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A Toolkit for Resilience Evaluation of Land Use Alternatives in a Multifunctional Peri-Urban Landscape

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1 ABSTRACT

Translating the concept of social-ecological resilience to practical applications in spatial planning remains challenging. The aim of this paper is to contribute to the scientific approach of spatial aspects of social-ecological resilience and adaptive capacity related to bioproductive space, with particular attention to food systems. We define ‘bioproductive space’ as all space providing ecosystem services through primary production processes and includes semi-natural as well as agricultural ecosystems. We argue that bioproductive space is resilient if it continues in delivering similar levels of ecosystem services under changing conditions.

A toolkit was developed to explore spatial resilience of bioproductive space. The first stage in the toolkit is a spatially explicit evaluation of various ecosystem services for different land uses. 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. Some of these variations are mostly society driven, e.g. changing bioenergy demand or more restrictive air quality targets. Others are rather driven by biophysical factors, like increasing need for buffering of extreme weather events under the impulse of global change. The third stage of the toolkit takes policy priorities into account. In a final stage, the output of the tool is synthesised by ranking the analysis results for different scnearios and policy priority settings. This toolkit allows spatial planners to explore and evaluate policy decisions against trade-offs between various land use alternatives, while taking ecosystem services into account. The toolkit is applied to a case study to demonstrate its use. Besides the potential for supporting policy makers, the toolkit provides useful feedback for adaptive farm and landscape management.

2 INTRODUCTION

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 (Millennium Ecosystem Assessment 2005). Meanwhile, injudicious use of remaining available space puts constraints on its provision of ecosystem services (Stoate et al. 2009). Urbanization leads to an increasing competition for the remaining open space (Kerselaers et al. 2013), limiting the adaptive capacity of food systems in peri-urban areas. The ecosystem service concept may contribute to an adaptive spatial planning paradigm, and as such, to more resilient land use. Adaptive management comprises combined insight in the system vulnerability, the detection of system crossing thresholds, and the presence of feedback loops towards an adequate (pro-active) response (Benson & Garmestani 2011). A framework for detecting early warning signals for regime shifts has been developed by Scheffer et al. (2009; 2012). A model concept for the assessment of threshold in various interacting scales (‘cascading thresholds’) was developed by Kinzig et al. (2006), and has seen some applications (e.g. van Apeldoorn et al. 2011). Nonetheless, the need for practical tools to incorporate resilience thinking in adaptive planning remains.

Resilience is quickly gaining momentum as a concept for understanding the dynamics of sustainability in social-ecological systems (SES) (Folke 2006; Turner II 2010), and the response of these systems to environmental and societal changes (Adger 2006). Resilience is defined in terms of the capacity to reorganize, renew and redevelop (Gunderson & Holling 2002). Essential to the concept of ecological resilience is the presence of several alternative stable states for an ecological system (Holling 1973). Within the theoretical space defined by all possible values of the variables that constitute a system, several stability

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domains may be found. These can be seen as more or less distinct sets of system states that are highly similar in structure and function. These stability domains demarcate alternate 'regimes', separated by thresholds (Scheffer et al. 2001). Phase shifts across these thresholds are well-known from resilience research on ecosystems (Zell & Hubbart 2013), most notably marine ecosystems like coral reefs (e.g. Bellwood et al. 2004; Hughes et al. 2005) and pelagic species assemblages (Daskalov et al. 2007), as well as freshwater ecosystems (Reynolds 2002; Carpenter et al. 2001).

Translating the concept of resilience to practical applications in spatial planning remains challenging. It can be applied to relatively simple and well controlled systems, but often fails to grasp disturbance dynamics in more complex social-ecological systems. When talking about social-ecological resilience (Davoudi et al. 2012), the idea of more or less static stability domains is questioned, as the system itself can be able to adapt (even pro-actively) to external and internal drivers (Carpenter & Folke 2006; Folke 2006). Social-ecological resilience recognizes the intrinsic complexity, uncertain and dynamic character of SES, and moves away from a linear cause-consequence reasoning (Kinzig et al. 2006). The social and biophysical components of the system are intimately linked, and can not be treated separately.

