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Responses of agricultural bioenergy sectors in Brandenburg (Germany) to climate, economic and legal changes: An application of Holling's adaptive cycle

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HIGHLIGHTS

- Bioenergy sectors respond to climatic, economic and legal changes in different ways.
- Responses to changes expose critical features and bottlenecks of bioenergy sectors.
- Resilience, potential and connectedness are critical features for bioenergy sectors.
- Stages of development of the biogas and biofuel production sectors are identified.
- Effective policy design needs to match the sectors' features and development stages.

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ABSTRACT

Agricultural bioenergy production is subject to dynamics such as yield fluctuations, volatile prices, resource competition, new regulation and policy, innovation and climate change. This raises questions, to what extent bioenergy production is able to adapt to changes and overcome critical events. These dynamics have important implications for effective policy development. Using a case study method, which draws on various data sources, we investigate in detail how agricultural bioenergy sectors in the German State of Brandenburg adapted to diverse past events. The case analysis rests on the adaptive-cycle concept and the system properties *potential*, *connectedness* and *resilience* as defined by Holling and Gunderson (2002a). Our case study concludes that Brandenburg's biogas sector has a low *potential* and *connectedness* within the system, and a low *resilience* against crop failures. The biofuels sector displays similar properties in the short term. In the medium term the *potential* could increase in both sectors. The properties imply risks and opportunities for biogas production and the possibility to develop towards a stage with a higher *potential* and a higher *connectedness*. But adaptive capacity is limited and there are certain barriers for the agricultural bioenergy sectors to overcome potentially critical states. Policy needs to be tailored accordingly.

1. Introduction

Bioenergy production was expected to contribute significantly to agricultural incomes, employment in rural areas, energy supply and greenhouse gas mitigation (European Commission, 2007). But current evidence for the European Union suggests volatile bioenergy outputs (EurObserv'ER 2010a, 2010b, 2010c) and the wider economic, social and environmental impacts of bioenergy are not conclusive (Buchholz et al., 2007, Fernando et al., 2010; Fargione et al., 2010). Agricultural bioenergy production can be an important activity for farm enterprises, as it is seen to offer possibilities for the diversification of income sources, increasing the value added to farm products, decreasing dependence on market prices and making better use of farm resources (Ehlers, 2008; Hillebrand et al., 2006; Müller et al., 2008; Tranter et al., 2011; Uckert et al., 2009). Agricultural bioenergy production is not smoothly developing and takes place in complex social–ecological settings. Challenges include new regulations and policy, volatile market settings and increasing costs for inputs (Klauss et al., 2009), fluctuating yields, competition for land and other resources, novel

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technology, high capital costs (Tranter et al., 2011), but also climate change (Bahrs, 2009; Banse et al., 2011; Qaim et al., (2009); Stock, 2009). Such diversity of critical factors raises the question whether agricultural bioenergy production is able to adapt to change and what policies are adequate to help it adapt. Questions of adaptation are of increasing concern in energy policy (O'Brien and Hope, 2010; Pereira de Lucena et al., 2009) and climate policy (Adger et al., 2009; Grubb et al., 1995; Rayner and Andrew (2010); Tol, 2005), but empirical analysis remains limited.

Our objective is to analyse how agricultural bioenergy sectors in the Federal State of Brandenburg responded to certain climate, economic and legal changes within the wider context of bioenergy production in Germany. We evaluate the specific properties of the agricultural bioenergy sectors in the Federal State of Brandenburg in several situations of change. The properties are related back to policy variables, such as the abolishment of cereal market intervention or increased payment for electricity from biomass.

Bioenergy is generally ill defined and many sorts of bioenergy are being discussed. Throughout we limit our analysis to specific sectors of bioenergy, which we call agricultural bioenergy. Agricultural bioenergy production in our case refers to (a) crops produced for automotive fuels (i.e. biodiesel and bioethanol) and (b) purposely grown crops and residue biomass of agricultural origin for electricity production including combined heat and power generated from biogas. They are the two dominating agricultural biomass sectors in Germany and the Federal State of Brandenburg. All other forms of bioenergy, such as short rotation coppice, wood and straw combustion and co-firing are used to very limited extents.

