Assessing spatial uncertainties of land allocation using the scenario approach and sensitivity analysis

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Abstract— **The paper assess uncertainty of future spatial allocation of agricultural land in Europe. To assess the possible future development of agricultural production and land for the period 2000 – 2030, two contrasting scenarios are constructed. The scenarios storylines lead to different measurable assumptions concerning scenario specific drivers (variables) and parameters. Many of them are estimations and thus include a certain level of uncertainty regarding their true values. This leads to uncertainty of the scenario outcomes. In this study we use sensitivity analysis to estimate the uncertainty of agricultural land use.**

Keywords— **spatial uncertainty, scenario approach, sensitivity analysis.**

I. INTRODUCTION

On a global scale, allocation of agricultural land and the level of food production are largely determined by socio-economic driving forces such as macro-economic growth, demographic development and technical progress. However, agricultural production is only possible in geographic areas having suitable biophysical characteristics. Since changes in socio-economic and biophysical factors development are difficult to predict, spatial allocation of agro-food production and resulting land use and their dynamic evolution in the future is uncertain. The goal of this paper is to assess uncertainty of future spatial allocation of agricultural land in Europe.

To assess the possible future development of agricultural production and land for the period 2000 – 2030, we constructed two contrasting scenarios Market Liberalization scenario and Public Intervention scenario. The assumptions are variables and parameters which are uncertain and this leads to uncertainty of the scenario outcomes. In this study we estimated the uncertainty of agricultural land use change given the uncertainty of future GDP and population size using a sensitivity analysis.

The two scenarios were implemented and run using a modelling framework which consists of two models: LEITAP – extended version of Global trade Analysis Project (GTAP, [1] and [2]) general equilibrium model of the world economy - and Dyna-CLUE [3] – a spatial land use change model implemented for the European Union.

This paper is organized as follows. Section 2 introduces the methodology used to calculate spatial uncertainties of land allocation. In Section 3, the uncertainty of future GDP and population development is assessed. The following section presents the simulation results and assesses spatial uncertainties of agricultural land allocation. We close with a summary in the final section.

II. METHODOLOGY

The point of a departure is the "conditional probabilistic futures" methodology which assigns probabilities to future scenario outcomes. The probabilities are derived from specific scenario assumptions which are subject to uncertainty. This approach is often called in the literature “input-constrained” (“storylines constrained”) conditional approach [4], since the conditions - storylines - impose constraints on the uncertainty distribution of the input assumptions. In this way input-constrained projections generate distributions of output (projections) conditioned on input (assumptions) distributions which are restricted by scenarios storylines.

To assess the possible future development of agricultural production and agricultural land development for the period 2000 – 2030, we constructed two contrasting conditional scenarios. To implement the scenario storylines in the modelling framework, they were translated to measurable assumptions concerning scenario specific drivers (variables) and parameters. Values assigned for these drivers and parameters differ per scenario. Many of them are estimations and thus include a certain level of uncertainty regarding their true values. This leads to uncertainty of the scenario outcomes. In this study we estimated the uncertainty of agricultural land use change given the uncertainty of future GDP and population size for the two scenarios using a sensitivity analysis.

The two scenarios were implemented and run using a modelling framework which consists of two linked models: the general equilibrium model LEITAP and the spatial land use change model Dyna-CLUE. We use 2001 GTAP database as starting point for the scenario analysis. To assess uncertainty, a sensitivity analysis was done in two stages. First, a systematic sensitivity analysis for the LEITAP model results is performed on the country level. Second, the Dyna-CLUE model translated country level results to the spatial 1x1 km dimension.

A. Scenarios

The two scenarios under investigation are Market Liberalization and Public Intervention. The Market liberalisation scenario depicts a world with fewer borders and less government intervention compared with today. Trade barriers are removed and there is an open flow of capital, people and goods, leading to a rapid economic growth, of which many (but not all) individuals and countries benefit. There is a strong technological development. The role of the government is very limited. Nature and environmental problems are not seen as a priority of the government.

The Public Intervention scenario depicts a world of regions. People have a strong focus on their local and regional community and prefer locally produced food. Agricultural policy is aiming at self sufficiency. Ecological stewardship is very important. This world is strongly regulated by government interventions, resulting in restrictive rules in spatial policy and incentives to keep small scale agriculture.

B. Modelling framework

The two scenarios are investigated using the LEITAP and Dyna-CLUE models.

The LEITAP is a general equilibrium model of the world economy model describing the economic processes on country or regional level. Based on expected GDP growth, demographic developments and policy changes, LEITAP estimates commodity production, prices and trade for each region of the world. Trade barriers, agricultural policies and technological development are taken into account.

Land use dynamics which take place in a more local scale are represented in the Dyna-CLUE model. Dyna-CLUE is a spatially explicit land use change model which allocates land use change based on competition between land uses and spatial allocation rules. Spatial and environmental policies are taken into account [3]. The model gets its input data from LEITAP on a European country bases and allocates land use within each European country on a grid level of 1 by 1 km.

The LEITAP and Dyna-CLUE models are linked together to account for the structure of land use change process. The demand for agricultural land in Europe is dependent on global developments in food consumption and agricultural production, world trade agreements and changes in the economy of sectors outside agriculture. The LEITAP model is used to accounts for the effect of global changes on European land use. The global-level assessment also allows an evaluation of the effect of changes in Europe on other parts of the world. LEITAP estimates the economic consequences for the agricultural sector by describing features of the global food market and the dynamics that arise from exogenous assumptions. This results in an assessment of the agricultural land changes at the level of individual countries in Europe and for larger regions outside Europe. At the same time, the two models also calculate changes in other sectors of the economy which are indirectly related to land use.

The global models can not produce assessments beyond the resolution of individual countries. Therefore the results need to be downscaled. Land use within a country is variable as result of local variations in social and biophysical conditions. Furthermore, the driving factors of landscape patterns are often region-specific as a consequence of different contextual conditions, specific variations in the socio-economic and biophysical conditions. The actual downscaling of the national level changes to the landscape level is done by at a spatial resolution of 1 km2 using the Dyna-CLUE model.

This results in landscape visualizations for the entire European Union (EU27), distinguishing arable land, pasture land, forest land, urban areas and other nature characteristics. This information, combined with additional data that covers fields like climate change, soil carbon and nature protection, delivers results for several indicators on the physical aspects of European rural areas. For socio-economic aspects, a down-scaling procedure was used to tell something on the socio-economic strength of European regions. Based on past trends of indicators (e.g. employment and GDP) at the regional (NUTS2/3) level, national indicators developments were downscaled.