3 RESILIENCE OF BIOPRODUCTIVE SPACE

The aim of this paper is to contribute to the scientific approach of resilience and adaptive capacity 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-)natural and agricultural ecosystems. 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 & Potschin 2010).

The approach 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. In analogy with Zell & Hubbart (2013), we 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".

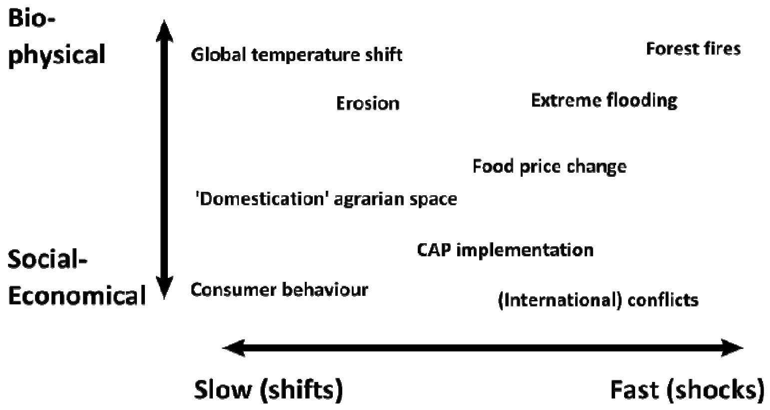

Figure 1. Drivers

Resilience aspects can be described on various spatial scales, and from interaction between these scales. Cumming (2011) points out the contribution of location, connectivity and context for adaptive forms of land use under the umbrella term 'spatial resilience'. The capacity for adaptation has a social and biophysical component, the latter depending greatly on biodiversity (Zell & Hubbart 2013; Colding & Barthel 2013). Biodiversity increases functional redundancy in a system, as well as the number of potential development paths, both to the benefit of the response diversity of the system to shocks. Also Walker & Salt (2006) list diversity as one of the principal criteria for the development of resilience of social-economic systems. Although functional diversity and variability within and across different spatial scales is a major component of resilience indeed, this is mainly so where it goes hand in hand with functional redundancy (Peterson et al. 1998) and high levels of response diversity (Bellwood et al. 2004).

4 DRIVERS AFFECTING FOOD PRODUCTION SYSTEM RESILIENCE IN FLANDERS

Resilience is meaningful only when described as a specific system's property relative to a specific driver (Carpenter et al. 2001). Drivers generate shifts (slow) or shocks (fast), and can can be of bio-physical or socio-economic nature (Figure 1). A driver may cause a directional change to the social-ecological system, driving alteration of the use of space within 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.

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% of the agricultural land is used for non-agricultural purposes (Verhoeve et al. 2015). Land 'horsification', i.e. use for recreational horsekeeping is part of this driver (Bomans et al. 2010), as well as competition for hobby animal feed production (Van Gossum et al. 2014). 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).

5 DEVELOPING A TOOLKIT FOR EVALUATING LAND USE ALTERNATIVES

The diagram in Figure 2 shows the design of the toolkit. On the input side is an assesment of the land use and possible land use alternatives, based on spatially explicit datasets of the biophysical system. The differences in ecosystem services delivered by these alternatives in comparison to the actual land use are quantified and valued. The assigned values are recalculated for different driver scenarios, weighted according to policy preferences, and aggregated. Adding drivers and policy priorities quickly leads to a large output matrix, making the output difficult to grasp. In terms of resilience, we are mainly interested in identifying these land use alternatives that provide, on average, the highest value of ecosystem services under various shock 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, both the mean ranking and standard deviation of this land use alternative will be low. A low mean ranking is indicative for a high relative preference for the alternative. A low standard deviation in turn, is indicative for a high spatial resilience of the alternative, in the light of the driver scenarios, and in comparison with the other alternatives. This toolkit allows spatial planners to explore trade-offs between various land use alternatives, taking ecosystem services into account. The toolkit is applied to a case study to demonstrate its use.

