Journal of Cleaner Production 177 (2018) 197–206

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Redesigning a bioenergy sector in EU in the transition to circular waste-based Bioeconomy-A multidisciplinary review

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ARTICLE INFO

Article history:
Received 5 September 2017
Received in revised form
27 November 2017
Accepted 19 December 2017
Available online 28 December 2017

Keywords:
Bioenergy
Sustainability
Circular economy
Bioeconomy
Waste-based indicators

ABSTRACT

The transformation of the energy system encompasses technological, societal, cultural, economic, and environmental aspects and calls for a more important role for citizens and communities. Bioenergy systems are subjects to legal, technical, environmental, economic, and social settings. At the regional level, bioenergy can incorporate agricultural traditions and offer waste-management solutions. Many are the stakeholders, with different perceptions and sometimes, conflictual interests. This study is a multidisciplinary, comprehensive review of recently published papers, on legal, technical, economic, and environmental layers of the bioenergy. It highlights the role of bioenergy in the transition to a Circular waste-based Bioeconomy. Three dimensions of sustainability (environmental, economic, and social) were discussed and some thermodynamic (energy, exergy, emergy) and environmental indicators applied to bioenergy systems, were cited. Findings conclude that in the context of Circular Bioeconomy, global bioenergy sector may face challenges, due to the new demand for biomaterials from the same sources. Bioenergy sustainable pathways should be selected at the base of high efficiency, towards closing loops and in the concept of cascade and integrated biorefineries. At the regional level, bioenergy systems may be integrated with the cascade biorefinery models or can offer waste management solutions by stand-alone, tailor-made decentralized systems. In redesigning the bioenergy sector, local knowledge, public health, and community's resilience should not be neglected, while social-environmental benefits should be considered in addressing the viability of bioenergy plants. Social acceptance can be improved by a better understanding of the scientific and technical issues and by developing a broader consciousness of the planet and life.

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1. Introduction

The European Union (EU) has been the leader in the promotion and development of renewable energy (EPA, 2017), and aims to reach 80% reductions of anthropogenic Green House Gases (GHG) emissions by 2050 (Wüstenhagen et al., 2007). Bioenergy in EU contributes to 41 days of the total, which means that from November 21st to December 31st, 2017, Europe could solely rely on bioenergy to fuel itself (European bioenergy day, 2017). While bioenergy can play a key role in decarbonizing electricity (IEA, 2016), it offers many other benefits, including energy security increase, rural development and, household income increase (Acosta-Michlik et al., 2011). At the regional level, bioenergy can incorporate agricultural traditions and offer waste-management solutions (http://www.biopad.eu/about-bioenergy/), while coupled with biochar production, it offers carbon sequestration and soil quality improvement (Zabaniotou et al., 2015) and closing loops in agriculture (Bădescu et al., 2017).

The transition to low carbon societies is different for every regional context, and the application of bioenergy plants may be contested, delayed, or impeded (Burnham and Eaton, 2017). Bioenergy deployment has been associated with risks and concerns, mainly regarding large-scale plants of combustion (Schubert and Blasch, 2010). These concerns are referred to biodiversity, deforestation, increased demand for agricultural land and water scarcity (GBEP, 2011), having an impact on the social acceptance of bioenergy and impending its deployment (Dwivedi and Alavalapati, 2009; McCormick, 2010).

Biomass is a source of renewable energy, providing heat and electricity, and it is the only source to produce transportation fuels, but environmental and socio-economic impacts of bioenergy systems should be evaluated to guarantee sustainable systems. While off-the-shelf technologies for producing heat and power from biomass are available, other conversion technologies with improved efficiencies are under development. These technologies target at improving storage characteristics of upgraded biomass

https://doi.org/10.1016/j.jclepro.2017.12.172
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Abbreviations

AC	Avoided Carbon emissions
AEBIOM	The European Biomass Association
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
BECCS	Bio-Energy with Carbon Capture and Storage
BECS	Biomass Energy Carbon Sequestration
CFB	Circulated Fluidized Bed
CHP	Combined Heat and Power
EEA	European Environment Agency
EEA	Extended Exergy Accounting
EEB	European Environmental Bureau
EIR	Emergy Investment Ratio
EU	European Union
EU28	28 Countries of the European Union
EWABA	European Waste-to Advanced Biofuels Association
FQD	Fuel Quality Directive
GBEP	Global Bioenergy Partnership
GHG	Green House Gas
IEA	International Energy Agency
ISI	International Statistical Institute
JRC	Joint Research Center
LCA	Life Cycle Assessment
NC	Net Carbon emissions
NEYR	Net Emergy Yield Ratio
NGOs	Non-Governmental Organizations
NPV	Net Present Value
RED	Renewable Energy Directive
RES	Renewable Energy Source

