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ORIGINAL ARTICLE

The geology – land use – nexus

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Abstract It is crucial that today's land uses are not decoupled even further from prevailing site conditions. Quite the contrary, the site-adequate use of natural resources ought to be mandatory. This is provided for to a certain extent by the concept of multifunctionality and the exploitation of locational geological potential. Nevertheless, an appropriate course of action has yet to be taken. This can be achieved by applying an appropriate geo-based land use concept. To this end, however, from the scientific perspective alone, there has to be a new level of quality in the interaction between the various specialist disciplines to resolve the nexus problem and to achieve systemic approaches. The gap between the knowledge available in geology and the aspired land use concepts appears to be particularly large. A land use concept that pursues a systemic approach and refers to an adequate extent to geological knowledge provides options for future site-adequate land use as the basis for respective decision-makers or decision-making processes, not any longer conducted by political constraints or economic incentives only.

Keywords Multifunctionality · Site-adequate land use · Ecosystem services · Land use conception

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The issue

Progress in land use techniques now enables land use choices to be made without factoring in the natural foundations of the land. Thus, attempts are practically being made to dissolve the site dependency of geological potential. This process of decoupling uses from locational conditions is necessarily associated with ecologically distorting effects (e.g. the solute balance is altered by agrochemicals and the application of supplements), leading ultimately to unsustainable management practices. Since land use is subject to the will and interests of the owner within the boundaries of social obligations, the owner's benefit understandably follows current market conditions—or those that are expected to prevail in the future. Goods and services that are expected to achieve the short-term maximisation of the owner's benefit are then produced or provided. The following question therefore increasingly arises: Why should land be made available for a certain use at all costs although the natural conditions make this unadvisable? Instead of decoupling land uses from site conditions, the site-adequate, resource-saving or -preserving use of land ought to be the rule. Therefore, a "land use concept" has to be discussed with the scope of offering decision makers potential options for site-adequate, environmentally sound and economically sufficient land use approaches. For mining ontologies (Maedche and Staab 2001; Ichise 2009) in the context of such land use concepts, this requirement might be covered to the greatest possible extend by the discussion of multifunctionality (Helming and Wiggering 2003). Nevertheless, discussions about land use concepts have to go beyond e.g. of the meanwhile more political discussion about multifunctional agriculture. By definition from a political point of view (OECD 2001), this provides a number of social and environmental benefits to society

Fig. 1 Assigning the term post-autistic from an economic discussion onto the land use situation

In 2000, a group of economics students at the Sorbonne in Paris protested against dominant schools of thought in economics. They coined the term "economie autistique" and called for an "economie post-autistique" that offers not only mathematical models that no longer match empirical findings (cf. Guerrien 2002; www.paecon.net). Similarly, a return to site adequate forms of use from current autistic forms of land use would cause us to talk of post-autistic land use.

[draw comparisons to ecosystem services (TEEB 2009)] by maintaining the economic and ecological structure of cultural landscapes. In the end, it turns out to legitimise continued financial support for agricultural producers by the multifunctionality argument. Thus, this discussion has to be directed back to those disciplines being in readiness for knowledge support about the sites and their particular "sensibilities". In this context, the so-called geological potential owes its emergence to the "fortunate interaction between various geological forces and processes" (Meyer 2002). Long periods of time were often involved before this geological potential could be formed. Therefore, geology is a robust data source that can only be changed to a limited extent by humans and that, above all, is available area-wide. In the form of parent rock, geology can act as the key to understand the system of the characteristic processes of entire regions. Thus, rock is formative within the soil zone; it determines the soil type; defines soil processes within soil genesis and has a significant influence on the chemical and hydraulic properties of a landscape (Burke 2002; Hintermaier-Erhard and Zech 1997; Ciolkosz et al. 1989). Likewise, the many morphological shapes are predetermined by geology since, for example, reliefs are primarily the product of local rock (Garcia-Quintana et al. 2004; Nikkarinen et al. 1996). Depending on the parent rock and weathering stability (or weathering resistance), characteristic landscapes with individual developments emerge (Garcia-Quintana et al. 2004).