C. Sensitivity analysis

Probability density functions are often used to represent the uncertainty related to scenario input variables or parameters. These functions can be used in the simulation experiments to produce probability density function of the scenario results. LEITAP modelling framework provides Systematic Sensitivity Analysis (SSA) tool which makes possible to conduct such an analysis. The SSA procedure follows Arndt [5], and uses a Gaussian quadrature. It provides an answer of the question: how sensitive are the results from a general equilibrium simulation to the particular values assumed for parameters or to particular shocks to exogenous variables? This approach produces estimates of means and standard deviations of simulation results in limited numbers of model runs assuming uniform or rectangular distribution of uncertain parameters or shocked exogenous variables under consideration. However, the resulting distribution of endogenous variables is in general unknown. In some cases (e.g., if model results are approximately linear with respect to SSA shocks), the endogenous variables can be approximately normally distributed. In any case, the SSA results can be used to obtain confidence intervals for endogenous variables using Chebyshev’s inequality.

The Dyna-CLUE model uses results of the LEITAP sensitivity analysis for estimating the high resolution spatial consequences of the estimated uncertainties. The Dyna-CLUE model applies a downscaling procedure which allows allocation of land use obtained form LEITAP on the country and sectoral level into land use grid composed of 1x1 km cells. The downscaling procedure is based on empirically constructed suitability maps, one of each allocated land use [3]. The model allocates land use in a manner that maximizes the total location suitability of all land use categories. The Dyna-CLUE model does not enable to incorporate the uncertainties related to the land use allocation in a manner similar to the SSA method. Fortunately, this limitation can be resolved by means of resampling procedure, where multiple model runs are constructed according to a random distribution of land use demand. This distribution of land use demand is based on the LEIAP results. The procedure generates multiple land allocation skims.

The sensitivity analysis presented in this document is limited to the uncertainties introduced by the LEITAP SSA for two land use categories: arable land and pasture land. The parameters of the Dyna-CLUE model remained constant for each of the two scenarios, thus the Dyna-CLUE model did not introduce additional variation to the results.

The data taken from the LEITAP model included the estimation of the land use change for several agricultural sectors. The estimations are in the form of growth rates and include an estimation of the mean and variance for the expected land growth of each agricultural sector in each EU country between 2000 and 2030. The mean and variance of the growth rate of arable and pasture land were calculated by combining the mean and variance of the land use changes in associated LEITAP agricultural sectors. The arable land growth rates were calculated as weighted average of growth rates of six LEITAP agricultural sectors: (a) Paddy and processed rice; (b) Wheat, Cereal grains; (c) Oil seeds; (d) Sugar cane and beet;(e) Vegetables, fruit and nuts, (f) Other crops. Similarly, the pasture land growth rates were calculated by combining three LEITAP agricultural sectors: (a) Cattle, sheep, goats, horses; (b) Animal products; (c) Raw milk.

The sector aggregation produced expected harvested areas growth rates for the period of 2000 to 2030 for each country. These growth rates were used to calculate expected areas of arable and pasture land for each given country. The expected area of arable or pasture land at year 2030 (t=30) for a given country and scenario was calculated according to:

$$MEAN_{c,s,lu,30} = MEAN_{c,s,lu,0} \cdot (1 + r_{c,s,lu}) \qquad (1)$$

where: $MEAN_{c,s,LU,t}$ is the mean area of land use lu∈{Pasture, Arable} in country c at time t, for scenario s∈{Market Liberalisation, Public Intervention}, $r_{c,s,LU}$ is the mean growth rate for land use lu, in country c, for scenario s between t=0 and t=30 calculated using SSA and LEITAP model.

The standard deviation of expected arable and pasture area for each country and scenario was calculated as follows:

$$STD_{c,s,lu,30} = MEAN_{c,s,lu,30} \cdot std_{c,s,lu} \qquad (2)$$

where $STD_{c,s,LU,30}$ is the standard deviation of lu area in country c, scenario s for time t=30 and $std_{c,s,LU}$ is the standard deviation of the growth rate of lu area calculated using SSA and LEITAP model.

The SSA analyses provided estimation of the mean and standard deviations of growth rates but it did not provide any indication regarding the distribution which the growth rates are taken from. Thus, we assumed that the statistical population of expected areas of arable and pasture land for each country and scenario at t=30 is taken from a bivariate normal distribution where the mean area of arable and pasture are set as $MEAN_{c,s,Arable,30}$ and $MEAN_{c,s,Pasture,30}$ respectively, and the standard deviation of the areas of arable and pasture land are set $STD_{c,s,Arable,30}$ and $STD_{c,s,Pasture,30}$ respectively. As the area of arable and pasture land can not be regarded as independent, the correlation between arable and pasture should be estimated for each country and scenario. The correlation is also needed in order to completely define the bivariate normal distribution. Unfortunately, the SSA method does not provide an estimation of the correlation between the two land use categories thus we based the correlation estimation on previous scenarios calculated for the EURURALIS project [6]. The predictions of arable and pasture land for each of the EURURALIS scenarios for year 2030 were used to estimate the Pearson product moment correlation between the two land use categories. Because of the limitation of the data set, the same correlation coefficients were used for the two scenarios. The correlation coefficients are presented in table 1.

Table 1. Pearson correlation between the area of arable and pasture land according to the EURURALIS scenarios results for 2030

Austria	0.30	Ireland	0.42
Baltic	0.40	Italy	0.68
Belg-lux	0.64	Malta	-
Bulgaria	0.67	Netherl	0.24
Cyprus	0.10	Poland	0.61
Czech	0.39	Portugal	0.47
Denmark	0.62	Romania	0.67
Finland	0.51	Slovakia	-0.10
France	0.67	Slovenia	0.30
Germany	0.68	Spain	0.70
Greece	0.80	Sweden	0.70
Hungary	0.42	UK	-0.06

For each country and scenario, 50 pairs of arable and pasture land areas were drown from the bivariate normal distribution. Each pair represents a single random combination of arable and pasture area at 2030 for a given country and scenario. Because the dyna-CLUE model runs are based on 30 iterations, each representing a single year, we postulated that the trajectory of area change for both land use categories is linear. Thus, the area of arable or pasture land for a given year was estimated according to:

$$\begin{aligned} AREA_{c,s,lu,t} &= (1 - t/30) \cdot AREA_{c,s,lu,0} + \\ &\quad t/30 \cdot AREA_{c,s,lu,30} \end{aligned} \qquad (3)$$

where: $AREA_{c,s,LU,t}$ is the area of land use lu at time t∈{0,1,2,..,30}.

For each country and scenario, 50 land use requirements were sampled and used. The dyna-CLUE model was used to create 50 land use maps of each country and scenario. The 50 maps were aggregated to create two types of maps: (a) probability maps for the occurrences of arable land and pasture in each cell location (b) probability maps for the occurrences of agriculture expansion and abandonment for the period 2000 and 2030.

We consider a land use occurrence or transition (expansion and abandonment of agriculture land) in a given location as significant if the same land use (or the same transition in the case of expansion and abandonment) was present in 95% of the produced maps. Thus, a land use event is considered significant if it occurs at least in 48 of the 50 maps.

We present maps in two forms (a) using the original 1x1 land use grid (b) using aggregated FARO-NUTS regions. The land use grid maps present the probability for the occurrence of a given land use event in each cell. The FARO-NUTS regional maps are presented as pair where one map presents the fraction of significant land use events in areas while the second map presents the uncertainty level of that occurrence. The uncertainty is estimated as the ratio between the number of insignificant occurrences and the number of significant occurrences.