In our study we focus on the adaptive use of agricultural resources for bioenergy production, rather than adaptation of specific bioenergy production technologies. In our approach, adaptation refers to the change and reorganisation of ecological, technical and social systems encountering changing external or internal circumstances (Holling et al., 2002b). Properties related to such adaptive change of a system are the flexibility of relations and behavioural patterns of system elements, the range of possible actions and the time-scales needed to implement strategies and actions for adaptation. Holling et al. (2002a, 2002b) propose *connectedness*, *potential* and *resilience* as the three properties that help to develop frameworks for assessing the development of a system. We aim to assess agricultural bioenergy sectors as systems and identify stages of development, based on the properties *connectedness*, *potential* and *resilience* of agricultural bioenergy sectors. The identified properties and stages of development enable us to evaluate the responsiveness of agricultural bioenergy sectors to specific changes and associated potentials, risks and limitations to adaptation.

We investigate changes in agricultural bioenergy production in Brandenburg that followed cross cutting events in agriculture and bioenergy production in Brandenburg and in Germany, such as droughts or changing input and output prices. The changes can have implications for the properties of *connectedness, potential* and *resilience,* and associated stages of development of agricultural bioenergy sectors. In our assessment of the development of the agricultural bioenergy sectors we identify stages and properties of the sectors that are critical for adaptive capacity. A more detailed comprehension of the link between the properties, the stage of agricultural bioenergy development and the respective needs to adapt, is needed when aiming to develop policy that supports more sustainable bioenergy production.

2. Analytical framework and data

2.1. Analytical framework

We use an explicit analytical framework as part of a case study method (Yin, 2003), bound to the adaptive cycle of a bioenergy sector. In the framework, events can induce a quantitative and/or qualitative change in a system. In our analytical framework the properties of a bioenergy system change quantitatively, for example in terms of size, and qualitatively, for example in changes of crops used, as a result of certain events (Fig. 1). A decisive question is what criteria and parameters are used to describe change. A simple parameter is the area used to grow crops for bioenergy. Events can result in an increase or decrease of the area cropped for bioenergy. Events can also have impacts on yields *and* result in an increase or decrease of the productivity of the land. Events, like new subsidies and regulation, can influence several parameters at the same time. Such events, however, would commonly feedback on production quantity and quality.

Different options to adapt to change exist and can be pursued with different intensities. They are depicted in Fig. 1 by the

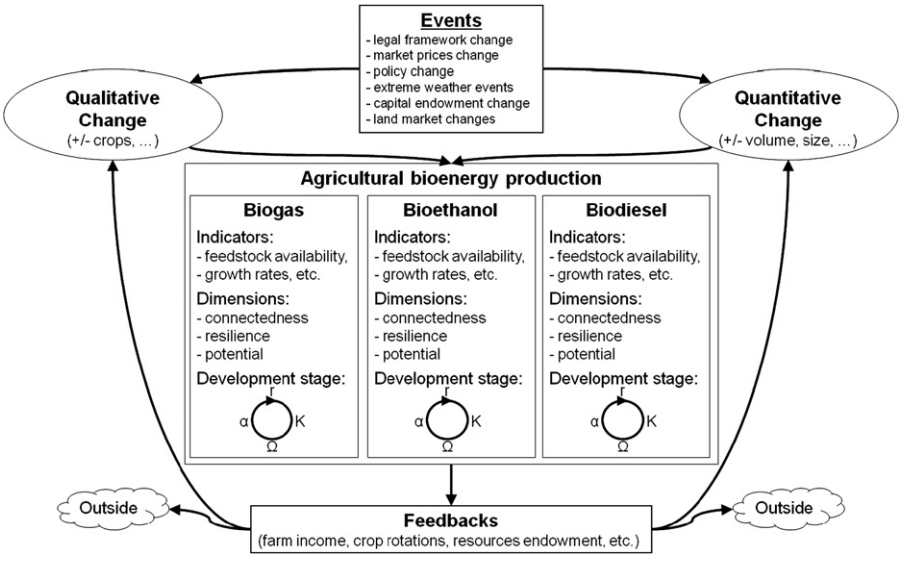

Fig. 1. Framework for analysing change in agricultural bioenergy production sectors with internal and external variables and evaluation properties (Authors' own).