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Sustainability constraints in determining European bioenergy potential: A review of existing studies and steps forward

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ABSTRACT

This paper reviews European land and bioenergy potential studies to 1) identify shortcomings related to how they account for agricultural intensification and its associated environmental effects, and sustainability constraints, and 2) provide suggestions on how these shortcomings can be improved in future assessments. The key shortcomings are:

The environmental impacts of intensification are nearly always ignored in the reviewed studies, while these impacts should be accounted for if intensification is required to make land available for energy cropping.

Future productivity developments of crops and livestock, and the associated land-use and environmental effects are currently limited to conventional intensification measures whereby the proportion between inputs and outputs is fixed. Sustainable intensification measures, which increase land productivity with similar or lower inputs, are ignored in the reviewed studies.

Livestock productivity developments, livestock specific intensification measures and their environmental effects are poorly or not at all covered in the reviewed studies.

Most studies neglect sustainability constraints other than GHG emissions in the selection of energy crops. This includes limitations to rainfed energy crop cultivation, a minimum number of crop species, the structural diversity within cropping areas and the integration of energy crops in existing or new crop rotations, while simultaneously considering the effects on subsequent crops.

These shortcomings suggest that the identification of sustainable pathways for European bioenergy production requires a more integrative approach combining land demand for food, feed and energy crop production, including different intensification pathways, and the consequent direct and indirect environmental impacts. A better inclusion of management practices into such approach will improve the assessment of intensification, its environmental consequences and the sustainable bioenergy potential from agricultural feedstocks.

1. Introduction

Land is a finite and increasingly scarce resource. Competition for land will increase to meet future food and fibre demand of a growing population [1,2]. The expected increase in the use of bioenergy as a renewable energy source requires an additional increase in total agricultural output and thereby further increasing the competition for land [1]. Producing additional agricultural output for bioenergy feedstock can be achieved by extending cropland and pastures into new areas, thereby replacing natural ecosystems (i.e. expansion), and/or by improving productivity of existing cultivated land through the increased or more efficient use of inputs, improvement of agronomic practices and crop varieties and other innovations (i.e. intensification) [3,4]. Both options have positive and negative environmental effects. Several studies suggest that increasing productivity rather than clearing additional land is preferred to meet the expected increase in demand for agricultural products [3–7]. If intensification is needed to make land available for bioenergy feedstock production, its environmental effects should be accounted for when quantifying the sustainability of bioenergy [8]. The environmental effects of intensification depend on geographic conditions and on how agriculture is organised and managed. Sustainable intensification measures include precision agriculture, multiple cropping systems using crop rotations, intercropping or agroforestry systems, zero or reduced tillage systems and the

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Table 1
General characteristics of the studies included in the review [a].

Study label[b]	Main ref.	Objective of study	Spatial coverage[c]	Spatial resolution	Timeframe	Approach - methodology	Model(s) used	Biomass categories			Type of potential
								Annual arable crops	Perennial crops	Agricultural residues	
Allen14	[23]	Estimation of additional production of perennial energy crops within Europe.	EU-28	EU-28	Current (2000–2012)	Resource focused – statistical	n.a.		✓		Technical
Bentsen14	[24]	Estimation of agricultural residues potential potentially available through agricultural intensification.	Global	World regions (North, South, West Europe[d])	2006–2008	Resource focused – statistical	n.a.			✓	Theoretical
Böttcher10	[25]	Estimation of bioenergy potentials and demonstration of harmonised approaches developed within the Biomass Energy Europe (BEE) project.	EU-27	Member State, EU-27	2010, 2020, 2030	Resource focused – statistical, spatially explicit and modelling	EPIC, EUFASOM	✓	✓	✓	Theoretical, technical, economic, implementation
Böttcher13	[26,27]	Transformation of technical potentials from Elbersen13 into economic potentials.	Global	Global, EU-27	2000, 2010, 2020, 2030	Demand driven – cost supply	GLOBIOM	✓	✓		Economic
Daioglou16	[28]	Estimation of residues availability for energy and material uses considering ecological and current uses.	Global	World regions (West, Central Europe[e])	1971–2100	Integrated assessment	IMAGE			✓	Theoretical, ecologically sustainable
deWit10	[29]	Estimation of technical and cost and supply potential for biomass resources.	EU-27 +CH+NO	NUTS-2	2010, 2020, 2030	Resource focused – spatially explicit	n.a.	✓	✓	✓	Technical, economic
EEA13	[8,11]	Review of the implications of resource efficiency principles for developing EU bioenergy production.	EU-27	EU-27	2020	Demand driven – cost supply	CAPRI, MITERRA, PRIMES, AGLINK-COSIMO	✓	✓	✓	Economic
Elbersen13	[30,31]	Quantification of technically constrained biomass potentials for different scenarios assumptions.	EU-27	NUTS-2	Current (2006–2008), 2020, 2030	Demand driven – modelling	CAPRI, MITERRA, GLOBIOM, GEMIS	✓	✓	✓	Ecologically sustainable
Fischer10	[32]	Estimation of available land for bioenergy production for different scenarios assumptions.	EU-27 +CH+NO	NUTS-2	2010, 2020, 2030	Resource focused – spatially explicit	n.a.			✓	Technical land potential, ecologically sustainable
Krasuska10	[33]	Estimation of surplus agricultural land theoretically available for non-food crops.	EU-27	NUTS-2	Current (2003–2007), 2020, 2030	Resource focused – spatially explicit	RENEW land allocation model				Theoretical land potential
Monforti13	[34]	Geographical assessment of potential bioenergy production from	EU-27	NUTS-2	2000–2009	Resource focused – spatially explicit	n.a.			✓	Ecologically sustainable

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