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RESEARCH ARTICLE

Trajectories of land use change in Europe: a model-based exploration of rural futures

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Abstract Land use change is characterized by a high diversity of change trajectories depending on the local conditions, regional context and external influences. Policy intervention aims to counteract the negative consequences of these changes and provide incentives for positive developments. Region typologies are a common tool to cluster regions with similar characteristics and possibly similar policy needs. This paper provides a typology of land use change in Europe at a high spatial resolution based on a series of different scenarios of land use change for the period 2000–2030. A series of simulation models ranging from the global to the landscape level are used to translate scenario conditions in terms of demographic, economic and policy change into changes in European land use pattern. A typology developed based on these simulation results identifies the main trajectories of change across Europe: agricultural abandonment, agricultural expansion and urbanization. The results are combined with common typologies of landscape and rurality. The findings indicate that the typologies based on current landscape and ruralities are poor indicators of the land use dynamics simulated for the regions. It is advocated that typologies based on (simulated) future dynamics of land change are more appropriate to identify regions with potentially similar policy needs.

Keywords Typology · Europe · Land use and land cover change · Abandonment · Urbanization · Rural typology · Landscape · Model

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Introduction

Land use change is both the result and a cause of diverse interactions between society and the environment. Because of these interactions land use change is a central topic in global change and rural development issues (Antrop 2005; Olson et al. 2008). Land use change is characterized by a high diversity of trajectories of change across space and time. Case studies have indicated that the specific trajectory is a function of the specific driving factors at a certain location (Geist et al. 2006; Geist and Lambin 2002). The same driving factors may lead to a different result at different locations as a consequence of a different context and different location characteristics. Therefore the analysis of land use dynamics has to be region-specific and account for different, concomitant trajectories of change.

In Europe a lot of attention is given to policy interventions that are designed to counteract some of the negative consequences of land use change, e.g. the protection of designated areas to avoid conversion to (intensive) agriculture or the compensation of farmers in less favoured areas to avoid land abandonment and depopulation (Koomen et al. 2008; Oñate et al. 2007). Many policies at the European level are not targeted at specific areas or situations but are, in principle, applicable to any farmer or other land owner that meets certain obligations (‘one size fits all’). It is generally acknowledged that by better targeting of policy interventions, such as rural development measures that focus on specific areas and issues, public investments are likely to be more efficient (MacDonald et al. 2000; Sonneveld and Bouma 2003).

Region typologies are a common tool to cluster regions with similar characteristics and possibly similar policy needs. Straightforward typologies include the typologies of OECD (2004) that distinguish rural from urban regions given their different characteristics and different policy requirements. While the OECD typology is only based on population density more advanced rural/urban typologies were produced by for example the EC (European Commission 2007), ESPON (2004) and the FARO project (van Eupen et al. 2009). The OECD (2006) classification also categorized regions as either leading or lagging in terms of employment rate to indicate some of the challenges for rural development and potential need for policy intervention.

From a biophysical perspective Jongman et al. (2006) and Metzger et al. (2005) created a typology of environmental conditions by clustering regions with similar climate and altitude while also accounting for oceanicity and northing to express differences in buffering due to influence of the ocean and day-length. This typology was created to characterize the variation in environmental conditions determining the environmental impacts of global change processes.

Peterseil et al. (2004) created a high-resolution typology of landscapes in Austria in terms of sustainability indicators. Their typology/classification of landscapes is based on fuzzy and statistical analysis of high-resolution data of land cover, landscape elements and landscape shapes such as parcel boundaries etc. The typology is capable of capturing subtle changes in landscape character. However, the authors only applied the typology to current conditions in Austria, disregarding the landscape dynamics in time.

These region typologies are all based on the current state of the region and use a static time horizon. However, changes in demography, land use and other factors will cause dynamics in regions: a rural region may become peri-urban in time while an agricultural region may become a region dominated by nature after agricultural abandonment and depopulation. Such changes may lead to a change in policy requirements and therefore have implications for policy design. For example, two regions that are both dominated by intensive agriculture may face completely different trajectories of land use change (e.g. further intensification versus agricultural abandonment) and therefore require different types of policy intervention. Including the expected trajectories of land use change inside a region typology is a tool to inform policy formulation. The land use dynamics will show the extent of the area in which similar problems and conditions are expected. Such a typology will also provide a context for case studies of specific land use trajectories and indicate other regions where similar dynamics are expected.

For a small case study in Spain Schmitz et al. (2003) present a typology based on landscape types. As part of this typology the authors indicate the direction of change in landscape type as a result of changes in the social determinants of landscape categories for assumed scenario conditions. The analysis is made for 27 municipalities and the results indicate that different municipalities, although belonging to the same landscape type, face different trajectories of landscape change. This is one of the few studies that combine the dynamics of landscape change with a typology of landscapes.

Most current typologies are based on aggregate data at the level of administrative units. Besides problems due to the relatively high level of aggregation (Muilu and Rusanen 2004) this approach disregards the importance of spatial variation and the linkages between spatial pattern and processes within landscapes. The shape and spatial distribution of landscape elements reveal characteristics of the processes in these landscapes and are therefore important to consider (Forman and Godron 1986; Turner 1989). Spatial patterns of land cover are often highly sensitive to changes in landscape function and character and therefore a good indicator of dynamics (Peterseil et al. 2004).

The objective of this paper is to provide a typology of land use change in Europe at a high spatial resolution based on a series of different scenarios of land use change for the period 2000–2030. The results are combined with common typologies of landscape and rurality in order to identify regions with similar conditions and land use dynamics.

