A spatially explicit multi-scale bioeconomic model to design and assess agricultural landscapes

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A SPATIALLY-EXPLICIT MULTI-SCALE BIOECONOMIC MODEL TO DESIGN AND ASSESS AGRICULTURAL LANDSCAPES

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1 Introduction

Agricultural landscapes drive the provision of several ecosystem services. These landscapes are the partial results of farmer cropping system choices at the field and farm levels. Cropping system choice is driven by a range of parameters that act at the field, farm and regional scales such as biophysical parameters, farm structure and regional quotas. Bioeconomic models can assess *ex ante* the impacts of policies on landscapes resulting from the modification of farmer choices. They have scarcely been used for assessing new spatially-explicit agricultural landscapes with the integration of the field, farm and regional scales (Delmotte *et al*., 2013). To assess the effects of policies on the landscapes change and the regional sustainable development, we built a regional, spatially explicit, multi-scale bioeconomic model of farmer cropping system choices. The model is tested in Guadeloupe, a French archipelago in the Caribbean islands.

2 Materials and Methods

The Multi-scale model of the crOpping Systems Arrangement and Its Contribution to sustAinable development MOSAICA produces new agricultural landscapes at the regional scale by optimising the allocation of cropping systems regionally at the field scale. It accounts for the constraints and opportunities at the field level (e.g. soil types), the farm level (e.g. the availability of production factors), and the regional level (e.g. the policies implemented). The inputs of MOSAICA are i) the geographic database of fields, ii) the database of activities that describe the cropping systems that can be allocated to fields and iii) a farm typology.
The geographic database is composed of fields represented by polygons with relevant information for the cropping system allocation defined with geographical information systems, statistical data or farm surveys. The activities are cropping systems defined with technical coefficients and externalities derived from previously published papers, relevant documentation or expertise from local advisers. The farm typology is built with a classification tree that can help observe farming system changes across scenarios. For each farm type a risk aversion coefficient is allocated and used as the calibrating parameter of the model. The model optimizes the overall farmer's utilities, which includes the revenue and the risk aversion coefficient which is the calibrating parameter, similar for all the farms initially classified in the same type. The allocation of cropping systems is modelled through a set of equations that model the choice of cropping systems by farmers at different scales, namely the field, farm, sub-regional and regional scales. The prediction capacity of the model was assessed in Guadeloupe at field and regional scales by comparing the initial crop areas and the simulated ones and the initial and observed farm types at farm scale. The outputs of the model are the new agricultural landscape and the calculation of 19 sustainability indicators. These indicators assess the impact of agriculture on society and environment at a regional scale by accounting for cropping system externalities at plot scale and the location of these cropping systems throughout the region by using scale change methods.
As an illustration of its possible interest, we used the model to assess the consequences of three scenarios accounting for expected future modifications of subsidies. In the “area reallocation” scenario, the subsidies are reallocated to each crop with an amount of 1768€.ha^{-1}. The “workforce reallocation” is the reallocation of subsidies per unit of workforce with an amount of 15569€ per worker. The “decoupling” scenario is the decoupling of subsidies from production.

3 Results - Discussion

Results from the evaluation were good at all the scale tested (similarity of 91% at regional scale, 80% at farm scale and 75% at field scale) which means that the model can be used for scenario analysis. The scenario modified the repartition of cropping systems in landscapes in a spatially explicit way. The results are summarized in this abstract at the regional scale (Fig. 1).The general trends observed throughout the three scenarios demonstrate a sharp decrease in sugarcane and banana production over the island with their total disappearance in the "area reallocation" scenario and in the "decoupling" scenario only for banana farms. By contrast, the areas devoted to pasture and fallow fields increase and the area devoted to crop gardening and orchards increase more progressively, as well. The consequences of these new landscapes are assessed based on spatially explicit indicators at the regional scale (Table 1).

