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Editorial

Biomass Energy Resources: Feedstock Quality and Bioenergy Sustainability

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1. Introduction

The fossil fuel society is facing environmental, socio-economic, and geopolitical issues. We can no longer postpone our transition towards sustainable economic models based on renewable energy sources. The threat of climate change resulting from human activities and the need to ensure environmental sustainability are now a global priority [1]. Much attention is now focused on the energy sector due to its prominence as the largest emitter of greenhouse gases and its related geopolitical tensions. During this historical period, the European Union is conscious of how vital it is to limit reliance on energy imports and discover new forms of energy production to improve energy security. The European Union has recently proposed a new and stricter package of proposals to reduce net greenhouse gas emissions [2]. The initiative called "Fit for 55", within the recent European Green Deal climate actions, sets a maximum emission threshold to be met by 2030, corresponding to 55% of the figures recorded in 1990. This program involves particularly the energy sector, which must increase the share of renewable energy to 40% in the same period. This is a rather ambitious target considering that, by 2017, renewable energies provided just 17.6% of the total energy supply in the EU. Consequently, this recent decision has also informed the new targets for the share of renewable energy established by the Renewable Energy Directive II, moving them from 32 to 40% by 2030.

Sustainable energy production can foster a neutral balance of GHG, especially when sources such as lignocellulosic biomass are highly available and their procurement does not interfere with food chains. From this point of view, biomass is considered an important renewable energy source to reduce net CO_2 emissions, contributing to climate change mitigation [3]. In particular, the use of biomass wastes for energy purposes is regarded as one of the most promising solutions by policymakers and the scientific community to achieve this goal [4–6]. Bioenergy is one of the main contributors to the renewable energy market. Biomass-based energy production is expected to increase in the next decades, expanding its role in the EU's renewable energy mix and harnessing its potential contribution to a low carbon economy.

Biomass includes a wide range of raw materials, mainly from agriculture, forestry, and marine fields. The biomass elemental composition is mainly represented by carbon, hydrogen, oxygen, and nitrogen, which constitute many components, including cellulose, hemicelluloses, lignin, extractives, lipids, fat, proteins, simple sugars, starches, water, hydrocarbons, ash, and other compounds. The variability of the characteristics is due to the multiple types and origins of vegetable raw materials and their components (e.g., wood, branch, barks, shell, leaves, straws, pits, and so on) [7].

Biomass residues and wastes are often difficult to utilise as energy sources due to several challenges, including heterogeneity of the material, high moisture content, poor biological stability, and low energy density [5,8,9]. Moreover, despite the numerous opportunities available, there are also critical issues related to the general sustainability of biofuels and the nature of the biomass from which they derive, also raising several ethical and social issues [10,11]. A solution that helps to avoid food/non-food competition is the use of lignocellulosic biomass, agro-industrial wastes, and agricultural residues [11–13], which, on average, represented about 442 Mt/year of production from 2006 to 2015 in Europe [14]. Thus, to support residual biomass use, a European policy on the redefinition of the waste and residue sector was implemented through the directive 2008/98/EC [15,16].

Sustainability issues play a central role in bioenergy applications. It is no coincidence that the Renewable Energy Directive (RED) has been revised, extending the sustainability criteria to solid and gaseous biomass fuels used for heat and power production [11]. The demand for renewable energy is expected to increase remarkably in the next years, especially during this historical phase where the energy issue is urgent in the EU. Traditional biomass sources will probably not be enough to satisfy sustainability criteria and meet future energy needs. This implies the need to draw from the widened field of agricultural residues, by-products, and wastes from the agroforest and agro-industrial sectors [11]. However, this kind of biomass material's limited bulk and energy densities affect the harvesting and logistic costs and partly limit its energy and environmental sustainability [17,18]. The dissimilarities in physical properties and chemical composition can affect a biomass power plant's combustion efficiency, maintenance, and logistics, partly limiting its energy and environmental sustainability. In order to meet expectations, the bioenergy sector must seek a higher degree of efficiency in the whole supply chain [19]. The initiatives also include re-considering the structure of the supply chain by introducing solutions, such as the pelletisation of agricultural residues, to improve the logistics and sustainability aspects of the supply chain and the quality of the biofuel [11,16,18].

