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# Modelling crop land use change derived from influencing factors selected and ranked by farmers in North temperate agricultural regions

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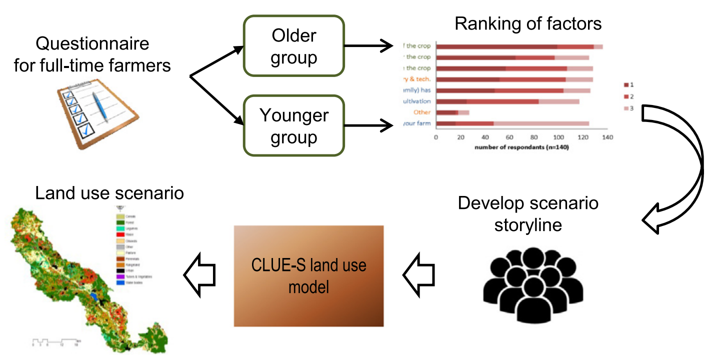
## HIGHLIGHTS

- Influencing factors of crop land use change were ranked similarly in all four groups.
- Directly related financial factors made up about half of the causes to change crops.
- The ranking given by farmers allowed to develop scenario storylines of future change.
- Farmer influencing factors for crop land change enhance land use scenario development.

## GRAPHICAL ABSTRACT

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## ABSTRACT

To develop meaningful land use scenarios, drivers that affect changes in the landscape are required. In this study, driving factors that influence farmers to change crops on their farm were determined. A questionnaire was administered to four independent groups of farmers who identified and ranked influencing factors pertaining to their choices of crops. The farmers were located in two mid-latitude agricultural watersheds (in Germany and Canada). The ranked influencing factors were used to develop a "farmer driven" scenario to 2040 in both watersheds. Results showed that the most important influencing factors for farmers to change crops were the "economic return of the crop" and "market factors". Yet, when the drivers of crop land use change were grouped into two categories of "financial" and "indirectly-related financial" factors, the "financial" factors made up approximately half of the influencing factors. For some responses, the "indirectly-related financial" factors (i.e. "access to farm equipment", the "farm experience", and "climate") ranked higher than or just as high as the financial factors. Overall, in the four farmer groups the differences between the rankings of the influencing factors were minor, indicating that drivers may be transferable between farms if the farmers are full-time and the farming regions have comparable growing seasons, access to markets, similar technology, and government programs for farm income.

In addition to the "farmer driven" scenario, a "policy driven" scenario was derived for each watershed based only on available information on the financial incentives provided to farmers (i.e. agricultural subsidies, income support, crop insurance). The influencing factors ranked by the farmers provided in-depth information that was not captured by the "policy driven" scenario and contributed to improving predictions for crop land use

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development. This straight-forward method to rank qualitative data provided by farmers can easily be replicated in other watersheds to improve environmental impact modelling.



## 1. Introduction

The growing awareness of land use change impacts on ecosystems (e.g. Bommarco et al., 2013; Fish et al., 2014; Ouyang et al., 2018), and the increasing interest to apply land use scenarios to simulation models, such as wildlife models (Malawska et al., 2014) or hydrological models (Bussi et al., 2017) necessitates the development of future land use trajectories. For these transformations in the landscape to be recognized and modelled, the drivers of land use change need to be identified. Drivers are synonymous with a forcing and are used to define processes exogenous to the system of interest but which have an associated effect (Meyfroidt, 2016). Drivers are region-specific and scale-dependent influenced by the composition of social demographics and governance, as well as the climate, the geography, and the availability of resources (monetary or natural). The interplay of these myriad factors cause the drivers of land use change to be complex, as a result the drivers tend be site-specific and it remains uncertain if they can be transferred to similar regions.

In agricultural areas, the principle actor for undertaking changes to landscapes is the farmer who is the chief executor of decisions pertaining to farm management, and ultimately is responsible for the existing pattern and quantity of crops and livestock in a region. In this context, the farmer is the most important decision-maker for land use change. To date, several land use models have enabled varying degrees of complexity to be incorporated that reflect human decision-making (Agarwal et al., 2002) and have helped progress away from assumptions in accordance with Von Thünen or Ricardian principles, which purport that external factors causing farmers to undertake agricultural land use change are based on theories of profit maximization (Miller and Plantinga, 1999; Irwin and Geoghegan, 2001; Briassoulis, 2008).

