Energy Policy 103 (2017) 165–178

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Third generation algae biofuels in Italy by 2030: A scenario analysis using Bayesian networks

Danilo Gambelli, Francesca Alberti, Francesco Solfanelli, Daniela Vairo, Raffaele Zanoli*

Università Politecnica delle Marche, Via Brecce Bianche, Ancona, Italy

ARTICLE INFO

Keywords:
Advanced biofuels
Microalgae
Scenario analysis
Bayesian networks
Climate change
Sustainability

ABSTRACT

We have analysed the potential for biofuels from microalgae in the Italian biofuels context. This scenario analysis considers alternative pathways for the adoption of biofuels from microalgae by the year 2030. The scenarios were developed using a probabilistic approach based on Bayesian networks, through a structured process for elicitation of expert knowledge. We have identified the most and least favourable scenarios in terms of the expected likelihood for the development of the market of biofuels from microalgae, through which we have focussed on the contribution of economic and policy aspects in the development of the sector. A detailed analysis of the contribution of each variable in the context of the scenarios is also provided. These data represent a starting point for the evaluation of different policy options for the future biofuel market in Italy. The best scenario shows a 75% probability that biofuels from microalgae will exceed 20% of the biofuel market by 2030. This is conditional on the improvement and development of the technological changes and environmental policies, and of the markets for bioenergy and novel foods derived from microalgae.

1. Introduction

The world economy depends to a large extent on energy derived from fossil carbon sources, as mainly oil, coal and natural gas (British Petroleum, 2013). In this context, we consider here the conditions under which innovative solutions in the biofuel sector might represent a trustable opportunity. In particular, the aim was to identify the conditions that might determine the success or failure of biofuels from microalgae (BFM), including economic, market, social and policy issues. We used scenario analysis to consider the potential evolution of the BFM sector in Italy by 2030. The design was to provide not only a description of the relevant factors that have crucial roles for BFM, but to evaluate the necessary conditions and likelihood of the most and least favourable scenarios. Particular attention was paid to the role of policy support under different economic and biofuel market scenarios.

According to the International Energy Agency (2007, 2008), the world population is currently consuming more oil than any other source of energy, and within the next 20 years, the global demand for energy/ oil is expected to grow by 50%. At present, 95% of all of the energy required for transportation comes from oil, and the energy generated from fossil fuels is still expected to meet about 84% of the global energy demands in 2030 (REF??). However, the present use of fossil fuels is widely considered not to be sustainable, for two main reasons. The first is the rising concern about energy security, as there is considerable debate on the estimation of the size of the fossil fuel reserves, and even the dilemma of “when the non-renewable energy will be diminished” remains to be answered (International Energy Agency, 2008). The second reason is strictly related to greenhouse gas (GHG) emissions, and consequently to the implementation of the Kyoto commitments. According to the Intergovernmental Panel on Climate Change (IPCC, 2014), emissions of carbon dioxide (CO_2) from fossil-fuel combustion and industrial processes contributed to about 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution for the increase over the period from 2000 to 2010.

In this context, the search for alternatives to fossil fuels is one of the main concerns of governments, scientists and businesses worldwide. Biofuels represent such an alternative. However, a unanimously shared classification for biofuels remains to be defined. In some cases, BFM are classified as second-generation biofuels, or as advanced biofuels, mainly to distinguish them from the first-generation biofuels. Here we refer to the recent classification of biofuels according to the European Parliament (European Commission, 2015), where they are classified as: first-generation biofuels, as those obtained from crops and animal fats, and based on mature and well-established technologies; second-generation biofuels, as those mainly obtained from ligno-cellulose biomass (i.e., wood); and third-generation biofuels, whereby, “The most accepted definition of third-generation biofuels is ‘fuels that are produced

* Corresponding author.
E-mail address: r.zanoli@univpm.it (R. Zanoli).

http://dx.doi.org/10.1016/j.enpol.2017.01.013
Received 26 April 2016; Received in revised form 28 December 2016; Accepted 10 January 2017
0301-4215/

from algae-derived biomass'" (European Commission, 2015, p. 52), although microbes are also considered by some as third-generation production sources (Alam et al., 2012). Furthermore, fourth-generation biofuels have been discussed, and these refer to engineered organisms that are optimised for enhanced carbon-storage performance (Demirbas, 2011; Lu et al., 2011).

Over the last few decades, first-generation biofuels have increasingly been adopted, and these are projected to steadily increase in production (British Petroleum, 2013). However, growing interest is being paid to second-generation and third-generation biofuels, which are not food competitors, and which might have better environmental performance, particularly in terms of lower GHG emissions. Currently, European Union (EU) policy supports advanced biofuels that compared to first-generation biofuels will contribute to lowering the environmental impact by indirect land-use changes (Council of the European Union and European Parliament, 2009, 2015).

In the present study, we have used scenario analysis to consider the potential transitions in the market of the third-generation BFM over the next 15 years (to 2030) in Italy, the production of which is still at a developmental stage (Council of the European Union and European Parliament, 2015). In particular, we considered the potential role of the main socio-economic, policy, technological and market drivers for BFM, and their implications in terms of indirect land-use change.