Method

The paper focuses on the development of a typology accounting for the dynamics in land use ('dynamic typology') which is compared to two different typologies based on current conditions ('static typology'). An overview of the method is presented in Fig. 1. The dynamic typology is derived for four different scenarios of plausible changes in world economy, demography and governance. Based on the scenario descriptions land use models are used to explore the possible consequences of these scenarios for land use. The model outcomes provide the basis of a typology of the main challenges faced by regions across Europe in terms of land use changes.

Land use modeling

The simulation of land use change and associated impacts is based on the use of multiple models to address the different scales of analysis and multiple inputs (Hellmann and Verburg 2009; Verburg et al. 2008). Because land use change at different locations in Europe is affected both by local conditions, such as topography, accessibility and demographic structure, and global processes such as global trade of commodities, market-support policies and migration, it is needed to apply a multi-scale approach accounting for the processes affecting land use change over the whole range of scales.

The main external driving factors that are specified as input to the models are demography, overall economic development (GDP), technological change and policies. There is a high level of uncertainty in the future development of these driving factors. In order to represent this uncertainty a scenario approach was used to summarize plausible divergent developments in these factors in consistent narratives. Projections of possible changes in demography and economic development were derived from existing scenario studies (Verburg et al. 2008). At the global level a macro-economic model was used to calculate the land use change response to changes in overall economic development, trade and agricultural policies, technology and demography. An extended version of the Computable General Equilibrium (CGE) model GTAP (Global Trade Analysis Project (Hertel 1997)) was used which combines the advantages of the global CGE approach with specific features of partial equilibrium models concerning land modeling (Meijl et al. 2006). The model links industries in a value added chain from primary goods, over continuously higher stages of intermediate processing, to the final assembling of goods and services for consumption. Extensions of the standard model were used to improve the treatment of agricultural production and land use. The land use structure was extended by accounting for different degrees of substitutability between land use types and an endogenous treatment of land demand and supply through a land supply curve specifying the relation between land supply and land rent (Meijl et al. 2006). In addition, biodiesel and bioethanol are separately placed in the GTAP input-output structure of the

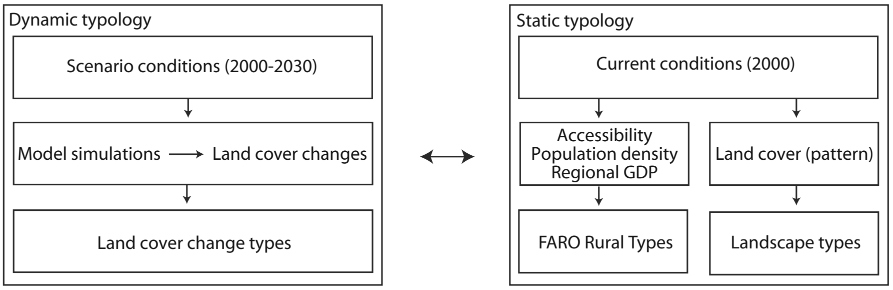

Fig. 1 Overview of the methodology used to create different regional typologies

petroleum industry, which means that the petroleum industry can choose between using oil, 'regular' petroleum products, biodiesel or bioethanol as inputs for fuel (Banse et al. 2008; 2009). The GTAP model distinguishes 36 world regions and individual countries within the European Union. Within these regions the land resources are assumed to be distributed homogeneously. However, land resources often show a high spatial variation and current use is often located in the most productive areas. Changes in land area used for agricultural purposes tend to take place in the more marginal areas with relatively low yields. Therefore, the model may overestimate the production increase upon area expansion. At the same time environmental processes such as climate change may affect production conditions of the different world regions leading to changes in the competitive advantage of regions to produce commodities. In order to account for both effects the IMAGE model [Integrated Model to Assess the Global Environment; (Alcamo et al. 1998; Strengers et al. 2004)] was used. The consequences of land allocation and climate change on the average productivity of different regions are input to a new simulation of the GTAP model. An iterative procedure is used until the output of both models is consistent (Eickhout et al. 2007).

Within Europe a more detailed assessment is made of the spatial patterns of land use change in order to identify which regions are expected to face specific land use change processes. A spatially explicit land allocation model, CLUE (Conversion of Land Use and its Effects, Dyna-CLUE version (Castella and Verburg 2007; Overmars et al. 2007; Verburg and Overmars 2009)) was used with a spatial resolution of 1 km^2 for yearly time steps. Seventeen different land use types are distinguished based on the CLC2000/CORINE land cover database (EEA 2005; Haines-Young and Weber 2006) including built-up area, rainfed arable land, pasture (semi-)natural vegetation, inland wetlands, irrigated arable land, recently abandoned farmland, biofuel crops, permanent crops, forest, and a number of different distinct (semi-) natural land use types such as beaches, glaciers, etc.

The CLUE model is based on the dynamic simulation of competition between land uses while the spatial allocation rules are based on a combination of empirical analysis of current land use patterns (Verburg et al. 2006; Wassenaar et al. 2007), neighborhood characteristics (Verburg et al. 2004), and scenario specific decision rules. The spatial allocation rules are configured separately for each country to account for the country-specific context and land use preferences. The land requirements for the different land use types to be allocated by the model are specified at the national scale for each country within Europe separately. Changes in agricultural land area are based on the results of the combined simulations with the global economic (GTAP) and integrated assessment model (IMAGE). Growth in built-up area is based on demographic development, immigration ratios and scenario-specific estimates of change in area used per person. Changes in natural vegetation are the result of both net changes in agricultural and built-up area and locally determined processes of re-growth of natural vegetation (Verburg and Overmars 2009). After abandonment of agricultural land re-growth of natural vegetation is simulated as a function of the local growing conditions (soil and climate conditions), population and grazing pressure and management. The possibilities to convert natural vegetation into agricultural land or residential/industrial land depend on the location and the type of natural area. Path-dependent dynamics arise from the combination of top-down allocation of agricultural and urban demand and bottom-up simulation of the (re-)growth of natural vegetation.