Farmers' decisions are complex because they are comprised of individual characteristics (inherent to the farmer) and external drivers (relating to the biophysical and socio-economic context of the farm); see Polhill et al. (2010), Karali et al. (2011) or Schaller et al. (2012). Thus, incorporating farm-level decisions in land use models requires detailed studies of the farm as well as of the specific local conditions for each case study. While the land use/land cover community recognizes that a myriad of drivers are responsible for land use change (Lambin et al., 2001; Geist and Lambin, 2002; An, 2012; Plieninger et al., 2016), the land use models are inherently limited by the paucity of data available (Verburg et al., 2002) especially at the local scale to better integrate farmer decisions.

Several studies point out that farmer decisions need to be better represented in land use models (Lambin et al., 2000; Verburg et al., 2004; Edwards-Jones, 2006; An, 2012; Rounsevell et al., 2012; Malawska et al., 2014). In particular, better data on land-change actors and their preferences, beliefs and behaviours are needed (Brown et al., 2013). Agent-based modelling efforts have especially made advances in collecting information from social surveys that are used to identify goals, motivations and behaviours of farmers, which are translated into computer representations of agents in simulations models (Rounsevell et al., 2012). Understanding decision-making processes that drive changes in the local land system require empirical research, particularly information about land managers values or preferences (Rounsevell et al., 2012).

Studies in developed countries that have collected primary data from farmers on decision-making influences, e.g. related to choices of livestock (Murray-Prior, 1998; McGregor et al., 2001) or crops (Aubry et al., 1998; Willock et al., 1999; Polhill et al., 2010; Karali et al., 2011), have provided important thematic analysis, farmer objectives and their implementation, as well as descriptive causes of change; all of which assist to gain a better understanding of how farmers undertake their operations. However, an elicitation of ranking or weights of driving factors were not considered in these studies which can be very helpful for modelling purposes.

The predicament of translating qualitative data into quantitative data for spatial scenario development is often encountered in land use change science, especially where questionnaires or surveys have been carried out, and has been coined "pixelizing the social" (Geoghegan et al., 2001). One method to overcome this complex problem is by using narratives of scenarios (e.g. Westhoek et al., 2006) which are referred to as scenario storylines (Rounsevell and Metzger, 2010 to derive future land use changes.

In this study, for the purpose of developing a spatially distributed land use scenario, four farmer groups in two developed agricultural regions were questioned to determine the causal influences that lead to an alteration of the crop type on their farm. A ranking of the proximate drivers causing a change in crop type was used to develop a scenario storyline of future land use in each region and to subsequently model the spatial land use changes to 2040. As a comparison, a second land use change scenario was also developed in which only the influential factors of land use change based on financial incentives available to farmers in each region were considered. Two agricultural watersheds were selected for this study to determine how the causal effects and the scenarios differed between the regions.

In this paper, the term "influencing factor" is used to define an identifiable individual factor that causes a farmer to switch one or more of his/her current crops. The term "factor" is used for any fact or variable mobilized in an explanation for land use change (Meyfroidt, 2016).

## 2. Methodology

### 2.1. Study areas

The study was carried out in Bavaria (Germany) and in Québec (Canada). The regions were chosen because they have comparable agricultural activities, while being situated in different geographical regions. Both have similar climates and growing seasons and are not limited by soil or climate constraints for undertaking cropping activities during a summer growing season; they have strong viable agricultural sectors, offering several possibilities for crop and livestock production; they have good access to national and international markets; and they have the possibility to expand production if desired. In both regions, ample government support is accessible for farming activities and governments also offer financial incentives for farmers to adhere to agricultural best management practices that protect the soil and especially the water resources. Both Bavaria and Québec have undertaken intensive farming activities during the past 100 years and have strong environmental policies (e.g. a water policy) that are in effect.

An in-depth study of the environmental, socio-economical, political, and cultural aspects of both watersheds was undertaken. Over the course of four years, detailed information on the agricultural activities in both areas was gathered by liaising with local researchers; querying farmers, keeping abreast of issues relevant to farmers, holding meetings with targeted agricultural and water management stakeholders (ministries and local authorities) to discuss current agricultural challenges in the watershed. Additionally, attending local conferences and combing