ES is high due to its high population density, strong urbanisation and its associated environmental pressures. These aspects make Flanders an excellent case for the study of ES interactions in an urbanized landscape and for exploring the merits of the ES concept for spatial planning.

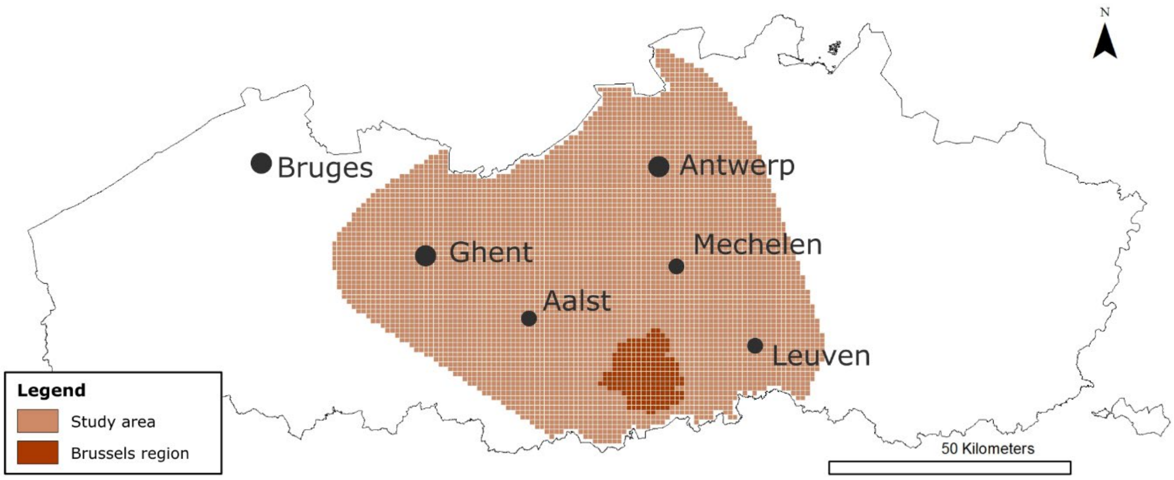


Figure 20. Study area.

We focus our analysis on the bioproductive space, which is all space that is capable of providing ES (Lerouge et al., 2015). As such, we approach open spaces as parts of a bioproductive landscape that delivers provisioning, regulating and cultural services, corresponding to the CICES classification of ES (Haines-Young and Potschin, 2014, 2010).

To assess the (mis)match between ES supply and demand, the study area was divided in 1x1km squares, which form the basic resolution of data collection and analysis. Due to data limitations, the Brussels territory could not be included in the analysis. The resulting study area comprised 4871 square kilometer grid cells.

We first had to made a selection of ES supply and demand maps. Next, we looked at pairwise spatial (auto)correlations between these services, and conducted a cluster analysis. The results of of the cluster analysis were interpreted by an expert panel in order to interpret specific ES bundles. Next, the (mis)match between these bundles was evaluated by the expert panel, and mapped. Hot spot mapping was used to identify the main hot- and coldspots of spatial (mis)match between supply and demand. Finally the hot and coldspot maps were compared with future land use change scenarios to explore where ES supply/demand mismatch may be excarbated in the future.

2.2 Selection of ESS supply and demand maps

Input datasets were selected from the 'NARA-T' repository, which contains datalayers of various indicators (e.g. qualitative and quantitative, stock and flow data, supply and demand data, or data from various sources or expressed in different units) related to ES supply and demand, and which is developed and made available by INBO and Ecoplan (Stevens et al., 2014). These datasets are publicly available, which is very important to facilitate the use of ES in planning practice (Tammi et al., 2017). All available datasets on supply of and (local) demand for ES were screened and evaluated on suitability for analysis in consultation with an advisory board including end users of the study. This improves the stakeholder understanding and relevance of the end results, and increases the chance of the study results being picked up and used in actual planning practice (Zulian et al., 2018). The main criteria used in the selection were the nature and relevance of the respective indicator, and the quality and resolution of the dataset. The supply maps mainly represent the degree to which a biophysicial structure is able to deliver a service, while the demand maps are more depicting the local need for a given service. Here, we would like to empathize that we use the term 'demand' in a broad sense of the word, and not in a strict economic sense. Our demand data encompass the exogenous societal need for local ES, independent of a specific willingness-to-pay for it or not. For each of the selected datasets, the mean value was calculated per 1 square kilometer grid cell, bringing all data to the same spatial resolution. With the exeption of the N-deposition dataset, all original datasets used are of a much finer spatial resolution, so this transformation does not lead to any spillover effects.

With respect to the nature and relevance, datasets were selected depicting the *flow* of ES, i.e. the supply ES per unit of area and time, as opposed to the *stock*, which is the total amount of an ES per area. A useful example is the ES carbon storage in biomass per square kilometer, where the annual increase or decrease of carbon in biomass represents the flow, and the total amount of C held within the standing biomass represents the stock. For this reason, datasets estimating the C, N and P soil stocks are not included in the analysis.

In this study, we aim to compare local ES supply with the local societal demand for ES (Burkhard et al., 2012). Therefore, the datasets need to separate supply and demand as much as possible. Some ES supply datasets however, also contain a demand factor by definition. For example, the ES erosion control in the available database was defined as the estimated degree of prevented erosion by vegetation on erosion prone soils. By this definition, the ES 'erosion control' can only be observed where there is an existing erosion risk (i.e., where there is a demand for erosion control). This makes it hard to assess whether a low value for the ES 'erosion control' is due to the absence of vegetation that delivers the ES, or due to a low erosion risk. We tried to separate supply and demand as much as possible for the analysis. However, for some ES, such as erosion control, this proved to be rather difficult.

2.2.1 Supply of ES

An overview of the datasets selected for analysis is provided in Table 6.

Table 6. Overview and description of ESS supply maps used for the analysis. Typology according to CICES: regulating (R), provisioning (P), and cultural (C).

Code	Type	Label	Description	Unit	Source
WOOD	P	Wood	Yearly increase in harvestable wood volume.	(m^3/Are)	(Broekx et al., 2013a)
INF_DEEP	P	Infiltration (deep)	Suitability for infiltration to deep aquifers	Score (0-100)	(Allaert et al., 2012)
ENERGY	P	Energy	Estimated production of energy crops	GJ/10ha/year	(Van Kerckvoorde & Van Reeth, 2014)
GRASS	P	Grass	Supply of grass	% yield to max.	(Van Gossum et al., 2014)
AGRIC	P	Agriculture	Supply of crops (exluding corn)	% yield to max.	(Van Gossum et al., 2014)
CORN	P	Corn	Supply of corn	% yield to max.	(Van Gossum et al., 2014)
VEGET	P	Vegetables	Supply of vegetables	% yield to max.	(Van Gossum et al., 2014)
FRUITS	P	Fruits	Supply of fruit	% yield to max.	(Van Gossum et al., 2014)
CLIMATE	R	Climate regulation	Proxy based on land cover and land use maps	Score	Groenkaart 2013 (ANB); (Jacobs et al., 2014)
NOISE	R	Noise buffer	Proxy based on land cover and land use maps	Score	Groenkaart 2013 (ANB); (Jacobs et al., 2014)
C_BIOM	R	C-Biomass	C storage in biomass	Kg/ha.year	(Broekx et al., 2013a)
AIR_QUAL	R	Air quality	Fine dust (PM10) captured by vegetation	kgPM10/ha	(Liekens et al., 2013)
EROSION	R	Erosion buffer	Estimated avoided erosion,	Tonnes/ha.year	Van der Biest K, Ecoplan WMS (2014)
INF_SURF	R	Infiltration (surface)	Estimated actual infiltration	Mm/year	Staes J, Ecoplan WMS (2014)
WAT_RET	R	Water retention	Estimated actual water retention	M^3/are	Staes J, Ecoplan WMS (2014)
WAT_SURF	R	Water storage (surface)g	Land use in recently flooded areas + Formally designated floodplains	0-5	(Schneiders et al., 2014)
DENITR	R	Denitrification	Estimated actual denitrification	mgN/m^2.year	(Broekx et al., 2013a)
POLLIN	R	Pollination	Suitable habitat for pollinators	1/0	(De Bruyn, 2014)
RECREA	C	Recreation	Share of accessible greenspace	-	(Bomans et al., 2014)

The provisioning services included in the analysis comprise wood production (WOOD), water production in terms of deep aquifer replenishment (INF_DEEP), and the production of non-woody energy crops (ENERGY). Because of the heterogeneity in spatial distribution between crop types, food production was divided in separate datasets for grass (GRASS), agricultural crops (AGRIC) (H1111), corn (CORN), vegetables (VEGET) and fruits (FRUITS) (Van Gossum et al., 2014). The production of game meat was not included in the analysis due to the limited resolution and quality of the available datasets.

Regulating services are represented in the analyses by 11 datasets. Three of these datasets are proxies, generated to account for import gaps in the available data. Proxies for Climate regulation (CLIMATE) and Noise buffering (NOISE) are based on a modified version of a high-resolution land cover dataset 'Groenkaart' (ANB, 2013), distinguishing between the categories 'water', 'not green', 'grass', 'low green', 'high green'. We reclassified this dataset using the key shown in Table 7, generating relativey simple ordinal proxies for the respective ES. The assumpions used in the reclassification were discussed with a panel of experts. The proxy for water storage (surface) was based on a combination of two available datasets: [land use suitability for water buffering in recently flooded areas] and [formally designated floodplains], reclassified to a ordinal scale representing suitability with 6 classes (WAT_SURF) (Schneiders et al., 2014). Both of these maps include an indirect demand factor, but not necesserily at the same location (more likely downstream).

Table 7. Key used in creating the proxies for Climate regulation and Noise buffering

Land cover class	P01 - Climate regulation	P02 - Noise buffering
Not green	0	0
Water	1	0
Grass	1	0
Low green (< 3m)	1	1
High green (>3 m)	2	2

Carbon sequestration in biomass (C_BIOM) is incorporated in the analysis as the yearly carbon storage based on quantitative estimates of the yearly volume increase of harvestable woody biomass (Broekx et al., 2013a).

The air quality in Flanders is generally poor, with fine dust as one of the main culprits of health issues (Bossuyt, 2013). The main sources of fine dust in Flanders are transport (a disproportional amount of vehicles have diesel engines), agriculture and residential heating (notably from wood stoves, Maenhaut et al., 2016). Vegetation has the capacity to capture fine particles from the air, which is seen as an important ES. We quantify the ES air quality (AIR_QUAL) using indicators published by Oosterbaan et al., 2006, which estimated the capture of fine particulate matter (PM10) by various vegetation types.

Loss of fertile soil material due to erosion is mainly an issue in the southern parts of the study area. Erosion control (EROSION) was included in the analysis using erosion reduction estimations attributed to the presence of vegetation types. Note that supply and demand are intrinsically interlaced here: the ES erosion control by vegetation can only be supplied in areas where there is an erosion risk, which is a factor of soil type and above all, topography. As such, a low supply of this ES can either be due to the absence of erosion-reducing vegetation, or due to the absence of an erosion risk, in which case there is no real demand for erosion reduction. For the next steps of the analysis, these issues were pointed out to the expert panel evaluating the ES bundles, making sure they would accurately interpret the potential (mis)match of each supply and demand bundle.

The superficial infiltration of water in the subsoil (INF_SURF) is important as part of a buffer against local flooding during extreme weather events. The dataset builds on an evaluation of the water infiltration potential based on soil drainage classification, local topography, soil sealing by buildings in the surroundings, as well as interception of precipitation by vegetation. A dataset on surface water storage basins to buffer peak discharges (WAT_SURF, see above) complements this map.

Water retention in the soil is important to increase the capacity to cope with extended periods of drought. We used a dataset (WAT_RET) that estimates the volume of water that is available during a structural drought period and is defined as the mean volume of water present above a depth of 1 meter below the surface.

Denitrification (DENITR) comprises the biological process of nitrate conversion to nitrogen, preventing nitrate to enter the groundwater system, which would lead to eutrophication of these systems.

For the ES pollination, a commonly used supply dataset represents the added value of pollination to pollination-dependent crops. But here again, supply and demand are intrinsically mixed. Instead, we included a dataset estimating the prescence of suitable pollinator habitat (POLLIN), under the assupmption that due to their presence, the ES pollination could be delivered regardless of the local demand.

We used a map on the share of available greenspace for recreation (RECREA) as a basic proxy for cultural services.

2.2.2 Demand of ES

After careful selection, we retained 11 data layers for local demand (Table 8).

Table 8. Overview and description of ES demand maps used for the analysis. Typology according to CICES: regulating (R), provisioning (P), and cultural (C).

Code	Type	Label	Description	Unit	Source
WAT_EX_BUF	P	Ground water	Ground water extraction zones and their respective buffer zones	Ordinal	DOV
POLLIN	R	Pollination	Estimated presence of pollination-dependent crops	Ordinal (0-5)	(De Bruyn, 2014)
NOISE	R	Noise	Zones with noise pollution	Ordinal	(De Blust & Van Renterghem, 2014)
FLOOD_BUF	R	Water buffering	Population density in flood-prone areas	Inhabitants/ha	(Schneiders et al., 2014)
EROSION	R	Erosion control	Per parcel erosion sensitivity	Ordinal (6-1)	DOV: (ALBON)
N_DEP	R	N-deposition	Atmospheric N-deposition	kg N/ha	Staes J, Ecoplan WMS (2014)
POLLUTN	R	Pollution	Risk for sources of diffuse pollution	%	Staes J, Ecoplan WMS (2014)
CLIMATE	R	Climate	Urban Heat Island map	°C deviation	(Technum, 2015)
NEIG_GRN	C	Neighbourhood green space	Demand for neighbourhood green space	1/0	(Simoens et al., 2014)
MUN_GRN	C	Municipal green space	Demand for Municipal green space	1/0	(Simoens et al., 2014)
RECREA	C	Recreation	Proxy: population density	Inhabitants/ha	(Simoens et al., 2014)

The demand for food provisioning services is missing, and could not simply be proxied by population density due to the global nature of the food market. The demand for locally produced food is arguably even harder to grasp. Even if population density was considered as a proxy, it was already used as a proxy to map the demand for local recreation greenspace (see further). Using the same proxy twice in the analysis has no added value and, depending on the analysis methods applied, might even inflate the demand for certain ES. Drinkwater supply (WAT_EX_BUF) is also a provisioning service. Here, we used a dataset from DOV demarcating buffer zones for groundwater extraction sites.

Several regulating ES were included in the analysis. The demand for pollination services (POLLIN) was estimated using the location of pollination-dependent crops. This demand was summarised on a 6-point ordinal scale that ranged from ‘no demand’ (0) to ‘very high’ (5).

The demand for noise buffering (NOISE) was included by looking at the modeled noise pollution from the main transport corridors. Where the modeled noise levels were

0, we assumed a background noise of 40dB(A) to make the calculated means more representative.

The Flemish housing and spatial planning policies did not prevent settlements to be built in natural floodplains. Combined with large-scale soil sealing and adaptations of rivers and streams to increase draining of water, downstream flooding of houses is common in some areas. The demand for surface water buffering (FLOOD_BUF) during periods of heavy precipitation was included in the analysis by estimating the number of people living in areas sensitive to flooding.

For the demand for erosion control (EROSION), we used a dataset from DOV with the erosion sensitivity on pacel scale.

An estimation of atmospheric N-deposition, based on the VLOPS model (VITO), was included as a proxy for the demand for N buffering (N_DEP) (Staes, 2016a). Regarding the environmental buffering against pesticides and nutriënts in general, an additional dataset was included that represented the risk for diffuse sources of pollution (POLLUTN) (Staes, 2016b).

The demand for climate regulation was included in the form of the urban heat island effect (CLIMATE), based on the 'Wageningen formula', which yields a dimensionless index of the relative strength of the heat island effect (Technum, 2015).

The demand for cultural services focusses on open air recreation and access to public greenspaces. We included the demand for so-called 'neighborhood greenspaces' (NEIG_GRN), which comprises green spaces with a minimum area of 1 ha within a walking distance of 400 meters, and 'municipal greenspaces' (MUN_GRN) which comprises green spaces with a minimum area of 10 ha within a walking distance of 800 meters. This indicator equales one if neighborhood greenspaces iss 'available' near a residental area and zero if there no neighborhood greenspaces is available near a residiential area or outside residential areas. As such these datalayers are not a pure ES demand nor ES supply maps. Therefore, we also included population density as a proxy for the general demand for recreational green spaces (RECREA).

