



## Analysis

# Ecosystem services and economic development in Austrian agricultural landscapes – The impact of policy and climate change scenarios on trade-offs and synergies



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## ABSTRACT

We have developed an integrated modeling framework (IMF) to quantify indicators for ecosystem services (ES) and economic development (ED) in agricultural landscapes. Austria serves as a case study in which impacts, trade-offs, and synergies of ES and ED are assessed for different agricultural policy pathways and regional climate change scenarios. Agricultural intensification and incentivized use of *provisioning* ES (e.g. biomass production) lead to higher macro-economic output (e.g. GDP) but usually reduce ES related to *regulation and maintenance* (e.g. ecological integrity, climate regulation), as well as *cultural services* (landscape diversity). We revealed both synergies for certain ES (e.g. biomass production and soil organic carbon stocks) as well as large spatial deviations from the national mean across the heterogeneous agricultural landscapes in Austria. Climate change scenarios (i) lead to substantial variation in ES and ED indicators and (ii) usually amplify trade-offs by stimulating land use intensification. Our findings depict the complex relationship between different ES and ED indicators as well as the importance of considering spatial heterogeneity and regional climate change. This assessment can help to improve targeting of agri-environmental schemes in order to provide a more balanced and efficient supply of ES and to foster rural development.

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## 1. Introduction

Land use choices in agriculture usually aim at producing biomass, which can be viewed as an ecosystem service (ES) from agricultural ecosystems. These services, by definition, contribute directly and indirectly to human well-being (MEA, 2003; TEEB, 2010) and are commonly categorized into (i) *provisioning services* such as supply of food, fodder, fiber and bioenergy, (ii) *regulation and maintenance services* such as

local and global climate regulation, soil formation and fertility, and (iii) *cultural services* such as landscape esthetics and recreation (for a detailed overview on the different types of ES see MEA, 2003 and Haines-Yong and Potschin, 2013). Many of these ES represent characteristics of a public good (TEEB, 2010), degraded at an unprecedented rate in the past decades and are likely under-supplied today (MEA, 2005). Some ES such as climate regulation, nutrient cycling, as well as biodiversity are likely to have already moved beyond certain global biophysical threshold levels (Rockström et al., 2009). In addition, the supply of one ES may affect other ES negatively at spatial and temporal scales (MEA, 2005; TEEB, 2010) due to their interdependency and non-linear relationships (Rodriguez et al., 2006). For instance, the increase in agricultural production has become a dominant driving force in diminishing the potential of ecosystems to provide ES related to *regulation and maintenance* as well as *cultural services* (Tilman et al., 2002; Bennett and Balvanera, 2007; Power, 2010; Bryan, 2013; Schirpke et al., 2014).

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Two significant driving forces – agricultural policies and climate change – may stimulate or depress the supply of particular ES significantly in the future. Agricultural policies such as agri-environmental programs can account for a more balanced supply of ES from agriculture (Power, 2010; Pirard, 2012). They may foster *regulation and maintenance* ES such as increasing soil organic carbon (SOC) levels, and *cultural* ES such as maintaining permanent grasslands, hedgerows or other landscape elements (Barraquand and Martinet, 2011). This frequently comes at the cost of *provisioning* ES such as biomass production for human use (Schmid et al., 2004; Badgley et al., 2007; Pretty et al., 2006). Climate change as a driving force likely puts further pressure on ES supply in agricultural landscapes (Schröter et al., 2005). This can happen directly as an impact on ecosystem functions and processes that provide ES (e.g. sediment loss, see Mitter et al., 2014) and indirectly through autonomous adaptation strategies by farmers (Briner et al., 2012; Leclère et al., 2013; Schönhart et al., 2014). The impacts of these two driving forces will strongly depend on regional and local socio-economic, and biophysical characteristics like farmers' responses, resource endowments, and soil conditions, thereby making it paramount to account for spatial heterogeneity (Bateman et al., 2013).

Besides theoretical approaches (c.f. Barraquand and Martinet, 2011; Hussain and Tschirhart, 2013) a bulk of ES research applies geographic information systems (GIS) or spatial mapping based approaches (c.f. Goldstein et al., 2012), multi-criteria analysis (c.f. Fontana et al., 2013) or integrated modeling frameworks (IMFs) (c.f. Schönhart et al., 2011a; Briner et al., 2012) in order to provide policy support. The overarching objective of applied ES research is thereby to generate knowledge on the sustainable supply of ES by eliciting causal relationships, trade-offs as well as synergies (Carpenter et al., 2009).

For example, Jiang et al. (2013) mapped changes in production value of agricultural and forestry land use (*provisioning* ES), carbon storage, and biodiversity in a landscape in the UK for a time period of 70 years. They revealed increases in production values at the cost of biodiversity. However, carbon storage remained unchanged at the aggregated level despite considerable shifts among land use classes. Maskell et al. (2013) reveal severe trade-offs between carbon storage and provisioning services for particular observed land uses. These authors suggest intermediate land use intensities to benefit from synergies among multiple ES. Maes et al. (2012) provide a GIS-based analysis at a spatial resolution of 10 km on ES and biodiversity at European scale. They confirm trade-offs between *provisioning* ES from agro-ecosystems, *regulation and maintenance* ES, and biodiversity but emphasize synergies at the local management scale by diversifying cropping plans and planting of buffer strips and cover crops.