5.1 Stage 1: Spatial explicit ecosystem service evaluation

Central in the toolkit is a spatially explicit evaluation of various ecosystem services for different land use alternatives. This evaluation should be quantitiative and allow for aggregation of the ecosystem services, i.e. that different ecosystem services can be combined and compared. For this purpose, we use monetary valuation. The differences in ecosystem service delivery are calculated between a baseline land use, e.g. the actual land use, and a land use alternative. The land use alternatives ideally correspond to real stability domains of the social-ecological system. The alternatives can reflect biophysical changes, landscape management changes, or combinations of both. Also, they might represent corner solutions. Corner solutions are extreme alternatives, not necessarily feasible but rather aiming at exploring the edges of the decision space for the social-ecological system.

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.

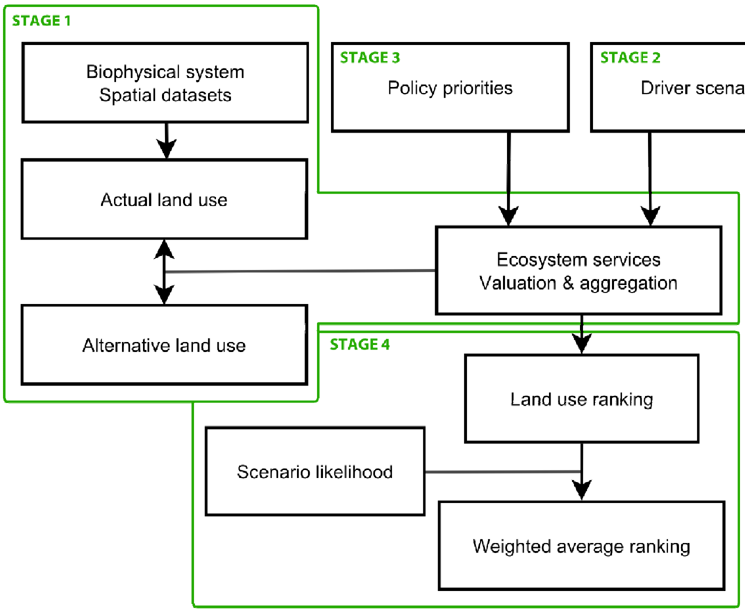

Figure 2. The structure of the toolkit.

5.2 Stage 2: Scenarios of slow and fast shocks

Bio-physical and socio-economic shocks can influence the value society attributes to 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 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 deleivered. A SES is considered to be resilient if it maintains the capacity to provide services that affect human well being, even when the SES is affected by a shock. The more a SES is capable to deliver positive services to human well-being despite socio-economic or biophysical factors affecting their demand and value, the more resilient it is. In this stage, the value of ecosystem services for different land use alternatives is calculated and this for different scenarios of changing demand and hence valuation of ecosystem services.

5.3 Stage 3: accounting for planning priorities

The previous stages allow for the calculation and aggregation of ecosystem services for various land use alternatives. However, spatial planners may decide to attach higher importance to certain ecosystem services because they consider the valuation over- or underestimates their importance. They may for example assume the valuation does not properly take into account future impacts. They may also take into account that there is a minimum quantity of ecosystem structure and proces required to maintain a well-functioning ecosystem capable of supplying services. Below this threshold, the SES might collapse and the economic value below this safe minimum standard drops to zero or becomes negative. Also, there may be high uncertainty as to the exact value of this threshold. However, 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. Therefore, the toolkit allows for assigning weights to individual ecosystem services. Alternatively, this 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.

5.4 Stage 4: ranking land use alternatives

For each shock scenario, we rank the land use alternatives according to the value of ecosystem services that they supply. A ranking of 1 is assigned to the land use alternative delivering the most societal benefits under the scenario in question. The second best land use alternative is ranked 2, and so on. This is done for each scenario. Subsequently, a mean ranking is calculated for each land use alternative. 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. Finally, when more schock scenarios are considered, the mean ranking may also change individual drivers.