2.3 Analysis of spatial patterns, trade-offs and synergies

Spatial analysis was done using ArcGIS 10 (ESRI) combined with the Geospatial Modelling Environment (GME, Spatial Ecology LLC). Statistical analysis was done using R 3.2 (r-project.org). Within the study area, 1x1 km gridcells were generated as sampling units, resulting in a total of 4871 cells, one square kilometer each. All ES datalayers were summarized on a per cell basis by calculating zonal statistics in ArcGIS.

Spatial autocorrelation was estimated in ArcGIS using Moran's I, applying an incremental radius from 1km to 10km (in steps of 1km). Trade-offs and synergies between ES were evaluated by estimating pairwise correlations using Pearson's correlation coefficient rp. We corrected for spatial autocorrelation (Clifford et al., 1989) by applying the methodology developed by Dutilleul et al. (1993). Analysis results were joined with the grid cell map in ArcGIS in order to allow further spatially explicit analysis and visualisation of the results.

2.4 ESS bundles

We used k-means clustering to group grid cells according to their supply or demand for ES. K-means clustering allocates the grid cells to a prespecified number of distinct clusters, hereby minimizing the within cluster sum of squares. Determining the optimal number of clusters wasbased on examining the within groups sum of squares over a range of possible cluster numbers to determine the point where adding an additional cluster does no longer significantly reduce the sum of squares. This approach remains in many cases somewhat pragmatic since it seldomly gives a clear cut off point. A panel of experts assessed for each clusters which combination of ES was 'typical' for the cluster. These combinations can be interpreted as ES bundles. The panel comprised 8 experts from various fields, i.e. the Flemish administration of spatial planning (3), researchers from the KU Leuven Department of Earth- and Environmental Sciences (1), experts from Flemish provinces (2), the Flemish Environment, Nature and Energy Department (LNE) (1) and the Research Institute for Nature and Forest INBO (1).

2.5 Supply-demand mismatch map and hotspot analysis

We wanted to assess the degree of spatial match or mismatch between supply and demand of ES. A mismatch between two ES bundles occurs where there is large discrepancy between the local supply of ES and the local demand for ES. Vice versa, where the local ES supply meets the local demand for ES, we consider this a match. As such, the (mis)match between supply and demand bundles can be mapped, but the question remains how problematic or beneficial this (mis)match is from a policy perspective.

An expert-based approach was used to evaluate each (mis)match and the extent to which a mismatch is problematic or a match is important to sustain. Therefore, we presented a cross table of all possible combinations of supply and demand bundles, and asked the same expert panel to provide two scores, each on a 5-point likert scale, for each of the possible combinations. For the first score, 1 is a 'perfect' match, and 5 is a 'perfect' mismatch. Consider this the unweighted (mis)match score. The experts were also asked to assess the relative importance (from a policy perspective) to improve the match for the given combination of supply and demand bundles. Here, a score of 1 corresponds to 'a mismatch is not at all problematic / maintaining a match is very unimportant', while a score of 5 corresponds to 'a mismatch is very problematic / maintaining the match is very important'. Consider this the 'weight' given to a specific (mis)match. The resulting mean scores were joined to the spatial dataset in GIS. The (mis)match scores and weights were combined by multiplication, resulting in a 'weighted' (mis)match score.

Supply-demand mismatch maps were generated depicting the unweighted and weighted (mis)match score, and both maps were subjected to a hotspot analysis. The hotspot mapping was done using the Getis-Ord Gi* statistic, which compares local means with global means, and maps the statistical significance of any deviation. The analysis was done on three different scale levels (2.5, 5 and 10 kilometers), and the results were combined in one map which gave a rich and nuanced image of cold- and hotspots.

Lastly, we compare the supply-demand mismatch maps with future land use scenario's. This was done to evaluate where one can expect that anactual supply-demand mismatch to be further exacerbated due to expected land use changes, such as advancing urban sprawl or loss of forested area. We used the ‘Business-as-Usual’ (BAU) and the ‘Spatially Neutral’ (SN) scenarios developed by VITO (Engelen et al., 2011; Poelmans and Engelen, 2014). Both scenarios have a horizon of 2050. The BAU scenario assumes no specific change in spatial policy regimes so that residential and industrial development continue at the same pace. The SN scenario assumes policy changes so that residential and industrial development grows at 3ha/day in 2020, but declines so that it becomes spatially neutral by 2030, i.e. meaning that there is no net increase in residential or industrial areas. We assume that in areas where soil sealing increases, ES supply declines and mismathces aggrevate. Grid level indicators of the development of residential and industrial area according to the BAU and SN scenario were multiplied with our supply-demand mismatch indicators. Hot spot mapping was used to draw a contour highlighting the areas where the situation is expected to be the worst.

3 Results

3.1 *Spatial patterns, trade-offs and synergies*

All ES supply maps exhibit positive spatial autocorreltation. This means that their spatial distribution is never completely random, but shows a certain degree of spatial association (Figure 21).

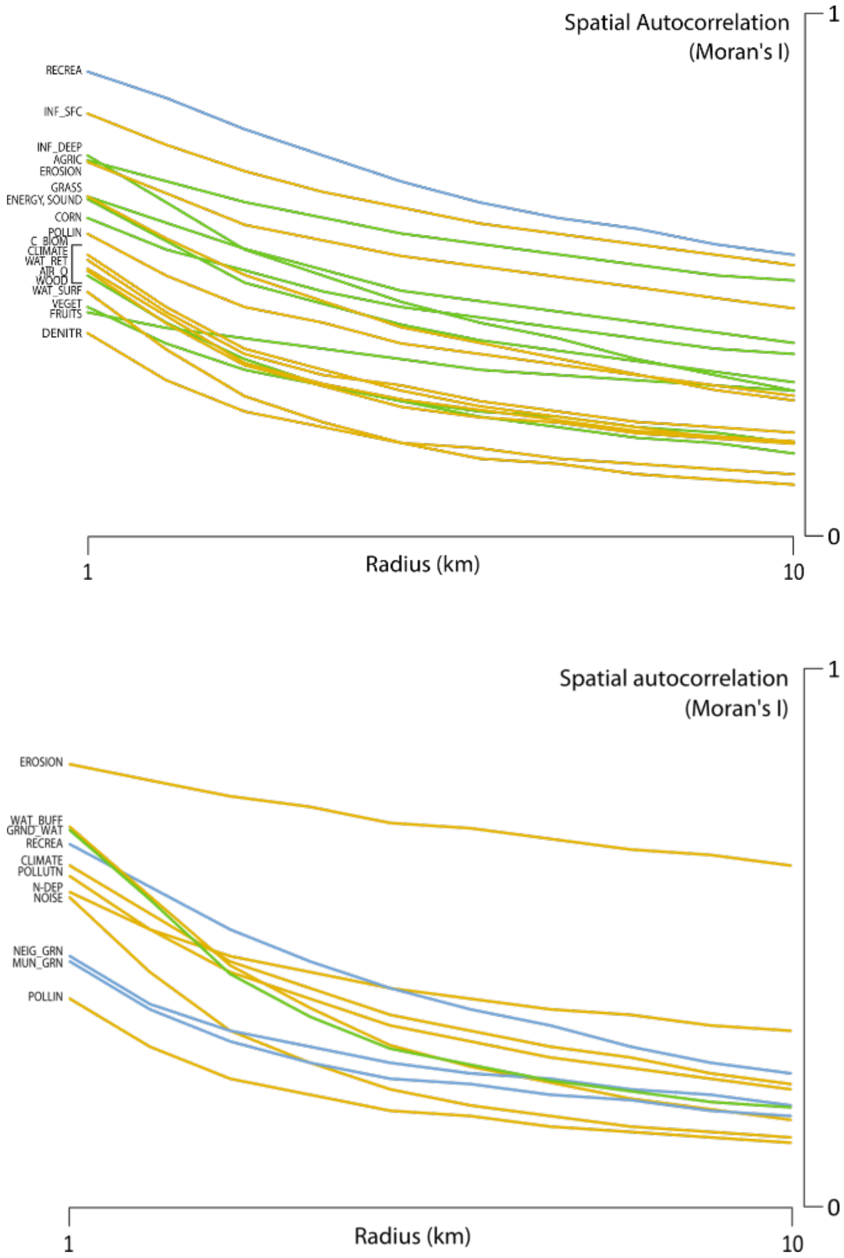


Figure 21. Moran's I as index for spatial autocorrelation indicates that the supply (top) and demand (bottom) of all of the ES studied, show a certain degree of spatial association. The degree of spatial autocorrelations decreases when calculated on larger scale levels, but the degree to which it decreases varies strongly between ES. Green: Provisioning ES; Orange: regulating ES, Blue: cultural ES.

For example, we observe that the supply of recreational ES is strongly grouped in the landscape, with regions where it is consistently high, and other regions with an overall low degree of recreational services. A similar pattern is observed for the demand for the ES erosion control, which is mostly limited to erosion-prone hills in the southern parts of the study area. On the contrary, ES like the denitrification or the demand for pollination, are much more scattered over the landscape, approaching a near-random spatial distribution on the larger scales.

Correlations between ES shedd light on potential trade-offs and synergies that are observed in the landscape. For the supply of ES, we found 62 statistically significant synergies, the most prominent ($r_p > 0.5$) are observed between:

- Climate regulation and wood production;
- Noise buffering and recreation, wood production, carbon storage in biomass, airborne fine dust captation, and pollination;
- Recreation and wood production, carbon storage in biomass, airborne fine dust captation, and pollination;
- Carbon storage in biomass and pollination;
- Airborne fine dust captation and pollination;
- Water retention and denitrification.

Still on the supply side, we observe 30 significant trade-offs, the most prominent of which ($r_p > 0.5$) are observed between:

- Noise buffering and and corn production (and we observe a similare trade-off with energy crops, grass production and agriculture;
- Water retention and deep infiltration.

On the demand side, the correlation analysis illustrates some strong synergies, but no strong trade-offs. The most prominent synergies are observed between the demand for:

- neighborhood green spaces and municipal green spaces;
- water buffering and recreation;
- climate (temperature) buffering and recreation.

Table 9. Spatial correlations between grid level ES supply indicators

CLIMATE	0,69*	0,48*	0,16*	0,76*	0,76*	0,86*	0,11	0,12	0,18*	0,16*	0,02	0,02	0,00	0,05	0,04	0,13	-0,05	0,69*
0,00	NOISE	0,62*	0,12*	0,78*	0,78*	0,65*	0,20	0,08	0,15*	0,20*	-0,31*	-0,10	-0,17*	-0,51*	-0,35*	-0,34*	-0,04	0,75*
0,00	0,00	RECREA	0,14*	0,55*	0,55*	0,47*	0,15	0,03	0,24*	0,24*	-0,13	-0,05	-0,14	-0,34	-0,14	-0,30*	-0,10	0,44*
0,00	0,00	0,00	WAT_SURF	0,15*	0,12*	0,18*	-0,08	-0,17*	0,43*	0,29*	-0,10	-0,05	-0,03*	-0,12*	-0,12*	0,17*	-0,37*	0,24*
0,00	0,00	0,00	0,00	WOOD	0,99*	0,88*	0,19*	-0,05	0,24*	0,26*	-0,04	-0,07	-0,09	-0,23*	-0,13	-0,14	-0,09	0,62*
0,00	0,00	0,00	0,00	0,00	C-BIOM	0,87*	0,22*	-0,03	0,21*	0,24*	-0,12	-0,04	-0,09*	-0,24*	-0,13	-0,16*	-0,06	0,61*
0,00	0,00	0,00	0,00	0,00	0,00	AIR_QUAL	0,08	0,08	0,21*	0,20*	-0,04	0,04	0,00	-0,03	-0,07	0,16*	-0,08	0,71*
0,10	0,04	0,39	0,09	0,01	0,00	0,21	EROSION	-0,41*	0,16*	0,03	0,00	0,09*	-0,12	-0,17	0,13	-0,09	0,18*	0,11
0,09	0,45	0,85	0,00	0,53	0,72	0,22	0,00	INF_SURF	-0,36*	-0,15*	-0,11	-0,11	-0,01	0,11	-0,38*	-0,06*	0,13	0,13
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	WAT_RET	0,59*	-0,11*	-0,05*	-0,06	-0,25*	-0,11	0,05	-0,56*	0,18*
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,62	0,01	0,00	DENITR	-0,12*	-0,08*	-0,07	-0,26*	-0,16*	-0,16*	-0,35*	0,10*
0,77	0,00	0,23	0,01	0,02	0,03	0,43	0,99	0,17	0,01	0,00	ENERGY	0,09	0,07	0,49*	0,41*	0,14	0,13	-0,26*
0,65	0,01	0,36	0,07	0,19	0,18	0,28	0,03	0,05	0,01	0,00	0,02	FRUITS	0,02	0,09	0,14*	0,04	0,12*	-0,11*
1,00	0,00	0,01	0,24	0,01	0,01	0,98	0,01	0,93	0,05	0,01	0,11	0,61	VEGET	0,13*	0,14*	0,09	-0,03	-0,15*
0,37	0,00	0,01	0,00	0,00	0,00	0,59	0,10	0,29	0,00	0,00	0,00	0,01	0,00	CORN	0,32*	0,41*	0,15*	-0,31*
0,53	0,00	0,27	0,00	0,03	0,03	0,20	0,25	0,00	0,03	0,00	0,00	0,00	0,00	0,00	AGRIC	0,09	0,16*	-0,40*
0,02	0,00	0,01	0,00	0,01	0,00	0,00	0,39	0,58	0,22	0,00	0,01	0,29	0,03	0,00	0,27	GRASS	-0,04	0,28*
0,37	0,43	0,10	0,00	0,02	0,12	0,11	0,00	0,02	0,00	0,00	0,01	0,00	0,05	0,00	0,00	0,43	INF_DEEP	-0,07
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,14	0,12	0,00	0,01	0,00	0,01	0,00	0,00	0,00	0,00	0,20	POLLIN

* significant at 1%

Table 10. Spatial correlations between grid level ES demand indicators

NEIG_GRN	0,69*	-0,10*	-0,02	0,12*	0,46*	0,01	-0,29*	-0,23*	0,02	0,41*
0,00	MUN_GRN	-0,08*	-0,02	0,06	0,28*	0,01	-0,21*	-0,29*	0,05	0,25*
0,00	0,01	POLLIN	0,00	-0,03	-0,07	0,05	0,09	0,17*	-0,02	-0,10*
0,53	0,37	0,85	NOISE	0,05	0,05	-0,05	0,29*	-0,03	0,01	0,16*
0,00	0,03	0,20	0,06	FLOOD_BUF	0,61*	-0,13*	0,06	0,04	-0,02	0,36*
0,00	0,00	0,04	0,14	0,00	RECREA	-0,16	-0,01	0,06	-0,03	0,66*
0,92	0,92	0,34	0,22	0,00	0,02	EROSION	-0,29	0,13	0,09	-0,22*
0,00	0,00	0,02	0,00	0,08	0,75	0,06	N_DEP	0,08	-0,04	-0,16*
0,00	0,00	0,00	0,27	0,29	0,18	0,21	0,27	POLLUTN	-0,04	0,01
0,65	0,13	0,61	0,84	0,50	0,45	0,21	0,51	0,32	WAT_EX_BUF	-0,05
0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,84	0,19	CLIMATE

* significant at 1%

3.2 ES bundles

Previous analysis demonstrates the existence of many synergies and trade-offs between ES. A such, measures to increase the supply of a specific ES often result in an increase or decrease in the supply of another, associated ES. Particularly from a policy perspective, it is key to understand the occurrence of ES bundles, i.e. series of ES that co-exist relatively often (cf. Raudsepp-Hearne et al., 2010; Turner et al., 2014; van der Biest et al., 2014). We identified six clusters for the supply of ES, and five clusters were identified for the demand for ES.

Based on the cluster analysis , we identified 6 distinct clusters for the supply of ES (Figure 22), each characterised by specific combinations of individual ES. These were labeled by the expert panel, based on an informed interpretation of the combinations of ES in each bundle: (1) surface infiltration; (2) agriculture; (3) forest services; (4) wetland buffer; (5) low ES supply; (6) mozaic landscape services.