D. Uncertainty of future GDP and population development and SSA setting

In our case, scenario assumptions differ by expected development of macro-economic and demographic variables in the future and by technological and policy assumptions. We derived the macro-economic drivers (GDP growth and associated employment and capital growth) from CPB [7] which calculated these growth rates with their macro-economic Worldscan model [8]. The demographic scenario characteristics - population growth rates - originate from SRES scenarios of the IPCC [8]. The similar assumptions were also use In EURURALIS project [6]. They are presented in Table 2.

However, macro-economic and population assumptions (projections) depends on number of factors and are uncertain. To quantify this uncertainty, we analyzed the historical GDP and population development for EU counties. The GDP and population historical data for 1967 - 2003 come from World Bank database World Development Indicators [10]. We have used these data to calculate 30 years growth rates of GDP and population for consecutive 30 years periods starting from 1967. So, the growth rats were calculated for periods: 1967 - 1996, 1968 - 1997,…,1974 - 2003. The averages, standard deviations and variation coefficients of these 30-years growth rates were calculated. This was done for all EU countries except of GDP for Germany and GDP for all new EU member countries (except of Hungary where GDP was available). Since for German GDP, too short data series were available, the Dutch variation coefficient was used for Germany in the simulation experiments. For EU12 countries (except of GDP in Hungary) too short data or too variable data series were available and therefore the variation similar to variation observed for the lower developed EU15 countries – Portugal and Greece – was used. The calculation results are presented in Table 2.

To assess uncertainties concerning agricultural land use and land distribution per sector resulting from the uncertainties related to GDP and population, we use SSA and consider GDP and population (and associated labour availability) as random variables with rectangular distributions. We assume that GDP and population fall within a band of plus and minus of standard deviation around the shock assumed for reference scenario (Table 3).

Table 2. Macro assumptions, growth rates in per cent in 2001-2003.

	Market Liberalisation		Public investment	
	Population	real GDP	Population	real GDP
Belgium	5.9	106.3	-3.9	26.0
Denmark	8.5	114.0	-0.2	35.4
Germany	3.4	85.9	-6.2	18.6
Greece	6.4	110.6	-4.5	30.0
Spin	3.1	140.7	-7.4	30.0
France	11.6	115.0	1.4	26.1
Ireland	27.3	143.1	15.9	54.9
Italy	-0.6	85.2	-10.9	7.5
Netherlands	18.2	111.4	2.5	32.5
Austria	2.9	105.2	-6.6	27.5
Portugal	6.4	110.7	-4.5	30.1
Finland	6.0	110.0	-2.6	32.3
Swede	7.4	112.2	-1.3	34.0
UK	9.1	97.8	-0.9	28.2
Cyprus&Malta	21.9	134.8	6.5	43.4
Czech Republic	1.5	150.7	-14.5	37.3
Baltic countries	-2.7	198.9	-18.2	57.0
Hungary	-5.7	145.5	-20.9	30.9
Poland	6.0	176.8	-10.6	47.4
Slovenia	3.3	105.1	-12.8	27.5
Slovakia	9.4	201.5	-7.6	59.4
Bulgaria&Romania	-3.4	340.1	-23.0	81.6
Rest of Europe	12.2	119.0	-2.8	25.3
Former Soviet Union	-0.1	215.3	-20.4	54.9
Turkey	45.5	293.9	23.5	128.7
USA, Canada, Mexico	26.4	113.0	24.3	58.7
Rest of America	33.1	179.9	36.3	116.2
Brazil	33.1	172.2	36.3	111.4
Oceania	6.4	99.4	8.4	41.6
Japan and Korea	-0.9	63.1	-2.0	18.8
China	10.6	430.8	20.2	239.9
Rest of Asia	28.1	319.2	30.8	210.9
Mediterranean countries	62.6	215.9	56.0	139.5
Nord Africa	58.3	291.8	56.0	190.6
Sub Saharan Africa	82.7	405.2	98.8	184.2
South Africa	82.7	281.3	98.8	129.0

Table 3. Real GDP and population: statistical characteristics of 30 years growth rates.

Country		Real GDP				Population			
				var (%)				var. (%)	
name	code	av.	st.dev.	in hist, data	used in SSA	Av.	st.dev.	in hist, data	used in SSA
Austria	aut	118.0	17.7	15.0	14.5	7.6	0.6	8.4	10.0
Belgium, Luxemburg	belu	101.2	14.9	14.8	14.5	6.1	0.1	1.8	5.0
Cyprus, Malta	euis				17.5	24.0	1.2	4.9	5.0
Czech Republic	cze				17.5	4.2	1.1	26.7	25.0
Denmark	dnk	72.2	5.4	7.5	5.0	7.8	0.7	9.4	10.0
Finland	fin	121.7	13.9	11.4	10.0	11.5	0.4	3.6	5.0
France	fra	104.0	12.5	12.0	10.9	15.3	1.2	7.7	10.0
Germany	deu				10.0	5.6	1.2	20.9	25.0
Greece	grc	103.5	18.3		17.5	23.3	0.3	1.2	5.0
Hungary	hun	76.0	7.2		17.5	-2.1	1.1	23.5	25.0
Ireland	irl	312.7	35.7	11.4	10.0	27.1	1.0	3.8	5.0
Italy	ita	104.9	14.9	14.2	14.5	6.7	1.3	19.7	25.0
Netherlands	nld	111.6	12.0	10.7	10.0	21.2	1.2	5.8	5.0
Poland	pol				17.5	17.5	2.6	15.1	15.0
Portugal	prt	166.6	28.3		17.5	15.3	4.4	28.5	25.0
Slovak Republic	svk				17.5	18.1	2.4	13.3	15.0
Slovenia	svn				17.5	14.9	2.2	14.5	15.0
Spain	esp	132.8	16.5	12.4	10.0	18.7	1.2	6.2	5.0
Sweden	swe	78.9	3.5	4.4	5.0	10.5	1.1	10.8	10.0
United Kingdom	gbr	90.7	3.7	4.1	5.0	5.6	0.3	5.7	5.0
Bulgaria, Romania	apeu				17.5	5.6	4.4	78.8	25.0
Baltic countries	euba				17.5	5.6	4.5	80.9	25.0

III. SENSITIVITY ANALYSIS RESULTS

A. Results of the SSA

Results of SSA for total land use growth are presented in Figures 1 - 2. The results show the following:

- GDP has, in general, the most pronounced impact on land use projections variation.
- with same exceptions, the variation of land use projections is higher for Public Intervention scenario characterized by lower GDP growth than for Market liberalisation scenario characterized by higher GDP growth
- land use projections for the new EU member countries have higher variation since GDP and population variations are higher for these countries than for old EU member countries;

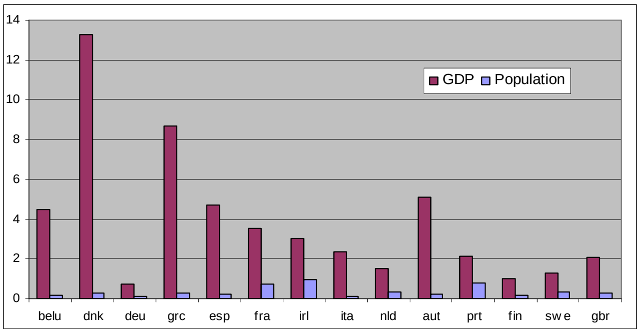


Fig. 1. Percentage variation of total land use growth projections resulting from GDP and Population uncertainty for Market liberalisation scenario for old EU member countries in 2001 - 2030.