The model simulations result in yearly maps of the land use pattern for the period 2000–2030.

Scenarios

The four scenarios follow the storylines of the Intergovernmental Panel on Climate Change (IPCC 2000) which are structured along two axes (Fig. 2). The two axis relate to the two key uncertainties regarding policy approaches to problems and long-term strategies. The vertical axis represents a range from a high level of global integration to a more regional approach, whereas the horizontal axis represents a range from market-orientation to a high level of governmental intervention to ensure specific economic, social and environmental objectives. This results in a series of four scenarios distinguished by different degrees of global (market) integration and different levels of (policy) regulation. Each of these scenarios is elaborated in terms of the demographic, economic and policy assumptions typical for the

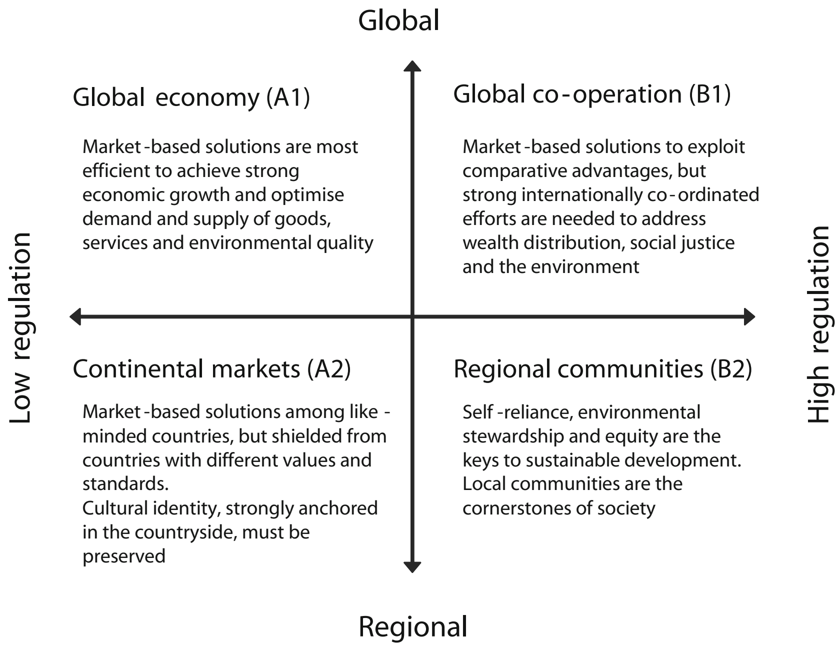

Fig. 2 Schematical overview of the four scenarios used in this study (after Westhoek et al. 2006)

scenario conditions in the European context. For this purpose the assumptions were combined with data and trends based on the current situation, changes in demography and technology as predicted by other studies and feedback from scientists and policy makers (Westhoek et al. 2006). A detailed list of all assumptions is provided by WUR/MNP (2008). Here we suffice with a short description of the scenarios:

The *Global Economy* scenario (A1) describes a world with less government intervention and fewer borders in comparison with today. Trade barriers are removed and there is an open flow of capital, people and goods, leading to rapid economic growth. Strong technological development will increase agricultural productivity. The role of the government is very limited and nature/environmental problems are not seen as a priority for legislation. Therefore, no targets are specified for biofuel production/consumption.

The *Continental Markets* scenario (A2) depicts a world of divided regional blocks in which each block is striving for self sufficiency, in order to be less reliant on other blocks. Agricultural trade barriers and support mechanisms continue to exist. A minimum of government intervention is preferred, resulting in loosely interpreted directives and regulations. Also in this scenario no assumptions are made with respect to policies concerning biofuels.

The *Global Cooperation* scenario (B1) represents different dynamics of land use. This scenario depicts a world of successful international cooperation aimed at reducing poverty and environmental problems. Trade barriers will be removed while governance aims at protecting the cultural and natural heritage values. A 5.75% blending obligation on the share of biofuels in the transport sector is assumed from 2010 onward.

People are assumed to have a strong focus on their local and regional community and prefer locally produced food in the *Regional Communities* scenario (B2). Agricultural policy is assumed to aim at self sufficiency and ecological stewardship is important. Strong government interventions through restrictions, spatial planning and incentives to maintain small scale agriculture are characteristic for this scenario. At the same time a 5.75% blending obligation on the share of biofuels in the transport sector is assumed.

Typologies

The dynamic typology is based on the simulation results of the land use models for the four scenarios described above. The simulation results are spatial datasets representing 17 different land use types at a spatial resolution of 1 km^2 and a yearly temporal resolution. To create a meaningful typology of the main trajectories of change at the regional level a generalization of the simulation outcomes is made. As a first step the main land use change trajectories are identified including agricultural abandonment, expansion of agricultural area and urbanization. In some instances these processes occur at isolated locations while in other cases larger areas are facing the same trajectory of change. In order to identify the main regions where these processes of land use change occur, a focal function is used to calculate the fraction of the total land area of the 25 km^2 neighborhood for each of the three land use change processes. A location is classified as 'abandonment' if at least 10% of the land in the surrounding 25 km^2 is facing agricultural abandonment. A location is classified as 'agricultural expansion' if within the neighborhood more (semi-)natural land is converted to agriculture than agricultural land converted to urban land. Again a threshold of 10% of the total land area is used. For urbanization a threshold of 5% of the land area in the surrounding 25 km^2 is used given the large impact of urban areas on landscapes and the relatively small areas of urban land use. Because urbanization may coincide with agricultural abandonment and/or agricultural expansion at the same location, two combined categories were created to also include region types with concomitant processes.