6 APPLICATION TO A CASE OF EXTENSIVE MEAT PRODUCTION IN FLANDERS

6.1 Case: extensive livestock production combined with nature development

This case comprises an extensive livestock farming in two subcatchments of the Demer catchment in Flanders. The region of Flanders, Belgium, has an outspoken peri-urban character (Kerselaers et al. 2013; Lenders et al. 2005). The farm started in 2001 by taking over a conventional dairy farm, but has since then followed an unconventional development path, 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. The extraction of nutrients is an important aspect of ecological grassland management for reaching these biodiversity targets, mainly due to the high background deposition of nutrients (Stevens et al. 2011; Oelmann et al. 2009). As such, nature management in Flanders generates a biomass waste stream. This waste stream is spatially and temporally spread, making adequate removal and processing a challenge. Grazing is an option, but most of the biomass is of inferior quality as feed and therefore requires adapted breeds which are less productive. An outline of the production system is given in Fig. 3.

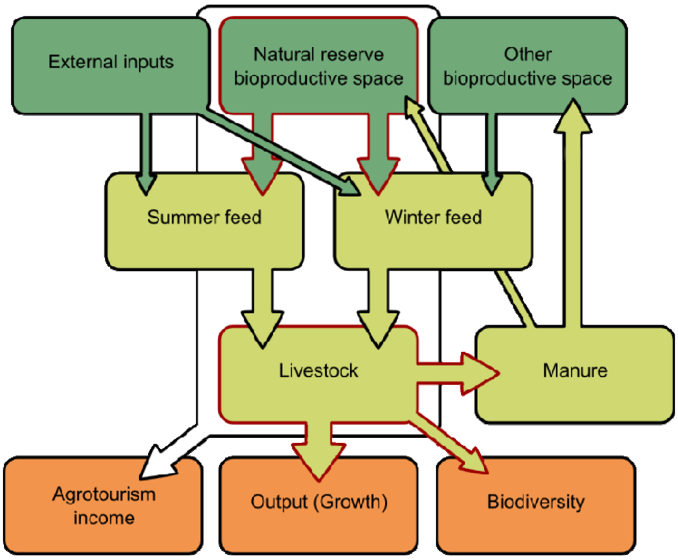

Figure 3. The livestock production system of the case farm is largely based on feed from a natural reserve.

Central in this diagram are two key components of the livestock production system, i.e. the bioproductive space of the farm, and the livestock itself. The bioproductive space used comprises 44 parcels covering about 113 ha in total. The farm uses relatively rare local breeds, namely the cattle breed Kempisch Roodbont, and the sheep breed Ardense Voskop. These breeds are sturdy and self-reliant, as well as able to digest the low-quality feed from extensive grasslands within the natural reserve. This low-quality feed forms the mayor

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component of the animals' diet, either by directly grazing the parcels, or cutting the grasslands for feed production. The choice for grazing or cutting specific parcels is largely determined by nature management targets. In addition, a number of parcels with a more intensive grass-clover cultivation are strategically included in the 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, contributing to reaching its biodiversity targets. 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. The productivity of these breeds is higher compared to some other typical breeds used in nature management, such as Galloway. This contributes to the economic potential of the farm.

6.2 Methodology

6.2.1 Stage 1: Spatial explicit ecosystem service evaluation

All parcels of the case farm were digitized in a GIS (ArcGIS 10.1), based on the farm registry. 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 2010; ANB 2013).

The actual land use was used as the Reference scenario. On a parcel by parcel basis and in collaboration with the farmer, 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, a corner solution, corresponds to a land use alternative that results from 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. To allow for an aggregation of the ecosystem services, monetary valuation was used. We relied on the methodology developed by Broekx et al. (2013), which is available in an online tool 'Nature Value Explorer'. This tool does not allow to calculate absolute values. Instead differences in value of ecosystem services supplied by the land use alternatives were calculated.