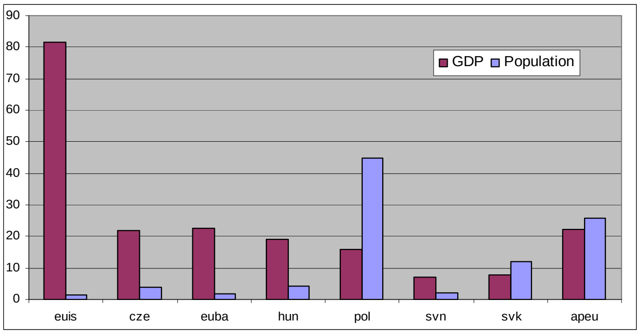


Fig. 2. Percentage variation of total land use growth projections resulting from GDP and Population uncertainty for Market liberalisation scenario for new EU member countries in 2001 - 2030.

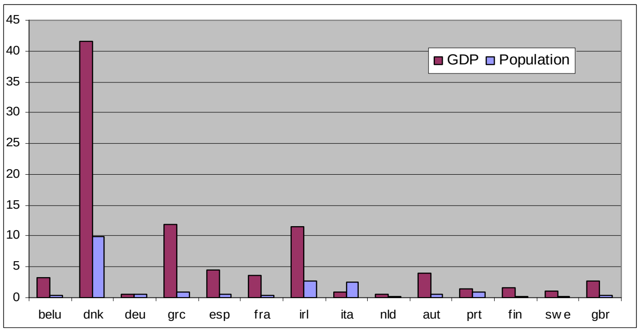


Fig. 3. Percentage variation of total land use growth projections resulting from GDP and Population uncertainty for Public Intervention scenario for old EU member countries in 2001 -2030.

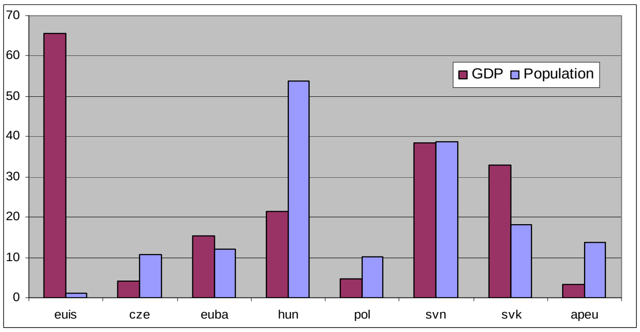


Fig. 4. Percentage variation of total land use growth projections resulting from GDP and Population uncertainty for Public Intervention scenario for new EU member countries in 2001 - 2030.

- population (and employment) variation has important impact on land in new EU members since population development in these countries is more uncertain (has higher variation) than GDP, this is especially prominent in Public Intervention scenario where these counties faces significant population decrease accompanied by relatively high GDP growth which makes population an significant production factor in these scenario.

Figures 5 and 6 present the 90% confidence intervals for total land use growth which results from GDP uncertainty in Market Liberalisation scenario. The figures show that differences in land use changes can be very significant if GDP growth is uncertain. For example for Belgium, the land use growth lays between 28 and 32 percent with probability 0.9.

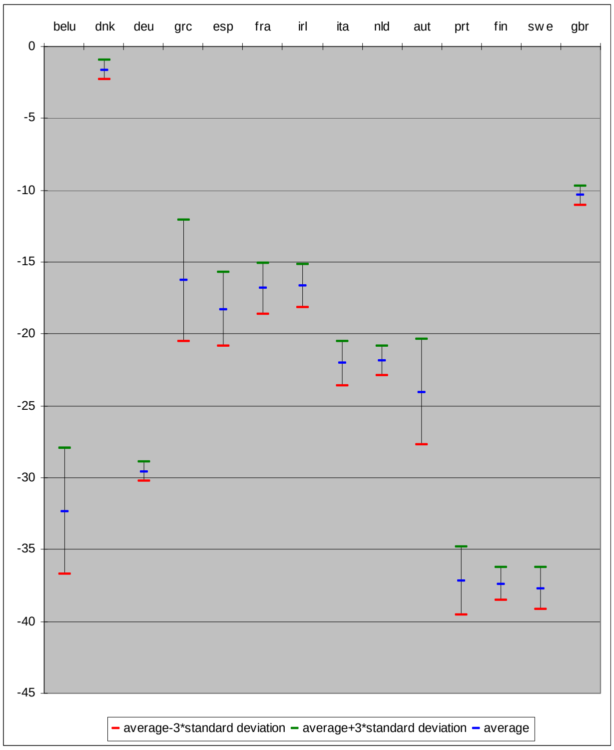


Fig. 5. The confidence intervals for total land use growth which results from GDP uncertainty in Market Liberalisation scenario for old EU member countries.