Quality is a crucial issue for the energy use of residual biomass, especially for agricultural biomass [20]. A strong commitment is needed in the development of qualitative standards, which are indispensable for orienting the market and the stakeholders of the sector [21–23]. It is also necessary to increase knowledge of the properties of raw materials, especially residual and agro-industrial ones [8,24–26], identifying the most important qualitative factors and the relationships between them [23,27–29].

The critical issues related to the quality of biomass are also overcome through the application of monitoring plans of the characteristics of energy materials along the supply chain up to the end-user [30–32] and the introduction of modern analytical techniques alternative to traditional ones, with particular attention to those based on infrared spectroscopy [33–38].

These techniques can tackle the problems related to the complexity of the chemical structure of biomass, providing rapid and cheap results and representing an important decision-making tool for the different stakeholders involved in the bioenergy chain [39]. The development of a rapid technique able to provide this information [40] could be valuable for the energy sector, making the results more realistic and useful for the power plant [30] and providing indications on biofuel traceability and sustainability [41,42].

Based on the aforementioned aspects, this Special Issue (SI) was proposed in this journal to promote research on these topics, especially the link between biomass quality and bioenergy sustainability. A research effort is required to exploit the available biomass materials, especially less traditional ones, by developing innovative production processes and measurement systems to produce sustainable biofuels and bioenergy.

2. Papers Published in This Special Issue

The interest in this SI was demonstrated by five research papers published between 2020 and 2022. Four corresponding authors submitted seven manuscripts, with ten others participating as co-authors. All the published papers deal with aspects connected with the SI's theme, such as residual biomass quality, sustainability assessment of solid biofuel production, and bioenergy sustainability assessment. The contributions, as expected, were mainly in the solid biofuel sector, where biomass quality has an important effect in terms of environmental sustainability. The SI enriches the current state of the art in this field, reporting the results of specific case studies.

Pizzi et al. [43] evaluated the different residues of rubber tree cultivation and their quality to give valuable indications for possible valorisation. This was carried out considering a significant number of samples coming from Africa and many analytical parameters. According to the study, from each hectare cultivated with rubber seed, about 30 kg of biodiesel could be produced, substituting about 26 kg of fossil fuels, with the related improvement in sustainability. They also found that capsules and shells could be used to produce enough thermal energy for drying rubber seeds and other products, further improving sustainability. Together with its energy uses, the extraction meal could be used as a bio-fertiliser or for feeding purposes in line with the circular economy concept. The information reported is useful to improve the latex production chain's overall sustainability and evaluate the possible bioenergy value chains. However, the study solely focused on assessing biomass quality, while no specific analysis was directly carried out on sustainability.

Ilari et al. [44] assessed the quality of different residual biomass typologies used by a specific power plant in Italy. They evaluated the carbon footprint of the produced energy by LCA, making possible the comparison with standard energy production. All the tested biomass samples showed results suitable for biofuel use in the power plant but with high variability in quality, especially ash content. The sustainability assessment is limited to global warming and energy use at the plant gate. On average, the carbon footprint resulted in 17.4 g CO_2eq./MJ electrical energy, entailing a saving of more than 90% with respect to fossil energy production. The authors highlighted that local sourcing of biomass materials with an efficient logistics system presents environmental benefits and significant economic advantages regarding various logistical aspects of biomass transport and energy distribution. The use of residual biomass determines a further improvement in sustainability.