As such this analysis, described in detail in (Lerouge et al, submitted), 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. The tool used provides lower and upper estimates for the differential values. To avoid overestimating the differential ecosystem services, we work with the lower estimates.

6.2.2 Stage 2: formulating driver and shock scenarios

For demonstrative purposes, five shock scenarios were formulated, including a baseline scenario for comparison (Table 1). 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. Three 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; FoodValueConv, assuming this increase only to apply to conventional food products, and FoodValueOrg, assuming this value increase only to apply to organic food products. This last driver scenario correspond for example with the emergence of a local market for organic produce, offering higher prices to the farmers involved. Finally, we formulated the RecValue scenario, assigning a valuation increase for cultural services (i.e., 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 of 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. In addition, four different sets of likelihood figures for these scenarios are formulated.

(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.

Scenario	Description	Likelihood			
		A	B	C	D
Baseline	Original comparison for reference.	0.17	0.3	0.1	0.05
FoodValueGlobal	Increased valuation of food (150%)	0.17	0.2	0.3	0.05
FoodValueConv	Increased valuation of conventional food (150%), status quo for organic food	0.17	0.05	0.2	0.05
FoodValueOrg	Increased valuation of organic food (150%), status quo for conventional food	0.17	0.25	0.05	0.2
RecValue	Increased valuation of recreational services (150%)	0.17	0.15	0.15	0.5

Table 1. Overview of scenarios and the likelihood distributions used for the demonstration

6.2.3 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, in correspondence to policy priority settings, we assigned more weight to certain individual ecosystem services during the aggregation. For demonstrative purposes, we used the weighting matrix provided in Table 2.

Ecosystem service	Equal importance	More importance 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

Table 2. Weights assigned to individual ecosystem services during aggregation to explore the impact of policy priorities

Once again, a baseline is included in which all ecosystem services are weighted equally, to allow for comparison between weighted and non-weighted analysis. The policy priority setting ‘Regulation’ implies regulating services to be assigned a larger importance by policy makers. Similarly, the setting ‘Production’ puts emphasis on provisioning services, ‘Recreation’ on cultural services, ‘Carbon’ on carbon storage in soil and biomass, and ‘Bioenergy’ on ecosystem services provided by woody biomass.

6.2.4 Stage 4: Ranking

The aggregated values are calculated for five policy priorities, over six driver scenarios, for 3 land use alternatives. This yields an output matrix of 5x6x3 comparison results indicating in Euros whether the land use alternative in its respective context represents societal benefits (positive balance) or costs (negative balance).

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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 (Table 1).

7 RESULTS AND DISCUSSION

7.1 Stage 1: Spatial explicit ecosystem service evaluation

The intermediary output of stage 1 is an evaluation of the differential ecosystem services provided by the land use alternatives (Lerouge et al, submitted), and is here updated using the most recent estimates from the case farm registry. The actual land use (Reference) is used as a reference for benchmarking (Figure 4). As expected, the conventional production-oriented scenarios IntensiveMIN and IntensiveMAX perform better for provisioning services, but worse 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.