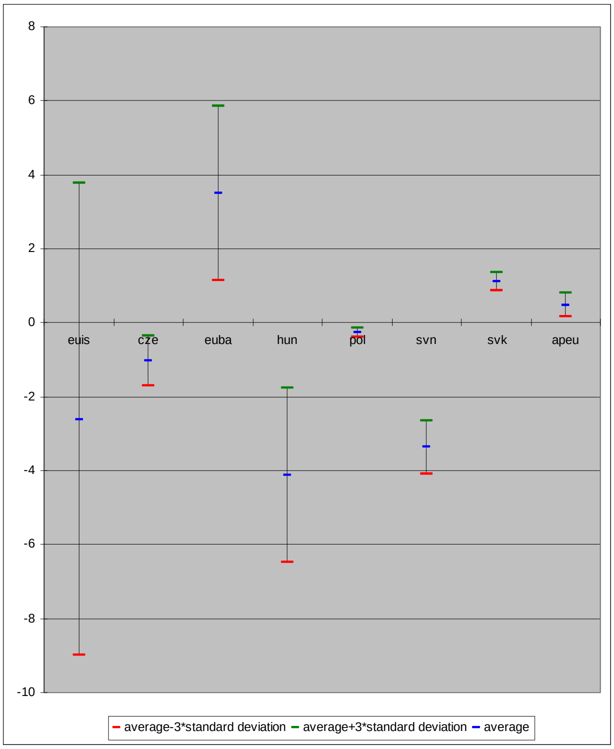
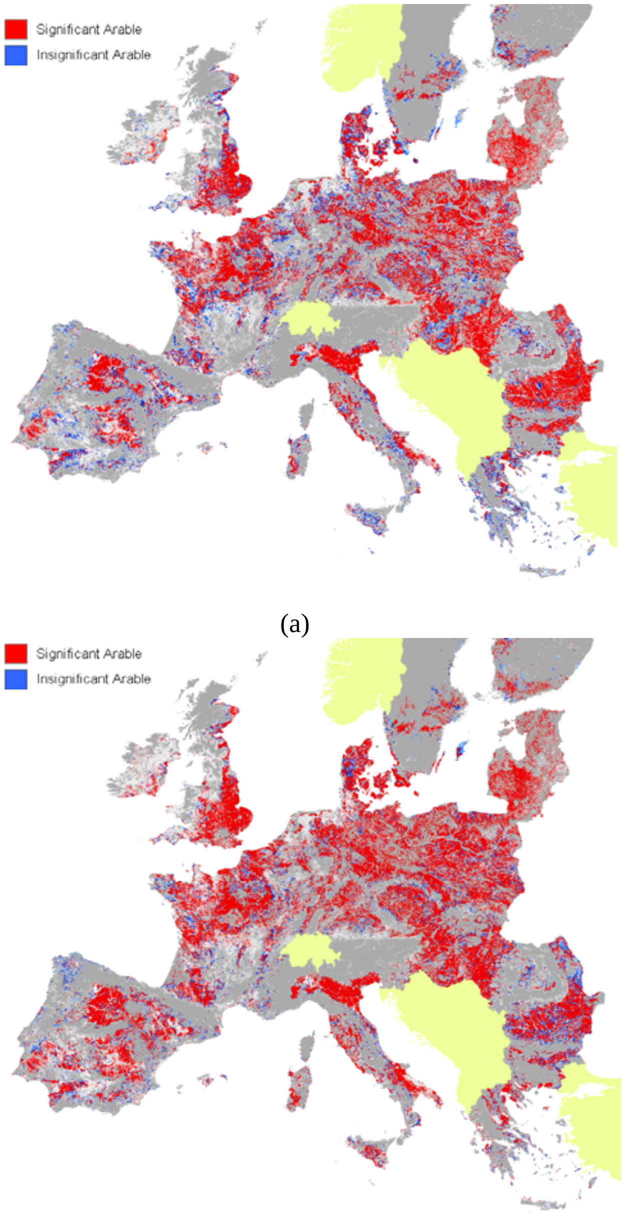


Fig. 6. The confidence intervals for total land use growth which results from GDP uncertainty in Market Liberalisation scenario for new EU member countries.

B. Spatial sensitivity of land allocation

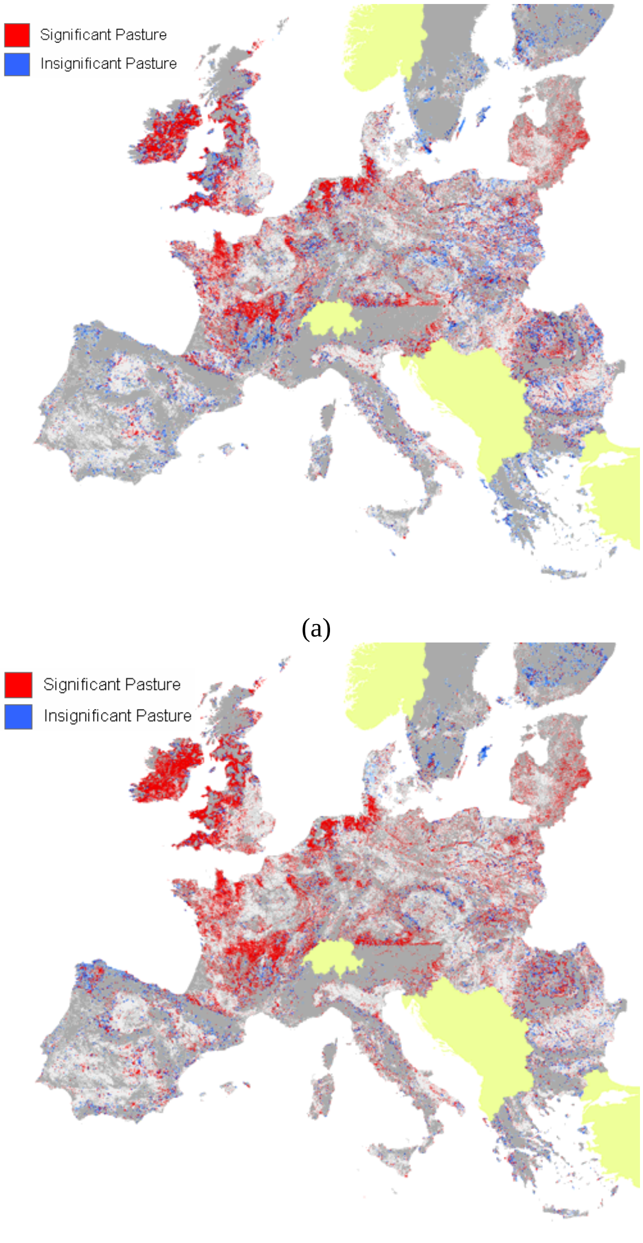
The likelihood maps for the occurrence of arable land in 2030 are presented in figure 7 for the two scenarios The areas marked in red represent areas which have a probability p>0.95 for the occurrence of arable land. Blue areas represent areas which have a non-zero (insignificant) probability p<0.95 for the occurrences of arable land. The grey area represents areas which have zero probability for arable land. In both maps, areas with insignificant likelihood for arable land tend to be located in high proximity to significant areas. In particular: insignificant occurrences of arable and pasture land tend to be located in the fringe of significant occurrences, this tendency reflects areas which might become arable or pasture if demand for land will be relatively high. A comparison between the two scenarios reveals that the Market Liberalisation scenario introduces more areas which have insignificant probability of arable occurrences compared to the Public Intervention scenario. Areas of considerable difference include the northern – eastern part of Spain, Sicily, southern Romania and parts of Hungary.