Meanwhile, there are many intentions for integrating existing data bases from the various specialist disciplines such as soil sciences, climatology, biodiversity research, landscape ecology, landscape planning, socio-economies etc. into a central data basis, particularly for complex issues concerning climate change or questions about biodiversity etc. Dealing with site-adequate land use, leading to the development of a new generation and quality of indicators and assessment processes for future land uses, there are persuasive arguments to involve geology into these approaches.

Closing the gap between geology, soil science and landscape ecology

Would it, then, not be easy simply to bring together the technically specialised disciplines with their respective expertise (Müller et al. 2011) and to join forces to develop an inherently consistent concept for, then, post-autistic site-adequate land use (Wiggering 2012)? Post-autistic site-adequate land use in this sense does mean to turn away from current "system-destructive" land uses (see also Fig. 1).

Regrettably, there continue to be major communication deficits between the disciplines, insurmountable methodological barriers or simply a lack of (science) policy incentives, or distorted ones, for such an approach. What is astonishingly striking is the 'gap' between specialist disciplines such as geology and soil science or landscape ecology, which are actually closely related to one another.

Soils are the result of lengthy weathering processes. Only if they are used adequately can they continue to contribute to added value, meeting society's expectations (ecosystem services; cf. Daily and Matson 2008; Burkhard et al. 2009; Grunewald and Bastian 2013). With soil organic matter, for example, Schmidt et al. (2011) talk in this context of an ecosystem property as the foundation for preserving functions and ecosystem services. Thus, only a very small step must be taken to talk of a new type of property rights (ecosystem property rights).

When, then, scientists from various disciplines equally warn that natural resources are being destroyed by current methods of production and the expectations placed in ecosystem services cannot be met, this should give us food for thought (cf. also Wohlmeyer 2012). The consequence would be a suitable change in course from today's autistic to post-autistic site-adequate production methods. Particularly, the threat and endangerment of the resource 'soil' (politically, the most neglected resource) underscores such demands (cf. Wiggering et al. 2008). This need not necessarily lead to new types of use (Ewert et al. 2005; Maracchi et al. 2005). Often, it suffices to change farming systems such as using different fertilisation regimes or introducing irrigation (cf. Wiggering et al. 2008). As such, it is not only sensible but also absolutely necessary to examine in depth the natural conditions of land and to align land use systems to this potential, in spite of the enormous economic pressure, thus simultaneously acting on calls for sustainable development and hence providing an orientation to the future.

Comprehensive research results have indeed been presented on the correlation between parent rock and soil genesis (Haslinger et al. 2007; Shaw et al. 2004; Carter and Ciolkosz 1991; Ciolkosz et al. 1989). The findings of the soil series dependent on the parent rock should generally be used to assign soil types and specific soil properties to a geological unit, to link these to suitable land cover categories (nexus) and, in conclusion, to illustrate site-adequate, sustainable landscape use involving exclusion criteria. For this reason, it is assumed that geology manifests the shape of the controlling gradients within the landscape. Particularly in regions with comparatively low weathering energy, mineralogy with specific physico-chemical properties of the parent rock has the greatest influence (Jordan et al. 2007; Darmody et al. 2000) on the quality of the site, since soil genesis processes are not yet very advanced. Correspondingly, Stendahl et al. (2002) find that the presence of mafic minerals is an important prerequisite for a high-quality site. Apart from nitrogen, mineral weathering provides all of the nutrients that are essential for plant growth, thus also controlling their long-term availability, which is why it does not suffice to consider topsoil only (Stendahl et al. 2002). Jordan et al. (2007) show for 14 chemical elements that element concentrations in soils (soil chemical composition) give a clear indication of the underlying types of rock. Hwang et al. (2005) interpolate point data from a total of 34 elements or oxides, enabling them to predict the geological unit in 80 % of the cases with the assistance of decision tree techniques, quantitatively confirming the close relationship between them. This relationship is by no means contested in any way, quite the contrary. Nevertheless, geology has so far played a minor role in landscape ecological analyses and planning in rural areas in connection with the description of land use potential and options (Garcia-Quintana et al. 2004; Hughes 1995). Although geological/geomorphological studies were focused on under the term 'physiographic regions' in the second half of the 19th century, their findings were superseded by the consideration of individual process in the twentieth century, with regard to sustainable landscape development (Garcia-Quintana et al. 2004).

