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Editorial

Special Issue on Assessing the Modern Bioenergy Potential and Strategies for Sustainable Development: Transformations through Nexus, Policy, and Innovations

Dilip Khatiwada [1] and Pallav Purohit [2,*]

[1] Division of Energy Systems, Department of Energy Technology, KTH Royal Institute of Technology, Brinellvägen 68, SE-100 44 Stockholm, Sweden; dilip.khatiwada@energy.kth.se
[2] Air Quality and Greenhouse Gases (AIR) Program, International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, Laxenburg A-2361, Austria
* Correspondence: purohit@iiasa.ac.at

This editorial aims to summarize the five scientific contributions that contributed to the Special Issue assessing the modern bioenergy potential and strategies for sustainable development, considering the several aspects, viz. biofuels–water nexus, policy analysis, complexities of biofuel investment plans/options, and participatory innovation framework.

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1. Overview

Modern bioenergy is widely acknowledged as a potential substitute for fossil fuels to offset human dependence on fossil fuels for energy. It has the potential to make an important contribution towards sustainable development, from rural development and poverty alleviation to energy security and climate change mitigation. Modern bioenergy would play a key role in the sustainable transformation of energy systems, along with its decisive contribution in developing a low-carbon growth path while contributing to energy diversification and security [1,2]. Nevertheless, there are concerns and scientific debate on sustainable bioenergy, especially on land-use change (LUC), food security, and biodiversity loss [3]. In order to minimize the potential risks and challenges, we need to understand interdisciplinary dimensions such as government policies, financing schemes, stakeholders' engagement, and intersectoral linkages while devising sustainable bioenergy strategies. Bioenergy accounts for the largest share of the global energy supply compared to all renewable energy resources [4]. In spite of the largest share among other renewables with 10% of the global primary energy supply [5], the current rate of bioenergy deployment is well below the levels required for low-carbon scenarios [6]. Accelerated deployment is urgently needed in order to ramp up the contribution of sustainable bioenergy across all sectors, notably in the transport sector, where consumption is estimated to triple by 2030. There is an increasing understanding that only bioenergy that is supplied and used sustainably has a place in a low-carbon energy future. Modern bioenergy has several positive benefits, and synergies need to be established between energy and food security through an integrated assessment of resources.

There is a plethora of bioenergy research either in the supply chains, conversion technologies, or techno-economic analysis of different biofuel production pathways [7]. However, little attention has been shown to how bioenergy production and consumption would have a role in sustainable development. What are the synergies and trade-offs between bioenergy use and the SDGs? The nexus approach can be useful in understanding the synergies and trade-offs, capturing the interdependence between scarce resources (e.g., water, energy, land). It is also critically important to explore cross-cutting issues such as socio-political, techno-economic, legal, and environmental ones when it comes to the deployment of biofuels for sustainable development. Investment plans also need to be addressed considering transformations and complexities associated with biofuels.

Innovation in the transition towards biofuel would only be possible if we consider a participatory approach considering people's behavior and societal needs.

2. A Short Review of the Contributions to This Special Issue

This Special Issue consists of four research papers and one review, contributed by experts in the field, on topics including (i) mapping bioenergy supply and demand in selected least developed countries; (ii) evaluation of water and energy nexus in Wami Ruvu River Basin, Tanzania; (iii) global investment failures and transformations in modern biofuels; (iv) a socio-political, techno-economic, legal, and environmental analysis of biofuel energy industry in Europe; and (v) the role of participation in the responsible innovation framework for biofuels projects.

2.1. Assessment of Modern Bioenergy: Conditions and Synergies

Bioenergy has crucial advantages over other energy sources as a tool for poverty reduction in the least developed countries (LDCs). Though biomass resources are widely available in rural areas of LDCs, little seems to have been done with regards to the national modern bioenergy sector. Khatiwada et al. [8] assess the surplus agricultural residues availability for bioelectricity in six LDCs in Asia and Africa, namely Bangladesh, Lao People's Democratic Republic (Lao-PDR), and Nepal in Asia and Ethiopia, Malawi, and Zambia in Africa. The results indicate that the surplus biomass feedstock available from the agriculture sector could provide the total current electricity demand in Malawi alone, followed by Nepal (45%), Bangladesh (29%), Lao-PDR (29%), Ethiopia (27%), and Zambia (13%). Findings from the study show that providing access to sustainable energy in the LDCs to meet the SDG7 by 2030 might be a challenge due to limited access to technology, infrastructure, and finance. Site-specific investigations on how much agricultural residue could be extracted in an environmentally benign manner for bioelectricity and increased investment in the bioenergy sector are key potential solutions in a myriad of options required to harness the full energy potential in the LDCs. Provision of infrastructure/technology, mobilization of actors/stakeholders, regulatory action by governments, and market creation are essential for modernizing traditional bioenergy [9]. Conversion efficiencies, investment costs, and government policies (taxes and subsidies) are the key factors influencing the technological choice [10].

