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An optimization framework for supporting decision making in biodiesel feedstock imports: Water footprint vs. import costs

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ABSTRACT

Given the expected rise in the importance and rate of decisions being made in the biofuel sector and the complexity of the system, this paper is focused on an analysis that, although well-established in economic and environmental evaluation theory, has not been widely used yet to assess biodiesel production.

The aim of this study, in particular, is to analyze, from a quantitative point of view, the water footprint resulting from the use of various types of crops for the production of Italian biodiesel, combining it with the import costs of these crops, based on the current trade partners, and the crop energy conversion efficiency.

The problem from the importing country's point of view is to minimize the total cost related to the import of crop products and, at the same time, to minimize the overall water footprint, ensuring a quantity of biodiesel produced at least equal to the pre-defined target set by the European Union for 2020.

The paper provides a first glance at addressing optimal resource allocation and the design of biodiesel imports in the EU regulation context, contributing to reducing the water footprint, without ignoring the economic aspects.

The study represents an original contribution for the identification of potential environmental policy drivers in the context of an economic sector characterized by potential growth, serving as a guide for the resolution of the trade-offs between biodiesel demand, import costs of feedstocks and water impact.

1. Introduction

The development of alternative energy sources represents a priority for the countries whose energy supply is heavily dependent on fossil fuels (Righi et al., 2016).

Since the use of biofuels represents an increasingly important energy source, worldwide there is an emerging interest in replacing fossil feedstock with biomass-based raw materials (Börjesson and Tufvesson, 2011).

In the last decade, policy makers, scientists, environmentalists and agricultural entrepreneurs have presented biofuels, and in particular biodiesel production, as a suitable option for energy supply (Cavalett and Ortega, 2010), even if several analyses have found contradictory results.

Different economic and environmental theories and approaches have been used to date to evaluate the effectiveness, economic efficiency and sustainability of biofuel production from greenhouse gas (GHG), energy, biodiversity and water points of view (Reijnders and Huijbregts, 2008; Kendall and Chang, 2009; Gerbens-Leenes et al., 2009a; Reinhard and Zah, 2009; Arvidsson et al., 2011; Skarlis et al., 2012; Kaercher et al., 2013).

When evaluating the whole production chain of this alternative source of energy some criticalities emerge and some doubts regarding renewability, cleanliness, and ecological friendliness remain too (Ji and Long, 2016). For example the variations in the environmental performance of biofuels are often due to differences in local conditions, the design of the production systems and crops utilized (Börjesson, 2009; Börjesson and Tufvesson, 2011). Furthermore, the development of first-generation biofuels is affected by the high price volatility of raw materials (Chiu et al., 2015).

The adverse sustainability balance of certain forms of bio-energy in a life-cycle perspective has been analyzed in recent years. Von Blottnitz and Curran (2007), reviewing studies comparing bio-energy systems to conventional fuels through a life-cycle approach, come to the conclusion that the balance of environmental impacts of current liquid fuels from biomass is ambiguous.

As demonstrated by a large number of contradictory results of LCA studies, significant disagreement and controversies exist regarding the

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actual benefit of biofuels compared to fossil fuels (Malça and Freire, 2011).

In this paper we focus on biodiesel because it is by far the most widely used biofuel in Europe (80% of the total biofuel production) and almost the only one in Italy (Russi, 2008). However, for a first approximation, our framework may also be reasonably considered to be extended to bioethanol, as well as to other countries, and not only to Italy, which is our case study.

Since biodiesel production is dominantly based on the conversion of oil (oil palm, rapeseed) accumulated in crops (Cassman and Liska, 2007), agriculture represents the essential sector for supporting this type of bioenergy supply.

Today agriculture represents the greatest water-depleting sector and its demand for water is expected to increase globally due to population and economic growth (De Fraiture and Wichelns, 2010; Miglietta et al., 2017). Therefore, the challenge for the scientific community and policy makers and planners consists of facing the ever growing demand for water, aware that the latter is a resource whose availability is becoming increasingly scarce (FAO, 2008).

In Europe this challenges is addressed by the Common Agricultural Policy (CAP 2014–2020) that intends to support investments to preserve water and improve irrigation infrastructures and techniques to protect water quality and quantity.

Irrigation is, in fact, necessary to provide an adequate water supply during the entire growing period of plants and allow high yields, but crop productivity also depends on several other factors such as climate, soil characteristics, water quality, type of crop and cultivation practices (Miglietta et al., 2015).

As we have just mentioned, there are a lot of problems linked to bioenergy, of which only some are considered in the framework of this paper: water use competition between biomass production for food and energy with repercussions primarily in developing countries (Kerckow, 2007) and water scarcity caused by the cultivation of energy crops in susceptible regions (Gerbens-Leenes et al., 2009a,b).

