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Incorporation of emergy into multiple-criteria decision analysis for sustainable and resilient structure of dairy farms in Slovenia

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ABSTRACT

The increasing and often conflicting challenges that agricultural production systems face today require a more comprehensive approach to planning in the sector, integrating the economic principles of production with its social characteristics and ecological impacts. The paper presents an innovative attempt to incorporate biophysical criteria into a standard socio-economic optimisation model, illustrated through a study of the Slovenian dairy sector. The biophysical perspective on the system's functioning is determined by means of emergy analysis. This is an environmental accounting approach which reflects the cumulative environmental support needed to produce a certain output. The eco-centric perspective on the emergy approach complements the standard socioeconomic perspective of value that reflects the utility of a product (anthropocentric perspective). The model is developed based on a preceding analysis of socio-economic and emergy-based performance characteristics of different production types at the farm level that, when aggregated, constitute the sector. The multi-criteria optimisation model is supported by weighted goal programming (WGP) and aims to investigate the effects of two opposing agricultural policy paradigms on the organisation of the sector at the national level. The results show that a protectionist or eco-social focus of public interventions results in the sector's organisation with rather contrasting performance characteristics. The model outcome that represents a compromise between the two agro-political paradigms clearly suggests that incorporation of the emergy criterion into the optimisation model leads to a diverse and balanced structure and a more favourable economic and biophysical performance of the sector. Accordingly, the results confirm the complementarity of economic and emergy approaches and provide implications for a more comprehensive planning of agricultural activity.

1. Introduction

Agriculture is the largest production (eco)system that is directly managed by humans to ensure their primary needs (Swinton et al., 2007). The interconnectedness of agriculture with the local and global environment (climate) and risks related to the high complexity of their interactions may be seen as a source of increasing and often conflicting challenges of modern agriculture. The growing demand for food and thus higher productivity remain the most important, but certainly not the only challenge for decision-makers in agriculture at the farm, national and transnational level (EC, 2010). Other challenges that are coming to the forefront are particularly those related to the sector's long-term sustainability, such as limited availability of natural resources and growing pressures on the local and global environment, as well as market volatility, abandonment of rural areas and declining rural population (EC, 2010; Godfray et al., 2010; OECD/FAO, 2012; Tilman et al., 2011). The complexity of the problem is especially evident in the livestock sector, which greatly contributes to the economy of many countries and has been recognised as an important player in ensuring food security. On the other hand, it also has a bad reputation for aggravating environmental problems related to climate change, groundwater pollution, etc. (Steinfeld et al., 2006; Leip et al., 2010; Sejian et al., 2015; Fort et al., 2017).

For these reasons, agriculture as a whole can no longer be treated solely as an economic activity. Instead, it needs to be understood as a wider and integrated system where the economic principles of production are intertwined with its social and ecological characteristics (OECD, 2000; van Zanten et al., 2014; Kragt et al., 2016).

The environment is still often neglected in everyday decision making, which may be ascribed to insufficient information or the pursuit of solely short-term economic objectives (TEEB, 2010). Several authors (Funtowicz and Ravetz, 1994; Patterson, 1998; Gasparatos and Scolobig, 2012) agree that the provision of adequate information to support policy decisions should be based on a variety of techniques, methods and approaches.

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Various objectives of agricultural policy and an increased demand for interdisciplinary research have had an important role in the development of bio-economic models. In a broad sense, these (mathematical) models fall under ecological or conventional economics and link different disciplines in order to answer multi-dimensional questions about the organisation of agricultural production systems. (Flichman and Allen, 2012). Linking bio-economic models with different methods, such as simulation and optimisation, is a promising tool for investigating trade-offs that may occur between different management alternatives (van Calker and Berentsen, 2004; Groot et al., 2007, 2012; Klapwijk et al., 2014; Hawkins et al., 2015; Mosnier et al., 2017).

Models as decision support tools for sustainable and economically viable agricultural production planning have to be based on a comprehensive economic evaluation that takes into account the natural boundaries in which agriculture operates (Daily et al., 2000). However, the integration of biophysical and economic components within a single modelling framework remains a challenge, both conceptually and technically (Flichman and Allen, 2012; Gasparatos et al., 2009; Gasparatos and Scolobig, 2012; Wam, 2010). Conceptually, our study challenges the assumption that biophysical and economic objectives contradict each other. Technically, this paper represents an innovative attempt to incorporate system-based biophysical evaluation into a standard socio-economic optimisation model, demonstrated on the case of milk production in Slovenia. The biophysical dimension of the sector's functioning is incorporated into the model by means of emergy analysis (Brown and Ulgiati, 2004a, 2004b, 2010; Odum, 1996, 1988), which has been widely applied to a variety of systems (see e.g. Amaral et al., 2016), most often to investigate interactions of the economic and natural environment in various agricultural systems and less commonly to dairy production (Vigne et al., 2013).