and other renewable and waste carbon sources, providing a flexible element for heat and power production and for balancing the grid stability, as well as for transport applications, contributing to the EU 2020 energy objectives. It is crucial, the new generation technologies to deliver possible economic benefits along the value chain, via power-to-gas and/or power-to-liquid concepts for CHP, transport, and storage applications (EU Horizon 2020, 2017). In addition, the shift of biomass conversion from one product to multi-products in the biorefineries model, in the transition to Bioeconomy, calls for careful consideration of sustainability issues (Devine-Wright et al., 2007).

The present paper attempts to shed light on important advances in the European Union over the last years, related to bioenergy deployment, based on sustainability considerations. The study goes through the legal, environmental, technical, economic, social, and new social/philosophical approaches, that affect bioenergy deployment. The purpose of this study is not to evaluate certain sustainability dimensions, but to review the dimensions of sustainability (environmental, economic and end social), in the transition to Circular waste-based Bioeconomy. It aims to highlight the pathways for the transition to a lower carbon energy future by redefining a sustainable waste-based bioenergy at the regional level, in EU.

2. EU bioenergy policies as a key driver

The EU latest Renewable Energy Sources (RES) policy, including bioenergy, was expressed by the Directive 2009/28/EC. This directive, called RED, was amended on 23 April 2009, by setting mandatory renewable energy targets for Member States up to 2020, and required at least 20% of EU total energy needs to be replaced by 2020 with RES, while all EU countries should ensure at least 10% biofuels in transport fuels, (European Commission Directive, 2009).

Seven years later, in 2016, due to many environmental concerns, socio-political changes, and new perspectives on sustainability, the European Commission published a proposal for the revision of RED, to ensure the target of at least 27% share of renewables in energy, by 2030 (European Commission, 2016), with updated sustainability criteria for biofuels in transport and bioliquids, solid and gaseous biofuels intermediates for CHP. The targets for electricity, heating and cooling, transport sectors, mix of different renewables technologies differ from country to country, due to the difference in available resources and energy markets.

On 13 February 2012, the Bioeconomy Strategy launched and adopted, under the lead of DG Research and Innovation, co-signed by DGs of Agriculture and Rural Development, Environment, Maritime Affairs, and Industry and Entrepreneurship, aiming to ensure that fossil fuels are replaced with renewables, as part of the shift to a post-fossil fuels society. In 2017, a planned updating of the Strategy was proposed for new political orientation. Bioeconomy is expected to play an important role in the low carbon economy and the European Commission long-term goal is to develop a competitive, resource efficient and low carbon economy by 2050.

On 30 November 2016, the European Commission presented the 'Clean Energy for all Europeans', package, for increasing competitiveness (EC, 2016). On 20 June 2017, the European Council adopted the 2030 Agenda for Sustainable Development. EU previously had proposed the agenda in September 2015, as an instrument to support sustainability.

Having strong synergies with the EU's objectives on climate and energy, with the 'Clean Energy for all Europeans' package, with the 'Agenda for sustainable development', (EU, 2016), and with EU priorities on jobs and growth, social agenda, and industrial innovation, the Circular Economy Package Action Plan adopted on 2 December 2015, by the European Commission. The EU 2050 vision for resource-efficient, low-carbon development, and living in harmony within the boundaries of the planet, was published by the European Environment Agency (EEA) (EEA, 2016), as set out in the European Union (EU)'s 7th Environment Action Programme (EU, 2013).

In 2016, the European Commission launched the Circular Economy Action Plan for Circular Economy strategy implementation (EU, 2017a, b). The package included legislative proposals on waste, and closing the loop approaches in the product lifecycles, covering the full value chain. According to Ellen MacArthur Foundation, a circular economy is a regenerative system in which resource, waste, emission, and energy can be minimized by closing material and energy loops (Ellen MacArthur Foundation, 2017).

In 2017, the EU Joint Research Center (JRC), prepared a report for assisting operators, stakeholders, the scientific community with all the necessary information in calculating the GHG emissions for different biomass pathways (Giuntoli et al., 2017), in the transition to Biorefineries and Bioeconomy.

3. EU strategies of circular economy and bioeconomy as pillars of sustainability

Many are the challenges that the planet is facing today, which are beyond climate change (Fig. 1). The increasing of planet's population (by 2050, the world population will reach 9.5 billion), challenges the need in food, natural resources, and raw materials (Venkata Mohan et al., 2016). Renewable resources are consumed

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