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Research paper

The mitigation potential and cost efficiency of abatement-based payments for the production of short-rotation coppices in Germany

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ABSTRACT

In Northern and Central Europe, short-rotation coppices (SRC) have become a profitable agricultural production alternative, particularly for marginal fields with suitable groundwater levels. Furthermore, the replacement of fossil fuels by the wood chips produced in SRC contributes to the mitigation of greenhouse gases (GHGs). Due to heterogeneous regional production conditions, the impacts on the economy, production and GHG mitigation are expected to vary widely by region.

Several studies investigate the specific agronomic, environmental and economic aspects of SRC. However, only a few studies present a concise analysis of more than one or all of these aspects or evaluate SRC as a mitigation strategy. This study complements the existing literature by estimating the mitigation potential from SRC in Germany. It presents an integrated modeling approach that considers agronomic and economic aspects and investigates the mitigation potential and the abatement cost efficiency arising from abatement-based payments.

The simulation of different payment scenarios indicates that SRC could mitigate up to 15% of the German agricultural sector's GHG emissions. The integrated model approach links a site model and the agro-economic model RAUMIS and can be regarded as a fruitful development for addressing SRC-related research questions as well as a promising base for further work.

1. Introduction

In Germany, short-rotation coppices (SRC) have become a new alternative product for marginal land requiring low levels of inputs [1]. Recent technological progress (e.g., in breeding, harvesting, pellet processing), increased demand for renewable energies and new political incentives (e.g., through energy policies) have improved the production conditions for SRC. In addition, compared to arable use, SRC is associated with higher biodiversity [2] and can elevate the structural diversity of landscapes [3]. Other advantages of SRC compared to annual arable crops are the reduced use of pesticides and fertilizer as well as the reduced risk of soil compaction and erosion [4]. In addition, the wood-chips produced in SRC can replace fossil fuels and can therefore mitigate climate change.

Although these developments have improved the competitiveness of SRC, producers have converted only a small agricultural area to SRC (e.g., on side strips), amounting to only 65 km^2 (out of about 160,000 km^2 total agricultural area) [5]. Due to the expected positive impacts for producers and society, researchers attempt to explain the producers' unwillingness to produce SRC and policy makers intend to develop policy instruments to increase their interest.

Due to the high competition for agricultural land between SRC and conventional production (cash crops and fodder production), assessing the potential impacts of a stronger promotion of SRC requires a regionally disaggregated analysis of SRC production in the context of competing land uses rather than investigating SRC as a stand-alone or in the context of partial agricultural programs.

1.1. Background: recent developments in SRC

In general, the cultivation of SRC requires low input costs. However, the conversion to SRC implies high entrance costs, a long-term investment period for capital and initial lag periods without

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harvest and revenue. Harvest costs represent more than 50% of the total costs and depend strongly on the topography [6]. Whether farmers adopt SRC depends on SRC's competitiveness with normal agricultural production activities. This competitiveness is influenced by the profitability of the SRC and of the conventional agricultural production, i.e., the opportunity cost of giving up this production. The competitiveness of SRC depends strongly on the site conditions, with factors such as climate (temperature, precipitation), soil characteristics (available water capacity and groundwater level) and topography (level terrain allowing mechanical harvest) influencing the profitability of SRC [7–10] and more conventional forms of agricultural use.

1.2. State of the art: recent studies in SRC

Most of the existing SRC studies focus on specific agronomic, economic or environmental aspects. Based on the applied methodology and research scope, this literature can be broadly grouped into several primary strands.

Agronomic studies addressing SRC production and site-specific topics represent the first important strand. Many studies are based on empirical or experimental data, and the results are based on a limited number of experimental plots or smaller regions. These studies focus on the availability of production factors such as water ([11] in Sweden) or assess production costs including harvesting costs [6]. Furthermore, regional yield potentials are derived ([12] for sites in Sweden) with respect to the site-specific selection of species ([13] for sites in Sicily) or varieties ([1] for sites in Poland [14], for sites in Denmark). Wickham et al. [15] provide a more comprehensive overview of these topics.