The surface infiltration bundle shows high values for surface water infiltration, and an average to low value for most of the other ES. Services associated with forests and woodland are low in this bundle, as are water retention and denitrification. This bundle is dominant in 1495 or 30.7% of the km grid cells. It is mainly present in the flat lowlands of the northern part of the study area.

The agriculture bundle combines high values for provisioning services (energy crops, fruit, vegetables, agriculture, corn, grassland) with the delivery of deep water infiltration and erosion control. There is a low delivery of noise buffering, superficial infiltration and denitrification, as is the delivery of ES associated to woodland. This bundles comprises 34.6 % of the grid cells (1683), and is the most common bundle in the study area. It is mainly present in the southern half, which is characterised by low undulating hills and valleys.

The forest services bundle is characterised by high values for regulating services like climate, air quality and erosion regulation, noise buffering, denitrification and carbon sequestration, alongside wood production, pollination and recreation. Other provisioning services are low. These are typically landscapes dominated by trees and woodland. This is a rare bundle type, with only 189 gridcells or 3.9% of the study area assigned to this bundle.

The wetland buffer bundle combines high values for water retention (i.e. soil acting as a sponge water reservoir to cover periods of drought) and surface water buffering with low rates for infiltration, showing average values for most of the other ES. The spatial distribution suggests that this bundle is mainly confined to river valleys, a total of 290 gridcells (6.0%).

The low ES supply bundle is mainly characterised by an overall low value for all of the studied ES. The 391 gridcells (8.0%) assigned to this bundle are mainly associated with densly populated urban areas.

The mosaic landscape services bundle shows high values for ES associated with trees and woodland, but markedly less so compared to the forest services bundle. Values are also relatively high for undeep infiltration, and overall provisioning services are low. A total of 823 gridcells (16.9%) are assigned to this bundle.

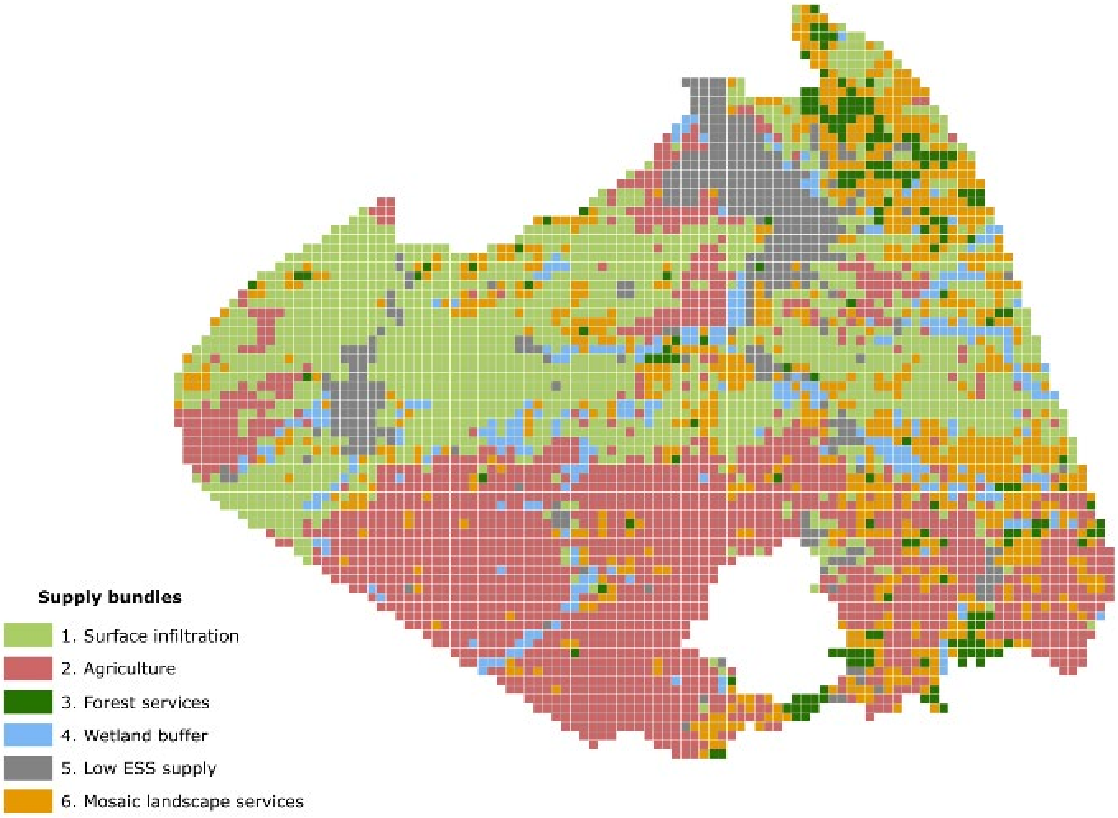


Figure 22. ES supply bundles**.**

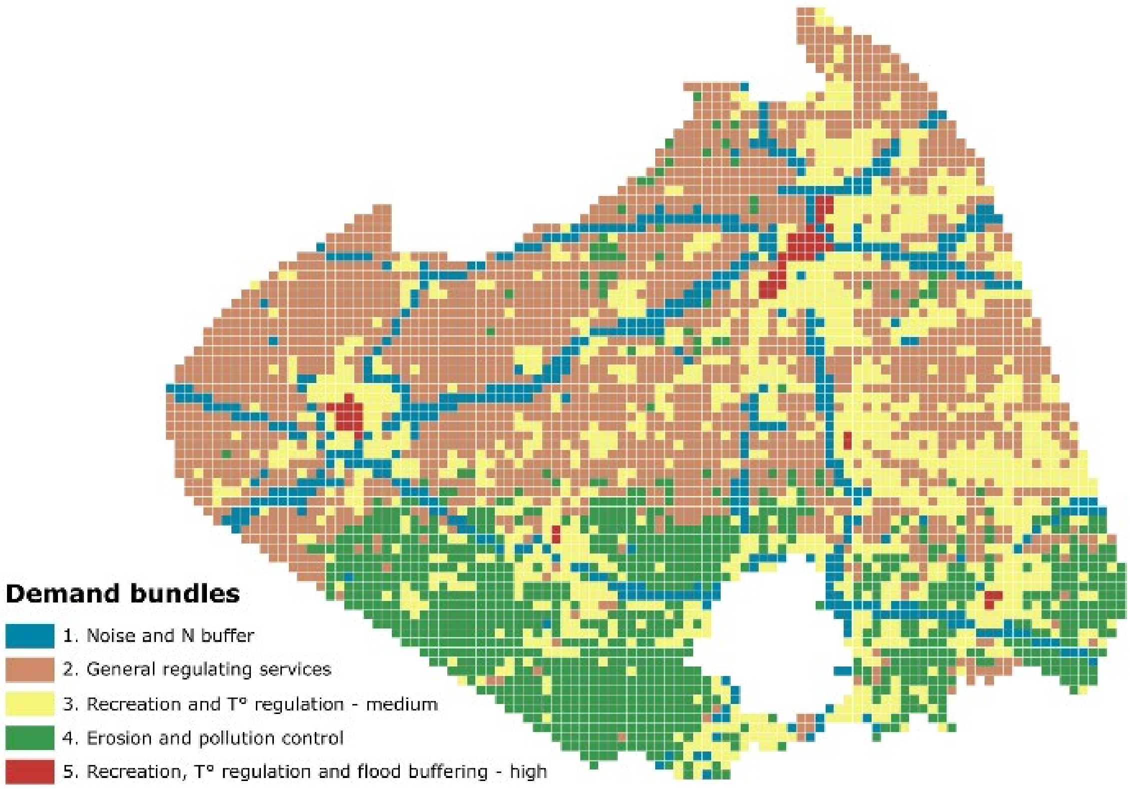


Figure 23. ES demand bundles.

On the demand side, 5 clusters were identified (Figure 23). We the same approach to interpret and label the distinct ES demand bundles: (1) *Noise and N buffer*; (2) *General regulating services*; (3) *Recreation and T° regulation – medium*; (4) *Erosion and pollution control*; (5) *Recreation, T° regulation and flood buffering – high*.

The *noise and N buffer* demand bundle is mainly showing a high demand for noise buffering. Also the demand for nitrogen buffering is high, while the demand for recreational space is relatively low.

The *general regulating services* bundle is characterised by a fairly even, but low demand for most of the included ES. The spatial distribution of this bundle on the map suggests it is mainly associated with rural areas under agricultural land use, mostly in the northern part of the study area.

The *recreation and T° regulation – medium* bundle is associated with high demands for urban peripheral needs: green spaces for recreation on various scales and distances, buffering of the urban heat island effect, and to some extent, a demand for potable water from groundwater aquifers.

The *erosion and pollution control* bundle shows a relatively high demand for some ES related to agriculture, i.e. erosion control, buffering against pollutants, and pollination. Here, the demands for recreational green space and buffering of the urban heat island effect and N-deposition are low. There is also a low demand for surface water buffering, but this should be interpreted with caution, since most of the grid cells of this bundle are located in upstream locations, this bundle might very well be vital in solving downstream flooding issues.

Finally, the *recreation, T° regulation and flood buffering – high* bundle can clearly be associated with urban core areas. Here, there is a high demand for surface water buffering, recreational green spaces, buffering for pollution, N-deposition and temperature. The demand for erosion control and pollination is low.

3.3 Supply-demand mismatch map

The (mis)match scores between ES supply and demand bundles ranged between 2.0 and 5.0 (Table 11), while weights ranged between 2.0 and 4.5 (Table 12). The frequency of each possible supply and demand combination is highly variable (Figure 24). The most frequent combinations are between the supply bundle 'surface infiltration' and demand bundle 'general regulating services', and between the supply bundle 'agriculture' and the demand bundle 'erosion and pollution control'.

Table 11. The (mis)match scores depict to which degree there is a mismatch between ES supply and demand (1=perfect match; 5= perfect mismatch).

(mis)match	**Demand 1** Noise and N buffer	**Demand 2** General regulating services	**Demand 3** Recreation and T° regulation – medium	**Demand 4** Erosion and pollution control	**Demand 5** Recreation, T° regulation and flood buffering – high
Supply 1. Surface infiltration	5,00	3,25	3,75	3,81	3,75
Supply 2. Agriculture	5,00	3,63	3,88	2,00	3,94
Supply 3. Forest services	2,00	2,94	2,00	2,63	2,88
Supply 4. Wetland buffer	4,00	3,13	2,63	3,63	2,75
Supply 5. Low ES supply	4,38	3,75	4,63	4,75	4,50
Supply 6. Mozaic landscape services	2,75	3,00	2,38	3,38	2,75

Table 12. The weights indicate how important it is to work towards a match for that specific supply-demand combination from a policy perspective, according to the expert panel (1 = less relevant; 5 = more relevant).

weights	**Demand 1** Noise and N buffer	**Demand 2** General regulating services	**Demand 3** Recreation and T° regulation – medium	**Demand 4** Erosion and pollution control	**Demand 5** Recreation, T° regulation and flood buffering – high
Supply 1. Surface infiltration	2,88	3,38	3,50	2,38	2,88
Supply 2. Agriculture	2,00	2,44	3,63	4,00	2,88
Supply 3. Forest services	3,69	2,75	4,25	3,75	4,13
Supply 4. Wetland buffer	2,00	3,13	3,88	3,00	4,13
Supply 5. Low ES supply	3,38	2,50	4,38	2,38	4,50
Supply 6. Mozaic landscape services	3,88	2,88	4,25	3,63	4,38

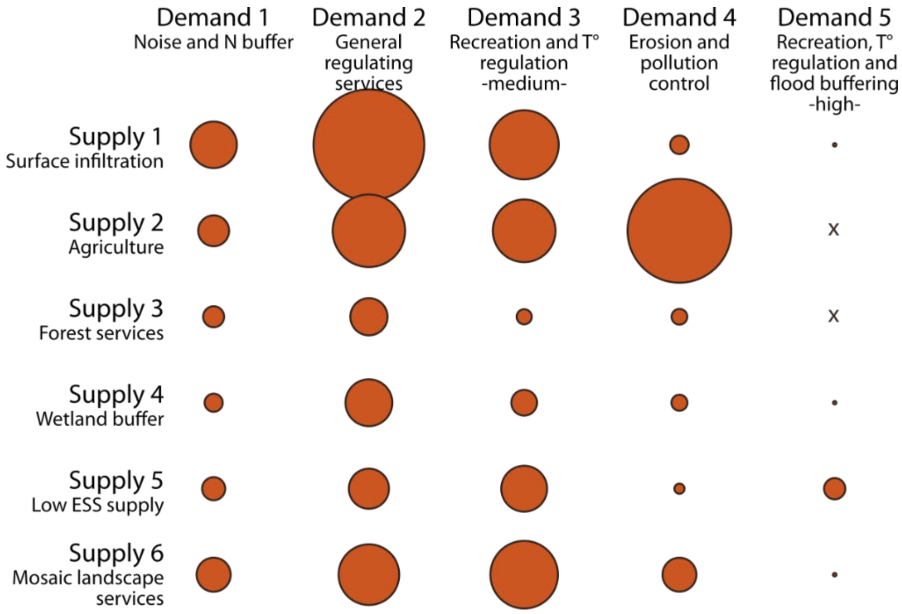


Figure 24. Observed frequencies of all possible supply and demand combinations.

Mapping of the unweighted results clearly shows a heterogenous unequal spatial distribution of the (mis)match between ES supply and demand, with important concentrations of mismatch near larger urban cores, and along major transport axes. In general, there is also higher mismatch in the central and northwest parts of the study area. Both of these patterns emerge strongly from the hotspot analysis (Figure 25). Significant concentrations of spatial supply-demand match, i.e. ‘cold spots’ on the map, occur mainly in the central southern and extreme northeastern portions of the map.

More nuanced patterns emerge when we take weights into account (Figure 26). After all, here we downplay the importance of less relevant (mis)matches, leaving both the truly problematic mismatches which are important to reduce, as well as the truly beneficial matches which are important to sustain. From this analysis, two larger mismatch zones remain, one corresponding with the core and agglomeration of the city of Antwerp in the north, expanding towards the city of Brussels. A second one corresponds with the city of Gent in the western part of the study area, stretching towards Antwerp. Smaller mismatch zones remain around the cities of Aalst, Vilvoorde and Leuven.

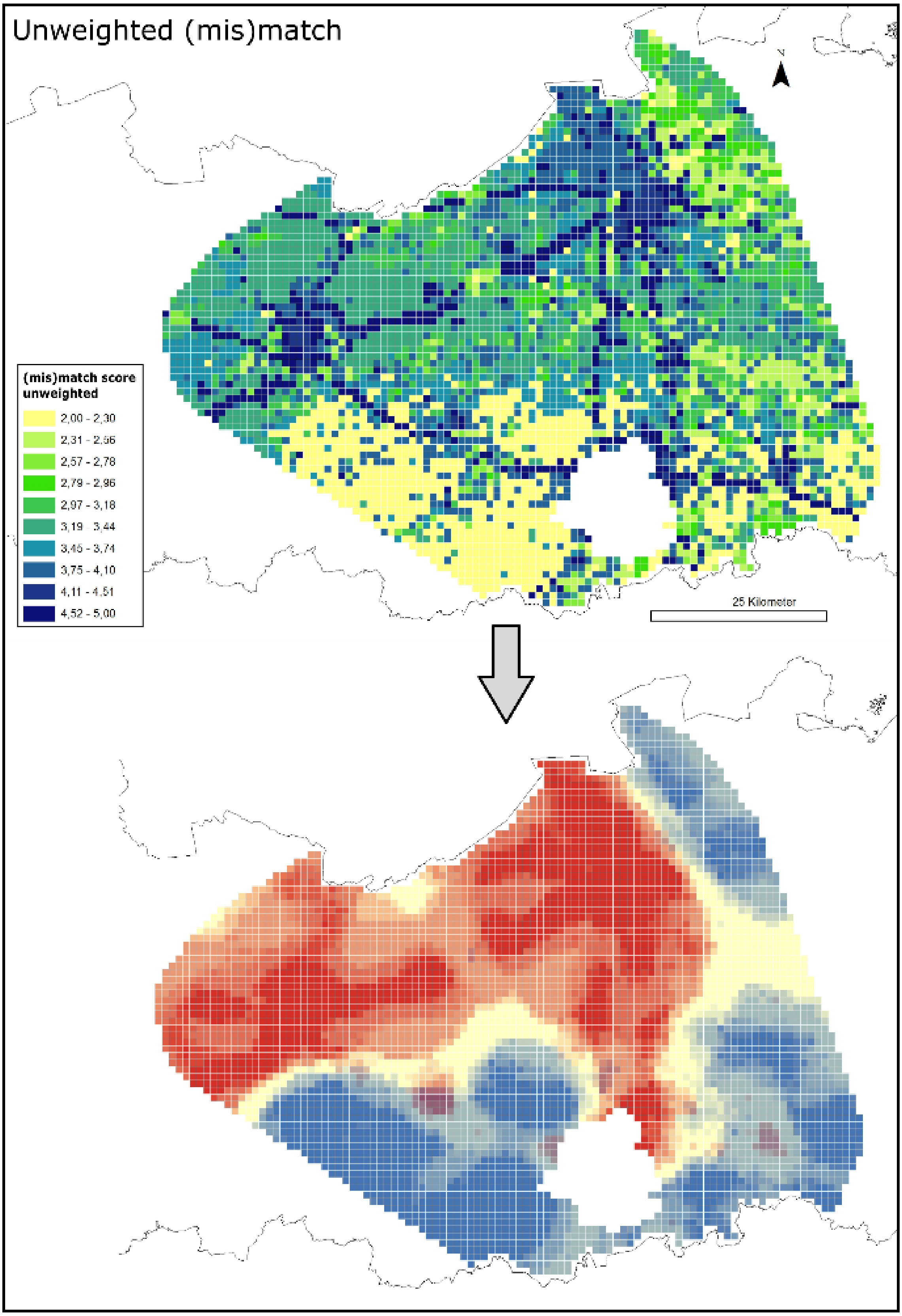


Figure 25. Weighted supply-demand mismatch (top) and hotspot maps (bottom) for the spatial (mis)match between ES bundles.