The biophysical concept of value (Cleveland, 1999) underlying emergy analysis is based on the notion that the geo-biosphere is a driving force of all global processes and supports the idea that the natural capital invested in a product, service or process represents its real value. Unlike the standard socioeconomic perception of value that is anthropocentric in nature, emergy does not reflect the usefulness of a product, but rather the cumulative environmental support to its existence. In contrast to standard economic approaches, which are based on the assumption that production occurs in a "closed system" with given and substitutable production factors, the emergy approach emphasises the importance of the resource generation process. This work investigates the complementarity of the two perspectives and the potential that their integration has to provide useful information to support more comprehensive (policy) decisions regarding agricultural production planning. The paper aims to investigate whether the integration of economic and biophysical (emergy-based) sets of criteria can not only improve the baseline performance of the sector (both in socio-economic and biophysical terms), but also yield more favourable results than a one-sided perspective (economic or biophysical) in production planning.

The modelling approach presented in this paper integrates the milk production system at two hierarchical levels. The work builds on a preceding analysis that investigated the performance of various farm-level milk production systems from multiple perspective (see Jaklič et al., 2014), which, when aggregated, constitute the Slovenian dairy sector. The aggregated model at the sector level represents the central focus of this paper. More specifically, it investigates the organisation and resource use in the sector and its multiple-perspective performance, while the greatest emphasis is placed on the influence that alternative approaches towards the planning of agricultural production (policy orientation) have on the sector's organisation and its potential socio-economic and/or biophysical improvements.

2. Materials and methods

2.1. System characterisation – milk production in Slovenia

Integration of the system's bio-physical and economic performance within a single modelling framework is illustrated by applying it to the milk production sector in Slovenia. Milk production is the most important agricultural activity in the country in terms of agricultural land use (about 23%) and contribution to agricultural output (about 14%) (KIS, 2014). In the past decades, the sector underwent consolidation, both in terms of production concentration and specialisation. In addition to a substantial decrease in the number of dairy farms, these structural changes resulted in increased intensity of production and improved milk quality. Since 2000, the sector has been facing abandonment of small family farms, while the number of other production systems has been continuously growing. By 2010, the number of dairy farms declined by 60% and the number of animals by 25%, while larger agricultural holdings increased four-fold and average herd size doubled. Nevertheless, due to naturally constraining farming conditions (largely mountainous and hilly terrain), Slovenian dairy farms still remain relatively small (13 ha) with small herds (9.9 animals) and low production intensity (5500 kg/cow) (KIS, 2011). Slovenian dairy production faces similar economic challenges as the Slovenian agricultural sector as a whole. The economic performance of Slovenian farmers is still relatively weak on average. In 2010, average factor income in agriculture was less than 40% of the EU-27 average and 25% of EU-15. Farmers' income stability and purchasing power have been challenged further by declining farm-gate milk prices caused by several factors, such as the abolition of the milk quota in the EU and shocks in international trade such as the Russian import ban (SURS, 2013). The pressure on farmers to look for alternative sources of income explains farm exits and production reorganisation. This suggests that recent structural changes are driven by changes in the economic environment and are likely to continue.

2.2. Methodological approach – schematic representation

The approach aimed at investigating the Slovenian dairy sector was developed in two stages (Fig. 1). In the first stage, the Slovenian milk production sector was categorised into nine model farm types. The Central Cattle Breeding Database managed by the Agricultural Institute of Slovenia, and the Agricultural census (SURS, 2013) represent the data framework for the definition of farm types, while their production characteristics (e.g. size, breeds, fodder composition) were acquired from expert estimates. Model farm types were further evaluated from the socio-economic and biophysical (emergy-based) perspectives and grouped into three clusters according to their performance, following the hierarchical clustering method (Jaklič et al., 2014). By re-aggregating the nine farm types, a model of the dairy sector in 2010 was specified, whose characteristics (farm and production structure, economic and emergy performance) served as a baseline reference for the model solutions obtained from the optimisation model developed in the second stage.

The development of the optimisation modelling tool at the national level represents the central focus of the research presented in this paper. The single-criterion (SC) optimisation model is based on linear programming (LP), whereas multiple-criteria (MC) optimisation is supported by (weighted) goal programming (WGP). The aim of the optimisation of the sector based on LP served as a support tool to investigate various alternatives for the organisation of the sector when pursuing one particular optimisation criterion (e.g. income, production, employment). It also served to determine the extreme characteristics of the sector, which were then included in the objective set considered in the MC scenario analysis. Finally, the MC optimisation model based on (W)GP was applied to investigate the impact of three different paradigms underlying the organisation of the sector and the effects that organisation has on the socio-economic and biophysical (emergy-based) performance of the milk production system. A more detailed description of the methodological approach is presented in the following subsections.