This typology is compared with two typologies based on the current regional characteristics. The first static typology uses the same land use classification as the dynamic typology. Based on the spatial pattern of land use and the dominant land use type a typology of landscape types is made. First the full legend of 17 different land use types is reclassified into three major land use categories: urban land use, agricultural land use and a class incorporating forest and (semi-)natural land use types. Locations are classified as 'urban core landscape' when 67% of a 9 km^2 neighborhood is occupied by urban land use. The same criterion is used to identify the core areas of forest and (semi-)natural landscapes. Peri-urban or densely populated rural landscapes are identified based on a use percentage of more than 25% urban/residential land use in a 25 km^2 neighborhood disregarding the urban core influence. Large scale agricultural landscapes are distinguished from mosaic landscapes when 80% of a 225 km^2 neighborhood is covered by agricultural use again disregarding the urban core and forest and (semi-)natural landscapes. The size of the neighborhoods is related to the overall characteristics and spatial extent of the different landscape types. However, both the exact neighborhood size and the classification criteria are arbitrarily determined. The values were estimated to generate results corresponding with other landscape typologies for Europe (European Environmental Agency 2005; Meeus et al. 1990) and allow a clear representation of the broad landscape patterns at the scale of analysis.

The second typology based on the current conditions was taken from the FARO project (Eupen et al. 2009). This typology is, in contrast to the first typology based on socio-economic and infrastructural conditions. Three rural types are distinguished based on a map of regional GDP and accessibility. Regional GDP is downscaled from administrative units (NUTS2/3) to 1 km^2 resolution by using population density as a proxy for economic activity. The accessibility map is calculated as a weighted average of the travel time to small, medium and large towns and cities accounting for the transportation network. A combination of high local GDP value and high accessibility is classified as peri-urban area while a low GDP combined with very poor accessibility is called 'deep rural'. Intermediate areas are classified as 'rural'. The combination of accessibility, population density and economic variables as indicators of rurality is frequently used in rural typologies (Bengs and Schmidt-Thomé 2006; Blunden et al. 1998).

Results

Figure 3 provides an illustration of the land use simulation results for the Global Economy scenario. The results for this relatively small area illustrate the high spatial variation in land use change trajectories. Under the scenario conditions, the main agricultural areas see some expansion of agricultural use while at the same time land abandonment occurs in large parts of the mountain area of the Pyrenees consistent with the ongoing trend over the past decades in this region (Mottet et al. 2006; Pueyo and Beguería 2007). The main urban centres of Toulouse and Barcelona are predicted to face strong increases in urban area. The high spatial variation in land use dynamics illustrates the need for high-resolution

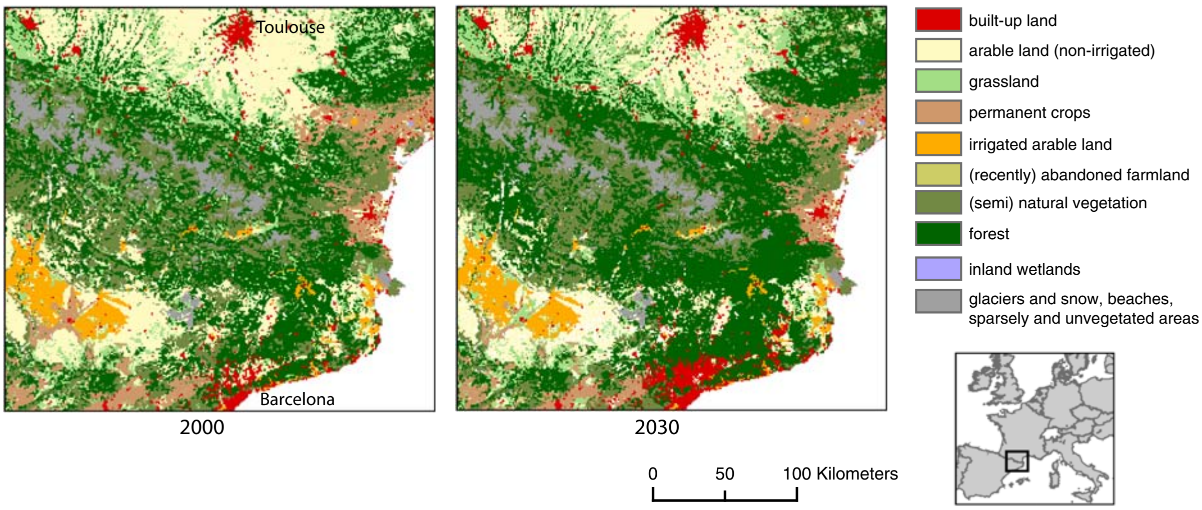

Fig. 3 Sample of the land use simulation results for the Global Economy (A1) scenario for an area in southern France/northern Spain

assessments to identify regions with similar patterns. Analysis at the level of administrative units such as the commonly used NUTS2/3 regions would be insufficient.

The results of the dynamic typology for all four scenarios are shown in Fig. 4. In three of the four scenarios agricultural abandonment is the dominant land use change. The Continental Market scenario shows large areas with expansion of agricultural area in order to meet the food, feed and fuel demands under conditions of high border protection combined with strong economic growth in Europe. Urbanisation is highest in the Global Economy scenario but concentrated in a small number of regions. Despite these overall trends it is clear that large regional differences occur. Whereas land abandonment is found in many countries in the Global Economy and Global Co-operation scenarios the Baltic States show an ongoing expansion of agricultural area. Even in some of the countries dominated by land abandonment small regions facing expansion of agricultural land are seen. Although the different scenarios predict different trends for Europe as a whole a number of regions show, irrespective of the scenario, the same trajectory of change. Other regions are very sensitive to the overall demand for different land uses and react differently in the different scenarios.