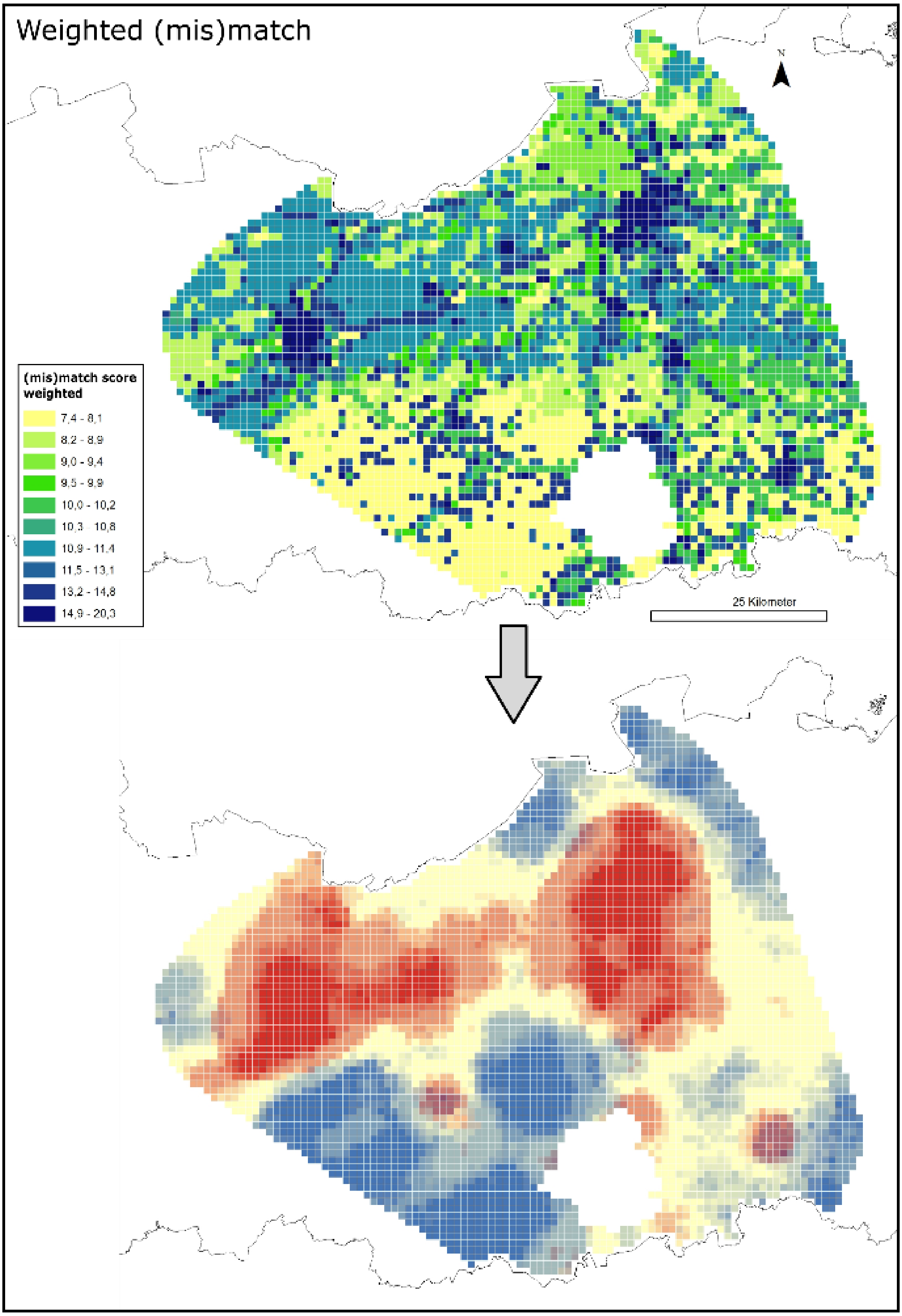


Figure 26. Unweighted supply-demand mismatch (top) and hotspot maps (bottom) for the spatial (mis)match between ES bundles.

3.4 Applying the analysis to existing future land use scenarios

If the residential and industrial footprint decreases, we expect less pressure on ES, i.e. the situation tends to improve. Likewise, an increase is indicative of more stress on the system, and a larger future mismatch between ES supply and demand. A multiplication of the land use indicators and ES supply/demand mismatch scores yields a map with high and positive scores for areas that are already characterized by a mismatch and this mismatch is likely to aggravate. Very low and negative scores are observed for areas where there is currently a mismatch, but where this mismatch is likely to decrease in the future. Intermediate positive values indicate that there is currently no problematic mismatch but that the problem might become worse. Intermediate negative values are observed if no problematic mismatch is currently observed and the problem is likely to decrease even further in the future. The change in residential and industrial footprint according to the respective scenarios for 2050 and calculated indicators based on these maps, are shown for the 'Business-as-Usual' BAU scenario (Figure 27) and the 'Spatially Neutral' SN scenario (Figure 28). On each of the indicator maps, we used hotspot mapping to highlight the most problematic focus areas. An increased mismatch is expected in some areas situated between the mayor cities, i.e. the regions between Brussels and Antwerp, between Ghent and Kortrijk, and between Antwerp and Ghent. The rural areas surrounding Ghent is also increasingly under pressure, as well as specific zones near Vilvoorde and between the smaller cities of Mechelen and Aarschot. While the pressure on ES delivery is expected to increase in nearly the whole study area, the demarcated regions are expected to face additional and more crucial issues with local ES delivery and this should be anticipated by spatial planning.

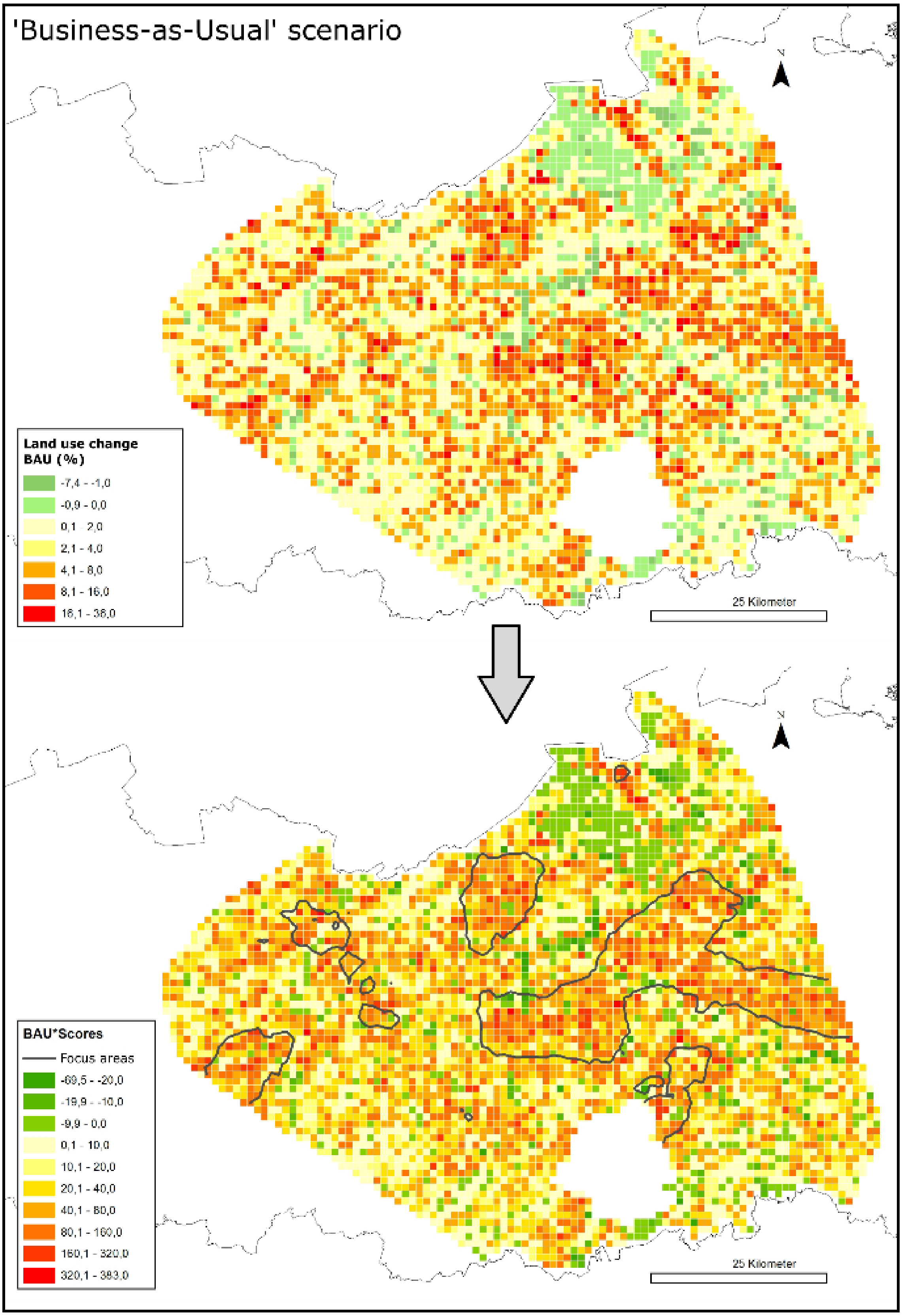


Figure 27. Estimated change in residential and industrial land use (top) and the calculated indicators (bottom) according to the BAU scenario. The most heavily impacted areas are demarcated with a contour using hot spot mapping.

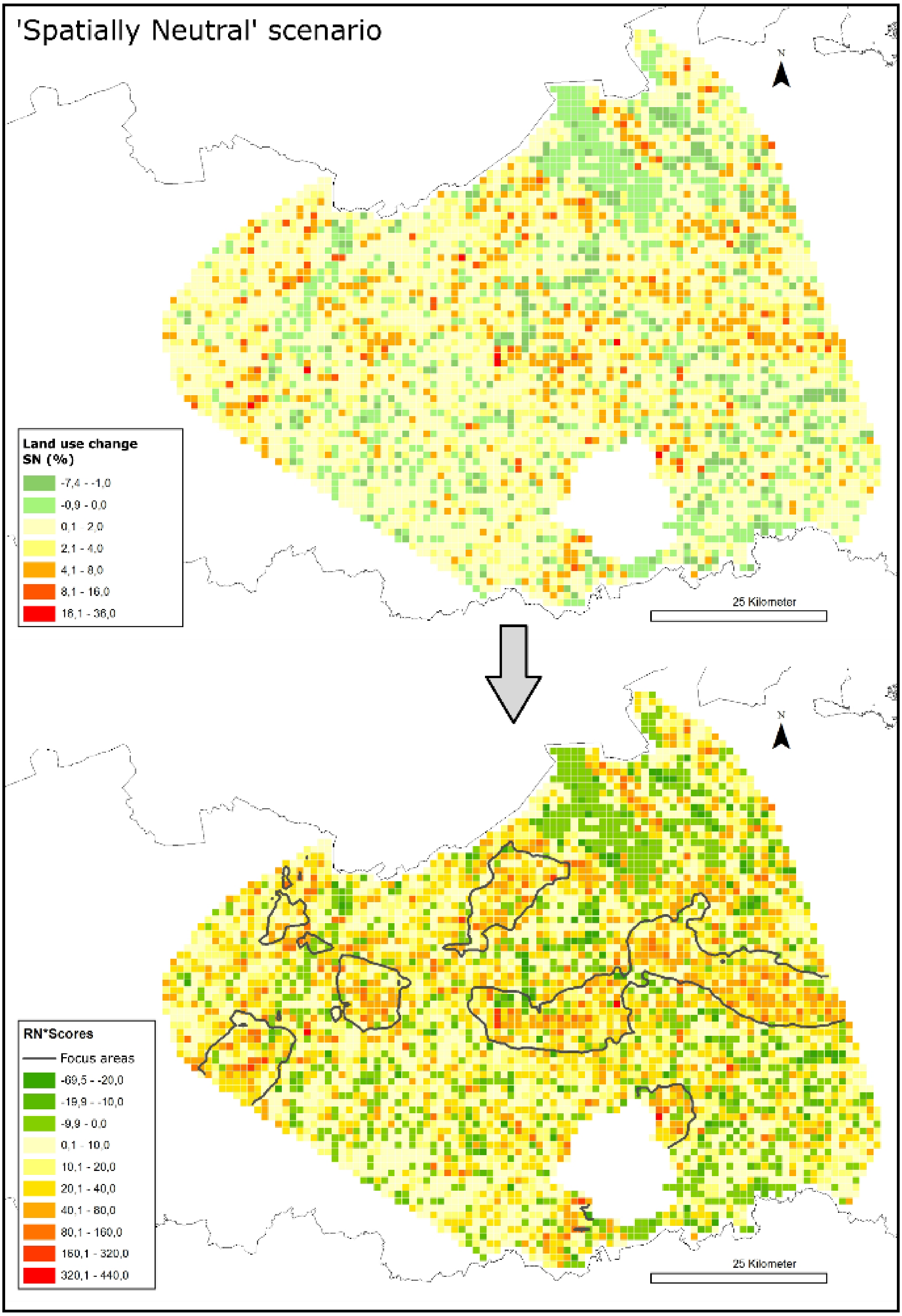


Figure 28. Estimated change in residential and industrial land use (top) and the calculated indicators (bottom) according to the SN scenario. The most heavily impacted areas are demarcated with a contour using hot spot mapping.

4 Discussion

4.1 Data and data availability

The analysis of spatial relationships between ES, as well as mapping ES supply-demand mismatches are strongly dependent on the availability and quality of the input data (Cabral et al., 2016; Kandziora et al., 2013). For Flanders, a lot of relatively high-quality data has been developed over the last years. However, proper quantification of ES remains a complex challenge and some recommendations are made from our experiences. For many ES, data is still of low quality, low resolution, or completely lacking. After careful consideration, we used 19 datasets on the supply side, and 11 datasets on the demand side, which is considerably more than most IAESSD studies to date (Wei et al., 2017). Although they form a decent overview of ES in Flanders, many data gaps remain to be filled. Mainly cultural ES are markedly underrepresented, because they are often difficult to objectively describe and quantify. This is exacerbated by a predominant focus on monetary approaches (Nieto-Romero et al., 2014).

In addition, we observe that there is a clear discrepancy in data availability between the supply and demand side, with most of the research efforts focusing on the supply, rather than on the demand of ES. High-quality data on the demand for ES is relatively scarce and, if available, difficult to link to specific supply datasets. This lowers their usefulness and an effort could be made to better link them because of the intrinsic relevance in the comparison of the two (Burkhard et al., 2012; Castro et al., 2014; Kroll et al., 2012; Wei et al., 2017). Moreover, research efforts to better map the local demand for ES will have to take complex spatial (Burkhard et al., 2012) and socio-economic (Wilkerson et al., 2018) factors into account.