Scenario analysis is a tool for strategic policy analysis that enables researchers and policy makers to consider decisions with enhanced awareness, due its cognitive implications for planned behaviour (Bunn and Salo, 1993). It is extensively used in the field of environmental and energy policy analysis (e.g., McCollum and Yang, 2009; Chen et al., 2013; Wang and Li, 2016; see also Bartolini and Viaggi, 2012, for scenario analysis of energy production at the farm level in Italy). Scenario analysis originated in the field of fuel and energy. Pierre Wack was the pioneer of scenario analysis, and he used scenarios that helped the Shell company to be prepared for the 1973 oil crisis, which no other model had considered (Wack, 1985).

However, most scenario analysis related to biofuel issues has focussed on first-generation biofuels only (e.g., Banse et al., 2008; Fischer et al., 2010; Franco et al., 2015). For scenario analysis based on second-generation biofuels in particular, the early studies were those of Alcamo et al. (2005), Alfstad (2008a, 2008b), Rosegrant et al. (2008) and Zah et al. (2010), the last of whom also considered BFM among the second-generation biofuels. More recent contributions were provided by Festel et al. (2014) and Liu et al. (2012). Here, Festel et al. (2014) compared different biofuels and fossil fuels in Europe between 2015 and 2020, and presented scenarios for the future development of raw material prices for each type of fuel considered. Liu et al. (2012) focused more on a better understanding of the environmental implications of the use of algae biodiesel on a large scale. Their scenario analysis highlighted the extent to which breakthroughs in key technologies were needed before algae-derived fuels can become an attractive alternative to conventional biofuels.

These previous scenario analyses have covered wide geographical and time frames, and also different methodological approaches. In the present study, the scenario analysis is applied to the Italian market of third-generation biofuels, as those obtained through microalgae production. We have followed an approach to scenario analysis that relies on subjective assessments (Van Der Heijden, 2004; Zanoli et al., 2012), which are dealt with using a formal and structured approach. More specifically, we developed this scenario analysis based on Bayesian networks (BNs), exploiting probabilities elicited from a team of experts. This study is part of a broader project that relates to the agronomic, technical and economic aspects of the production of BFM. The researchers who are participating in this project provided expertise from these different disciplines. This expertise has been collected and elaborated upon using a web application for probabilities elicitation in a BN environment.

This paper is structured as follows. In the second section we provide details of the BFM sector. The third section considers our approach to scenario analysis through BNs. The fourth section describes how our scenario analysis was developed, according to the variables selected, the model definition, and the probabilities elicited. The fifth section presents the results from the analysis in terms of the different scenarios for the evolution of the market of BFM in Italy. In the sixth section, we discuss the main results on the basis of the relevant literature.

2. Context: biofuels from microalgae

According to European Council Directive 2009/28/EC (Council of the European Union and European Parliament, 2009), the substitution of fossil fuels with biofuels has been proposed for the EU as part of a strategy towards reductions in the energy import dependency and GHG emissions from road transport. This EC Directive 2009/28/EC set mandatory targets for all Member States to achieve a minimum of a 10% share of renewable energy in transport fuel by 2020. However, the new Directive (Council of the European Union and European Parliament, 2015) indicates the new focus of the European policy concerning biofuels. This explicitly tackles some of the issues related to first-generation biofuels in particular, and focusses on the implication for indirect land-use change, and on the need for support in favour of advanced biofuels.

There are several kinds of biofuels that are currently available as substitutes for the use of conventional fossil fuels, such as bioethanol, biodiesel, biogas and bio-hydrogen. To date, the production of biodiesel and bioethanol has attained the highest share at the global level (International Energy Agency, 2008; Liew et al., 2014). Indeed, the EU is the largest producer, consumer and importer of biodiesel. In 2012, while the global production of fuel ethanol reached 83.1 billion litres, that of biodiesel reached 22.5 billion litres, with Europe producing 44% of the global biodiesel (Council of the European Union and European Parliament, 2015). The top countries for the production of biodiesel in Europe are Germany, France, Spain and Italy, which together account for about 85% of the total biodiesel production in the EU. More specifically, about 405,800 t of biodiesel were produced in 2013 in Italy (EUROSTAT, 2015), although this was still below the domestic demand at the time, which was about 1,335,000 t (Assocostieri, 2015).

Biodiesel certainly has the potential to have an important role in systems of sustainable energy, as it brings significant advantages in terms of both environmental and socio-economic impact. It is a renewable and biodegradable fuel, and as such, it does not overburden the environment with CO_2 emissions, as CO_2 from the atmosphere is absorbed by the vegetable-oil crop during the photosynthesis process (Alcantara et al., 2000; Antolin et al., 2002). Also, the emission of pollutants and harmful substances during its combustion is significantly reduced, as biodiesel does not contain any aromatic hydrocarbons or sulphur (Agarwal, 2007). However, although biodiesel provides various benefits compared to fossil fuels, there remain several concerns related to the sustainability of this renewable energy source.

As the production of first-generation biofuels is mainly from agricultural food crops (Demirbas, 2009), this has induced competition for both agricultural land and water resources. Concomitantly, this issue has engendered several concerns over the social and economic impacts of first-generation biofuels, with the rising dilemma of food versus fuel now seen as a crucial theme for governments, scientists and businesses worldwide (Thompson, 2012). Also, there is growing evidence of potential limitations in terms of GHG reductions when land-use change is taken into consideration (see e.g., Naik et al., 2010; Organisation for Economic Co-operation and Development, 2008; Sims et al., 2010). Additionally, according to Pimentel et al. (2009), there are two further problems related to first-generation biodiesel production: the relatively low yields of oil crops, and the high energy requirement for the oil extraction process.