Figure 5 shows the two static typologies used in this study. Although the two typologies overlap in some regions they address different characteristics of the regions. Tables 1 and 2 summarize the spatial distribution of the dynamic region types over the two different static typologies. It is obvious that irrespective of the scenario urbanization mainly occurs in the urban core and peri-urban landscape types and the peri-urban rural type. Abandonment is important in all three rural types. Although deep rural regions may contain marginal areas for agricultural use and relatively poor access conditions, this rural type also contains highly suitable areas for large-scale, intensive agriculture. Therefore, different change trajectories are observed in this rural type at the same time. More overlap between the static and dynamic typology is observed when comparing the land use dynamics with the landscape types. Most changes in agricultural area, both abandonment and agricultural expansion, are found in the mosaic landscapes. Agricultural dominated landscape are less dynamic in all four scenarios. This result can be explained by the limited vulnerability of farming in the most suitable farming regions to changes in markets and policies. Mosaic landscapes are mainly found in areas with hilly to mountainous terrain with often strongly varying and relatively poor conditions for agricultural use. In these areas farmers may face difficulties to compete at the same market as farmers in the more well-off regions. Upon declining demand or reduction of policy support, farming may decrease in the mosaic

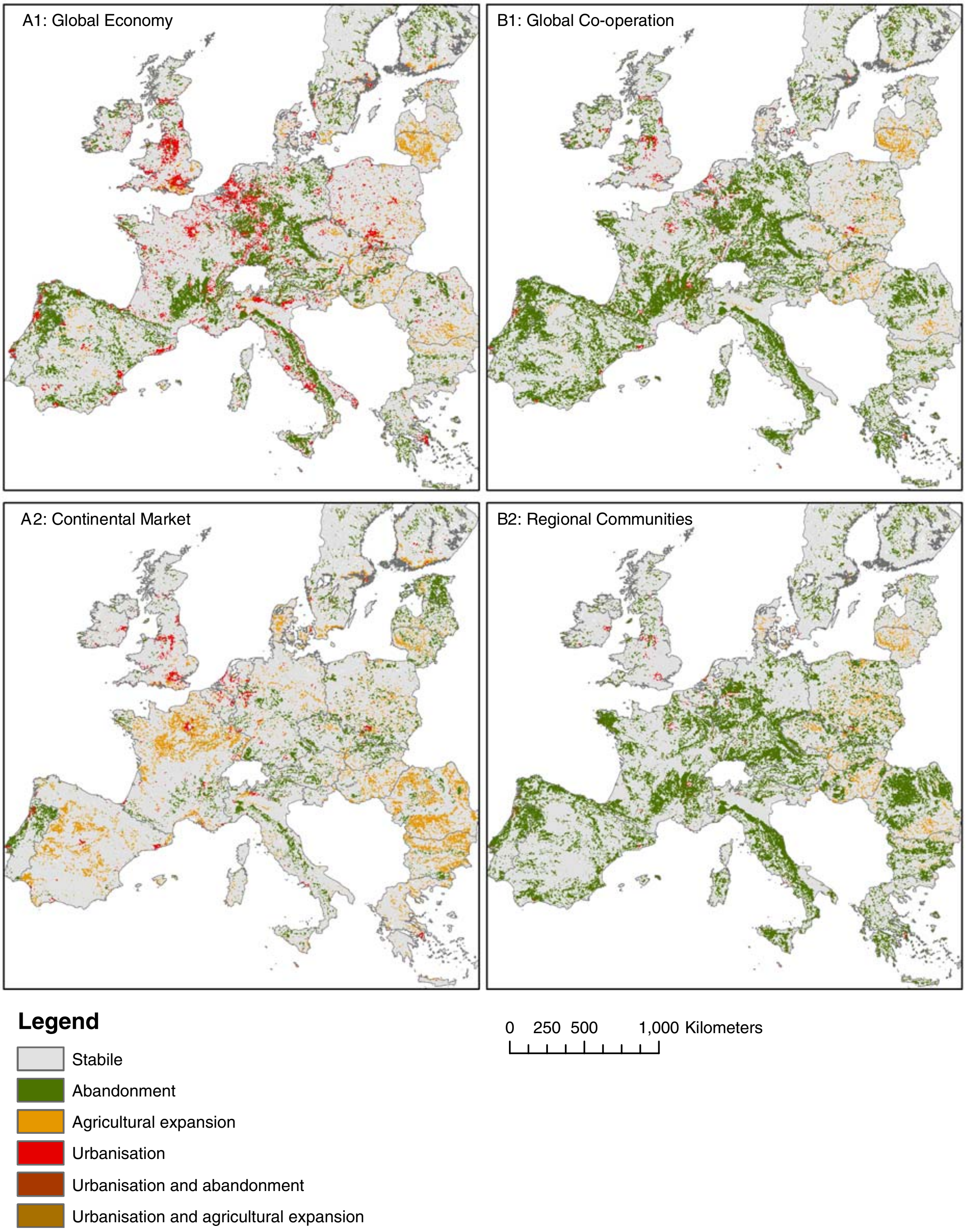

Fig. 4 Typology of the dynamics in simulated land use for four scenarios

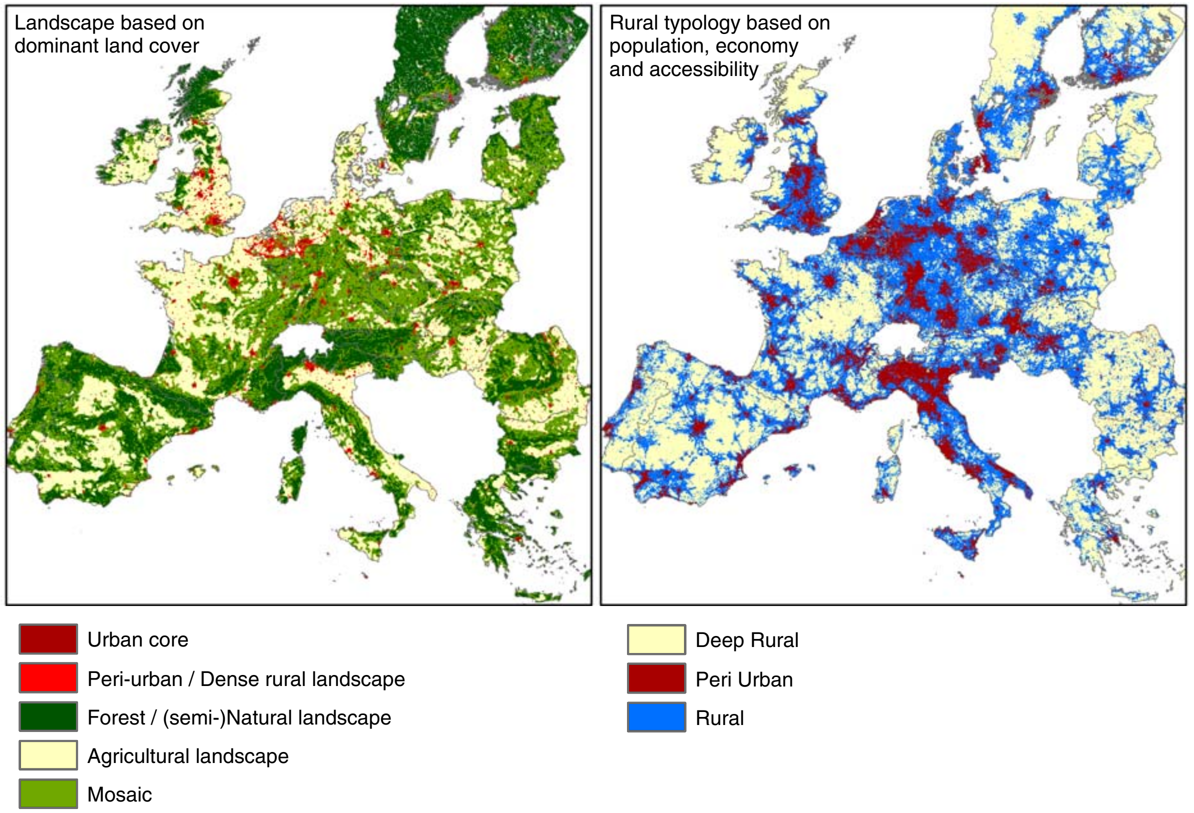

Fig. 5 Two possible typologies of the current conditions in Europe based on respectively the dominant land cover in 2000 and a typology of the degree of rurality (van Eupen et al. 2009)

landscapes. However, in case of increasing agricultural area, e.g. as a consequence of increasing food, feed and fuel demands, these landscapes offer opportunities for expansion of farm area often associated with scale enlargement and loss of landscape qualities.

Besides a tabular overlay of the static and dynamic typology it is also possible to map the correspondence of both typologies. Figure 6 presents an overlay of the abandonment regions with agricultural landscapes for a small part of southern Europe (mainly Italy). The figure shows that abandonment occurs in part of the agricultural landscape. At the same time large parts of the same landscape type are completely unaffected by future land use change. That being the case, the 'static' typology overlaps in only some parts with the 'dynamic' typology. In spite of the differences between locations of abandonment between scenarios, some regions are, irrespective of the scenario, foreseen to face abandonment.