Specifically challenging when comparing supply and demand, are datasets implicitly combining both. An example is noise buffering, where the data also contains a nuisance factor, i.e. the ES noise buffering can only be delivered where there is noise nuisance, which is entirely dependent on the presence of potential recipients. Obviously, this issue can be linked directly with the anthropocentric nature of the ES concept. Spatial analysis of ES supply and demand therefore requires ES mapping that is solely based on the bio-physical structures and processes in the actual landscape on the supply side, and the local societal demand for ES on the demand side.

Related to this problem, is the potential issue of self-selection, which can result in underestimating the mismatch. Let's use the example of pollination to illustrate this problem, which emerges if the observed demand for a service is dependent on the supply. In a region where pollinator populations (e.g. wild bee and bumblebee) are in decline, farmers may respond by switching to crops that are not pollinator-dependent. This response in turn results in a decreased demand for pollinators, and our approach will underestimate or even fail to detect the mismatch caused by declining pollination services. Since we do not research causalities behind established mismatches, this can be seen as a caveat in the methodology. A possible solution lies in combining our quantitative approach with focused qualitative research, but that was beyond the scope of our research.

Finally, analysis on larger spatial scales is often confronted with a lack of standardization between the authorities and institutes involved. The case of Flanders illustrates this very bluntly by the large blind spot in many datasets, which is the administrative region of Brussels. Mapping ES is a regional capacity, and there is are few efforts for standardization of spatial datasets between regions. The same problems often arise across national borders. In particular for delocalized ES (where the benefits of delivering the services do not necessarily correspond with the location where the services are delivered) such as water buffering capacity against flooding, this is can be problematic. This underlines the importance of working towards standards for ES assessment, as pointed out by Galler et al. (2016).

4.2 Spatial analysis

An extensive review on IAESSD literature is provided by Wei et al. (2017). Our research adds to that body of literature by (1) taking into account a comparatively large number of ES on the supply and demand side; (2) combining indicator-based assessment with mapping and participative approaches, and (3) evaluating future land use scenarios and mapping hotspots of supply-demand mismatch.

ES in the study area are not randomly distributed but occur in specific patterns associated with social and biophysical structures and processes in the landscape, a result which is consistent with other research (eg. Butler et al., 2013; Turner et al., 2014; van der Biest et al., 2014). Moreover, when looking at a broad range of ES, specific bundles can be recognized, and most observed ES show some degree of spatial correlation with each other. This result may seem rather straightforward, but from a policy perspective, it has major implications. After all, any policy that singles out one specific ES, is bound to influence the delivery of a broad range of other ES, either positively or negatively. This is a good argument to base policy on ES bundles, rather than on single services (Bennett et al., 2009; Raudsepp-Hearne et al., 2010). For the study area, our research offers insights on the specifics of the many spatial synergies and trade-offs between ES supply and demand bundles. These results should not carelessly be generalised and applied to other regions. Some synergies and trade-offs will indeed prove to be rather fundamental (e.g. water retention will by definition be in trade-off with water infiltration), while others will depend on the landscape context.

In the process of defining the ES bundles, we deliberately chose not to use ordination techniques (like PCA or FA) prior to clustering. Although these techniques can make clustering more efficient, e.g. by avoiding double use of information, the advisory board indicated that the results are harder to interpret because the ordination adds an additional layer of complexity. Initially, ordination techniques were applied in the analysis, but we felt the analytical benefits did not outweigh the consequences of the additional cognitive burden if introduced. Since this research aims at contributing to meaningful policy decision making, and the results were to be interpreted correctly by a diverse expert panel, we chose to omit the ordination in favor of interpretability of the results.

Combining the spatial analysis with an evaluation of ES bundle mismatch by expert panel seemed very helpful to take some of the complexity of the reality on the terrain into account, as well as to bring some nuance by prioritizing the observed (mis)matches. Involving stakeholders throughout the process considerably increased the usability of the results (Zulian et al., 2018).

The supply-demand mismatch map is based on a one-on-one comparison of corresponding grid cells only, without taking into account the surrounding grid cells. Nonetheless, a mismatch in any given grid cell might be partially solved by ES delivered by surrounding cells. Therefore, a more advanced comparison of the supply and demand maps, taking into account neighboring cells using an inverse distance weighted function, might bring some nuance to the supply-demand mismatch map. However, this is computationally complex and will most likely not have a large impact on the resulting hot spot analysis, since all of the ES show significant autocorrelation. More importantly, the actual quality of the input data is at this moment still the main limiting factor to the quality of the results.

Combining the supply-demand mismatch map with the hotspot mapping delivers a rich and complex set of maps, showing various emerging spatial interactions. For example, the situation in and around the urban regions of larger cities in the northers part (i.e., Ghent and Antwerp) differs clearly from the situation in and around provincial cities more to the center and southern parts of the study area (i.e. Leuven and Aalst). The latter show more small-scale, more complex but less problematic patterns of mismatch. The urban cores combine a high intrinsic demand for ES with limited areas of green space, which inevitably results in a significant mismatch. These patterns are in line with the 'paradox of the compact city' as highlighted by (Larondelle and Lauf, 2016), where compact cities are promoted as environmentally efficient but are nonetheless leading to an increased supply-demand mismatch. The zone of influence of these cities however, are often asymmetric in their characteristics (e.g. Brussels), showing amongst others, more mismatch along major transport axes. Results like these truly spark regional planning discussions, while the underlying ES bundles remain relatively straightforward to interpret and to work with. As such, this approach proves its worth in facilitating the conversation and cooperation across various sectors on how to incorporate ES in spatial planning (Galler et al., 2016).

5 Conclusion

This paper develops a methodology that allows the ES concept to become more operational for land use planning. This study starts with an investigation of synergies and trade-offs between individual ES using spatial statistical analysis techniques. Next, it combines individual ES into ES supply and demand bundles using clustering techniques. Expert evaluations are used to assess (mis)matches between all combination of ES supply and demand bundles, and to assess the relative importance (from a policy perspective) to improve the match for a given combination of supply and demand bundles. ES demand/supply mismatches are spatially mapped and a comparisons with land use change scenarios allows to designate areas where the mismatches might be exacerbated.

The above methodology is applied to the Flemish Metropolitan Core, which stands as an example for polycentric structure with a highly fragmented landscape and high population density. A heterogenous unequal spatial distribution of the (mis)match between ES supply and demand is observed, with important concentrations of mismatches near larger urban cores and along major transport axes. The expert evaluations allow to downplay the importance of less relevant (mis)matches and hence to highlight the truly problematic mismatches which are important to reduce, as well as the truly beneficial matches which are important to sustain. From this analysis, two larger mismatch zones remain, one corresponding with the core and agglomeration of the city of Antwerp in the north, expanding towards the city of Brussels. A second one corresponds with the city of Gent in the western part of the study area, stretching towards Antwerp.

Our approach provides insights that are useful for spatial planners as it focus attentions towards priority areas, i.e. areas where there is a mismatch between ES supply and demand, and where it is important to reduce the observed mismach. In addition, insights on the specifics of the many spatial synergies and trade-offs between ES supply and demand provide a basis to develop a spatial policy based on ES bundles rather than a policy that singles out one specific ES. Furthermore, one can investigate for the priority areas which mismatch combinations are most abundant. Our results provided input for landscape designers in the application of qualitative analysis techniques to draft general guiding models for spatial planning in the priority areas. Implementation of these general guiding models can then help to reduce mismatches and help to align ES supply with ES demand.

Chapter 5.
General conclusions

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General conclusions

1 Main research findings

Decision makers, from individual farmers to spatial planners, are in need of appropriate diagnostic tools to estimate trade-offs and synergies associated with land allocation and land use intensity decisions. Often there are trade-offs between food and biomass production on the one hand, and other non-provisioning ecosystem services on the other hand. However, in order to do so, one must be able to put all ES to a common denominator. The potential of operationalizing ES concepts in adaptive land management and planning was explored. For this, combinations of monetary valuation, spatial analysis and expert assessment were used, and the problem was approached on different scale levels. The research results demonstrate that the ES concept is able to support decision makers in land use optimization problems for adaptive planning, answering the principal research question. On how this can be done, is elaborated in the following sections.

Chapter 2 presents an assessment on the farm scale using an integrated approach that combines spatial and economic analyses. It relies on the ES concept to evaluate land use alternatives. The approach is able to contribute to optimizing land use from the societal perspective, and allows for benchmarking farm-level land use alternatives by comparing the services that they would deliver under different land allocation scenarios. In essence, this entails a choice between the delivery of a combination of ES through integrated, multifunctional forms of land use, or the promotion of a single or limited number of ES, typically biomass production. The conclusions of the chapter refers to this as a sharing vs. sparing dilemma. However, this statement must be nuanced somewhat, as we did not explicitly compare sharing scenarios with sparing scenarios. Rather, a comparison was made between land sharing scenarios and scenarios of land monopolization for food production. A scenario of land sparing should include the assessment of a land use strategy in which intensive agriculture is complemented by intensive nature development. Therefore, it is difficult to draw direct conclusions for the sparing vs. sharing dilemma. But in comparing sharing with monopolization, specific conclusions can be drawn about the strategy that works best in the context of the case study, for which a land sharing approach performs better than land monopolization. The analysis does demonstrate that the optimal land use allocation partially depends on the a number of contextual aspects, most notably landscape characteristics like (non-)suitability for agriculture, and socio-economic characteristics like proximity of people (i.e. population density and patterns), and demand for local or recreation. The importance of context is also stressed by Eyvindson et al. (2018) for timber production. They argue that, in order to reach regional biodiversity conservation goals, forest management should mainly aim for production forests where biomass production potential is highest, while choosing for nature conservation-oriented management in areas that combine high ecological values with lower production potential. This is, in essence, a form of land sparing. Summarizing, food production should be balanced with other ES and biodiversity by taking the specific landscape context into account (Holt et al., 2016).

In the analysis, the societal value of a number of regulating and cultural ES was indirectly taken into account, (next to the value of provisioning services), most of which are externalities in our market system. Even where conservative value estimates were used, merely considering these cultural and regulating ES resulted in shifts in preference towards more integrated solutions that promote larger bundles of ES. Since this is particularly the case in landscapes with higher degrees of fragmentation and urbanisation, it will likely be a strategy of choice in Flanders' urban fringes. As such, in the context of our research, it can be a viable strategy to opt for land sharing, except on parcels that due to protection or regulations (e.g. EU Habitats) are excluded from production. However, in the absence of biophysical constraints, it might well be the other way around. With this results, the second research question on how a more integrated, ES-based approach is able to affect decisions on optimal land use, is answered

Chapter 3 explicitly builds on the results from chapter 2, and presents a methodological framework that was developed to explore adaptive management of bioproductive space. As such, this chapter is more about provoking thought and discussion on spatial resilience, rather than presenting specific results. The methodological framework itself comprises four stages. The first stage is a spatially explicit evaluation of various ecosystem services for different land uses (cf. the analysis in Chapter 2). In a second stage, bio-physical and socio-economic drivers or shocks, i.e. future scenarios, are introduced. These can influence the value society attributes to specific ecosystem services. The third stage of the methodology takes policy priorities into account. In a final stage, the output of the approach is synthesised by ranking the analysis results for different scenarios and policy priority settings.

This methodology allows spatial planners to explore and evaluate policy decisions against trade-offs between various land use alternatives, while taking ES into account. This method is applied to the case of Chapter 2 to demonstrate that, from a societal perspective, the optimal strategy can be highly context- and preference-dependent. Besides the potential for supporting policy makers to think about the broader implications of land use changes for community wellbeing, the methodology provides useful feedback for adaptive farm and landscape management. By summarizing the result into a relative ranking index, we did not go as far as to develop a resilience indicator, but the ranking does provide useful insights in some resilience aspects against background scenarios of shifting policy and preferences. As such, the research was able to contribute to answering the third research question.

Chapter 4 focuses on spatial ES analysis for practical applications in spatial planning. In order to make the ES approach operational for planning and management of bioproductive land, it is important to deal with the diversity of services, and the broad range of interactions between ES. In this study, we compared local ES supply with the local societal demand in the Flemish Metropolitan Core, a polycentric urban network with a highly fragmented landscape. Trade-offs and synergies between services were evaluated and ES bundles, series of ES that often co-occur in a landscape, were defined by combining spatial analysis techniques with an expert evaluation. This resulted in sensitivity maps that depict where there is a mismatch between local ES supply and demand. These maps were compared with predictions of possible future land use changes according to existing scenarios.

The research results indicate that ES in the study area occur in recognizable patterns, associated with social and biophysical structures and processes in the landscape. The sensitivity map delivers a rich and complex image of various emerging spatial interactions. We also illustrate where an existing mismatch between local ecosystem service supply and demand risks to be further exacerbated due to potential land use changes, which contributes significantly to answering research question four. As such, the results provides a means for practical application of ES in spatial planning, as illustrated in the concluding sections of this chapter.

2 Implications for research

2.1 Contribution to the literature

The research presented in this dissertation has demonstrated that the ES concept is **useful for evaluating land use alternatives**. Taking various ES into account provides broader insight in decision making processes as compared to linear decision making based one or few indicators. Moreover, the ES concept serves as a bridge concept to enhance understanding of complex interactions and trade-offs in decision making. By looking at the structure-function-value chain of ES, we can use the concept for evaluating **different land use scenarios, under various regimes**. This can be done by evaluating ES delivery and value under different shift and shock scenarios, reflecting external and internal changes in socio-economic context (e.g. changes in demand for specific services, changing preferences for services, and so on), and/or changing ecological and biophysical conditions.

We have been explicitly taking **spatial aspects** into account, like for example the heterogeneity of ES demand in Chapter 4, or the variability of biophysical context in Chapter 2. The same relevance can be attributed to spatial aspects related to the functioning of ecosystems, like ecological quality, connectivity or area thresholds (as was also in part demonstrated in Chapter 2). All these factors affect the outcome of land use evaluations, effectively demonstrating that taking spatial aspects and the landscape context into account is a prerequisite for these sorts of ES assessments (cf. Luskin et al., 2018).

Furthermore, the term 'bioproductive land' was coined as a useful concept to develop and integrated regional approach for land use evaluation. We argue that **all bioproductive land** is relevant in finding solutions for optimal land use strategies. Some bioproductive spaces are capable of delivering considerable ES, but are largely neglected in planning and research. These 'hidden' forms of land use are often true blind spots for adaptive land management, unless properly addressed. The farm diversification and recreational use of semi-natural land of the case study presented in Chapter 2 can be considered a form of hidden land use, as is the *tare land* sensu Bomans et al., (2010a) which were also taken into account in the same chapter. Other authors have focused on different types of hidden potential, like roadsides for biomass production (Van

Meerbeek et al., 2015), domestic gardens (Dewaelheyns et al., 2016, 2014), rooftops (e.g. greenroofs) and urban greenspaces (Niemelä, 2014; Van Mechelen et al., 2015; Whittinghill et al., 2014).

Finally, our research emphasised the need to find common ground between actors and institutions, and to find **nuance** in research and deviate from binary reasoning. Optimal land use allocation strategies are more often than not context-dependent, scale dependent, and actor dependent.

2.2 Lessons learnt and limitations

The principles of the research approaches and concepts outlined in this dissertation should be applicable elsewhere in the world, in particular in regions with high populations densities and diffuse urbanisation patterns. The use of indicators to capture ES supply and demand has been successfully applied in a larger number of studies worldwide (Baró et al., 2017; Burkhard et al., 2012; Turner et al., 2014; Wei et al., 2017; a.o.). With the term bioproductive space, a strong concept is introduced for land managers to abandon the sectoral view on landscape services. Nonetheless, some limitations and uncertainties can be identified, which are addressed in the following paragraphs.