A second strand of the literature develops yield potential or site models based on the empirical results for regional production conditions. These studies either provide spatial analysis of yield potential and site-suitability maps for entire production regions ([16] for the UK [17], and [18,19] for England and Wales) or an impact assessment ([20,21] for Saxony). Further studies consider SRC in the broader context of agricultural production or other land use forms. Some of these studies are based on production data and provide farming recommendations [22,23]. Other regional studies are based on site models and assess the production potential given land use and societal constraints [24–26]. However, the distribution and extent of SRC in these site models is derived from agronomic information and legal/societal constraints and is not driven by economic decision-making algorithms. Therefore, these studies derive a technological potential that normally greatly exceeds the economic potential.

The third strand of the literature addresses the economics of SRC. These studies address issues such as production costs and determining factors [27] or analyze the production chain of SRC [28,29]. The explanation of the farmers' reluctance to convert agricultural land to SRC has gained some importance in recent years [30–32].

To evaluate the relative profitability of SRC, most studies use a representative gross margin computation of selected crops [32–35] or representative sites [36]. However, the studies consider neither the site conditions of complete regions nor the competitiveness of SRC in the context of a region's agricultural structure.

In a last strand of the literature, SRC is evaluated with respect to its impacts on biodiversity, sustainability and greenhouse gas (GHG) emissions. The studies can be based on empirical data [2,3], impacts on biodiversity, models [37], isoprene emissions, producers' recommendations [38] or conceptual works [39,40].

Only a few studies include agronomic, economic and environmental aspects by using empirical and/or model-based approaches and integrating research results for more than one of these aspects for study regions ([41] and [42] for the UK [43], for Eastern Germany). Strohm et al. [5] provide a concise study with a multidimensional assessment of SRC and consider subsidies as political instruments to support SRC production in Germany. Their study is based on case studies and representative farm-type models and thus is not representative of SRC production and does not allow for a regionally differentiated impact assessment.

Many studies cover different aspects of SRC using different approaches. However, assessing the economically feasible mitigation potential and the cost efficiency of abatement-based payments for production concisely and consistently requires a research framework that covers Germany completely with respect to (1) the regional site conditions for SRC production, (2) the regional agricultural production programs and regional competitiveness and (3) the agro-economic production behavior, all while (4) accounting for GHG emissions.

This study complements the existing literature by estimating the mitigation potential from SRC. It presents an integrated modeling approach in which SRC is a component of agricultural production at the regional level. The developed model considers agronomic, agricultural and economic aspects and allows for an evaluation of the GHG mitigation effects of SRC. The study investigates the marginal mitigation costs based on payments for mitigated GHG emissions and the impact of the payments on the competitiveness of SRC.

We describe the integrated model applied in this study in Chapter 2. Chapter 3 presents the scenario assumptions and the simulation results. Chapter 4 discusses the methods, the scenarios and the results in the context of other studies, and it is followed by the conclusions in Chapter 5.

2. Method: the integrated model approach

The integrated model approach used in this study links the agricultural supply model RAUMIS (Regional Agricultural and Environmental Information System) with a newly developed site model for SRC. RAUMIS uses the site model estimations of regional yields and cost data to calibrate regional production functions for SRC. Thus, RAUMIS simulates regional agricultural production, including SRC, in competition with conventional agricultural production and allows for the analysis of simulated markets and policy settings (Table 1).

2.1. Regional agriculture, the environment and the economy according to the agro-economic model

The regional agricultural supply model RAUMIS [44,45] uses 40 different agricultural crops and animal production activities to represent the agricultural system for 326 regions in Germany. As a regional economic model, RAUMIS maximizes agricultural income by optimizing production programs. It computes indicators for environmental impacts and allows for the simulation of price and policy scenarios.

In RAUMIS, conventional production activities are based on statistical data. Based on these data, non-linear production functions are derived and calibrated using the PMP method according to [46]. The non-linearity accounts for factors that are not directly observed but influence the past distribution of activities (e.g., risk aversion, site heterogeneity, etc.) [47].

Due to the novelty of SRC production, the empirically observed historical data required to estimate parameters defining the non-linearity are missing. Thus, the SRC production activities were calibrated as linear production functions into the non-linear model. However, the non-linearity of the conventional production function drives the simulation behavior of the SRC functions in a non-linear