Discussion

Typologies are generally designed to group regions with similar conditions and, potentially, similar needs for policy intervention. The current study indicates that in terms of land change trajectories static typologies are both incapable of grouping regions facing similar challenges and distinguishing areas requiring similar policy interventions. The local conditions and the national level context determine the trajectory of change rather than the overall regional conditions as summarized in the 'static' typologies. Given the importance of processes operating over different scales it is likely that other typologies based on current conditions of the regions also fall short in identifying regional challenges in terms of land use change. Therefore the addition of dynamic information from scenario and simulation studies to the typology is of great importance to identify regions with similar challenges in terms of land use dynamics. The current

Table 1 Percentage of the area of the dominant landscape type facing change in land cover between 2000 and 2030 for four scenarios

Dominant land cover type	Stabile	Agricultural abandonment	Agricultural expansion	Urbanization	Urbanization and abandonment	Urbanization and expansion
Global Economy (A1)						
Urban core	55	1	1	42	0	0
Densely populated/ peri-urban	51	3	3	40	2	1
Forest/(semi-) natural	88	10	1	1	0	0
Agricultural	86	6	4	4	1	0
Mosaic	63	25	5	5	2	0
Continental Market (A2)						
Urban core	72	1	4	23	0	1
Densely populated/ peri-urban	68	2	10	17	1	2
Forest/(semi-) natural	90	5	4	0	0	0
Agricultural	89	4	7	1	0	0
Mosaic	72	14	13	1	0	0
Global Co-operation (B1)						
Urban core	79	2	2	17	1	0
Densely populated/ peri-urban	73	9	3	13	2	0
Forest/(semi-) natural	86	14	1	0	0	0
Agricultural	81	16	2	1	0	0
Mosaic	59	40	3	1	1	0
Regional communities (B2)						
Urban core	84	4	1	10	1	0
Densely populated/ peri-urban	75	15	3	5	2	0
Forest/(semi-) natural	87	13	1	0	0	0
Agricultural	79	18	2	0	0	0
Mosaic	56	40	3	0	0	0

study has shown how simulation results can be generalized to create a typology that indicates regional tendency in terms of land use dynamics for a specific scenario. The differences between the scenarios indicate the importance of looking at the typology results in the context of the assumptions underlying the scenario definition.