First and foremost, by introducing bioproductive space, the focus lies strongly on the ecological interpretation of spatial resilience. It is not the intention of this research to underplay the importance of socio-cultural aspects of spatial resilience. I do follow the reasoning, however, that social and cultural aspects of resilience are embedded in ecological resilience, as Plummer and Armitage (2007) argue in the context of adaptive co-management of (natural) resources. Without well-functioning ecosystems delivering ES in a sustainable manner, it is very hard to establish socio-cultural resilience. Still, the focus on the ecological component of spatial resilience should not solely be seen as a limitation to the research. Rather, we acknowledge that with this, we focused on one -albeit crucial- aspect of a multi-faceted issue, but most certainly an aspect that is undervalued or missing in some key aspects of spatial planning. Nonetheless, it would certainly be very useful to look into socio-cultural dimensions of, a.o. the (mis)match between ES supply and demand. Some suggestions on follow-up research are made in the following section.

One of the most important practical limitations that emerged more than once in the course of this research, but is also more widely regarded as an issue, is related to the nature and availability of data. Most of the ES indicators are, in essence, proxies for the real ES supply or demand. Estimating ES indicators always comes with a certain degree of uncertainty, which is not always known. A second layer of uncertainty lies within the monetary valuation process despite the development of solid methods for monetary valuation. Due to the fact that many ES are public goods with the related market failure problems, discrepancies might still exist between the societal value of a given ES, and the real societal costs necessary to maintain the delivery of that ES (Galler et al., 2016), with the former often larger than the latter. This indicates towards an underprovisioning of ES from a societal point of view. The highly detailed case study was able to highlight a potential issue with indicator-based approaches of ES valuation using benefit transfer functions. Such an approach has clear merits, but is at risk of underestimating potential value of innovative forms of land use. In particular at smaller spatial scales, simple ES estimation models often fall short (Hauck et al., 2013; Ruckelshaus et al., 2015). De Groot et al. (2012) pointed out that the practice of using monetary valuation methods for making informed land management decision still needed more development, and indicator-based assessments still need continuous improvement to better capture the reality on the terrain (Wei et al., 2017). While contemporary indicator based ES models certainly have validity, they still need to be validated and checked with great rigor when applied to inform small-scale decision making processes (Zulian et al., 2018).

Solutions should aim at capturing the complexity of social-ecological systems while producing results that are transparent and easy to understand (Evans, 2019; Ruckelshaus et al., 2015; Zulian et al., 2018). Despite our efforts to provide transparent and applicable solutions, we might only have succeeded partially in this respect. In Chapter two, we provided an in-depth view on an innovative farming strategy, but focussing on one case increased the likelihood of farm-specific factors to be dominant. Therefore, only the principles of the analysis can be applied in a broader context. The methodological framework developed in chapter three relies heavily on monetary valuation (with associated uncertainties) and scenarios which are subject to certain assumptions, but the framework is nonetheless promising in the light of improving valuation techniques and scenario predictions. When mapping the ES bundles for Chapter 4, we opted for a simplified analytical approach to make the results easier to interpret by the expert panel, at the expense of more elegantly demarcated ES bundles with a lower degree of double counting. Although we stand behind the choice to simplify the ES bundle analysis in favour of a better outcome of the expert analysis, it is difficult to quantitatively substantiate this choice. In general, our approach to land use optimisation is largely anthropocentric. Other, more conservationist approaches -from the ecological perspective- are not included, which can be seen as a limitation to the research. This can be resolved by pairing ES assessments with insights from biodiversity evaluations.

The analysis of ES supply-demand mismatch presented in Chapter 4 has a strong focus on the spatial mismatch. Ideally, an analysis should also take temporal mismatches into account (Wei et al., 2017). At this point, the available data is not well-suited to include the temporal dimension in a mismatch analysis. Another extension of the analysis would be to simultaneously consider different spatial scales, similar to what was done for the hotspot analysis in the same chapter. Research in an urban setting by Holt et al. (2015) demonstrated how results of an indicator-based ES assessment might vary depending on the chosen scale. In addition, Motiejūnaitė et al. (2019) argue for cultural ES that beneficiaries of said ES also vary across scales, with ES provided by particular (groups of) species are rather enjoyed by local beneficiaries, while ES provided by landscapes are often enjoyed by both locals and visitors. Therefore, the spatial scale for the analysis should be carefully chosen based on the spatial resolution of the available data and the scale of application of the results. A step further would be to incorporate models taking ecological connectivity and biodiversity into account, in the analysis (cf. Opdam et al., 2006). Recent efforts, a.o. by Pelorosso et al. (2017) are taking promising steps in that direction.

The inter- and transdisciplinary approach of the presented research proved to be a clear strength: results that are formed in collaboration with experts from various fields including stakeholders on the terrain (i.e., transdisciplinary), is a prerequisite to achieve results that have some legitimacy in the reality of the planning challenges ahead. Not only the usability, but also the effective uptake of analysis results is highly dependent on the manner and degree of participation during the process of the research (Zulian et al., 2018). Therefore, in line with Brink et al. (2018), the importance of participation and stakeholder involvement across disciplines can be underlined. However, transdisciplinary work is by no means easy or straightforward, and requires continuous efforts by both researcher and collaborator to translate results, concepts and terminology back and forth. Combining quantitative, qualitative and participatory methods from the fields of landscape ecology and bio-economics (i.e. interdisciplinary work) was key to advance the work and integrate aspects of the structure-function-value concept of ES in tools for spatial planning.

2.3 Scope for future research

Future research should aim at further refining indicators for ES supply and demand bundles. Indicators for small scale urban application should be developed. In recent years, efforts in this direction have been done for the Nature Value Explorer. In addition, data should also be collected for underrated land use categories, such as tare land or the garden complex.

Being able to respond to shifts and shocks in a pro-active manner is an essential component of spatial resilience. Indicator-based ES assessment can help, but only when high quality data on ES supply and demand are available (Zulian et al., 2018). Since we focused on the ecologic aspects of spatial resilience, there is still work to be done on the socio-cultural aspects of the optimization of bioproductive space. Better insights are needed in the relationships between ES delivery and the beneficiaries of these ES (Motiejūnaitė et al., 2019; Quijas et al., 2019; Zulian et al., 2018). For instance, the research presented in Chapter 4 established insights in the local match or mismatch between ES supply and demand bundles. It would be relevant to assess how people from different socio-cultural backgrounds are able to enjoy or have access to local ES, or what socio-cultural motivations exist among land managers to foster particular ES.

Monitoring efforts should aim at capturing changes in nearly real time. For this, we need to rely on a multitude of different data sources. Remote sensing data, coupled with participatory research (e.g. through citizen science initiatives) and data mining techniques, play a considerable role in gathering the required actual data to establish up-to-date indicators. ES assessments should consider all different types of beneficiaries. After all, the attitude of potential beneficiaries towards ES might differ significantly depending on educational and cultural background, a.o. (Motiejūnaitė et al., 2019). Citizen science initiatives can be particularly promising if they include participants with different socio-cultural backgrounds. Both the garden complex and public green spaces are potential focus areas for this. Initiatives to collect such data should try to standardize data collection in order to allow spatio-temporal comparison of data (Galler et al., 2016), and should focus more on making data and software solutions publicly available and open source (de Groot et al., 2010; Pelorosso et al., 2017, 2015). On larger scales, this requires cross-border initiatives to coordinate data collection, between neighbouring states and regions, and on the international level (de Groot et al., 2010). This does not necessarily means that the data collection itself should be organized internationally. Rather, it is a call to continue efforts in drafting international standards for data collection and management. Rigorous standards should allow for better spatial and temporal integration of various datasets, even across geopolitical borders. There is also still a lack of long-term studies (Quijas et al., 2019). Longer time series of standardized data could allow for early-warning methods protocols to be defined, e.g. based on the analytical methods proposed by Scheffer et al. (2012, 2009). In any case, the evaluation continuously needs to be made whether additional data gathering efforts (with associated costs) effectively lead to a better decision-making process (Albert et al., 2015).

One on the most crucial hurdles to take, is to properly connect the dots between adaptive planning policy that uses concepts rooted in ES, and biodiversity and human well-being (Brink et al., 2018; Galler et al., 2016). These efforts too, will be rooted in transdisciplinary and participative approaches (Brink et al., 2018). ES assessment should be paired with analysis of ecological integrity and biodiversity (Dominati et al., 2019; Liquete et al., 2016). Moreover, Galler et al. (2016) point out the importance of considering the normative background for spatial planning (i.e., which target ought to be set out). Examples are the precautionary principle (von Haaren et al., 2014) and biodiversity conservation (von Haaren et al., 2012). We need to be able to decide which critical thresholds of ES delivery we require to maintain, and what ecological structures and functioning is needed to maintain them (Fisher et al., 2008). This should be a focus in current research, but should above all inspire policy makers. It is imperative not to neglect the underrated aspects of all these relations (Pires et al., 2018), like the significance of cultural ES, less vocal actors in society, subsoil biodiversity, etc (Motiejūnaitė et al., 2019). A possible way forward is to enrich the land sharing – land sparing framework. When comparing sparing and sharing strategies, one typically focuses on the evaluation of biodiversity and provisioning ES. However, additional and more nuanced insights could be provided regarding the optimal strategy if regulating and cultural ES are considered as well, and if local supply and demand are also taken into account.

3 Policy relevance, implications and recommendations

3.1 Challenges for adaptive spatial planning

The recent strategic vision of the Flemish Spatial Policy Plan ("Beleidsplan Ruimte") (Ruimte_Vlaanderen, 2018), further called 'strategic vision', is used as the reference for crosschecking the policy relevance of this dissertation and to formulate challenges and policy recommendations. Based on this strategic vision, it is clear that spatial planning policy in Flanders is already on the path towards a more integrated adaptive practice. The strategic vision sets the importance of a more flexible system of governance to adapt to shifts and shocks as one of its leading principles (Ruimte_Vlaanderen, 2018). In general, the strategic vision calls for a more multifunctional development of open space, but insights and guidelines on which ES bundles are to be developed where and on what scale, are largely missing. The presence of networks of small open spaces, in particular in and near urban areas, is considered an opportunity for developing multifunctional bioproductive spaces and green-blue networks. The importance of open spaces for both the preservation of biodiversity and the delivery of a number of other ES, e.g. water retention and flood control, is explicitly stated. Measures to preserve open spaces include the intention to stop the further decline of unsealed space, and to allow for and actively support innovative forms of land use. The strategic vision explicitly couples the direction for development of rural areas to their region-specific context. This context refers to a.o. the degree of urbanisation and landscape qualities. This is to some degree reminiscent of the conclusions reached in Chapter 2 and 3 of this dissertation. Various challenges for Flemish spatial planning are identified. These challenges can be related to ecology, to spatial aspects, or rather to socio-economic aspects.

From an ecological perspective, it can be determined that land use is highly multifunctional and intertwined, while in spatial planning policies for the rural component of the territory, monofunctionality remains the norm rather than the exception. The potential of a more integration-friendly form of spatial planning does at first not seem to be compatible with the day to day practice of delivering licences for development. Yet, the fine-scale analysis from this research suggests that a flexible culture of spatial planning is the way forward. A more nuanced and integrated planning and land management practice, based on the selective promotion of bundles of ecosystem services, focusing on spatio-temporal mismatch between ES supply and demand, and involving bottom-up initiative from local actors is needed (Baró et al., 2017). This demands a participatory approach, aiming to engage a broad range of stakeholders on the terrain, allowing innovations in need of support to be recognized and inspiration be shared. Off course, an integration-friendly spatial planning requires reliable indicators to identify good practice. From an ecological perspective, the ES concept shows great potential in this respect.

From the spatial perspective, the first challenge for a strategic spatial-explicit development of bundles of ES lies in the actual recognition and valuation of small open spaces. Day-to-day practices in the highly fragmented and urbanized landscape of Flanders are not yet adjusted accordingly, causing scale-dependent dissociations between land and spatial policies. Planning still bears the heritage of the focus on larger landscape units while systematically underrating and undervaluing the potential role of small fragments. The 'AGNAS' procedure during the late nineties and early two thousands ('Afbakening Gebieden Natuurlijke en Agrarische Structuur') for example focused mainly on the larger landscape units for the demarcation of the agricultural and natural structures. This is exacerbated by the systematic neglect and/or underappreciation of small fragments in policy, research and development. So, although the potential of smaller fragments has recently been explicitly recognized in the strategic policy vision, details on how to deal with processes of privatization (e.g. encroachment of agricultural land by private gardens) or domestication (e.g. use of agricultural land for recreational purposes) of spaces (Gulinck et al., 2013; Verhoeve et al., 2015) are currently missing. Not only large-scaled transformations are relevant. The addition of many small and sometimes very local changes in the landscape lead to larger changes over larger scale and time. Insights from the field of landscape ecology might prove useful to realize the potential contribution of a multitude of small fragments to improve spatial resilience (cf. Opdam et al., 2006).

From a socio-economic perspective a challenge lies in the obvious discrepancy between a relative static framework of spatial planning, and the increasingly dynamic reality of global change, market fluctuations and shifting preferences of land users and consumers. More generic aspects of spatial planning are in some cases ill-adapted to the complex dynamic economic realities on the terrain. The strategic vision on the spatial policy plan pushes integrated area development as a promising way to include bottom-up initiatives in area development, including a.o. local actors. While this is not a miracle solution to solve the aforementioned discrepancy, it does provide a potential means to include local dynamics into the decision making process, given a number of conditions are met. One condition is that governmental bodies engaging in participation, take this approach seriously and allocate sufficient time and resources to allow for actual two-way participation. Another condition is that civilians engaged in the participation process, have access to actual and correct information. When relevant, they should be properly compensated for adaptative measures taken under impulse of new policies, or for associated changes to their living or working conditions.

3.2 Policy recommendations

Increasing spatial efficiency is an important principle in the current spatial policy plan. However, the potential of bioproductive space delivering ES remains undervalued in the operationalization of the idea of spatial efficiency. Spatial planners, designers and land managers should be stimulated to evaluate how their design/development/project affects bioproductive space, and how it can create, restore or improve bioproductive space. This question should become self-evident. But in order for his to become a natural reflex, planners, designers and managers should be well versed in the ES concept, the local and regional demand for ES, the actual state of ES delivery, and the potential for trade-offs and synergies. A lot of the required information is already available in some form. Also for the open space, a form of spatial efficiency can be conceptualised. Here, to be spatially efficient means to deliver the ES bundles that are most needed in that particular area in a sustainable way. In order to align different stakeholders from various backgrounds to collaborate on developing specific ES bundles in a region, guide models can be created. Examples of such guide models are presented in Section 3.3 of this chapter.

Thus, spatial policy should increasingly embrace the idea of developing bioproductive land to foster the supply of ES. The concept of bioproductive space can act as a development guideline. Tools and decision support systems to be developed to achieve this like vulnerability maps and guide models, should be based on solid research grounded in landscape ecology, hydrology, climate science, etc. (Dominati et al., 2019). It is up to research to prioritize the functions and services to be delivered, and to translate results to practical tools and solutions for policy makers and land managers. However, care should be taken to allow for sufficient degrees of freedom to implement innovative strategies to develop land use systems that are able to deliver the required services. Solutions should detect and include dynamics and developments that would otherwise remain under the radar of research and policy. It is likely necessary to develop new perspectives on bioproductive land (Dewaelheyns et al., 2018; Dominati et al., 2019; Gulinck et al., 2013). In doing so, functions and services to be delivered by bioproductive land can be lifted out of a sectoral planning black box. One of the strategic goals put forward in the spatial policy plan is to enhance ecological connectivity and biodiversity, and preserve soil quality and biodiversity (Ruimte_Vlaanderen, 2018), against a backdrop of increasing anthropogenic pressure on ecosystems. Achieving this goal requires rigorous action, including land sparing strategies to create sufficiently robust ecosystems that are able to deliver the buffer functions required to cope with the environmental impact of infrastructure and agriculture. This can be paired with highly spatially efficient settlements.