2.2. Water–Energy Nexus: Trade-Offs and Synergies

Land, water, and energy resource systems are integrated when it comes to the production of energy in general and bioenergy in particular [11]. In African nations, national and regional development targets for water and energy sectors seldom consider the nexus between the two, risking imbalances and inefficiencies in resource allocation and utilization. A typical example is the development and expansion of biofuel in the Wami Ruvu River Basin, Tanzania (WRB). Miraji et al. [12] applied the Water Evaluation and Planning (WEAP) model to the WRB to investigate the water–energy nexus (WEN), specifically, whether the development plan calling for biofuel expansion is a sound approach. The results indicate that WEN is much stronger in biofuel irrigation consuming 69.3% and 61% of total biofuel's water and energy requirements, respectively. By 2035, the nexus continues to be stronger, consuming 54.5% and 49% of total biofuel's water and energy requirements, respectively, and thus first-generation biofuels use much more resources in the growth than the refining process. An additional 768.2 million cubic meters of water and 413.4 million kWh of energy are needed for planned biofuel expansion, and reallocating water to biofuels in water-scarce regions causes related problems for other sectors, such as increasing water use for the industry, agriculture, and energy sector by 67%, 45%, and 9%, respectively, which could further exacerbate stresses on water and energy supplies in the basin. Biofuel generation relies heavily on energy imports, as it consumes substantially more energy than it produces. Policies should promote the coordinated development of sustainable biofuel programs that are less water-intensive with very low inputs of fossil fuels.

2.3. Investments in Modern Biofuels: Failures and Transformations

Substantial investments are needed in the promotion of modern biofuels [13]. There has been a heightened global interest in large-scale *Jatropha* cultivation for the past few decades, and this has encouraged investment in the crop in many developing countries [14]. *Jatropha* could be an alternative to conventional fuel as it contributes to climate change mitigation. However, *Jatropha* investment plans have not met global expectations. Antwi-Bediako et al. [15] review and synthesize the transformations and complexities in failed *Jatropha* spaces in the six major *Jatropha* investment destinations across the world—Mexico, India, China, Ethiopia, Mozambique, and Ghana. The review shows that the intended goal of establishing global *Jatropha* investments to serve as an alternative source of fuel failed because of the unexpected complexities of the hype. In all of the countries studied, promoters of *Jatropha* investments, including central government and private investors, subscribed to a "wait-and-see" approach for global *Jatropha* investments. Failure of the investments along with unmet expectations led to land-use changes from *Jatropha* to the cultivation of other crops (often food crops) or total land abandonment. The authors emphasize the importance of paying considerable attention to other feedstocks that might have a better future as alternatives to fossil-based energy for the deployment of sustainable bioenergy. Furthermore, the findings provide meaningful justification for policy- and decision-makers in the development space to tacitly reflect and appraise new investment initiatives or interventions before endorsement.

2.4. Promoting Biofuel Industry: Interdisciplinary PESTLE Analysis Approach

Biofuel production is expected to be an intrinsic confluence with the renewable energy sector in the coming years under the European regulations for renewable energy. Key standpoints for the promotion of biofuels are the reduction of national carbon emissions and rural deployment. Despite the jubilant outlook on biofuels for sustainable development, research efforts still tend to link the biofuel industry and regional growth. To overcome a variety of caveats in the development of modern bioenergy/biofuels, a novel approach, the "Political, Economic, Social, Technological, Environmental and Legal (PESTEL)" framework, has been used [16]. Achinas et al. [17] explore and review the biofuels industry through a PESTLE approach and discuss the interrelation between technological facets and sustainable deployment. The variety of the production characteristics and sustainability factors that were analyzed as a result of this approach highlight the complexity of the industry faced by policymakers and production companies. Socioecological aspects (origin of the feedstock, i.e., from agricultural land or a waste stream; food security; water scarcity; biodiversity loss), environmental governance (lifecycle emissions and land-use change), and economic landscape (yield and efficiency, cost of the conversion process) are found to be the key correlated dimensions in the assessment framework.

2.5. Innovation in Biofuel Projects—A Participatory Framework

The growth in biofuel investments brings with it concerns about the social and environmental impacts of the sector. Several tools and frameworks have been used to address these concerns, including the Responsible Research and Innovation (RRI) framework. Postal et al. [18] analyze whether this framework can be applied in contexts where local culture and values differently shape the freedom of speech and engagement, such as in developing countries in which biofuel innovation projects are often implemented. A literature review focusing on eight case studies of other authors is used to explore the role of "participation" as a structural element of the RRI framework and the impact of its absence where effective participation in the innovation development process is not possible. The authors describe the case of biofuel development, articulating four integrated dimensions of responsible innovation: anticipation, reflexivity, inclusion, and responsiveness. They highlight how the RRI inspirational normative framework, designed to influence innovation, is misused to judge its impacts. More than that, the conclusions of such misused applications reflect more the difficulties involved in applying guidelines than the responsible character of the innovation, whose impacts are usually defined upfront materially and measurably.

In conclusion, these five articles are a clear illustration of the challenges involved, and possible solutions, in the drive towards using modern bioenergy and strategies for sustainable development. Modern bioenergy is essential when the world is transforming towards environmentally friendly energy systems and low-carbon development. They should be developed while creating synergies with other sectors of the economy such as agriculture, industry, and rural development. The coordinated development and management of land, water, energy, and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems are critically important. Synergies and trade-offs should be balanced considering the optimal utilization of the resources for sustaining living standards and preserving the environment. The sustainability of the biofuel industry should be explored through a socio-political, techno-economic, legal, and environmental analysis approach, and the interactions between technological facets and sustainable deployment should be discussed. When it comes to large-scale biofuel investment, challenges need to be tackled while considering multilevel perspectives and global value chain frameworks. Finally, responsible and participatory innovation provides democratic governance of emerging biofuel technologies.

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