In contrast to most current region typologies that are based on administrative units the typology in this paper is created for high-resolution pixels. Although the use of administrative units corresponds with levels of policy implementation and census information, it is insufficient to deal with the variation in regional characteristics given the diverse trajectories of land change within administrative units. Administrative boundaries often disregard variation in environmental and socio-economic conditions and are, therefore, not appropriate to distinguish regions with similar land use dynamics. Muilu and Rusanen (2004) argue that the boundaries within rural areas form gently grading transition zones making rural change difficult to evaluate in terms of conventional statistical areal units. The argument of these authors to use high-resolution data is also connected with the concept of ecological fallacy. Many administrative regions can contain both rural and urban elements despite their classification in regional statistics. Spatially aggregated

Table 2 Percentage of the area of the rural types facing change in land cover between 2000 and 2030 for four scenarios

Rural type	Stabile	Agricultural abandonment	Agricultural expansion	Urbanization	Urbanization and abandonment	Urbanization and expansion
Global Economy (A1)						
(peri-) Urban	62	9	3	23	2	0
Rural	75	17	4	4	1	0
Deep Rural	85	12	2	1	0	0
Continental Market (A2)						
(peri-) Urban	77	6	8	8	0	1
Rural	82	9	8	1	0	0
Deep Rural	86	6	8	0	0	0
Global Co-operation (B1)						
(peri-) Urban	71	20	2	6	1	0
Rural	70	27	3	0	0	0
Deep Rural	79	19	1	0	0	0
Reginal communities (B2)						
(peri-) Urban	70	25	1	2	1	0
Rural	70	27	3	0	0	0
Deep Rural	80	19	1	0	0	0

average data obscure the variations which occur within the areas concerned which may be important determinants of the processes of interest (Gibson et al. 2000).

The typologies of landscape and land dynamics presented are based on a simple, straightforward analysis of the land use (changes) in a pre-defined neighborhood. Instead of these expert rules empirical techniques such as cluster analysis (Ballas et al. 2003) or factor analysis (Schmitz et al. 2003) could have been used. However, the disadvantage of such techniques is that the resulting categories may be rather complex and difficult to interpret. Therefore, the categories of the typology were set by expert-rules based on the main land use change processes.

The simulation of land use change is based on the demand for agricultural production and land requirements for residential area and the industry/services sectors. The land claims of these land functions dominate land use change. However, many rural development policies aim at managing land by attempting to promote and provide alternative functions such as the protection of agro-biodiversity or landscape characteristics. The protection of landscape structure is rewarded because of the aesthetic qualities or cultural heritage values of landscapes (Hunziker and Kienast 1999; Soliva et al. 2008). In the past such functions were mostly the unintended consequences of land use and land management (Willemen et al. 2008). Nowadays land management can be targeted at the production of these land functions as an alternative to food and feed production. Future land use modeling studies should better account for these land functions as determinants of land use change (Verburg et al. 2009).

The current study has added an extra dimension to regional typologies by including the challenges regions may face in future. Such a dynamic typology may be extremely useful for better targeting regional development policies and/or spatial planning. The simulated dynamics in land use are indicative of the changes and challenges that regions will face. Regional policies are aimed at stimulating a successful adaptation of the region in response to these changes. In case of land abandonment, this may include a change in employment opportunities towards the industry and services sectors or incentives to attract more tourists to the region by providing alternative sources of income and employment (Makhzoumi 1997). Regions facing urbanization may need to adapt to the

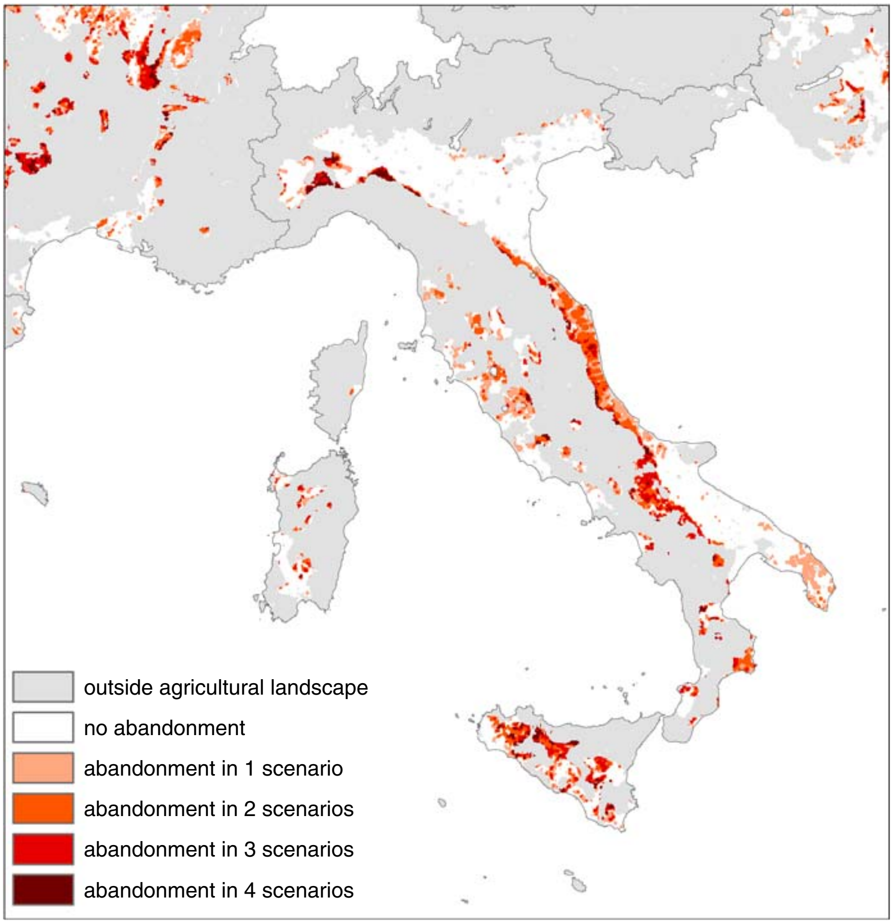

Fig. 6 Detail of map indicating the frequency of simulated abandonment within the agricultural landscapes as defined in Fig. 5