Providing economically and environmentally sustainable biodiesel production requires an optimization of the structure and functioning of the supply chain (feedstock origin, imports, water requirement), adjusted to the specific conditions of the legal system (Gold and Seuring, 2011).

For this reason appropriate water management represents a priority in the agriculture sector, especially for those Countries in which water pressure is hidden, since, through imports, indirect water impact is exerted abroad.

Given the expected rise in the importance and rate of decisions being made in the biofuel sector and the complexity of its system, this paper is focused on an analysis that, although well-established in economic and environmental evaluation theory, has not been widely used yet to assess biodiesel production.

The aim of this study, in particular, is to explore the trade-offs between the economic cost of imported feedstocks and their water footprints in order to determine the optimal feedstock mix for future water sustainable biodiesel production in Italy. The analysis is conducted by using water footprint values, available in literature, resulting from the use of various types of crops for the production of Italian biodiesel, combining it with the import costs of these crops, based on the current trade partners, and the crop energy conversion efficiency.

The choice of the water footprint arises from the fact that it is a multidimensional indicator that includes different types of water volumes (evapotranspirated rainwater, surface water or groundwater, polluted water) in its computation and is useful to assess the pressure on water resources, considering the localization of impacts from a global perspective.

Through the use of partial linear optimization techniques, the study evaluates and identifies the most water and economically efficient mix of imported crops that could support the predicted Italian biodiesel consumption for 2020 in a EU regulated context.

This paper is structured as follows: Section 2 provides a comprehensive background on the biofuel sector and legislation in the EU and in Italy. Section 3 provides an overview of the data source and presents the developed methodology. Section 4 reports the results of the study, focusing on some insights deriving from the optimization framework. Section 5 provides discussion about the usefulness of the proposed framework in supporting decision-making processes in biodiesel feedstock imports and some general conclusions.

2. Background

2.1. Overview of biodiesel sector in Europe and in Italy

The European Union has adopted measures on renewable energy and climate change (Regulation 443/2009/EC, Directive 2009/28/EC, Directive 2009/29/EC, Directive 2009/30/EC and Decision 406/2009/EC), which aim at achieving a rate of 10% of biofuels in transport fuels by 2020 (European Parliament, 2009a,b,c,d,e; Afionis and Stringer, 2012; Righi et al., 2016).

In 2015 BP found that from 2004 to 2014 in Europe there was a fall of 17.9% in the consumption of fuel for locomotion and industrial use. A positive peak was registered in 2006 with 726.5 million metric tons of fuel used. Italy, from 2004 to 2014, reduced its fuel consumption by 36.8%, with a positive peak of 89.7 million metric tons in 2004, ranking first among the EU27 members (BP, 2015).

In spite of these encouraging figures, Italy is still dependent on foreign energy sources. In fact, in the first half of 2015, Italy imported 14.9% more than it did in 2014, 41.8% of which is imported crude oil from OPEC nations (Unione Petrolifera, 2015).

Biofuels are regarded as some of the most innovative, growing and promising renewable energy products. Since they have special characteristics and can be blended with traditional fuels, they are usable with current technology in the automotive industries (Miglietta et al., 2016).

Biofuels refer to liquid, gas and solid fuels derived from biomass and that have evolved from the first to the fourth generation on the basis of the biomass origin and production technology (Naik et al., 2010). The first generation biofuels derive from crop based feedstock, the second from non-food feedstock, the third from algae and the fourth from genetically engineered crops (Dutta et al., 2014).

As reported in Demirbas (2009), the major first generation biofuel products are biodiesel and bioethanol. Both of them have very similar chemical properties (Fazal et al., 2011) and represent a primary source of bioenergy (Hammond et al., 2008).

Biodiesel is a mix of fatty acid methyl esters extracted from vegetable oils by the transesterification of triacylglycerides with an alcohol.

It is now well recognized that the type and source of biodiesel affect considerably the potential environmental benefits and impacts (Zah et al., 2007; Naik et al., 2010; Dutta et al., 2014).

Thanks to its characteristics similar to diesel (Yusuf et al., 2011), biodiesel in the last centuries blended with fossil fuels (Janaun and Ellis, 2010) for transportation uses.

Lately, with the increase of biodiesel demand, production has increased significantly worldwide (Liew et al., 2014) and, in Europe, there was constant production growth from 2.4 to 26.3 billion liters in the period between 2004 and 2014.

Due to the increase in biodiesel use, it is foreseeable that it will be difficult to place large stocks on the market. Therefore, it will be necessary to support biodiesel production through feedstock imports.

The major feedstock for biodiesel in Europe is rapeseed oil and some small amounts of sunflower oil (Worldwatch Institute, 2012). In Europe, Italy, with a capacity of 2.5 M metric tons (USDA, 2015) ranks fourth in the production of biodiesel, following Germany, France and Spain (USDA, 2011).

Many factors have inhibited the development of the Italian biodiesel industry over the years. These include: lack of aid through economic