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Original article

Conceptual vision of bioenergy sector development in Mediterranean regions based on decentralized thermochemical systems

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ABSTRACT

A conceptual vision of gasification and pyrolysis systems, fueled with agro-residues and agro-industrial by-products, is discussed in this study. The aim is to plan actual implementations and possible developments of bioenergy in Mediterranean rural regions, towards accelerating the transition to post-fossil fuels regions, with self-sustainability. The study is an integrate approach of bioenergy systems, it discusses the issue of supply and availability, the methods to estimate them, it sheds light to thermochemical processes feedstocks implications, incorporates general sustainability issues and proposes model for accelerating the bioenergy applications in Mediterranean countries, which are facing an economic crisis. Various agricultural residues of Mediterranean areas were analyzed; their characteristics found to be almost similar, due to similar climate conditions of growth. This allows to vision a bioenergy development, based on small tailor-made decentralized systems, fueled with mixed feedstocks. The discussed approach of combining pyrolysis for renewable energy generation and biochar production to be used as soil amendment, can offer an attractive strategy towards reducing greenhouse gas emissions and closing the loop in agriculture. This approach can boost sustainable development in rural areas, enhance the potential of efficient decentralized bioenergy systems and promote the creation of diversified productive activities (green-business) in the agricultural sector, in strict connection with branches of green-industrial companies, while closing the loop from agriculture back to agriculture.

Introduction

The EU energy policy is currently addressing the use of energy by a smooth functioning of the domestic energy market, ensuring a reliable supply from external sources, and a significant reduction in greenhouse gas emissions, by increasing the share of renewables, and the energy efficiency [1]. Within this general frame, the use of biomass, mainly from inside the EU, could offer a significant contribution in providing a renewable and environmentally friendly energy source. A sustainable development of the bioenergy sector, considering the whole system from the early stage of biomass supply to the final energy use, should not compete with food and feed, while protects natural resources and safeguards human health [2].

Process integration enables higher technical efficiencies, better fuel standards and regulations, as well as lower costs in facilities investment and operational management, and are further essential elements in promoting the takeoff of the bioenergy sector. Polygeneration strategies for obtaining multiple energy products from biomass offers higher efficiency and flexibility [3]. Polygeneration is defined as production of at least three different products, which in case of gasification typically are heat, electricity, and biofuels, while in the case of pyrolysis can be heat, electricity, biofuels and biochar.

Biomass feedstocks show a high degree of variability, resulting in its increased use and conversion into a wide spectrum of bio-based products and bioenergy vectors. Solid biomass can be converted to liquid and gaseous biofuels by thermochemical processing, having some advantages over other biomass conversion methods, such as combustion and anaerobic digestion, in terms of higher efficiency, complex feedstock processing, and decentralized electricity production, likely to play an important role in future energy supply [4].

A critical review of the most up-to-date thermo-chemical routes, with focus on pyrolysis for biochar production or gasification for CHP is presented, with emphasis assigned to decentralized CHP low-cost facilities. Over the last years, significant progress in all aspects of biomass

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Nomenclature

AAEM	Alkali and alkaline earth metallic species
ASTM	International Association for Testing Materials
BET	Brunauer–Emmett–Teller
BFB	Bubbling Fluidized Bed
CEN	European Committee on Standardization
CFB	Circulating Fluidized Bed
CHP	Combined Heat and Power
CLCA	Consequential Life Cycle Assessment
CUBE	Calculating Uncertainty in Biomass Emissions
Db	Dry basis
DLUC	Direct Land Use Change
EU	European Union
FAOSTAT	Food and Agriculture Organization Statistics
FTIR	Fourier Transform Infrared
GHG	Green House Gas
GIS	Geographical Systems
ILUC	Indirect Land Use Change
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LHV	Lower Heat Value
LUC	Land Use Change
OS	Olive Stones
OTP	Olive Tree Pruning
PAHs	Polycyclic aromatic hydrocarbons
RED	Renewable Energy Directive
SOC	Soil Organic Carbon
TGA	Thermogravimetric Analysis
VP	Vineyard Pruning
WS	Wheat Straw