However, there are exceptions: for example, Thwaites and Slater (2000) employed this approach, which yielded valid results for a site assessment they had undertaken. Haslinger et al. (2007) suggest that land movements blur the starting material reported in the geological map, making ecological interpretation difficult. Similarly, Jordan et al. (2007) explain freak values with regard to the soil chemical composition dependent on local rock by the blurring of different types of material.

In general, however, the question is rarely answered which ecologically regularly recurring sites develop on rock from a consistent static assignment and whether these interrelations can be exploited to assess whole regions in terms of their site characteristics. This also applies to the question whether a loss of information between geology and soil as a central basis for assessment with regard to site-oriented land use at the regional scale can be expected (Fig. 2), and the extent of such loss.

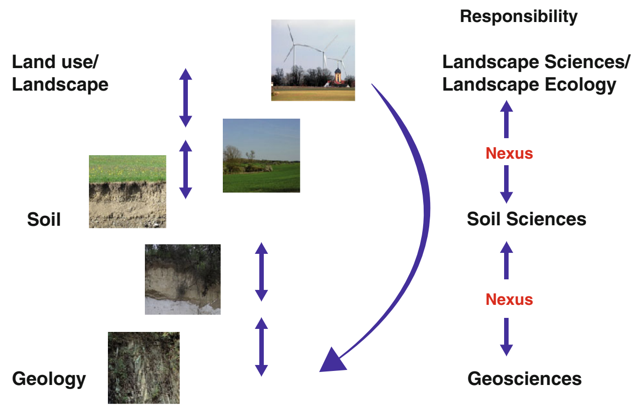

Fig. 2 Schematic interrelation between geology/soil/landscape

In areas that are underdeveloped in terms of soil science, the lack of area-wide location data has led to the development of geology-based approaches that "deliver reproducible information about site-specific conditions" (Binner et al. 2005). Geology is also an important data basis in the development of various digital soil science maps, particularly in geologically young regions containing Quaternary deposits.

It is also essential to understand the interaction between geology and the biosphere, which helps us to comprehend ecosystems. For this reason, research approaches must be adapted and developed that integrate geology as a basis for decisions on land use in rural areas (Hughes 1995). The correlation between geology, individual tree species and the potential natural vegetation cover (Socha 2008; Black and Abrams 2001; Forsyth 1970) and the associated processes between the lithosphere, pedosphere and biosphere is actually sufficiently documented (Neely and Barkworth 1984; Rohrer 1983; Wentworth 1981; Forsyth 1970). For example, Haslinger et al. (2007) determined that vegetation reflects the parent rock better than the geological map to which they had access. Garcia-Quintana et al. (2004) reached a similar conclusion, after yielding better results for designating geological units using vegetation boundaries from aerial images than determining them directly in the field.

In urban land use planning, meanwhile, geology is the central data basis for undertaking suitability analyses for settlement areas, particularly in rapidly developing countries such as China (Dai et al. 2001). Risk assessments concerning the endangerment of infrastructure due to land movements on inclines, for example, are also carried out using geology (Ohlmacher and Davis 2003). Mainly methodological approaches with regard to the designation of potential land coverage suitability in rural areas can be used and transferred, in part, from these studies.

The importance of also taking into account local rock in the isolated examination of individual processes is highlighted differently. In water-body protection, for example, the local geology plays an important role alongside the current land use to be able to interpret a region's measured nutrient and trace substance content against the geogenic background load (Xie et al. 2005; Zepp 1999). Following many years of research into source acidification in different uplands, Beierkuhnlein et al. (1999) discovered that the parent rock superimposed the after-effects due to buffering to such an extent that it was very difficult to make statements about the anthropogenic degree of acidification.

