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Research paper

Soil-related ecosystem services trade-off analysis for sustainable biodiesel production

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ABSTRACT

There have been strong calls globally to improve the sustainability of biodiesel production from oilseeds. Nevertheless, there is a lack of robust methodologies that are able to depict the local impacts of intensive feedstock production on soil properties and functions. The aim of this study is to quantify and map the potential biodiesel production from oilseed (e.g. soybean, sunflower and rapeseed), and understand possible trade-offs with other soil-related Ecosystem Services (ESs) such as i) habitat for soil organisms (supporting service), ii) soil carbon storage (regulating service), iii) groundwater quality protection (regulating service) and iv) food crops (provisioning service). This method is tested on current intensive agricultural areas of the Veneto region plain of Northern Italy. The results suggest that the study area has a sustainable biodiesel production potential of 20.7 dam^3 per year, which is only 52% of the regional target for the year 2020. The areas that are currently under other annual crops (primarily cereals and maize) can also have a significant further contribution that if exploited would greatly exceed the regional target. This finding indicates that achieving the regional target will be impossible without having significant trade-offs with other soil-related ES or causing land use change. The proposed methodology could provide a tool that could be integrated within (and potentially improve the effectiveness of) biofuel certification schemes, strategic environmental assessments of renewable energy pathways, and regional energy plans.

1. Introduction

Soil contributes to the provision of several Ecosystem Services (ESs), such as food, erosion regulation, and carbon storage [1–5]. Soil biodiversity influences multiple ecosystem processes and functions that are necessary for the provision of many ESs [6,7]. As a result, increasing attention has been devoted to soil management practices such as tillage, fertilization and farming practices [7–9].

In Europe, soil is considered as a non-renewable natural resource, and has become the subject of protection according to the Soil Thematic Strategy [10]. Moreover, the Seventh Environment Action Programme, which has been in force since January 17th, 2014, implies that Member States should increase efforts (i) to reduce soil erosion, (ii) to increase soil organic matter, and (iii) to remediate soil quality in contaminated sites.

As a non-renewable resource, soil is increasingly under stress due to multiple drivers such as urbanization, agricultural intensification and climate change among others [4,5,7,11,12]. Biofuel supply chains may have severe negative impacts on soil as for example due to deforestation [15], competition with food production [19], increased greenhouse gas emissions and loss of soil carbon storage [18–20], land use change [13,15,21], soil degradation [22], and biodiversity loss [15,23,24]. Moreover, high water consumption [25] and air/water pollution [13,15] associated with biofuel value chains can have indirect effects on soil characteristics that can collectively affect “the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health” [4,26]. Furthermore, biomass for bioenergy is a provisioning ecosystem service that may compete with the provision of other ESs whose provision depends on soil such as food crops and carbon sequestration to mention just a few [13,14].

However, according to the EU Renewable Energy Directive (EU RED) 2009/28/EC [27] biofuels are a valuable fuel option that can support Member States in meeting the 10% renewable sources target for transport fuels by 2020. With respect to the sustainability

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of feedstock production, voluntary schemes and bilateral/multilateral agreements are valuable tools to support local feedstock supply and rural development as reported in COM 2010/C 160/02 [28]. Such schemes can enhance biofuel sustainability [29–31], connect feedstock supply to local production, and support the innovation and development of the agro-food industry in Europe [32,33].

Under the EU RED [27], the European Commission has established some minimum requirements with respect to the sustainability of biofuel feedstock production. These include (i) greenhouse gas emission savings from the entire biofuel lifecycle (i.e. from feedstock production to biofuel consumption); (ii) non-conversion of land with high carbon stocks; and (iii) non-conversion of land with high biodiversity [27]. Biofuels and bioliquids used in the EU must conform to these sustainability criteria if they are to count towards the national renewable energy targets established by EU RED [27], and to access supporting policies (and related funds) [31,33].

However, soil quality receives variable recognition among the 19 certification schemes approved by the European Commission (see Table A1, in the Supplementary Electronic Material). While not all certification schemes have strong regulations for soil, all account for the contribution of soil to GHG emissions, explicitly through compliance with the methodology for GHG emissions that is included in Annex V.C of the EU RED [27], and its follow-ups [28,34]. Similarly, cross-compliance with good agricultural practices is considered in every certification scheme.