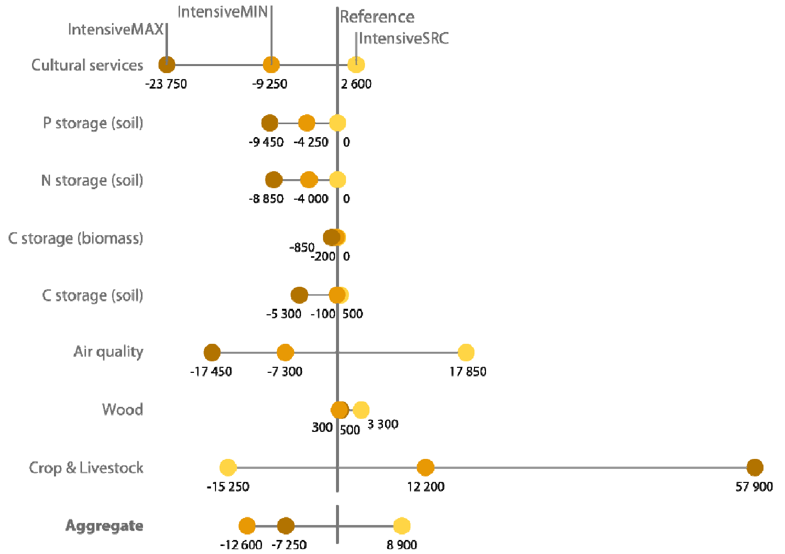

Figure 4. The evaluation of ecosystem services indicates relative societal benefits provided by the studied land use alternatives (baseline scenario, no weighting applied).

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. Because a short rotation coppice stand is likely to be visually less appealing compared to a young forest stand, for example due to the strict geometric pattern of the plantation, 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) 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 tradeoff between sophistication and ease of use.

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 to improve on 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 & Inoue 2013).

7.2 Stage 2: Driver scenarios

In Figure 5, 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.

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).

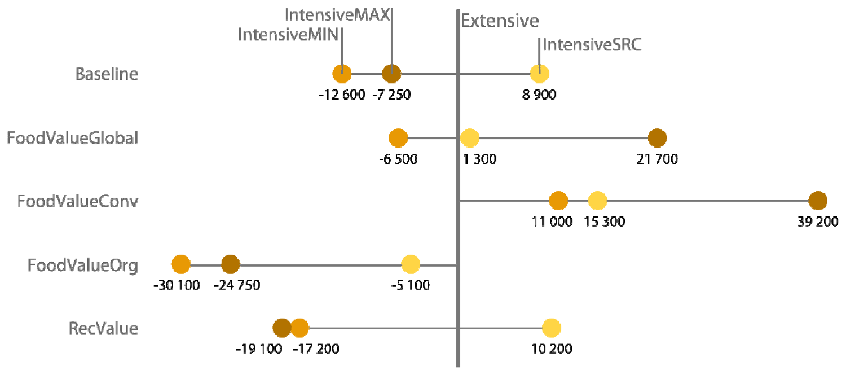

Figure 5. Relative performance (in terms of ecosystem services) of land use alternatives for each of the driver scenarios.

7.3 Stage 3: Applying policy priority settings

Figure 6 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.

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

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alternatives are performing. More focus on bio-energy production or on the supply of regulating services increases the performance of IntensiveSRC land use alternative.