In ecological landscape assessments to evaluate the quality of a site, approaches are currently being pursued in which single parameters or subindicators are recorded in small study areas or on individual areas, and combined into an indicator by weighting, using statistical methods (Velasquez et al. 2007). Although in connection with laboratory analyses these field- and process-oriented 'bottom-up' approaches lead to very precise local results, they have so far been infeasible for large study areas owing to the great amount of effort involved (Guggenberger et al. 2007). One possibility is 'upscaling', where results from small study areas are transferred to larger areas (Röder et al. 2003). Here, too, however, no universally valid theories on deriving regionalisation rules exist as yet (Volk and Steinhardt 2001). Instead, a plethora of methods exist side by side that pursue both knowledge-based and geo- or regression-statistical approaches.

In the assessment of land coverage suitability and potential, soil has so far played the leading role in all considerations (Ziadat 2007). To this end, however, current data have to be available since soil, unlike geology, is usually changed to a greater extent by anthropogenic influences. Exceptions with regard to geology are large-scale changes such as earthquakes, volcanic eruptions, and so on. However, geology can be deeply, extensively altered in mining regions, particularly in regions featuring underground or surface coal extraction or regions where salt or ore mining involving considerable mass displacements is practiced (cf. Wiggering 1993). In the generally considered context, however, these are exceptional situations.

Since it is an expensive and time-consuming process, by no means all regions are represented on large-scale soil maps because this necessitates extensive updating and aggregation. The availability of soil data is therefore often a limiting factor (Ziadat 2007; Wu et al. 2001), necessitating supplementary information or a switch to other data bases (Thwaites and Slater 2000). In addition, it should be borne in mind that existing geological and soil data are potentially subject to such considerable anthropogenic overprint, which can lead to false conclusions being drawn with regard to recommendations for use.

The land use concept as a framework for proceeding jointly

The challenge is to develop site-adapted, sustainable and region-specific land use systems under changing framework conditions such as the climate and globalisation. The knowledge and available data from the various specialist disciplines should be utilised in a new synthesising manner and geology should have a share in this. The development and discussion of suitable conceptual approaches is a key requirement for this. However, even then recommendations for measures and implementation steps would still be lacking. It must be made clear that today's agriculture and forestry should similarly meet the requirements of biodiversity, leisure and recreation in addition to producing food, animal feed and so-called non-food raw materials. At the same time, the continued expansion of settlements and their infrastructure reduces the area available for agricultural and forestry use. Altered energy provision via biomass production and use, photovoltaic systems and wind turbines, and the grid connections they require, will also bring major changes to land use in future years. Ambitions to packetize these demands within conceptional approaches take place almost without consideration of geology, not realising how important the functions due to geology are. At the same time, the functions of the deeper underground, soils and the landscape as a whole are being discussed in connection with diverse ecosystem services (cf. current endeavours to conduct so-called TEEB surveys (TEEB = The Economics of Ecosystems and Biodiversity) everywhere (TEEB 2009). As a foundation for this, the deliberations on ecosystem properties brought into the discussion by Schmidt et al. (2011) should simultaneously be considered. Since all of these different uses and claims refer to the same land, conflicts of interest and usage are inevitable. Land use conflicts in all kinds of regions are therefore more or less inevitable, which is why it is essential to devise a land use concept tailored to these issues to foster spatially explicit decision support (cf. also Bryan 2003; Wiggering 2012), ultimately to prevent the degradation of existing resources (Ziadat 2007). Mapping ontologies within this discussion about land use concepts, at first glance sementical problems as well as overlappings between numerous comparable approaches may occur. Basely all are neglecting the importance of the geology within this context.