This research advocates for a better integration of spatial planning with land governance, natural and agricultural policies and practices. This implies a revision of the chronology of planning: large shifts of shocks require fast, even proactive decision making, leading to quick action on the terrain. When taking this to the extreme, it might even reverses the approach of spatial planning. Instead of first establishing a zonal plan and let land management develop according to that plan, a scientifically grounded approach establishes which ES are prioritized where, and land management can approach this challenge in an integrated way. A promising tool to further develop and implement in this respect are Payment for Ecosystem Services (PES) schemes (Bennett and Gosnell, 2015; Hauck et al., 2013; Wei et al., 2017). PES schemes combined with integrated assessment of ES supply and demand (IAESSD) models can provide the necessary incentives for the farmer or land manager to make land allocation and management decisions that increase the provision of ES that are in local demand. The application of PES schemes can have positive effects on the socio-economic development of local communities. In particular when focusing on regulating and cultural ES (Schirpke et al., 2018). Coupling PES schemes to the local need for ES delivery is essential in fostering spatial resilience. Schirpke et al. (2018) also report a spill over effect to larger spatial scales, in terms of knowledge capacity building, innovation and the availability of financial stimuli for nature and landscape management, while direct economic benefits remain mostly limited to the local level. The fragmented, urbanised landscape in Flanders needs to reshape its many peri-urban areas into multifunctional places where land sharing strategies provide large bundles of ES in a multifunctional landscape (Baró et al., 2017; Tscharntke et al., 2012). PES schemes can play a significant role in stimulating land managers to opt for more sustainable, conservation-oriented strategies. Since PES are often limited in time however, they cannot fully replace other conventional funding channels.

Improving data availability and model transparency and accessibility is the way forward to allow for more participation and a broader collaboration in the adaptive management of bioproductive land. Therefore, we recommend researchers and governmental agencies in particular, to continue working to make data and tools publicly available and easily accessible. Well-documented public data repositories, citizen scientist initiatives and open source software solutions are the future. These should help foster new alliances and improving the collaboration between different sectoral agencies (e.g. nature and agriculture), as well as between non-governmental and governmental actors (Galler et al., 2016).

Initiatives in Flanders like the Ecoplan Monitor, Nature Value Explorer, the 'waarnemingen' database[5], and the NARA data repository[6] are significant steps to bring monitoring data and results to stakeholders, analysts and the broader public. In particular the Nature Value Explorer shows great potential to evolve into a major tool for adaptive

[5] Accessible at *waarnemingen.be*
[6] Accessible at *www.inbo.be/nl/interactieve-kaart-ecosysteemdiensten-vlaanderen*

planning, if the tool would be adapted to include information on regional and local priorities for adaptation. In Chapter 4 , we developed vulnerability maps for future scenarios, based on the ES bundle mismatch maps. Incorporating such vulnerability maps, drafted on a number of scale levels (regional to local), would constitute a crucial addition to strengthen valuation tools like the Nature Value Explorer to play a key role in adaptive planning. In this way, region-specific adaption goals can be included in societal cost-benefit analysis. Two important fields for improvement can be highlighted here. Indicator-based tools like the Nature Value Explorer evaluate scenarios, which are always an approximation of the reality on the terrain. As the underlying models improve, usually the accuracy of the scenarios improves as well. However, our case study from Chapter 2 exposes an important caveat in this approach: it is difficult to predict the effect of truly innovative solutions, not only because of the innovative aspect, but also because they often start on a small, local scale. We recommend to actively benchmark innovative cases against more classical approaches to land management, to actively identify and promote innovative forms of land use by highlighting exemplary cases (which is already done in the context of spatial efficiency), and to stimulate pilot projects (Ruimte_Vlaanderen, 2018). Also, we advocated earlier for the integration of biodiversity in land use evaluation. This is, admittedly, not an easy hurdle to take.

3.3 Towards a practical application of ES in planning and management of bioproductive land

A well-established integrated assessment of ES supply and demand can provide key insights for spatial planning and land management. Moreover, the ES concept proves to be a practical framework to facilitate coordination and cooperation between stakeholders and actors from various backgrounds (Galler et al., 2016), and to find common ground between actors with opposing interests. As such, the framework can contribute to finding new alliances for the governance of bioproductive land.

However, the power of ES as a boundary concept facilitating discussion tends to deteriorate over time as principal actors have distinct normative backgrounds, leading to a different interpretation of the nature and meaning of the ES concept (Galler et al., 2016). This stresses the importance of paying attention to finding a common interpretation of the concept at the start of any transdisciplinary project for integrating ES in the management of bioproductive land. Experiments by Opdam et al. (2015) have also illustrated that careful framing of ES concepts might stimulate the willingness to engage in a participatory process by stakeholders with vastly different backgrounds. The ES concept could be applied as a bridging guiding concept in the practice of integrated area development as put forth by the Flemish spatial planning policy. We have experienced the difficulties of transdisciplinary research first-hand during follow-up research based on the results of chapter 4, in particular when trying to translate the technical output from spatial and statistical analysis to form the basis of subsequent research by design (Lerouge et al., 2016). This required an iterative approach, establishing a back-and-forth dialogue, where the participants with different backgrounds cooperated to establish a common understanding of the fundamental academic research concepts and subsequently, translate the academic concepts to region-specific landscape design principles.

This way, we managed to translate the theoretical results from the research presented in Chapter 4, to practical research-by-design in the form of guide models. These guide models consist of series of principal drawings of typical landscape sections for various Flemish ecoregions, complemented by a series of illustrated design principles to develop bundles of ES. The Flemish ecoregions consist of a coherent division of the Flemish territory into geo-physically relatively homogeneous units. We chose to develop guide models per ecoregion (Sevenant et al., 2002), because the delivery of ES is closely associated with the functioning of the particular landscape system. The landscape sections depict the current situation, as well as a vision on landscape development, based on the specific ES bundles that are to be developed in that particular ecoregion. In their present form, these guide models can serve as support in spatial planning processes. But the guide models can also as bridging frameworks in participatory initiatives. In some cases distinct guide models were drafted for a single ecoregion, depicting possibilities for land use optimization under different priority scenarios. For example for the ecoregion ‘Pleistocene river valleys and mid-Flemish transition areas’, one guide model was developed for a scenario focusing on natural development, renewable energy and water retention. However, for areas with dominance of livestock farming and horse keeping, a separate guide model was drafted. The guide models are developed in Dutch. To illustrate the application of these guide models in this dissertation, two models were translated to English and included below.

The first example shows a river valley landscape section and corresponding guide model in the *Kempen* ('Campine') ecoregion, in the northeast of Flanders (Figure 28 - Figure 29). This region is characterized by sandy soils with a complex hydrology of local to regional groundwater systems. Therefore, the guide model follows the principles of the hydrological landscape structure of Van Buuren (1997), which divides and organizes the landscape following the underlying local to regional groundwater systems. The actual land use in the Kempen ecoregion is largely dissociated from this underlying structure. The branches of the Nete river are canalized over long stretches and engineered for rapid drainage. Settlements and infrastructures cross this landscape, regardless of its biophysical structure. The historic broadleaf forest cover has been removed or replaced by conifers. Locally, the structures of valley bogs, fed by local groundwater systems, are preserved, but they are isolated and their functioning is limited. Intensive agriculture leads to increasing eutrophication of ecosystems.

For this ecoregion, our analysis highlighted opportunities to match supply and demand for mixed recreation, agriculture- and forest related ES, combined with different ES related to water supply. Because of the characteristics of typical landscapes in the Kempen ecoregion and the importance of water infiltration for Flanders, the guide model focusses heavily on the use and preservation of local and deeper groundwater currents. On the higher grounds that feed deeper aquifers, the emphasis lies on water infiltration combined with increasing forest cover. In these areas, intensive agriculture can be transformed into more extensive, multifunctional forms of agriculture in combination with forests, much like the exemplary case described in Chapter 2. Innovative hybrids of agriculture combined with forestry, i.e. agroforestry solutions, have the potential to provide great added value in providing a range of ES that are in local demand, while contributing to the reduction of nutrient loads in the regional groundwater systems. In the longer term, the Nete valley can be transformed to a wetland complex, providing ES like flood buffering, recreation, drinking water production, biomass production, while contributing to the restoration of local biodiversity. Also the valley bogs show mayor potential for biodiversity restoration, and form important nodes for future recreation networks. The conversion of conifer forests to mixed deciduous forests results in improved water retention capacity, and combined with heathland restoration, contributes to local biodiversity.

The second example is a guide model for the ecoregions of the 'Pleistocene riviervalleien en Midden-Vlaamse overgangsgebieden' (Figure 30 - Figure 31). These ecoregions in the centre of the Flemish region are similar to one another in terms of biophysical landscape structure and land use, with a high degree of fragmentation due to urban sprawl and ribbon development. However, they differ in terms of soil characteristics, ranging from sand – sandy loam to loam. Again, the contemporary patterns of urbanization have been developed irrespective of landscape morphology or functional relations with the underlying subsoil and hydrology. Moreover, ribbon development created visual barriers in the landscape, effectively isolating open spaces (Gulinck and Dessein, 2002). Nonetheless, some of these isolated open spaces retained their functionality to some degree, and are dominated by agricultural land use. This agricultural land use has seen a gradual transition towards forms of 'domestication' and non-agricultural developments, like horsification (Bomans et al., 2009; Dewaelheyns et al., 2018; Gulinck and Dessein, 2002; Verhoeve et al., 2015).

The guide model tries to steer development of these fragmented landscapes towards effective combinations of multifunctional bioproductive spaces. The idea is to acknowledge the reality on the terrain, i.e. of a combination of conventional agriculture with more domesticated forms of land use, but also to reconnect this with the biophysical structures of the landscape by developing the underlying stream valley structures. There, the focus lies on developing regulating ES like water retention, denitrification, pollination and pest control, to name a few. In doing so, planners and land managers need to be aware of emergent opportunities for the development of ES bundles. Not every bioproductive space is developed in the same manner. Rather, a land sparing strategy is proposed on this level of scale, where some open spaces are developed into more conventional, intensive forms of agriculture, creating space for nature development to provide the necessary buffer functions. On a regional scale however, the impression of a hybrid, multifunctional landscape emerges. The essence here is that land uses are combined in configurations seeking emergent functions and properties, from heat exchange to ecological buffers, the whole becomes more than the sum of its parts.

Summarizing, these guide models visually highlight specific issues with current land use practices, and couple this with potential landscape design principals based on fostering ES bundles. Doing so, the particular properties of the social-ecological system in that landscape are taken into account. This research by design takes place on two scale levels: on a regional level, the guide model provides an inspiring image for a possible future landscape design. On the local level, one can design integrated solutions combining different ES, focusing on the ES bundles that are most critical to develop (Lerouge et al., 2016). Such insights, for instance, are able to feed the policy priority settings of the analytical framework developed in Chapter 3.

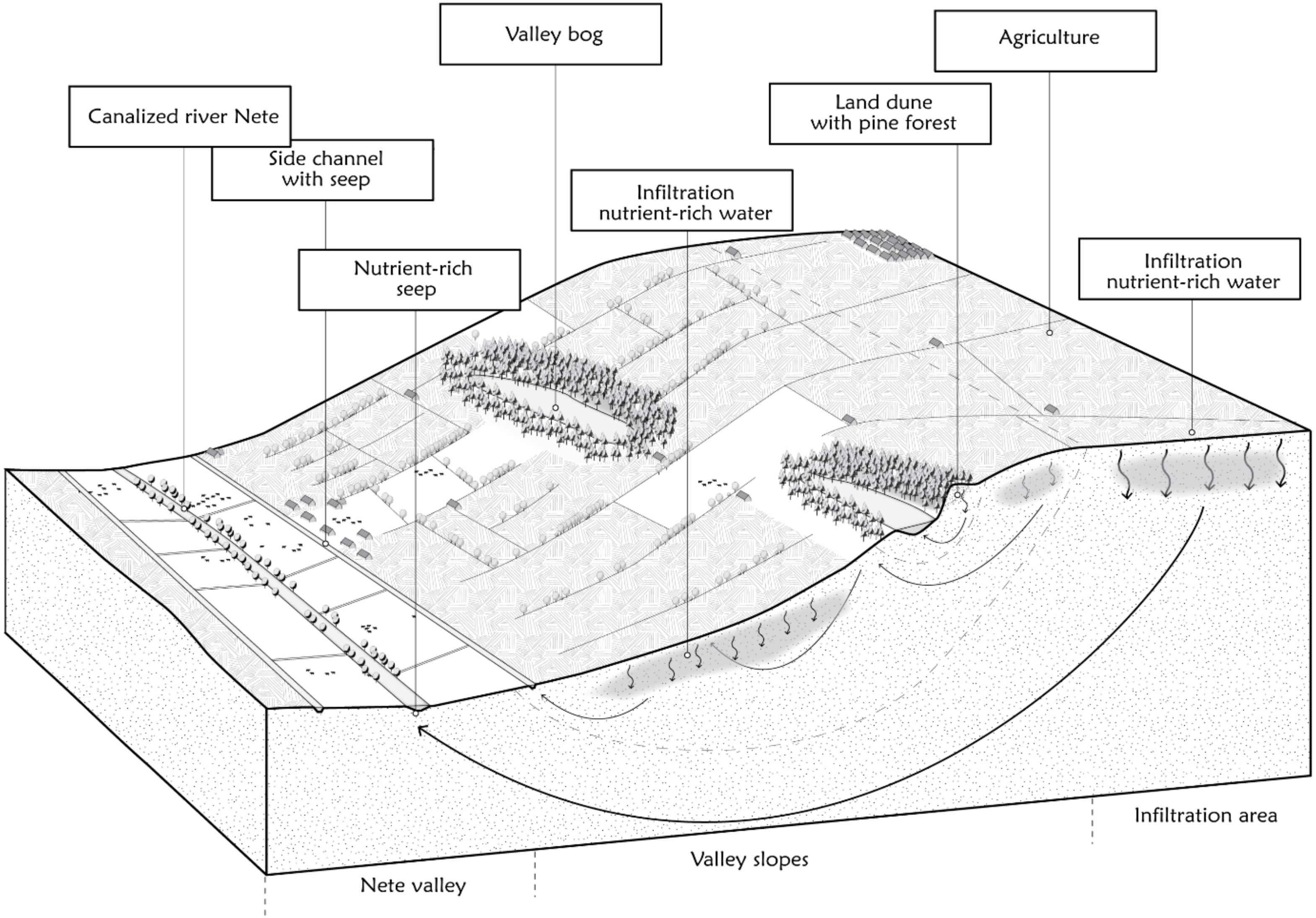

Figure 29. Kempen ecoregion: landscape model depicting existing situation (Illustration by David Verhoestraete).

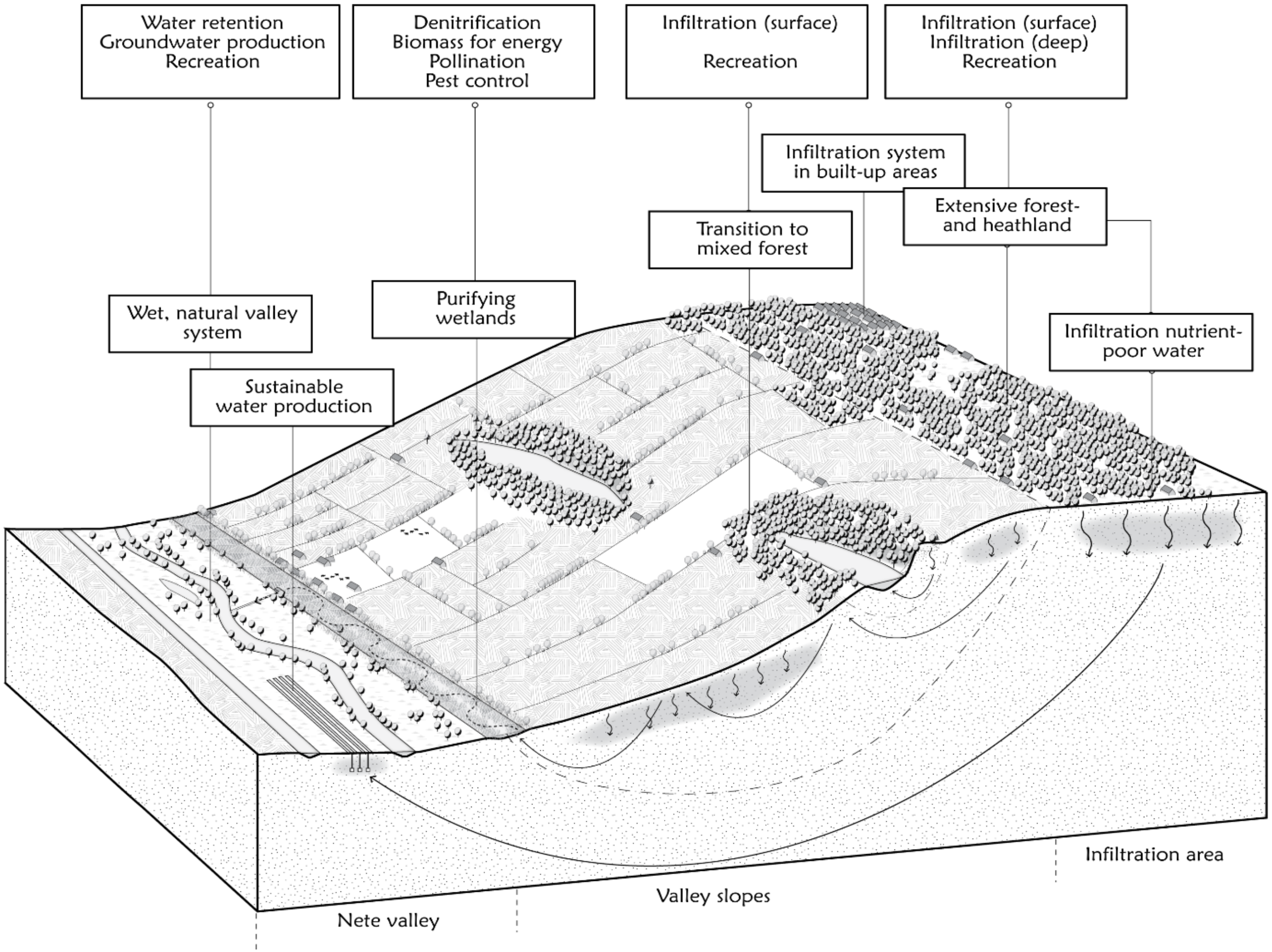

Figure 30. Guide model for the Kempen ecoregion (Illustration by David Verhoestraete).