However, only two certification schemes requite the detailed monitoring, and the related audit of soil protection and erosion control, soil organic matter, and soil biological, chemical and physical conditions, i.e. the International Sustainability and Carbon Certification (ISCC) and the Roundtable on Sustainable Biomaterials (RSB). In these schemes, a soil management plan is considered as valuable but it is not compulsory. RED CERT and the Round Table on Responsible Soy (RTSR) consider soil quality indicators. Solomon and Bailis [35] acknowledge that, when it comes to soil, the standards of certification schemes vary in scope, ranging from general principles to specifications in land management and tillage practices. They suggest that cross-compliance and certification (as a formal procedure) are the primary approaches to assess the sustainability of feedstock production [35].

In general, certification schemes have to apply common and harmonized standards as a response to local environmental conditions [31,36], while at the same time recognize that it is necessary to consider the effects of these local characteristics [37,38]. For example, the RSB certification scheme foresees a possible adaptation to specific "political, legal, customary and/or technical social, environmental, cultural, ethical and/or economic conditions in a particular geographic region" [33]. As a result by accepting that sustainable bioenergy systems are embedded in unique social, economic, and environmental contexts [39], the effectiveness of certification schemes often depends on local conditions [37,38]. Moreover, cross-compliance with environmental sustainability criteria (exclusively applied to biomass produced in the EU) is accounted for only through the formal verification of meeting pre-established regulations. There is no on-site impact verification for feedstock production [36,40], especially in relation to the preservation, maintenance and enhancement of soil properties and quality. Moreover, certification schemes appoint feedstock producers individually, at farm level [41,42]. In this respects they cannot account for the possible cumulative effects of feedstock production, or even exclude "considerations of indirect land use change and social and environmental impacts above farm or plantation level" [31,36].

Considering the importance of soils for biofuel sustainability, our study applies concepts from the ecosystem services literature to quantify the potential biofuel production in the Veneto Region of Italy, and its expected trade-offs with other soil-related ES. It views feedstock for biodiesel (oilseeds in this case) as a provisioning ecosystem service (as stated by the Common International Classification of Ecosystem Services [43]) that depends on soil and primary productivity. In particular, the main objectives of the study are to:

i) quantify the fraction of current oilseed production that can be considered as environmentally sustainable for biodiesel production, with respect to soil-related ESs;
ii) identify potential areas that might be converted for biofuel feedstock production (oilseeds), while avoiding significant trade-offs with soil-related ES.

Section 2 outlines the methodology used to elicit biofuel potential and ES trade-offs. Section 3 quantifies biodiesel potential and trade-offs with other soil-related ESs namely i) habitat for soil organisms (supporting service), ii) soil carbon storage (regulating service), iii) groundwater quality protection (regulating service) and iv) food crops (provisioning service). Subsequently these results are discussed with respect to existing gaps in biofuel sustainability certification practices and the energy plan for the Veneto region (Section 4).

2. Methodology

2.1. Study site

Italy produced approximately 1.2×10^3 dam^3 of biofuels in 2014, of which 99% was biodiesel, and 99.8% was certified as sustainable. This was primarily for domestic consumption, with approximately 20.7% of the Italian production capacity being located in the Veneto region [50]. Despite substantial domestic production most of the feedstock consumed in 2014 was imported from other European countries (47%), with the rest coming from developing countries outsite of the EU (of which 46% from Indonesia) [51]. Palm oil, largely from Indonesia and Malaysia, is the primary raw material for biodiesel production in Italy (47%), followed by rapeseed oil (27%) and soybean oil (6%) [51].

Considering its importance for the domestic Italian biodiesel production, we chose the Veneto plains region as the study site for this analysis (Fig. 1). It has a surface area of 10,311.91 km^2 (56% of the regional total surface) and is part of the soil region of the "Po plain and moraine hills" [44]. It is characterized by quaternary alluvial and glaciofluvial deposits, with an average slope of 1% and altitude that ranges between sea level at the coast of the Adriatic Sea to 70 m above mean sea level.

Soil degradation in the Veneto plain region is mostly related to urbanization and intensive agriculture (Fig. A1, Supplementary Electronic Material). The main oilseeds produced are soybean (*Glycine* max L.), sunflower (*Helianthus annuus* L.) and rapeseed (*Brassica napus* L.). For our study, yield conversion parameters are calculated for areas that overlap with the administrative boundaries of the Provinces as delineated by ISTAT [45]. These provinces represent areas with the same climatic conditions, which is consistent with the bioenergy potential study of Motola et al. [46].

For our study, we consider 76% of the entire Veneto region (i.e. 7847.35 km^2) (Table 1). Artificial surfaces, natural areas, wetlands and water bodies (i.e., land classes 1, 3, 4, and 5 in the first level of the CORINE Land Cover Classification) are not considered. Thus, the potential trade-offs due to indirect land use change [47–49], are excluded from this study. The areas under oilseeds (i.e. soybeans, sunflowers and rapeseed) and other arable uses are derived from