Journal of Cleaner Production 88 (2015) 61–70

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Assessment of the sustainability guidelines of EU Renewable Energy Directive: the case of biorefineries

Dries Maes [a,*], Miet Van Dael [a,b], Bernard Vanheusden [a], Liesbet Goovaerts [b], Patrick Reumerman [c], Nathalie Márquez Luzardo [d], Steven Van Passel [a]

[a] Centre for Environmental Science, Hasselt University, Martelarenlaan 42, 3500 Hasselt, Belgium
[b] VITO, Boeretang 200, 2400 Mol, Belgium
[c] BTG Biomass Technology Group, Josink Esweg 34, 7545 PN Enschede, The Netherlands
[d] School of Life Sciences and Environmental Technology, Avans Hogeschool, Lovensdijkstraat 61-63, 4800 RA Breda, The Netherlands

A R T I C L E   I N F O

Article history:
Received 22 November 2013
Received in revised form
6 March 2014
Accepted 7 April 2014
Available online 30 April 2014

Keywords:
RED guidelines
Sustainability
Sustainability assessment
Multiple pathways
Biorefineries
Biomass

A B S T R A C T

Sustainability guidelines can help to safeguard the sustainable use of biological materials. When these guidelines are legally prescribed, their influence on the economic viability of bioenergy, biofuel and bioliquid projects is increased substantially, through their impact on national subsidy regimes and international trade. One of the key examples is the European directive 2009/28/EC, or the Renewable Energy Directive (RED), and the related COM/2010/11 that integrate guidelines for calculating greenhouse gas impact for various bioenergy pathways. This paper looks further into the sustainability results when influenced by principal decisions that are legally open for debate. Therefore, a concise review is conducted of the legal state-of-the-art on whether a product is waste or not. The review pinpoints uncertainty, leading to four potential legal scenarios. The sustainability of a complex biorefinery is analysed for each scenario. The results show (i) a high sensitivity to the principal decisions on the nature of waste materials in the scenarios, and (ii) to the definition of boundaries between the processes. More detailed rules for the application of the RED guidelines are needed, and should be complemented with methods specifically targeting all relevant sustainability aspects, thereby enhancing the overall understanding of the sustainability of the process.

1. Introduction

There is an increasing demand for biological materials for the production of energy and fuels. A public concern to preserve the sustainability of these developments is reflected in the rapid evolution of sustainability guidelines and rules set out by governments and international institutions. The sustainability of products is a complex issue that depends on numerous factors (Clancy et al., 2013) and, therefore, these rules are very diverse. There is growing consensus on the importance of measuring the Greenhouse Gas (GHG) impact in most guidelines, but other aspects such as land use change, food security, social impacts or sustainable water use, remain hard to integrate in official sustainability measurements (Scarlat and Dallemand, 2011). Related policies supporting renewable energy and fuel production need important design improvements. General practical pathways of sustainable fuel production can be set out, for instance the use of biological waste streams or the growth of perennial plants on degraded farmland. But the current policies require significant improvements before these can nudge bioenergy production pathways towards these solutions (Tilman et al., 2009).

In itself, assessing the sustainability of a biofuel production pathway is a challenging task. There are several explanations for the contradictory results regarding the sustainability of biofuels. For example, the variations in the GHG performance of biofuels are often due to differences in local conditions and the design of the specific production system, different calculation methods and system boundaries (Börjesson and Tufvesson, 2011). Many methodologies are an application of Life Cycle Assessment (LCA), as it aims to consider the impacts during the whole life cycle of biofuels. However, several problems of bioenergy LCA studies related to the use of input data, functional units, allocation methods, reference systems and other assumptions (Cherubini and Strømman, 2011).

* Corresponding author.
E-mail addresses: dries.maes@uhasselt.be (D. Maes), miet.vandael@uhasselt.be, miet.vandael@vito.be (M. Van Dael), bernard.vanheusden@uhasselt.be (B. Vanheusden), reumerman@btgworld.com (P. Reumerman), nm.marquezluzardo@avans.nl (N. Márquez Luzardo), steven.vanpassel@uhasselt.be (S. Van Passel).

http://dx.doi.org/10.1016/j.jclepro.2014.04.051
0959-6526/

This empirical difficulty is only increased with innovative bioenergy technologies. Straightforward production pathways consist of one or two cultivated streams of biomass that are transformed to one type of energy carrier. Sustainability assessments of these single pathway technologies are clear-cut in terms of attribution, allocation and categorisation of streams. In contrast to single pathways, innovative bioenergy pathways are often combined to create economic synergies and environmental benefits. This gives rise to elaborate flexible biomass supply chains (Gold and Seuring, 2011). Innovative transformation processes of biomass can produce simultaneously materials and energy flows. New combustion projects not only focus on clean sawdust or wood particles, but also on polluted streams (Nzihou and Stanmore, 2013). Fermentation projects combine various flows of biomass, such as roadside clippings (Pick et al., 2012), organic municipal waste and agricultural by-products (Weiland et al., 2009). These projects produce energy flows such as heat, and electricity, but also other products, such as fertilizers, liquefied biogas, purified CO_2 or animal fodder (Van Dael et al., 2013). Novel processes continue this development with the production of renewable hydrogen (Urbaniec et al., 2010). Also microalgae are gradually fit in new production chains (Holma et al., 2013). Higher degrees of complexity are achieved by biorefineries (Bozell, 2008). Based on the principles of green chemistry (Manley et al., 2008), these concepts are integrated plants creating a vast range from renewable energy carriers to high value chemical products in a sustainable set-up (Warner et al., 2004). This higher degree of integration can lead to more environmental benefits (Fatih Demirbas, 2009), but also to more exigent sustainability assessments.