GIS based and spatial mapping analyses on observed and scenario-based land use changes are well prepared to provide detailed information on ES indicators, and reveal potential trade-offs, synergies, impacts or vulnerabilities. Nonetheless, there are some shortcomings. First, some of the studies assess a wide range of ES indicators (c.f. Raudsepp-Hearne et al., 2010) but only few focus on biodiversity (Bateman et al., 2013; Bryan and Crossman, 2013; Nelson et al., 2009) or landscape amenities (Bateman et al., 2013; Reyers et al., 2009). Second, national or supranational analyses are still uncommon (c.f. Metzger et al., 2006; Lorencová et al., 2013) and regional case studies remain a dominant approach. Third, detailed bottom-up economic modeling of land use and management choices such as land use intensities or crop rotations are rare, although the opportunity costs of alternative land uses (Goldstein et al., 2012; Swallow et al., 2009) and monetary valuation of non-market ES (Bateman et al., 2013; Bryan et al., 2010; Bryan and Crossman, 2013; Naidoo and Ricketts, 2006; Nelson et al., 2009) are often accounted for. This could be an important shortcoming as different management measures can have substantially different impacts on ES supply (Syswerda and Robertson, 2014). The GIS

mapping study by Koschke et al. (2013) emphasizes on the importance of detailed data on both land use change and management to reveal trade-offs among different ES and to provide spatially explicit policy recommendations.

In contrast to the widely applied GIS based and spatial mapping analyses for ES assessments, integrated modeling frameworks (IMFs) can overcome some of the shortcomings raised above. IMFs depict impact chains by linking disciplinary data and models (e.g. from climatology, soil sciences, agronomy, animal husbandry, and economics) and are thus suitable to disentangle the complex interactions between the human system and the environment (Falloon and Betts, 2010; Zuazo et al., 2011; Laniak et al., 2013). This enables the quantification of ES impacts (Rounsevell et al., 2012) and helps to derive better recommendations on mitigating ES trade-offs and supporting ES synergies. Despite the advances in IMFs (Janssen et al., 2011; Laniak et al., 2013), multi-regional IMFs at a high spatial resolution with focus on ES supply, trade-offs, and supporting synergies are still rare but required to derive robust conclusions under regional heterogeneities (Crossman et al., 2013).

Current state-of-the-art IMFs with explicit or implicit consideration of ES all share a focus on land use modeling but they differ greatly with respect to indicator selection, scenarios, scale, model linkages, and model types considered. Regarding indicator selection most studies do not cover the full range of ES categories, usually focusing on *provisioning* and *regulation and maintenance* ES (Barthel et al., 2012; Briner et al., 2012; Leclère et al., 2013), and only rarely also on *cultural* ES (Schönhart et al., 2011a). In recent years some large scale projects such as SEAMLESS-IF (van Ittersum et al., 2008; Ewert et al., 2009) and SIAT (Helming et al., 2011a,b; Sieber et al., 2013) have been initiated to pursue the development and use of IMFs in land use science. Both SIAT and the regional IMF GLOWA (Barthel et al., 2012) provide the same high spatial resolution as our IMF (i.e. 1 km), although some local case studies provide even finer spatial analyses at the field or sub-field level (Briner et al., 2012; Schönhart et al., 2011a). SEAMLESS-IF can provide spatial resolution at field level, however, most results are reported at farm or regional level. Except for SIAT, which does not assess climate change impacts and employs the land use allocation model DYNA-CLUE, a common denominator in the various model linkages is the use of bio-physical process models or statistical crop models in order to account for changes in climate, which then provide input to various types of farm models, either optimization models (SEAMLESS-IF, GLOWA, Briner et al., 2012; Schönhart et al., 2011a, b) and/or agent-based models (GLOWA, Leclère et al., 2013). Further linkages include forest growth models (SIAT, Briner et al., 2012), hydrological models (GLOWA), agronomic models (Schönhart et al., 2011a), partial equilibrium models (SEAMLESS-IF, SIAT), macro-economic models (SIAT), and econometric meta-models (SEAMLESS-IF, SIAT).

This article aims at providing scientific support for policy interventions by exploring trade-offs and synergies between indicators for ES and economic development (ED) in Austrian agricultural landscapes. We therefore apply a state-of-the-art IMF that reveals and assesses the interlinkages between ES and key system drivers such as regional climate change and policies (Carpenter et al., 2009), agricultural land use and management measures (Swift et al., 2004; Horrocks et al., 2014) as well as biophysical processes (Swinton et al., 2007). Our analysis considers most aspects required by state-of-the-art ES research, such as an *interdisciplinary* approach (Carpenter et al., 2009; Rounsevell et al., 2012), high spatial *heterogeneity* (Metzger et al., 2006; TEEB, 2010; Rounsevell et al., 2012), multiple *drivers* (Carpenter et al., 2009; Crossman et al., 2013), integration of key *stakeholders* (Rounsevell et al., 2012; TEEB, 2010), an unusually *wide range of ES indicators* (Tallis et al., 2008; TEEB, 2010; Kinzig et al., 2011), and, in contrast to most studies, *macro-economic* effects (Bryan, 2013).

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