decreasing and reduced role of agriculture and a need for alternative land functions such as recreation (Antrop 2004). Regions with agricultural expansion may be in need of policy intervention to avoid irreversible loss of ecosystems and landscape qualities (Herzog et al. 2006; Herzon et al. 2008). While the region typology as presented in this paper provides some guidance on the spatial extent and location of these policy challenges more region-specific information is needed for adequate policy design targeted at specific region types. There is only a need for policy intervention if regions lack sufficient adaptive capacity or territorial/social capital to adapt to the changes by itself (Adger 2003a; Brand and Jax 2007; Lee et al. 2005; Pelling and High 2005; Smit and Wandel 2006). At the same time, if a region completely lacks the adaptive capacity for a specific transition it is highly doubtful if investments in promoting the transition are likely to be successful. Therefore, the analysis of the adaptive capacity of regions is a third, essential input of region specific information needed to better target policy intervention in regional development. A prominent literature has grown within ecology concerned with adaption, adaptive capacity and vulnerability in terms of the ability of people and environments to adjust to climate change (Adger 2003b; Folke 2006; Smit and Wandel 2006). This resilience literature has mainly focused on a systems ability to absorb shocks and while acknowledging that adaptive capacities, including regional territorial capital, are important for cushioning system shocks, they provide little insight into these territorial features. Policy documents sometimes refer to territorial capital or endogenous potential while referring to the variation in characteristics that influence the development of a location (OECD 2001). One

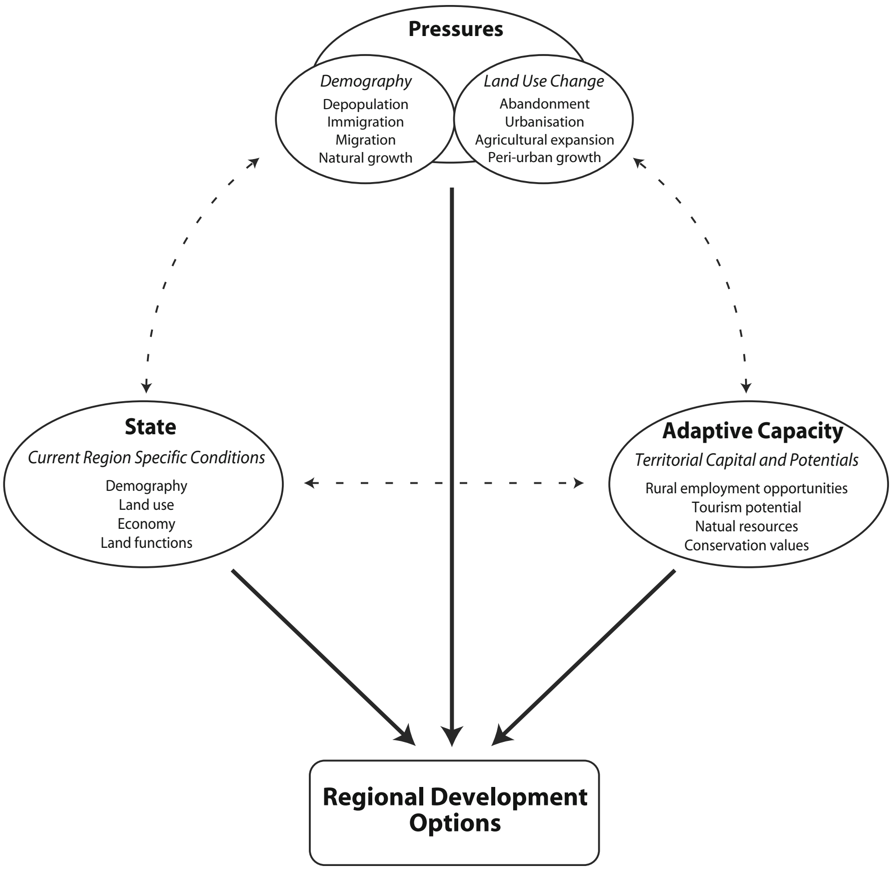

Fig. 7 Regional characteristics needed to explore and design region-specific development options

example of a typology including characteristics indicative for adaptive capacity is presented by Blunden et al. (1998). Their categories indicate areas that are developed and balanced as well as areas with development potential and areas that require economic restructuring. These types are based on a number of characteristics derived from the economic profile of the region. Because the authors use neural networks to link the region types to variables listed in the region's economic profiles it is not possible to reveal the causality used in the analysis (Blunden et al. 1998). It is a challenge for future typologies to include more information on the adaptive capacity of regions to deal with the consequences of land use dynamics (Fig. 7). Although the state, pressures and adaptive capacity are different ways to characterize a region, the strong interlinkages between these three characteristics of a region are apparent. The pressures a region is facing are, to a certain extent, the result of the adaptive capacity of the region. High population densities may lead to urbanization while an aging population may be indicative of land abandonment. Including economic and demographic trends as part of the typology would be a means to specify the challenges of the region in more detail. The current response to a declining agricultural land use in terms of out-migration or diversification of the economy provides an indication of the adaptive capacity. In the current study the pressures only relate to land use changes as result of changes in land requirements for agriculture and urban uses. Therefore, a more in depth study of the adaptive capacity of regions would be valuable to indicate how regions can adapt to these changes.

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