Ilari et al. [45] analytically defined the quality of residual woody biomass produced in marginal areas and the solid biofuels obtained from that biomass material. They found that a debarking process improved the quality by significantly decreasing the ash content. The produced pellet showed low durability, suggesting use near the production point to avoid problems due to transport and storage. Based on the information reported, due to the limited quality of these biomass materials and related biofuels, they should be used to satisfy the company's energy needs, limiting problems and improving sustainability.

Ilari et al. [14] studied the impact of heat production from vineyard pruning pellets by LCA, considering two different systems based on a mobile pelletiser (PS1) and on a stationary pellet plant (PS2). An energy characterisation of vineyard pruning pellets was carried out to evaluate pellet quality. The LCA impact assessment methods selected were Eco-Indicator 99 (H) LCA Food V2.103/Europe EI 99 H/A and ReCiPe Midpoint. The two methods returned similar results, with PS1 being slightly more impactful than PS2. The major contributors to the final impact are direct emissions and ash management, which contribute most to human health and ecosystem quality. Both these scenarios are significantly less impactful with respect to the baseline scenario of heat from fossil fuels. This is even more evident if the valorisation of wood ash is considered. Moreover, the authors correctly pointed out that using this solid biofuel can simultaneously help avoid the combustion of these pruning materials directly on the field without a specific combustion device, which is very likely to happen. This could save a significant amount of direct emissions affecting global warming and even reduce ecosystem toxicity and impacts on human health.

Ilari et al. [46] studied the impact of heat production from the wood of the tree species Hophornbeam widely spread in Italy and the Balkans. For the Hophornbeam, scientific evidence demonstrates that coppice management favours a greater level of biodiversity right after cutting, making active management useful also for the environment. The analysis showed how the impact of the scenario for firewood is less than that for wood stoves. Although there are differences in the combustion processes, they do not show substantial differences in impact for the use step. The more significant impact of the woodstove scenario is entirely due to the increased use of fuels, lubricants, and machines for the wood splitting and cutting phases. The comparison between short distance chains (BS1) and medium distance chains (BS2 and AS) shows a foreseeable lower impact for a short chain. The authors compared the results with the values of similar supply chains included in technical standards such as the RED II regulation and the EU directive 2018/2001. Their results are lower but comparable—3 g CO_2eq/MJ in the present study (baseline) against 5 g CO_2eq/MJ reported by the 2018/2001 regulation, referring to wood chips from wood logs with transport distance in the 0–500 km range.

3. Conclusions

Environmental sustainability analysis helps to assess the coherence of a biomass energy chain. This analysis can also direct the choices of policy-makers and administrative decision-makers towards solutions that are not always understandable by the operators themselves. The results make it possible to highlight virtuous supply chains, avoiding evaluations based on impressions and, sometimes, on habits. Generally, these environmental assessments are carried out using the Life Cycle Assessment method, as demonstrated by the papers in the present SI.

A relationship is also emerging between sustainability and raw material or biofuel quality. The most representative parameter of this ratio is moisture content. This factor has always limited the biomass supply chains by reducing the combustible product's energy density, undermining the sustainability of the logistic processes of a supply chain.

An excellent example of a virtuous supply chain and an exercise in the application of sustainability is the vine pruning pellets produced using a mobile pelletising machine. The use of residual biomass and densification close to the origin of the raw material represents an effective combination in making this solid biofuel sustainable and of higher quality than the raw material, which is removed from polluting combustion in the field with harmful effects on human health.

Although we can obtain biomass through forest management, overexploitation leads to serious environmental issues. In contrast to the widespread idea that unmanaged woods and forests guarantee a high biodiversity, regular coppice management can lead to increased biodiversity due to the inclusion of species associated with different habitats, such as pasture. This potential relationship between mild forest resource management and biomass production was highlighted in one study. However, this topic has not been thoroughly investigated.

The response to the SI can be considered satisfactory because the published papers contribute by adding specific information on different bioenergy production chains. Still, it is also evident how difficult it is to couple sustainability assessment with biomass and biofuel quality analysis in the same work.

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