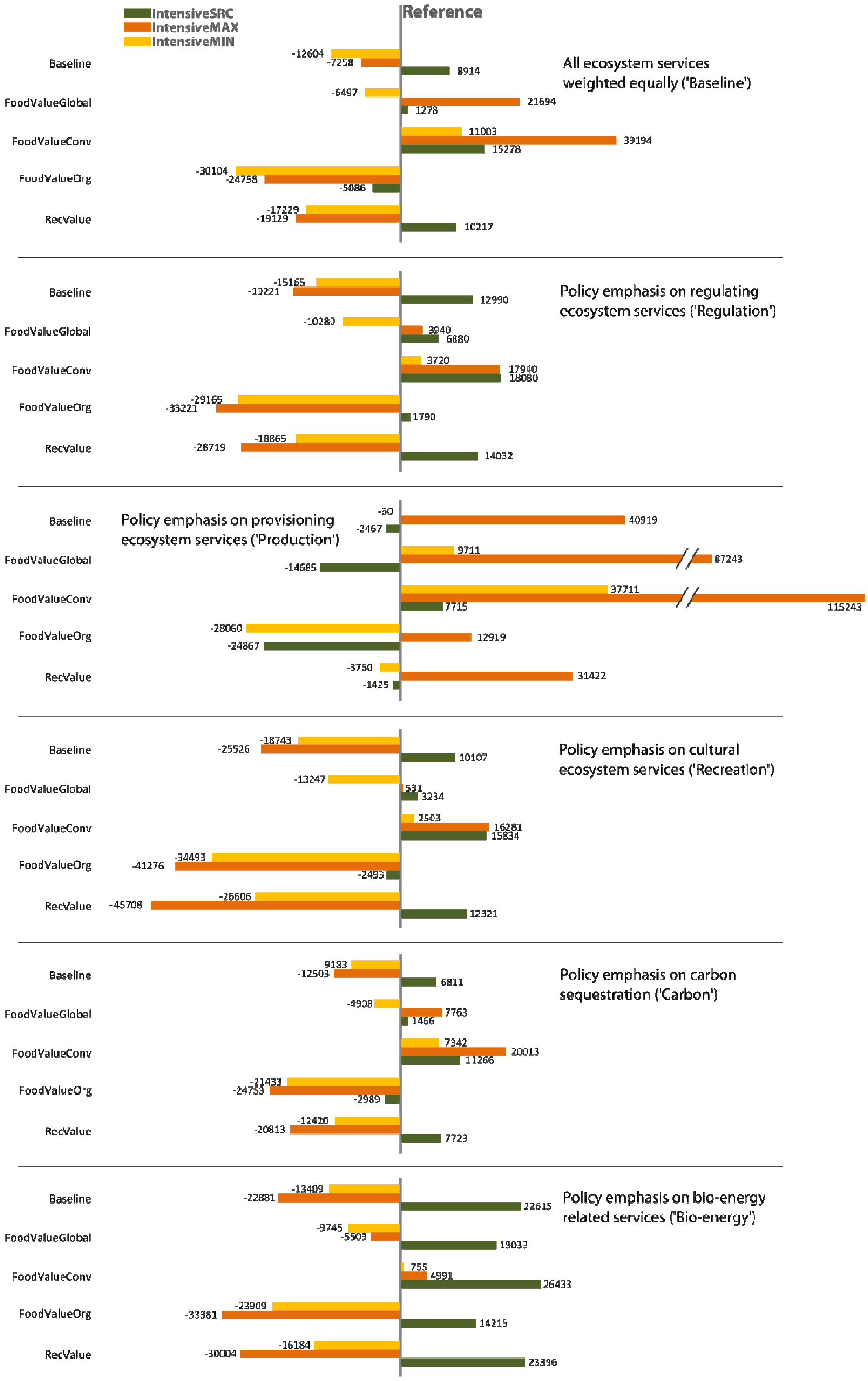

Figure 6. Relative performance (in terms of ecosystem services) of land use alternatives for each of the driver scenarios and for different policy priorities

7.4 Stage 4: ranking land use alternatives

Ranking the land use alternatives is a meaningful way to summarize the results from the scenario analysis. Changes in the ranking of land use alternatives under various scenarios are indicative for the spatial resilience of these land uses under the shifts and shocks the scenarios represent. In particular 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 can said to be spatially 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 the scenarios factors, 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.

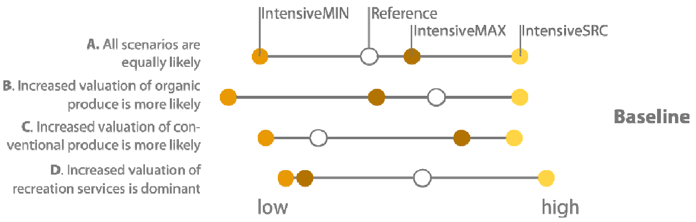

Figure 7. Ranking of land use scenarios with no specific policy priorities formulated ('baseline').

If policy emphasizes regulating services, extensive land use alternative is systematically ranked second, while the IntensiveSRC alternative would be highly preferred and resilient.

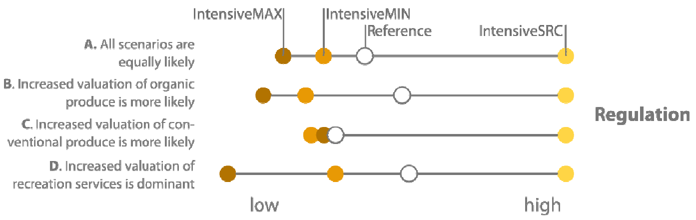

Figure 8. Ranking of land use scenarios with policy priority for regulating ecosystem services.