(a)

(b)

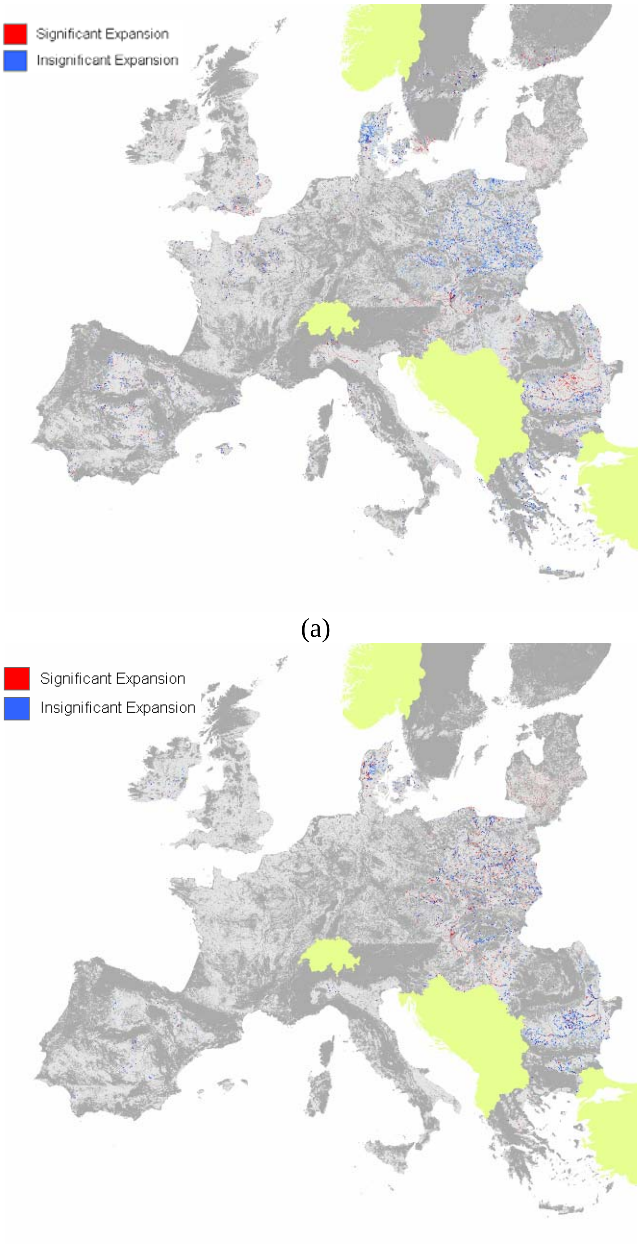
Fig. 7. Probability for Arable land in the year 2030 according to the (a) Market Liberalisation and (b) Public Intervention scenario



(a)

(b)

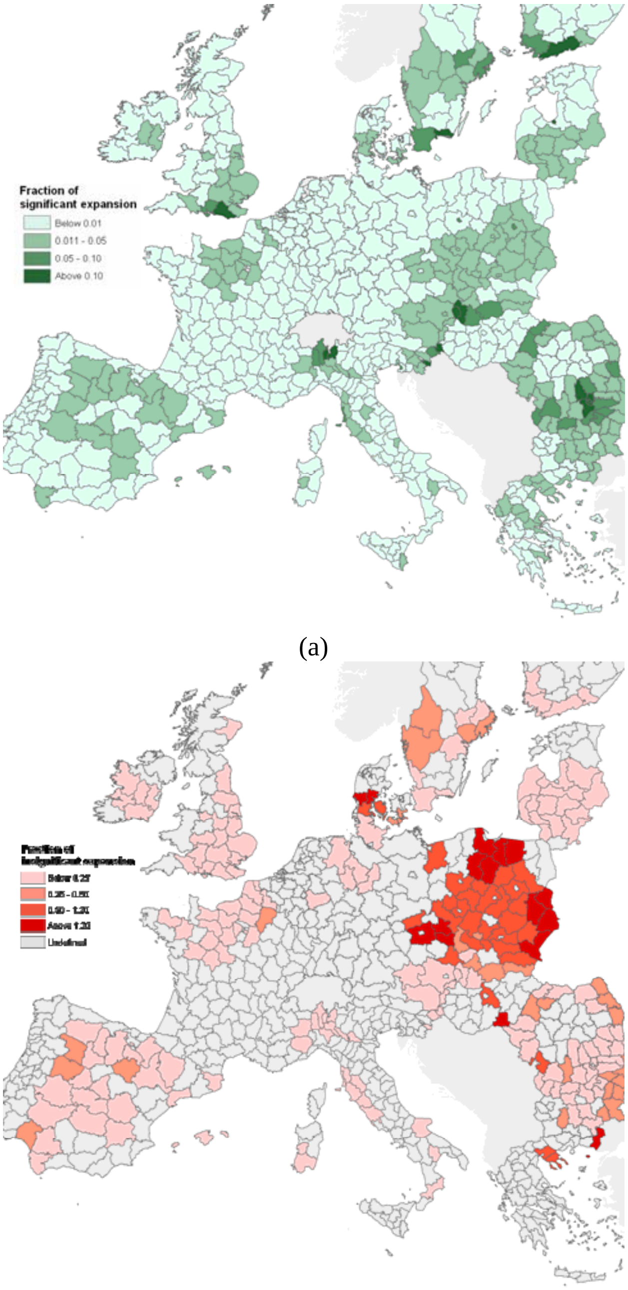
Fig. 8. Probability for pasture land in the year 2030 according to the (a) Market liberalisation and (b) Public Intervention scenarios



(a)

(b)

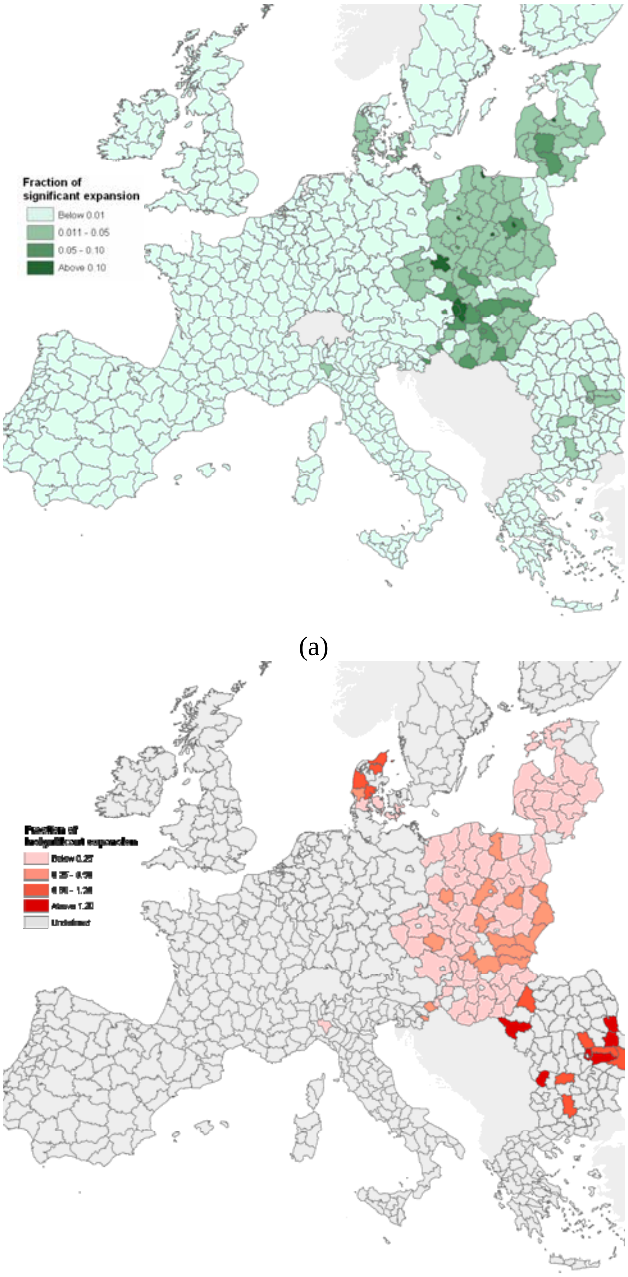
Fig. 9. Probability for agriculture expansion in the year 2030 according to the (a) Market Liberalisation and (b) Public Intervention scenarios