Nevertheless, it can by no means be assumed that an appeal to common sense will lead to land users reverting to the site-specific use of the resource 'land' as long as other decision criteria are imposed externally with such urgency. It therefore seems even more essential for one or even several test regions (cf. ZALF' ScapeLabs; ZALF 2013), liberated from these economic constraints, to follow a different path and to develop so-called post-autistic, site-adequate land use. The 'time' factor alone currently contradicts the idea that this path will be followed voluntarily, for rational reasons (cf. Wohlmeyer 2012). After all, current research approaches in applied research are far too short-sighted. Only such a long-term, large-scale landscape experiment, liberated from all external economic constraints, for example, on a suitable farm (trial farm; *i.e. 'in farm'* rather than *'on farm')* can facilitate a shift to 'new' production systems. In the political arena, it has become fashionable for various productions to develop so-called strategies (cf. biomass strategies, renewable energy strategies, biorefinery strategies, and so on). Unfortunately, however, such strategies are often merely situation analyses. What is more, they are usually only designed for 10, or possibly 20 years, meaning that these too fall far short of what is required. This discussion immediately would benefit from introducing the mindset of geology about time scales. However, research strategies are also far too short-sighted (cf. Horizon 2020), meaning potentially appropriate research approaches are stifled. Today's so-called field experimentation also focuses too little on long-term projects. The necessity to supply public service tasks is so compelling that a response to imminent problems is nearly always only possible, rather than looking ahead to future issues. In addition, all of the areas mentioned take a disciplinary approach or demonstrate disciplinary or sector-specific responsibilities, which are repeatedly viewed as a barrier to a systemic approach. But this also does mean, that geologist on their part have to go offensive into these discussions to offer their specific knowledge in this field. Nonetheless, the first step, therefore, would be to seek to undertake long-term landscape research directed at the points mentioned, with long-term landscape monitoring. On the one hand, political commitment is required to develop these research strategies. On the other hand, there must be incentives to ensure that the respective specialist disciplines consider it worthwhile—in terms of acquiring third-party funding and publishing possibilities—to pursue this cross-sectional path.

At this point in time, however, it must be stated that the principle of sustainability for future landscapes and site-adequate land use is often desired, but its implementation has so far proved to be difficult, as has repeatedly been—and continues to be—pointed out (Antrop 2006; Wiggering 2012). One starting point for the implementation of more efficient land use systems is an orientation towards natural resources (Glemnitz and Wurbs 2003; Herrmann 2001): natural landscapes are not fictional, but can only be developed if natural qualities, functions and framework conditions have been analysed in detail (Antrop 2006; Bastian and Lütz 2006; Volk and Steinhardt 2001), starting with the geology.

In many cases, such strategies are implemented by way of incentive programmes and direct subsidies, without capturing and weighing up the effects they have on other strategies and expectations. A land use concept based on the outlined approach is capable of showing how the complexity of land use can be captured, conflicts of interest and usage identified and solutions developed for resolving them. Unfortunately, this does not fit in with prevailing research promotion mechanisms.

Conclusion: land use concept

The scarcity of the resource 'land' is obvious. Notice is taken of current land use—the distribution of land use forms for settlement, infrastructure, agriculture, forest, 'pure nature', and so on—and any change, such as the ploughing up of grassland, the designation of a development area and even the one-sided cultivation of a crop, is perceived as a threat.

If land and how it is used is also perceived by everybody and reflected and commented upon by all or most people, then it by no means constitutes a shared asset, but is subject to the commitment and interests of the owner, within the boundaries of social obligations. The owner's benefit, in turn, follows current market conditions—or those that are expected to prevail in the future. Goods and services that are expected to achieve the maximisation of the owner's benefit are then produced or provided. Due to increasing codification, the decision-making scope for land users is restricted to intervene by regulatory law where externalities lead to market failure.

After all, the type and intensity of land use is the subject of a multitude of strategy plans in the political area: in addition to producing food, animal feed and raw materials (e.g. timber), agriculture and forestry are now also able to increasingly generate energy sources. In addition, the requirements of biodiversity and recreation must also be taken into consideration. At the same time, the continued expansion of settlements and their infrastructure reduces the area available for agricultural and forestry use. Since all of these different uses and requirements refer to the same land, conflicts of interest and usage are inevitable. How to deal with these inevitable usage conflicts is touched upon in multifunctionality concepts (Wiggering et al. 2003, 2006; Brandt and Vejre 2004). And the recent debate on ecosystem services in particular (Grunewald and Bastian 2013) calls for realisable approaches to avoid conflicts. The respective specialisms are indeed able to use their expertise to resolve these issues. Unfortunately, however, most usually proceed separately, and sometimes even in competition with one another, meaning that systemic approaches are often still a long way off. In this context, geology as a systemic approaching discipline, familiar with complex issues and long-term processes, should not feel cut out this challenge.