If policy emphasizes provisioning services, the ranking shifts completely. The IntensiveSRC alternative becomes the least optimal. Surprisingly, even under these priority setting, the Reference alternative shows higher societal benefits than the IntensiveMIN alternative.

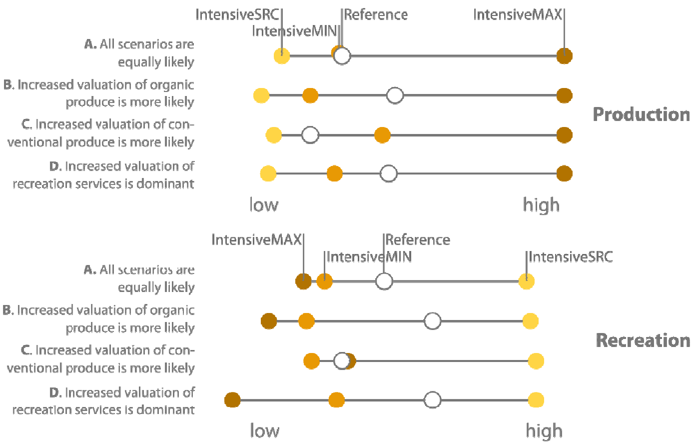

Figure 9. Ranking of land use scenarios with policy priority for provisioning and cultural ecosystem services.

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, then 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.

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.

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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.

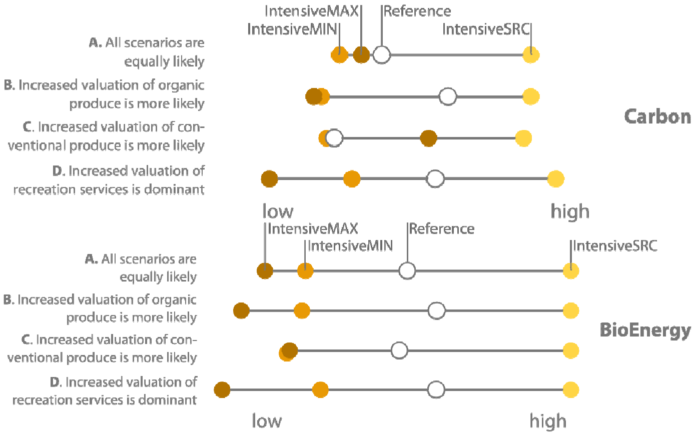

Figure 9. Ranking of land use scenarios with policy priority for carbon storage and bio-energy production.

8 CONCLUSIONS

The need for improving the capacity of agricultural systems to ensure ecosystem services has been thoroughly recognized (Stoate et al. 2009; Swinton et al. 2007; Zhang et al. 2007; Firbank et al. 2012). The term Ecological intensification" comprises a varied set of principles to achieve this (see Doré et al. 2011). It is defined by the FAO as the "maximization of primary production per unit area without compromising the ability of the system to sustain its productive capacity" (FAO, 2009). But also in an urbanized context, the importance of ecosystem services delivered by bioproductive space gains attention as a vital component of (cognitive) resilience building (Colding & Barthel 2013).

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.

Once the toolkit is sufficiently solid and validated, this comparison might assist in determining the required valuation changes (e.g. by organizing local food chains and aggregating demand) or levels of subsidies required to bring about land use changes. Another useful application might be in determining crucial unresolved positive externalities, e.g. in the framework of organizing payments for ecosystem services. Coupled with a monitoring network, the toolkit can assist in evaluating and providing a feedback loop to adapt such schemes. In particular when the underlying ecosystem service assessment tools become more spatially explicit, the toolkit can a valuable contribution to the adaptive management of bioproductive space.

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