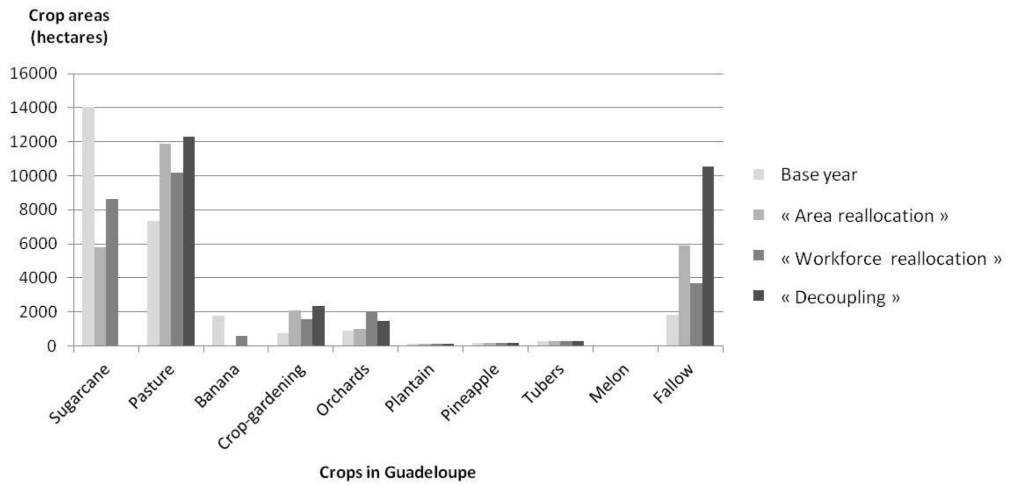

Fig. 1. Evolution of crop acreage from scenarios

Table 1. Spatially explicit assessment of agricultural landscapes from scenarios

Indicators	Base year	"Area reallocation"	"Workforce reallocation"	"Decoupling"
Agricultural added value (M€.y^{-1})	96	138	125	162
Total amount of subsidies (M€.yr^{-1})	75	60	62	72
Ratio of nutrients produced over needs	15%	20%	23%	23%
Potential electricity production with crops (MW.yr^{-1})	33	16	24	0
Total needs of workforce (persons)	3105	2566	2928	2772
Area of risk of contamination of food crops (ha)	1170	2013	1529	1843
Ratio of water bodies potentially polluted	35%	14%	27%	18%
Amount of water needed for irrigation (m3.yr^{-1})	17.7	14.7	19.6	15.1
CO2 emissions from farming (kT eq CO2.yr^{-1})	158	142	149	135
Diversity of crops across landscape (Simpson's Index)	3.0	3.1	3.4	2.7

In terms of economic sustainability, these three developed scenarios were relevant because they performed better than the base year in terms of economic sustainability especially the “area reallocation” scenario with the increase of the agricultural added value to 138M€.yr^{-1} and the decrease of subsidies to 60M€.yr^{-1}. For social sustainability, the scenarios performed better in terms of food self-sufficiency, especially scenario 3, with an increase of nearly 50% in food-self-sufficiency. In focusing on environmental sustainability, the pressure on biodiversity and water resources decreased over the three scenarios.

The modelling of farmers cropping system choices and the creation of agricultural landscapes resulting from the modification of a set of rules at different spatial scales is useful for the prototyping of landscapes. This multi-scale modelling is especially important for addressing sustainability issues, such as food security or biodiversity preservation that require multi-scale strategies for resolution. Our set of indicators can even assess the trade-offs in the provision of services by displaying the direction of change in the indicator value between the base year and the scenarios.

4 Conclusions

The bioeconomic model MOSAICA integrates the different scales involved in the decision-making process of farmers and policy makers, *id est* the plot, farm, sub-regional and regional scales. This integration of agricultural systems allows for the testing of the multi-scale policy and parameter changes that are involved in agricultural production and the assessment of these changes on the provision of ecosystem services with spatially explicit indicators.
Our model could be relevant for testing spatially targeted policies aimed at improving the contribution of agriculture to sustainable development.

References

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