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A synthesis of the ecosystem services impact of second generation bioenergy crop production

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ABSTRACT

The production of bioenergy from second generation (2G) feedstocks is being encouraged by legislation targeted at addressing a number of controversial issues including carbon emissions driven by land-use change and competition for crops used in food production. Here, we synthesise the implications of 2G feedstock production for a range of key ecosystem services beyond climate regulation. We consider feedstocks typical of temperate systems (Miscanthus; short-rotation coppice, short rotation forestry) and transitions from areas of forest, marginal land and first generation (1G) feedstock production. For transitions from 1G feedstocks, studies suggest significant benefits may arise for a number of ecosystem services, including hazard regulation, disease and pest control, water and soil quality. Although less evidence is available, the conversion of marginal land to 2G production will likely deliver benefits for some services while remaining broadly neutral for others. Conversion of forest to 2G production will likely reduce the provision of a range of services due to increased disturbance associated with shortening of the management cycle. Most importantly, further research is needed to broaden, and deepen, our understanding of the implications of transitions to 2G feedstocks on ecosystem services, providing empirical evidence for policy development, particularly for commercial deployment where landscape scale effects may emerge. A programme of research that mixes both the natural and social sciences based on an ecosystem service framework, and occurs concurrently with large scale commercial deployment of 2G feedstocks, would address this gap, providing evidence on the effectiveness of policies to promote production of 2G feedstocks on a wide range of ecosystem services.

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1. Introduction

Meeting the world's growing energy demands while reducing the environmental impacts associated with energy production and use [1] is a key societal challenge for the next 50 years [2]. It is within the context of environmental sustainability, alongside energy security, that the recent upsurge in production of bioenergy – particularly biofuel for transport – has emerged. Although biofuels have been used in transport since the early 20th century, the last few decades has seen a dramatic increase in production [3] from 314,567 barrels per day (BPD) in 2000 to 1897,202 BPD in 2011 [4]. This has been driven by a number of factors including an increase in oil price over the same time period potentially making biofuel economically competitive, by policy commitments to increase energy security, and as a mechanism to reduce greenhouse gas (GHG) emissions [5–7].

Concurrent with increased production of biofuel, a number of significant societal and environmental issues associated with first generation (1G; food and feed) based feedstocks have emerged [8–10]. First, additional demand for food and feed based crops to produce biofuel may have contributed to increased food prices and threatened food security through multiple pathways [11,12]. Second, compared to conventional fossil fuels, relative life cycle carbon emissions of some feedstocks have been questioned. By incorporating land-use change into emission calculations studies suggests they can release as much, or more, carbon as conventional fuels [13–15] leading to significant "pay-back" times before carbon savings are realised [14].

In response to such emerging issues, the European Union (EU) has proposed a significant policy shift that would reduce the use of 1G feedstocks from 10% to 5% [16]. Although implementation is still being debated, with a final decision due in 2015, the policy is intended to encourage the development of the second generation (2G; dedicated lignocellulosic) feedstock industry. This is consistent with long term roadmaps for energy production that point to an increasing role of 2G feedstocks in the medium term, driven by factors such as energy security and blend mandates, coupled with technology innovations such as selective breeding for yield and biomass densification [17].

Given the environmental and societal issues associated with energy production [18], and specifically issues of food security and climate regulation, the concept of ecosystem services provides a framework to examine the implications of transitions to 2G feedstock production [8]. Although a number of different classification schemes exist [19–21] broadly speaking ecosystem services can be divided into four main categories; (i) provisioning services such as crops and livestock, water availability and timber and forest products; (ii) regulating services such as disease and pest control, hazard regulation and pollination; (iii) supporting services such as nutrient and water cycling; (iv) cultural services such as heritage goods and recreational opportunities [20]. In the current study the term ecosystem services is used as a general term that encompasses the pathway from ecological processes to the delivery of benefits to humans [22]. However, as our synthesis does not examine specifics of the social and economic systems in which the ecosystem services are being provided, our discussion is concerned with the pathway to final ecosystem services [19,22] from which goods and benefits to society will flow.

The importance of incorporating ecosystem services into analysis of the implications of 2G feedstock deployment stems from the realisation of the value of these services to society, and the concurrent understanding that many services are in decline or threatened [20,21]. A notable exception to this trend is crop, livestock and timber production [20,21] which has seen a dramatic increase over the last few decades due to modern production techniques. This increased production has come at a cost, with these resources now considered to be principal drivers of environmental degradation and loss of biodiversity [23] with associated implications for the delivery of many ecosystem services [24,25]. As trade-offs between the delivery of different ecosystem services are inherent [26–28] decisions about the deployment of energy technologies must be based on knowledge of implications for a broad range of services, providing policy makers and managers with the ability to balance competing environmental and societal goals. Here we consider both the evidence available and how incorporating a broad range of ecosystem services can provide such a perspective on the implications of 2G feedstocks.

2. Methods

The aim of this synthesis is to consider the implications for ecosystem service provision of land-use change associated with conversion to 2G feedstock production. Specifically we consider land-use change from three references states representing likely transitions within Europe and specifically the UK: (i) arable land (i.e. used in the production of crops destined for food or feed production or as 1G feedstocks), (ii) marginal land, (iii) forest (both plantation and natural). Our review uses the framework of the Millennium Ecosystem Assessment [21] that divides ecosystem services into provisioning, regulating, supporting and cultural categories, although for policy relevance we identify services representing those considered in the UK National Ecosystem Assessment [20]. This approach frames the question within a context that policy makers are familiar with, although we recognise that a number of alternate classification systems, such as the Common International Classification of Ecosystem Services (CICES) [19], exist.

Searches were performed in Web of Science (WoS) during December 2014 using the ecosystem service keywords detailed in Table 1 together with 'biofuel', 'biodiesel', 'bioethanol', and 'bioenergy'. In using these latter terms our aim was to capture a representative sample of studies that examine effects of biofuel feedstock production on ecosystem services. Although our focus is on candidate feedstocks for Europe and the UK, this broad approach captures studies that consider the implications of analogous crops deployed in other regions of the world.

Our search strategy was designed to be neutral in terms of land-use due to problems associated with terminology. While studies relating to transitions from arable and forest can be readily identified, there is inconsistent use within the literature of the term "marginal" land. The importance of capturing studies that consider marginal land arises from the fact that such land is stated as being crucial for 2G feedstock production [29–31]. A number of definitions of marginal land exist (see [32,33]), with the interplay of a range of factors leading to its characterisation as an area that