(a)

(b)

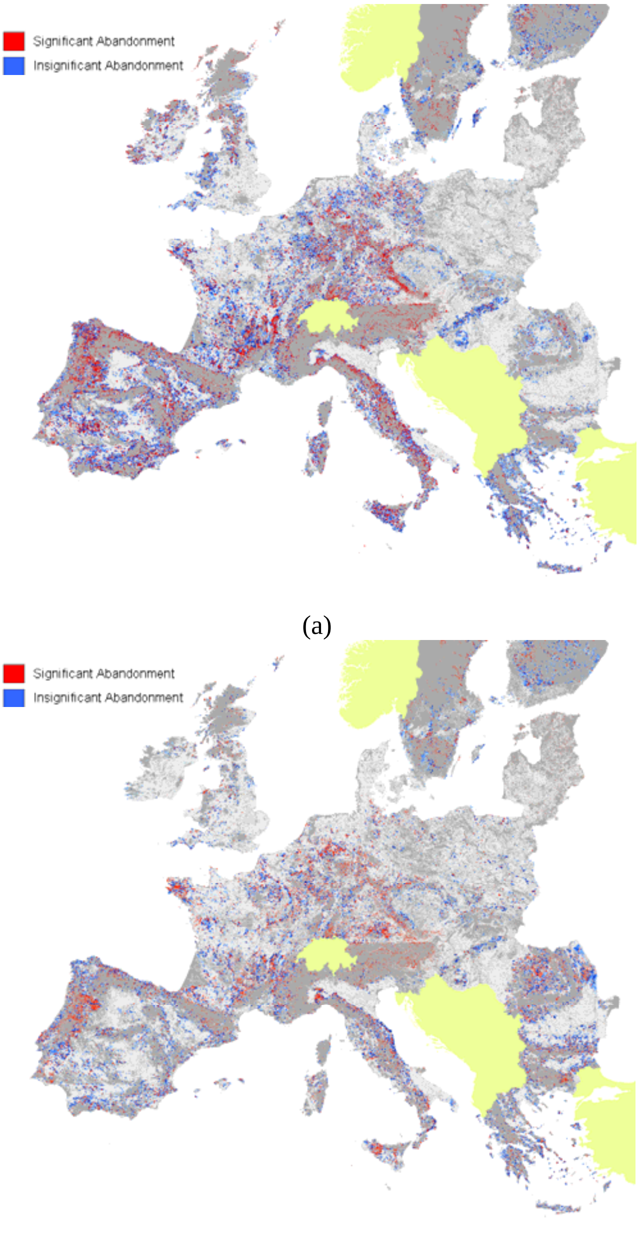
Fig. 10. The intensity of land expansion for the Market Liberalisation scenario: (a) fraction of significant expansion area out of the agriculture area in 2000 (b) the level of uncertainty of land expansion (the fraction of insignificant expansion area out of the significant area)



(a)

(b)

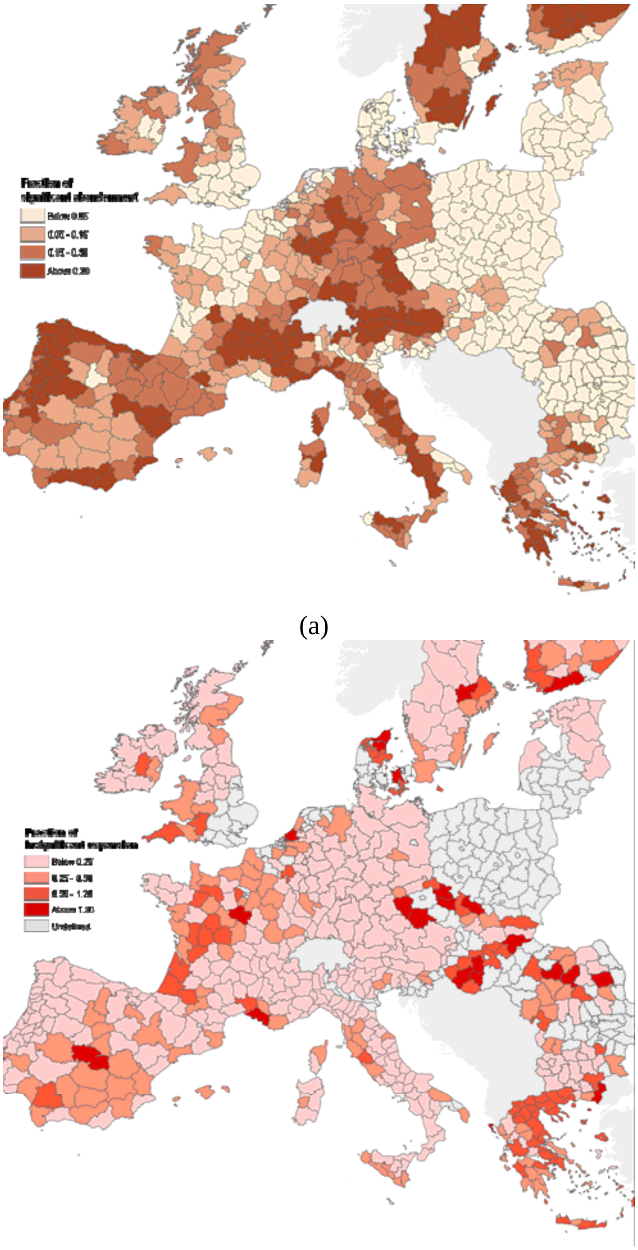
Fig. 11. The intensity of land expansion for the Public Intervention scenario: (a) fraction of significant expansion area out of the agriculture area in 2000 (b) the level of uncertainty of land expansion (the fraction of insignificant expansion area out of the significant area)



(a)

(b)

Fig. 12: Probability for land abandonment in the year 2030 according to the (a) Market Liberalisation and (b) Public Intervention scenarios



(a)

(b)