and bioenergy research, was observed and key breakthroughs in several technological areas were accomplished. Moreover, relevant sustainability issues raised public and political discussions on complex questions, with important scientific and technical implications (such as energy and GHG balance, direct and indirect land use change, competition with food and feed, possible water overexploitation and biodiversity threats due to intensive cultivation of energy crops). For future developments, essential elements to assess carefully the suitability of the whole value chain should follow strategic criteria. These criteria are related to security and stability of the energy supply, actual energy conversion gains, energy planning, energy transmission, distribution, logistics or storage, environmental advantages (mainly with respect to climate change mitigation), equitability and social development [5]. An analysis should be complete enough to include the main possible value chains, according to an integrated approach, starting from the feedstock local availability up to the specific end-use of the energy products.

There are considerable amounts of biomass in the form of agro-residues and agro-industrial processing wastes in Mediterranean countries (olive oil and wine processing wastes, straw residues, etc.), which are available at relatively low or zero cost compared to dedicated bioenergy feedstock. These are promising sources for small-scale production of bioenergy and biochar in a closed loop, overcoming existing concerns related to large scale, such as spatial distribution, production costs, and an unstable supply. The estimation of the amount of resources is very important for the viability of a thermochemical system, considering the high degree of heterogeneity in feedstock, the uncertainties in their technical availability, their sustainable recoverability and economic viability of utilization. Several tasks such as the evaluation of the extent of the biomass supply basin, location of the energy facility, estimation of transportation costs, the number and distribution of the storage points, and several other biomass logistic issues can be assigned to GIS on this respect. The analysis of the characteristics of typical Mediterranean agro-residues can provide knowledge for the considerations of specific technological issues of thermochemical conversion systems and give insights to their implication in pyrolysis for biochar production or gasification for CHP. Other relevant knowledge gaps can be detected in considering the technological conditions affecting biochar quality, specifically during the pyrolysis process and with respect to feedstock of different composition and properties to be used to feed the system. Thus, there is still ample room to perform experimental evaluations and significantly improve the level of knowledge about the biochar-pyrolysis system. Prior to any investment decision related to agro-residues thermochemical-based treatment, the design of the whole value chain should fully meet sustainability requirements, seasonal availability, and final energy utilization or end-product. This long series of predicaments is part of a complex system that should be systematically assessed and globally optimized.

The objective of the present study is to fill the above gaps and contribute towards establishing a global and up to date conceptual vision of thermochemical energy conversion processes, to plan actual implementations and further developments. For the analysis, three main parameters were taken in consideration:

(a) feedstock categories,
(b) reference geographical area and
(c) the size or capacity of the proposed bioenergy facilities.

Altogether, these three features contributed in defining a specific bioenergy vision and the corresponding deployment strategy.

The two feedstock categories considered, were crop-residues and agro-wastes. These terms are used to describe all the organic materials that are obtained as by-products from harvesting and processing agricultural crops. These feedstocks can be categorized into *primary* and *secondary* residues, respectively. Primary residues (crop-residues) are generated in the field (they can be left on the soil or collected at the same time or after the main product has been harvested), whereas secondary residues (agro-wastes) are obtained during the subsequent industrial food processing. To the extent these wastes and residues are assuming importance for other productive uses (biomaterials, fine-chemicals, soil amendments, as well as energy conversion) they should be considered as co-products, to which assign an increasing economic value in parallel to the main products.

The second considered feature of this study was the origin of this feedstocks. The feedstocks are byproducts of crops characterized by Mediterranean climate conditions, with reference to European countries bordering the northern coasts of the Mediterranean Sea. The Mediterranean climatic region experiences winter rain and summer drought, giving rise to a distinctive type of agriculture with an intensive and highly specialized farming. A variety of crops are raised. This type of farming is also found in irrigated semi-desert and desert areas in similar latitudes.

The third feature pertains to the distributed energy generation model. Distributed generation refers to a variety of technologies that generate electricity at or near where it will be used, such combined heat and power (CHP). It may serve a single structure, such as a home or agro-industrial unit, or it may be part a smaller grid that is also tied into the larger electricity delivery system, helping support delivery of clean, reliable power.

Assessment of the agro-residues availability

The use of local available biomass is considered a prerequisite to start up the supply chain activities. Crop-residues and agro-wastes are