Journal of Environmental Management 192 (2017) 171–183

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Climate change and the economics of biomass energy feedstocks in semi-arid agricultural landscapes: A spatially explicit real options analysis

Courtney M. Regan [a], [*], Jeffery D. Connor [b], Ramesh Raja Segaran [a], Wayne S. Meyer [a], Brett A. Bryan [b], Bertram Ostendorf [a]

[a] School of Biological Sciences, University of Adelaide, PMB 1, Glen Osmond, SA, 5064, Australia
[b] CSIRO Land and Water, Waite Campus, SA, 5064, Australia

ARTICLE INFO

Article history:
Received 19 April 2016
Received in revised form
13 January 2017
Accepted 21 January 2017

Keywords:
Real options analysis
Climate change
Spatial
Biomass
Economic
Australia

ABSTRACT

The economics of establishing perennial species as renewable energy feedstocks has been widely investigated as a climate change adapted diversification option for landholders, primarily using net present value (NPV) analysis. NPV does not account for key uncertainties likely to influence relevant landholder decision making. While real options analysis (ROA) is an alternative method that accounts for the uncertainty over future conditions and the large upfront irreversible investment involved in establishing perennials, there have been limited applications of ROA to evaluating land use change decision economics and even fewer applications considering climate change risks. Further, while the influence of spatially varying climate risk on biomass conversion economic has been widely evaluated using NPV methods, effects of spatial variability and climate on land use change have been scarcely assessed with ROA. In this study we applied a simulation-based ROA model to evaluate a landholder's decision to convert land from agriculture to biomass. This spatially explicit model considers price and yield risks under baseline climate and two climate change scenarios over a geographically diverse farming region. We found that underlying variability in primary productivity across the study area had a substantial effect on conversion thresholds required to trigger land use change when compared to results from NPV analysis. Areas traditionally thought of as being quite similar in average productive capacity can display large differences in response to the inclusion of production and price risks. The effects of climate change, broadly reduced returns required for land use change to biomass in low and medium rainfall zones and increased them in higher rainfall areas. Additionally, the risks posed by climate change can further exacerbate the tendency for NPV methods to underestimate true conversion thresholds. Our results show that even under severe drying and warming where crop yield variability is more affected than perennial biomass plantings, comparatively little of the study area is economically viable for conversion to biomass under \$200/DM t, and it is not until prices exceed \$200/DM t that significant areas become profitable for biomass plantings. We conclude that for biomass to become a valuable diversification option the synchronisation of products and services derived from biomass and the development of markets is vital.

1. Introduction

De-carbonising global electricity generation is seen as key to stabilise atmospheric greenhouse gas levels (Edenhofer et al., 2014). Biomass production for use in electricity generation (hereafter biomass) is proposed as a renewable energy source that can contribute to the mitigation of climate change through direct CO_2 sequestration and through the replacement of higher CO_2 emitting fuels such as coal and oil (Bryan et al., 2008; Evans et al., 2010; Styles and Jones, 2007). The use of biomass (often in the form of agricultural residues, bagasse, forestry residues) is widespread globally, producing 280 TWh of electricity, equivalent to 1.5% of global electricity generation per annum (Eisentraut and Brown, 2012). But for biomass to play a significant role in future global energy supply, dedicated energy crops often grown on current

---

[*] Corresponding author.
E-mail address: courtney.regan@adelaide.edu.au (C.M. Regan).

http://dx.doi.org/10.1016/j.jenvman.2017.01.049
0301-4797/

agricultural land will be essential (Coleman and Stanturf, 2006; Evans et al., 2010).

Economically, biomass production has been found to be potentially competitive with conventional agricultural enterprises as the yields associated with production of woody perennials are often less sensitive to climatic variables and require fewer inputs (Bryan et al., 2010b; Heaton et al., 1999; Styles et al., 2008). In agricultural areas with variable climate and soil, the introduction of short rotation woody perennial production systems that use adapted woody species could provide a valuable diversification option. Moreover, it may offer the opportunity to buffer seasonal and annual variations in rainfall that cannot be reliably used by annual crops (Hobbs, 2009a). Internationally, where biomass supply chains are more developed, landholders have been slow in switching land use, particularly between agriculture and forested use despite potential profitability (Plantinga, 1996; Schatzki, 2003; Stavins and Jaffe, 1990). An explanation of this perceived investment inertia is that financial analysis of land use change has traditionally assumed the decision to switch land use can be modelled based on the Net Present Value (NPV) which compares current agricultural land uses with biomass alternatives (Yemshanov et al., 2015). However, several factors are commonly omitted from NPV analysis. Among them are sunk investment cost, investment irreversibility, significant uncertainty over future returns and flexibility in the timing of investment (Dixit and Pindyck, 1994; Trigeorgis, 1996). These omitted factors influence land holder decisions (Ihli et al., 2013) and lead to the erroneous NPV analysis conclusion that the land currently in agriculture would be more profitable in other forest based land uses (Frey et al., 2013; Parks, 1995; Stavins and Jaffe, 1990).