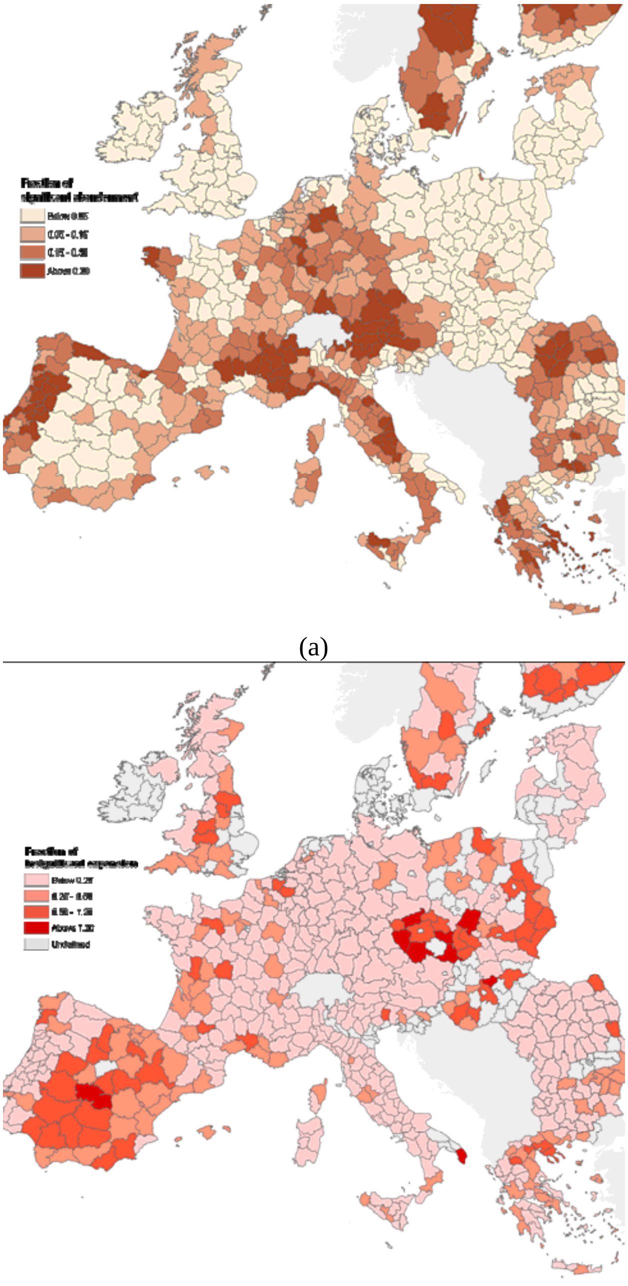
Fig. 13: The intensity of land abandonment for the Market Liberalisation scenario: (a) fraction of significant abandonments area out of the agriculture area in 2000 (b) the level of uncertainty of land abandonment (the fraction of insignificant abandonment area out of the significant area)

Figure 8 presents similar maps for occurrences of pasture land. These maps also exhibit higher degree of insignificant pasture land area in the Market Liberalisation scenario compared with Public Intervention scenario. Regions that exhibit considerable differences between the two maps includes Eastern Europe and also parts of southern France.

Figures 9-11 represent the likelihood of agriculture expansion for the two analyzed scenarios. The likelihood of expansion is represented as the probability that the land use in a given location will be converted from non agricultural use in 2000 to an agricultural use in 2030.

Figure 9 presents agriculture expansion using the original 1x1 km grid (in a similar manner to the maps of arable and pasture land) while Figure 10 and 11 present's agriculture expansion aggregated to administrative units (NUTS regions).

The first map presents the fraction of significant areas of expansion out of the areas which were agriculture in 2000. The second map presents the ratio of insignificant and significant expansion areas which is used to as a measure of the uncertainty. As expansion of agriculture is not a dominant process in both scenarios, very few regions exhibit expansion. Most expansion occurs in Eastern Europe in the Public intervention scenario while additional areas like in Hungary Romania and Spain exhibit expansion in the Market Liberalization scenario. For Eastern Europe, the level of uncertainty of agriculture expansion in the Market liberalization in higher compared to the Public Intervention scenario. In the Market liberalization maps, medium levels of land expansion corresponds to low level of uncertainty in Spain while in the Pubic Intervention scenario both the rate of expansion and uncertainty are low.



(a)

(b)

Fig. 14: The intensity of land abandonment for the Public Intervention scenario: (a) fraction of significant abandonments area out of the agriculture area in 2000 (b) the level of uncertainty of land abandonment (the fraction of insignificant abandonment area out of the significant area)

Figures 12-14 presents the likelihood for land abandonment. The likelihood for land abandonment is represented as the probability that agriculture land use in 2000 will be converted to an unused land use in 2030. Land abandonment occurs more in the Market Liberalisation scenario and to a lesser extent in the Public intervention scenario. In general, land abandonment occurs throughout Europe excluding areas of Eastern Europe and some areas of northern France. In both scenarios, areas with high intensity of land abandonment usually also characterized by low degree of uncertainty while areas with low intensity of land abandonment are characterized with high level of uncertainty.

IV. CONCLUSIONS

The aim of any sensitivity analysis is to examine the dependence of model results on uncertain parameter values. The sensitivity analyses conducted in this study focused on the effect of the uncertainty in GDP and population size values on the land use resulting from the LEITAP model simulations and also on the spatial consequences of these uncertainties which were evaluated using the Dyna-CLUE model.

The results of the LEITAP model suggests that GDP and yield have the most pronounced impact on the uncertainty of land use projections compared with the population size impact. The Public Intervention scenario is characterized by lower GDP growth and relatively high level of land use uncertainties while the Market Liberalisation scenario is characterized by higher GDP growth and lower level of land use uncertainties. The SSA also reveals that some counties exhibit a higher degree of uncertainty of land use projections than others, for example land use projections for the new EU member countries have higher variation since GDP and population variations are higher for these countries than for old EU member countries

The results of the Dyna-Clue model reveal that insignificant occurrences of land use change tend to appear around significant occurrences. Insignificant areas are likely to represent areas which might have become significant if the demand for land would be higher. The most prominent land use process that occurs in both scenarios is abandonment of agriculture land.

The relatively wide spread areas of insignificant land abandonment can be considered as areas sensitive to abandonment that might become significant if the rate of abandonment increases. In general, the areas that have significant likelihood for land abandonment represent areas that have the lowest suitability for agriculture, thus these areas are always selected for abandonment in most of the model runs. Areas with insignificant probability for the occurrence of abandonment represent areas where land abandoned occurs in some of the model runs. This suggests that the suitability of these areas for agriculture is somewhat better.

The majority of areas exhibit medium and low level of uncertainties of land abandonment but relatively high levels of uncertainties were found in relation to land expansion. However, the reason for the large number insignificant areas of land expansion is the result of the low rate of land expansion which results in a high “signal to noise” ratio.

In general, the sensitivity analysis of the Dyna-CLUE model simulation reveals that the produced land use patterns are relatively in-sensitive to the uncertainties introduced. A consequence of the in-sensitivity is that the spatial patterns of the two scenarios can be considered as distinct or “significantly different”. In other words, the results Dyna-CLUE model suggest that it is unlikely that the pattern produced by a random set of input variables taken from the first scenario will be similar to a pattern produced by the second scenario. We should note that the sensitivity analysis only reveals the sensitivity of model output to the given uncertainty in inputs. A larger variation of input variables or the introduction of variability to a larger set of variables is likely to introduce more variation in the results of both models.

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