Particularly in view of additional future challenges, it must be stated that, for example, altered energy provision via biomass production, photovoltaic systems and wind turbines, and the grid connections they require, will also bring about major changes to land use in future years. In many cases, such strategies are implemented by way of incentive programmes and direct subsidies, without, again, capturing and weighing up the effects they have on expectations and other strategies, most of which aim at solving individual problems. In this connection, adaptation to climate change is particularly important. These issues concede the case for a concerted approach by specialist disciplines, which possess the necessary problem-solving competence as e.g. the geologist do have.

A land use concept is capable of showing how the complexity of land use can be captured, conflicts of interest and usage identified and solutions developed for resolving them, meeting a key function of providing a framework for interaction between disciplines and responsibilities.

A land use concept is not just another planning tool that stands side by side with existing tools such as spatial planning and regional planning or expert planning such as landscape programmes and forestry framework planning, and so on. Instead, a land use concept is a tool that can be used not only to consistently generate detailed area-related planning, but also to enable future strategic planning to be derived in a more realistic manner.

The land use concept makes visible the conflicts of interests caused by these claims to land, and develops proposals to resolve them. In addition, a land use concept shows political decision-makers the need for action, as well as the options for action, to adapt regulatory law, incentive and support schemes, and other forms of strategy planning, to needs.

To develop a land use concept, first of all (a) existing land use systems must be analysed, and the strengths and weaknesses, as well as opportunities and risks specified. A key area here is capturing the exogenous factors that determine the type, extent and intensity of land use systems. These include not only regulatory law, but also the expectations and requirements of consumers and the general public. The exogenous factors particularly include the requirements laid down in support programmes and incentive schemes, and an assessment of their bindingness (layer 1).

In parallel with the analysis of existing land use systems (b) the condition and potential of sites in their current and future states are assessed (layer 2). In this connection, not only geology, soils and climate are considered, but also the location (e.g. concerning centres of consumption or infrastructure) and natural endowments such as the occurrence of species. This is then connected to a risk and sensitivity analysis.

In an additional step (layer 3) (c) the requirements and expectations on land use are derived from existing strategy planning and from the present and future demand for ‘general’ goods and services (ecosystem services) (Grunewald and Bastian 2013). And in this context in particular, the individual specialist disciplines (including geology) must assume responsibility for assessing the respective opportunities and risks involved, offering scenarios as basis for decision making.

The steps described above generate layers that, when superimposed, reveal not only land use potential, but also, above all, conflicts of use and interest. The actual conceptual step is weighing these against one another and, where necessary, making adjustments to strategy planning, the regulatory framework, incentive and support schemes or actual land use systems.

The aforementioned method requires a great deal of specialist and interdisciplinary competence in the analysis phase; at the conception stage, the participatory involvement of relevant stakeholders is the key to success.

As a methodological approach, it is evident to draw e.g. on available GIS technologies etc. to merge the multifaceted information and to support narrations. This does step into a linkage to meanwhile common impact assessment procedures (Helming et al. 2011, 2013). Such an analysis of intended and unintended impacts can be undertaken by screening of so-called impact areas e.g. offered by the European guidelines of impact assessment (CEC 2009). These have been compiled with the rationale to treat the three dimensions of sustainable development equally, and to cover possible topics that might be of relevance for the unequal decision-making process. This gives the opportunity to use established guidelines as a check list for assessment. Implementing the idea to involve the knowledge of geology as a site parameter, this will raise further questions and broaden the discussion on impact areas. Nevertheless, it will bring more fundamentals into the assessment of the respective site-situation and therewith focus the discussion on site-adequate land use approaches.

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