Real options analysis (ROA) has been proposed as a better model of investments decisions under conditions of uncertainty that are costly to reverse and where significant flexibility exists to delay investments (Dixit and Pindyck, 1994). ROA investment triggers, defined as the levels of revenue required to invest in a new land use, are often higher than NPV required returns if the investment involves inter-temporal opportunity costs (Musshoff, 2012). The effect of including ‘option values’ in investment decision analysis can be substantial (Regan et al., 2015; Schatzki, 2003). Unlike NPV analysis, the revenues required to trigger land use change must not only compensate the landholder for establishment cost and foregone returns from agriculture, but also for lost management flexibility and the revenue uncertainty from the new enterprise (Reeson et al., 2015).

Many of the key uncertainties influencing agricultural production such as rainfall, temperature and soil types vary spatially (Bryan et al., 2014). Heterogeneity of these factors has been widely included in NPV analysis in order to understand the spatial distribution of *cost-effective* land use change (Bateman, 2009; Bryan et al., 2010a; Crossman et al., 2011) which have found that landscape heterogeneity is likely to affect the location and timing of land use change. While qualitatively acknowledged, spatial variability has been largely overlooked in quantitative ROA of land use change. Limited exceptions demonstrating differing conversion threshold prices and conversion probabilities across space include Dumortier (2013), Yemshanov et al. (2015) and Sanderson et al. (2016).

Another gap in the ROA of land use change is the effect of climate variability through time on yield. It has been shown to be the principal source of risk affecting long term economic viability of rain-fed agricultural systems in NPV assessments for semi-arid regions such as south east Australia (Kandulu et al., 2012). Despite NPV assessment showing that climate change is likely to provide landholders with additional production risks, surprisingly few studies have addressed the effect of climate change on agricultural land use change in a ROA framework. Hertzler (2007); Hertzler et al. (2013) and Sanderson et al. (2016) are exceptions. They address these factors across an agricultural region with ROA employing spatial transects as an analogue for temporal changes due to climate change. There are limitations to this approach as temporal climate change effects are only roughly approximated by spatial transects. They exclude, for example, accounting for changing CO_2 concentrations and their interactions with higher temperatures (Sanderson et al., 2016).

In this study we address both the gap in broad spatial coverage and the gap in accounting for climate change in ROA of land use changes. This study specifically modelled land use change from agriculture to biomass production in a spatially explicit framework across a broad region accounting for effects of climate change on yield variability. The analyses allow for the assessment of regional biomass industry viability with calculations and spatial mappings of areas where biomass land use is economically viable at several price points under alternative assumptions about climate change.

This article is organised as follows: The next section discusses the stochastic simulation-based real options model applied. This is followed by mapping the land use conversion to biomass with varying price and climate change assumptions. The final discussion focusses on how conclusions about regional biomass industry viability differ with ROA and traditional NPV analysis in the context of climate change futures.

2. Methods

2.1. Study area

Our study focused on the lower Murray region of southern Australia (Fig. 1). The dominant land use covering 50% of the region is rain-fed mixed farming, consisting of the dryland winter cropping of cereals (wheat, barley, oats), pulses (beans, lupins, peas), oilseeds (canola) and grazing of sheep (Bryan et al., 2011). The average farm size in the region is approximately 1000 ha (Kandulu et al., 2012). The region is typical of semi-arid rain dependant farming regions found globally. These regions, similar to our study area, cover approximately 15% of the global land area (UNEMG, 2011), including large areas of southern Africa, western North America and the Middle East. Such semi-arid areas are characterised by high rainfall variability within the growing season, between years and in longer-term cycles. Combined with generally low average rainfall (250 mm–600 mm/year), rainfall variability is a primary risk to agricultural enterprises in these areas (Hansen et al., 2012; UNEMG, 2011).

2.2. Climate scenarios

IPCC climate change models predict average temperature increases in the study area between now and 2100, ranging between 1.0 and 6.0 °C, depending on Representative Concentration Pathways (RCPs) (Pachauri et al., 2014). Bryan et al. (2010b) developed feasible climate change scenarios for the study area based on climate change modelling for southern Australia (Suppiah et al., 2006). We used three of the four climate scenarios developed by Bryan et al. (2010b) (Table 1); baseline (S0), moderate drying and warming (S2) and severe drying and warming (S3).

2.3. Representing spatial diversity

Despite the general categorisation as semi-arid, climatic diversity is found across southern agricultural areas in Australia. These regions are often broadly categorised into “low”, “medium” and “high” rainfall zones according to mean annual rainfall for both agronomic and economic analysis. While the precise definition of