Due to these trends, sustainability assessment methods face difficulties to assess such complex processes holistically (Maes and Van Passel, 2014). Translating this sustainability assessment in binding legal regulations is even more challenging, and requires coherence with other legal instruments and international agreements. The European Union (EU) has historically been proactive in the creation of official sustainability rules for renewable energy, biobased fuels and gases. Despite other contradicting EU initiatives, the sustainability rules and regulations drafted by EU policies remain important predecessors for other likeminded initiatives anywhere in the world (Afionis and Stringer, 2012). Within the legislative body of the EU, the European Renewable Energy Directive 2009/28/EC (RED) forms an important part of the entire European energy policy, and a crucial part in any future structure of international biofuel trade (Kaditi, 2009). The RED (EC, 2009), and the related COM/2010/11 (EC, 2010b) provide guidelines for calculating GHG impact in order to guarantee the sustainable use of renewable sources. These sustainability guidelines are essentially based on CO_2 equivalent emissions over the entire life cycle of the biomass project. The calculations are complemented with controls for sustainable land use and respect for social rights. Research projects already addressed several important advantages and limitations of the RED sustainability guidelines. There are for instance difficulties to correctly account for indirect land use change and local variability (Van Stappen et al., 2011). Soimakallio and Koponen (2011) also discuss related topics, such as trade-offs, timing and allocation problems. Tufvesson et al. (2013) conclude that the current calculation method has a limited systems perspective since the actual utilisation of some residues is not included in the calculations. Also the core, the GHG accounting, is being discussed. When comparing three different GHG accounting methods, diverging results for partial life cycle assessments are found (Whittaker et al., 2011). Even more precisely, Hennecke et al. (2013) compare two calculation tools that are both based on the RED guidelines, and still show diverging results.

Given the importance of the RED-guidelines, this paper adds to this strand of research by looking at the effects of legal uncertainty in the analysis of complicated production processes with multiple bioenergy pathways. Such complex pathways result in the co-production of different resources. Much depends on the classification of the resource streams as material or waste for which the RED guidelines follow other legal texts. A concise review of the legal state-of-art concerning this waste regulation shows that the choice whether a resource is waste remains often debatable. Furthermore, where multiple outputs are generated, the RED provides an allocation rule. But the allocation rule departs on particular instances from standard biophysical allocation procedures. These aspects have a large impact on the results of the sustainability assessment. In order to investigate the effect of the RED focus on single pathways directed towards fuels and energy, we apply the RED guidelines to an advanced Energy Conversion Park (ECP) in the Netherlands (Van Dael et al., 2014). The ECP is a complex multiple pathway structure, producing fuels, energy and materials. The sustainability analysis is performed according to the RED guidelines using the Bioenergy Sustainability Assessment Tool (B-SAT) and compared to those of a Cumulative Exergy Extraction from the Natural Environment (CEENE) analysis (Dewulf et al., 2007). The results are compared particularly in relation to the horizon of the analysis over the biomass pathway, and the effect of different allocation rules for output valuation.

The paper is structured as follows. Section 2 provides the principal details of the RED guidelines that are shaped by the single pathway approach and provides more details about the legal framework concerning waste. Section 3 describes the four potential legal scenarios as a result. It also elaborates the two sustainability assessment methodologies that will be used to analyse the scenarios. Section 4 presents the general set-up of the ECP and the practical case under investigation. Section 5 presents and discusses the sustainability assessment results. Section 6 concludes.

2. Consequences of divergence from single pathways for the RED guidelines

The easiest case of renewable energy production is composed of one single process, utilising a group of inputs and producing one single renewable energy stream as output. Divergence from this single pathway case can happen on multiple instances in the production chain, and causes uncertainty to apply the RED guidelines. (1) The process itself can produce multiple energy streams and materials as outputs. The emission burden of the process will have to be allocated among the different outputs, and this requires an allocation rule. (2) Earlier in the production chain, inputs can be the result of other industrial activities. Inputs only carry an emission burden covering their entire preceding production chain if they are of added value. Waste materials from industrial activities do not carry this burden. The decision whether an input is a waste material or not, has therefore a strong effect on the result of the sustainability analysis. (3) The energy production process can be split into multiple interconnected processes. The sustainability can be either analysed for every single process separately, or this division can be disregarded and the entire site can be analysed as a black box with multiple outputs. This principal decision has again a strong effect on the results.

This section focuses on the principles related to instance (1) and (2). The RED guidelines provide an allocation rule for co-products. The differences with other related allocation rules will be discussed. The principal decision whether a material is waste or not, is subjected to the evolution and interpretation of the related laws and regulations. The third point and its effect will be analysed in Sections 3 and 4.