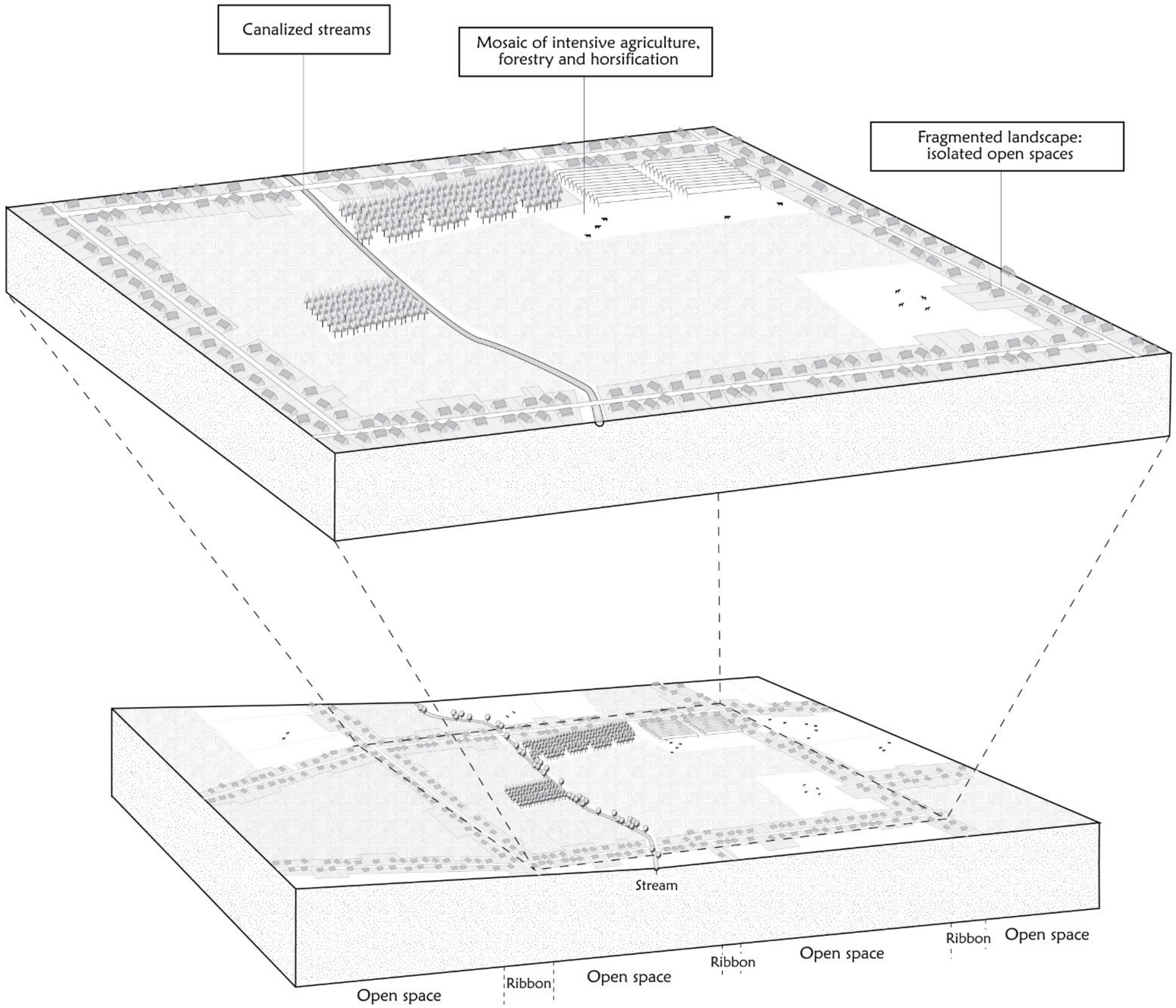

Figure 31. Ecoregion ‘Pleistocene riviervalleien en Midden-Vlaamse overgangsgebieden’, current situation (illustration by David Verhoestraete).

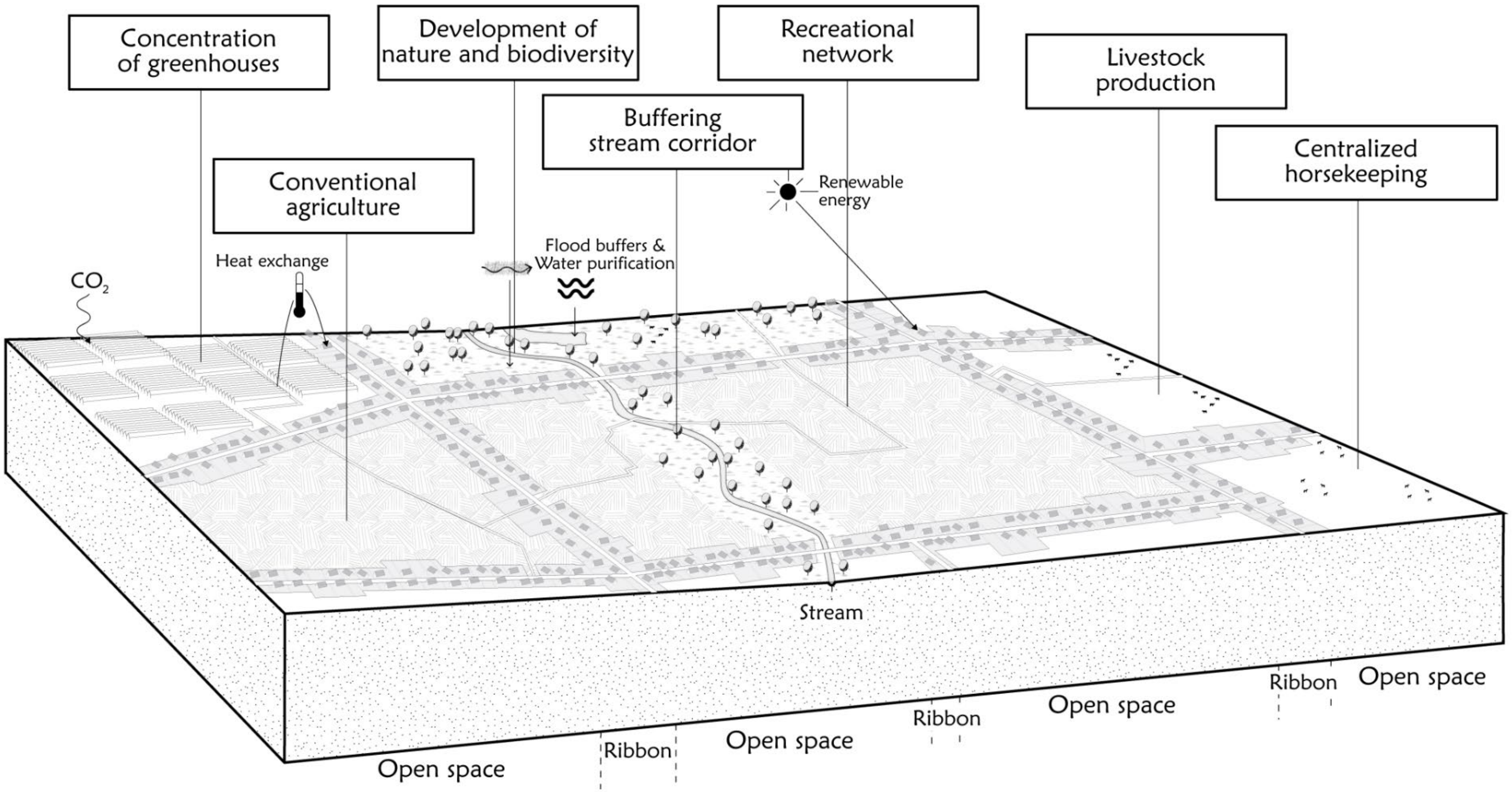

Figure 32. Guide model for the ecoregion 'Pleistocene riviervalleien en Midden-Vlaamse overgangsgebieden' (illustration by David Verhoestraete).

4 Concluding remarks

This dissertation makes a case for integrating undervalued ecosystem functions and services into spatial planning and land management. In doing so, there is a need to start from the reality on the terrain, and to seek emergent qualities through innovative forms of land use. The development of resilient bioproductive space in Flanders requires an operationalization of the ES concept into adaptive planning practices. Land use and land management decisions should be grounded in well-founded, scientifically established local and regional needs for ES.

We do not transcend nature, but are part of it. By undermining the structure, functioning and diversity of ecosystems, we have drastically reduced our capacity to deal with the current and upcoming strategic challenges of climate change, providing food and a healthy environment, and equality. Overcoming these challenges requires transdisciplinary efforts. From the ecological and biophysical perspective, valuing the services nature provides is a necessary step toward adaptive planning and management of our bioproductive space.

While the current spatial planning policy includes a promising vision on the strategic development of our bioproductive space, concerns can be raised that the implementation might be 'too little, too late' in the light of the impending shifts and shocks we face. But even if we embrace a strictly utilitarian attitude towards our natural world, the outcome should still be that we want to conserve and develop our remaining bioproductive space to the maximal extent. After all, the biodiversity it comprises, represents our stock of functional processes in our agro- and ecosystems, which is the key to ES delivery and thus, to the well-being of all.

“It is not the strongest of the species that survives,

nor the most intelligent.

It is the one that is most adaptable to change.”

\- C. Darwin -

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Curriculum Vitae

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Bioscience-engineer in land- and forest management, major forestry and nature conservation, minor (sub)tropical agriculture (KULeuven, 2005, distinction)

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In a nutshell

I'm driven by a broad interest in natural history and the science of human-nature interactions. After my degree I had a diverse career in research, consultancy and education. As a consultant, I mainly focused on executing and coordinating impact studies for the international dredging sector. I did research in the fields of landscape ecology, spatial resilience and the relation between ecology and spatial planning. Currently, I'm teaching at PXL University College, Hasselt.

Science communication and education has always been constants throughout my career. For this, I combine skills as a presenter and graphic designer. I also work as a citizen scientist on a number of projects.

Career

2016 – present: lector at PXL University College, teaching and coaching students in a.o. ecology, ecosystem services, environmental sciences and elementary statistics at the professional bachelor training agro-and biotechnology.

2012 – 2017: Doctoral researcher at KU Leuven, partially in the framework of the Flemish support centre on space, on the topic of "Adaptive and Resilient Bioproductive Space in Flanders".

2010 – 2012: project leader at Ecorem nv: Environmental impact assessments in Belgium and abroad as a licensed EIA expert Ecology (MB/MER/EDA-716), feasibility studies, ecological monitoring, management plans, GIS-analysis, etc.

2007 – 2009: project engineer at Ecorem nv.

2005 - 2007: research assistant ecology for Prof. Martin Hermy at the Forest, Nature and Landscape Division (Earth & Environmental Sciences, KULeuven): Urban greening, landscape ecology.

Permanent training

Environmental law – EIA (2018)
Choice experiments summer school (2013 & 2016)
Academic writing (English, 2014)
Effective Graphical Displays (2014)
Survey design and data analysis (2013)
Natural Resources Economics and Policies (2012)

Skills

Policy supporting and trans/interdisciplinary research, incl. surveys and statistical analysis, and publishing.
Science communication (in English and Dutch):

- Reporting and publishing, incl. publishing in scientific journals;
- Presenting and teaching: broad experience with seminars and lectures, as well as drafting, preparing and coordinating courses;

Graphics: experience illustrator, incl. scientific illustrations (charts, infographics) and photography.
Project coordination, incl. writing proposals.
Technical skills: building and maintenance of fossil preparation lab, fine preparation skills, adhesives.
IT and software:

- Writing, presenting, spreadsheet, … apps (incl. Microsoft Office);
- Statistics: R, STATA and SPSS;
- GIS: ArcGIS, QGIS (+GRASS);
- Graphics (vector and raster): Inkscape, Photoshop, CorelDraw, The GIMP;
- Reference managers: Mendeley, Endnote;
- Editing software: Scribus. Publisher.

Self-reliant: independent ecological and geological fieldwork in harsh and remote arid or tropical conditions.

Extra-professional activities

Fossil preparator and conservator: I own a laboratory for fossil preparation, and built a scientific collection on trilobite fossils from the Rheno-hercynian and Moroccan Devonian. On occasion, I prepare specimens for scientific research institutes. I give lectures and publish on the subject. As a citizen scientist, I'm part of a small research collective doing original research on Devonian trilobites (www.trilolab.net), and co-founder of the science education website www.fossiel.net, which contains one of the largest paleontological relational databases online to date. I had three new species named after me as an appreaciation of my work as a fieldworker and preparator: *Acastava lerougei* from the Emsian of Belgium; *Cyphaspis lerougei* of the Emsian of Morocco, and *Magreanops monachus* of the Frasnian of Belgium ('monachus' is a reference to a monk's work, which is an apt description of the preparation process).

Parkour athlete and coach at Circus in Beweging, Leuven.

Publications

Articles in internationally reviewed journal & peer reviewed

- Van Viersen, A, Lerouge, F (in press). Cornuproetine (proetide) trilobites with nine thorax segments from the Devonian of Morocco, Germany and the Czech Republic. Paläontologische Zeitschrift.
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Selected seminars and lectures

- Lerouge, F. & Viersen, A.P. van, 2019. What's in a name? Taxonomie als fundament voor onderzoek - de casus Morocops. Scientific poster @ the PaleoTime-NL, Harderwijk. (prize winner Outreach Poster Award - 2nd place).
- Plandag 2016. Organisatie en moderatie sessie 'Ruimtelijk-inhoudelijk verruimen'.
- Lecture "From desert to desktop: life and afterlife through the compound eyes of a trilobite": seminar series with multiple lectures in the Netherlands, a.o. for the Museon @ The Hague. (2015)
- VRP lab 'Offensief Open': inleidende lezing 'De ruimtelijk-structurerende werking van ecosysteemdiensten'. Atelier Bouwmeester, Brussel (2015)
- Lecture "Walk the Line: zoeken en prepareren van trilobieten uit het Ma'der bekken, Marokko": succes seminar series in Belgium and The Netherlands, o.a. voor het Natuurhistorisch Museum Maastricht en de Belgische vereniging voor Paleontologie. (2013-2016)
- Visuele presentatie 'Revisiting Production And Ecosystem Services For Evaluating Land Use Alternatives: A Farm Scale Application'. ICAE Conference "Agriculture in an interconnected world" (2015)
- Seminarie Global Land Project Open Science Meeting, Berlijn: "Bioproductive space and regional resilience – development of an analytical framework" (2014)
- Seminarie BVLE PhD workshop: "Revisiting agricultural production and ecosystem services for evaluating land use alternatives" (2014)
- Seminarie Midterm event Steunpunt Ruimte "Ruimtelijke veerkracht van bioproductieve systemen" (2013)
- Seminarie ILVO: Sustainable and resilient open space in Flanders – a spatial and economic analysis (2013)

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