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Paving the way for sustainable bioenergy in Europe: Technological options and research avenues for large-scale biomass feedstock supply

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ABSTRACT

Meeting future policy targets for bioenergy development worldwide poses major challenges for biomass feedstock supply chains in terms of competitiveness, reliability and sustainability.

This paper reviews current knowledge on the sustainability of agricultural feedstock supply chains and emphasizes future research needs. It covers annual and perennial feedstocks, and environmental, economic and social aspects. Knowledge gaps and technological options to assess and meet sustainability criteria are reviewed from plot to landscape and global scales.

Bioenergy feedstocks present a wide range of dry matter yields, agricultural input requirements and environmental impacts, depending on crop type, management practices, and soil and climate conditions. Their integration into farmers' cropping systems poses specific challenges in terms of environmental impacts, but also opportunities for improvements via the use of grass–legume intercropping or residues from biomass conversion processes. Taking into account the spatial distribution of bioenergy crops is paramount to assessing their environmental impacts, in particular, on biodiversity or the food versus energy competition issue. However, few modeling frameworks convey the full complexity of the underlying processes and drivers, whether economic, social or biophysical. In particular, social impacts of bioenergy projects are seldom assessed and there is no methodological consensus.

The main research areas identified involve multi-crop and multi-site experiments, along with modeling, to optimize management practices and cropping systems producing bioenergy, possibly on alternative lands and under future climate changes; the design of innovative cropping systems using expert knowledge to ensure suitable integration into farmers' cropping systems; the collection of detailed data on the location of bioenergy crops to validate theoretical modeling frameworks and improve sustainability assessment; tackling direct and indirect effects of bioenergy development on land-use changes via coupled economic and agronomical models; investigating the effect of perennial stands on biodiversity in relation to previous land-use and landscape structure; and further developing currently-available methodologies to fully appraise the social implications of bioenergy projects.

Contents

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1. Introduction

Biomass is expected to be a major player in the energy transition toward low-carbon economies, in response to the pressing challenges of climate change and dwindling fossil resources. According to the recent IPCC scenarios of energy transition, bioenergy may contribute up to half of the total use of primary energy worldwide by 2050 [1]. Such high expectations are reflected in the ambitious bioenergy targets recently set in the EU, the US, Brazil or India, with bioenergy being attributed a 20–30% share of the overall energy mix within the next 20 years. This implies a several-fold increase compared to the present production of bioenergy, and poses major challenges for agriculture and forestry, since this expansion will for a large part rely on dedicated energy plants, including lignocellulosic crops and short rotation forestry [2]. In Europe for instance, bio-energy is the fastest growing renewable energy source with a production that almost doubled over the last 15 years, currently supplying 6% of the total primary energy [3]. Around 3.1 Mha in the European Union (EU) is currently used for bioenergy, mainly for biofuel production as biodiesel and ethanol, and biogas, all involving arable food and feed crops. A small proportion is derived from dedicated bioenergy crops. These crops are mostly perennials grown to generate electricity and heating, with the most frequent species being miscanthus, willow, reed canary grass and poplar. They were covering 50,000–60,000 ha in Europe in 2008, and about 100,000 ha in 2010 [4,3], underlining a rapid development. Such a trend is likely to continue since it is estimated that 17–19 million ha should be converted to bio-energy crops to meet the targets of the SET-plan in the EU, whether for heat, electricity or liquid biofuels production [3]. Meeting this demand raises considerable challenges for feedstock supply chains in terms of competitiveness, reliability and sustainability [5]. First, the availability of terrestrial land to grow the feedstock imposes major constraints on potential biomass supply, and secondly the conditions for a sustainable and reliable supply are yet to be defined [6].

The production of biomass from lignocellulosic crops interacts with a host of environmental, ecological, economic and social issues, together with human health [2]. Environmental impacts encompass water availability and quality, soil and air quality, biodiversity and climate through the emissions of greenhouse gases (GHG) and C sequestration in soils [e.g., 7,8]. Following the controversy on the GHG benefits of first generation biofuels [9], concerns have also been raised for lignocellulosic crops [6], mostly pointing at our limited knowledge of their environmental and economic performances.

The above-mentioned societal concerns with biomass have pressed the need for a certification of bioenergy chains,

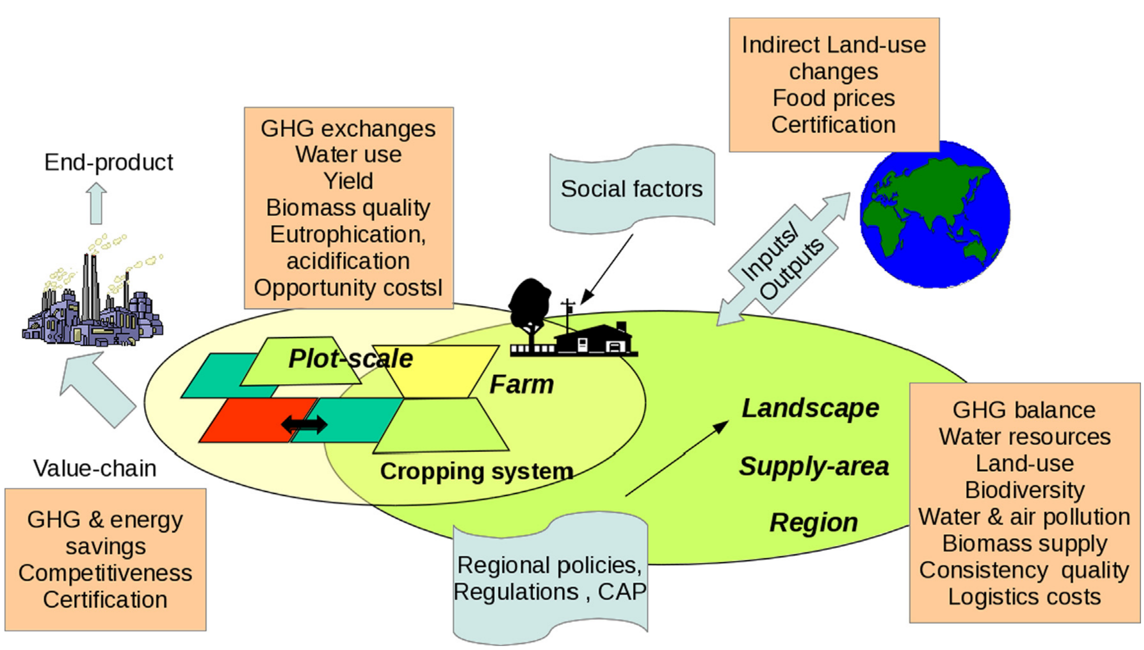

Fig. 1. Drivers and performance criteria for bioenergy value chains, from plot to global scales. Blue flag-shaped boxes = drivers; orange rectangular boxes = performance criteria.