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EDITED BY

Arnab Bhowmik,
North Carolina Agricultural and Technical
State University, United States

REVIEWED BY

Dipti Rai,
North Carolina Agricultural and Technical
State University, United States

*CORRESPONDENCE

Neeraj Hanumante

✉ Neeraj.Hanumante@gmail.com

[†]These authors have contributed equally to
this work and share first authorship

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Can agro-biomass valorization be the fulcrum for sustainable development?

Neeraj Hanumante^{1*†} and Neeta Maitre^{2†}

¹Energy Institute, The University of Texas at Austin, Austin, TX, United States, ²Department of Computer Engineering, Cummins College of Engineering for Women, Pune, India

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1 Introduction

Agriculture is critical for the survival of human civilization. We obtain food, such as millets, lentils, fruits, etc., as well as non-food products like cotton, jute, rubber, etc., from agriculture. In the Indian context, agriculture contributed to about 20.2 percent of the Gross Value Added (GVA) of India for the year 2020-21 (PIB Delhi, 2021), and 1,48,078 thousand hectares (75%) and 49,242 thousand hectares (25%) of land are used for growing food crops and non-food crops, respectively (Department of Agriculture and Farmers Welfare, 2021). These products, in their final form, constitute only a fraction of the total biomass produced in the process. For example, Dhanraj et al. (2021) summarized the ratio of residue to crop for cotton, sorghum, sugarcane, wheat, and rice. The ratio ranges from 0.25 for sugarcane to 3.8 for cotton. In other words, for 1 kg of cotton produced, 3.8 kg of residual biomass needs to be disposed of. Thus, there is a significant untapped potential for residual biomass.

One of the main utilities of this biomass is the production of biofuels. According to one estimate by International Energy Agency (2023) (IEA), 6% of the global energy is supplied using biomass-based resources. Studies have been conducted to explore the use of these resources; for example, Hiloidhari et al. (2014) analyzed the potential of bioenergy from crop residue in India. They considered 26 main crops, which produce about 686 MT of crop residue. Their analysis indicated that if this agro-biomass is utilized effectively to produce bioenergy, it could compensate 17% of India's total primary energy consumption (bioenergy equivalent to about 4.15 EJ). As discussed by Samer (2019); Otoni et al. (2021), another route of utilizing the agro-biomass is the production of bioplastics and other advanced materials. However, these routes are relatively less explored than biofuel production routes and are yet to be established. This overall process of value retention of agro-biomass is termed agro-biomass valorization.

If this residual biomass is not used for any of the uses discussed above, then typically, it is treated as waste. There is a cost associated with the disposal of this material. Further, the decomposition of waste biomass releases methane, which is a greenhouse gas, thus, contributing to climate change. Moreover, it can also cause health hazards. Owing to the

short crop cycle, *in-situ* burning is considered one of the ways of disposal of agro-biomass, which again leads to all the above problems. Annual air pollution spike in the northern part of India is caused by such practices. Venkatramanan et al. (2021); Baghel et al. (2023) have studied these aspects in more details. Hence, we can say that, apart from being a great source of high-value products, agro-biomass valorization can also help in reducing the intensity of several problems.

2 Agro-biomass valorization and SDGs

The scale of most of the scientific problems involving humans can be identified as micro, meso or macro. This classification is standardized across different disciplines. For example, the works of Serpa and Ferreira (2019) in sociology, Dopfer et al. (2004) in economics and Gilberthorpe and Papyrakis (2015) in the field of industrial ecology. The micro level focusses on individual level, meso on a group or regional level and macro on an even larger level could be a province, state, country and even the world. Methods and analysis approaches change with the level. Selection of appropriate level for analysis depends upon the problem at hand. Since, the sustainable development is a global issue and we are looking at a propagation of influence of a systemic change, we carry out an assessment at a macro level.

Studies so far have indicated that agro-biomass valorization can help in reducing dependence on fossil fuels *via* the production of biofuels. One can directly interpret that this is a step towards progress in Sustainable Development Goal (SDG) 7, which is “Ensure access to affordable, reliable, sustainable and modern energy for all” (United Nations, 2021). However, we ponder a larger question: can the agro-biomass valorization’s potential be leveraged to accelerate overall sustainable development? In other words, can it positively and significantly impact all the SDGs? In this article, we deliberate on this question using a systems thinking approach as discussed by (Arnold and Wade, 2015). Dörgö et al. (2018); Zelinka and Amadei (2019) “have carried out studies exploring connections between various SDGs. These examine a detailed picture of the interaction between various objectives of each of the goals. In contrast, we take a macro view to develop a holistic understanding to identify future directions of research.

Figure 1 shows the relationship between various SDGs when analyzed to propagate the influence of agro-biomass valorization. Different levels of SDGs are formed proportional to the influence they receive. First, we examine the SDGs whose progress has direct contributions to agro-biomass valorization. These are SDGs 9, 7, and 17. SDG 9 aims to “Build resilient infrastructure, promote sustainable industrialization and foster innovation”. A resilient infrastructure that can accelerate the innovation process is essential to utilize the full potential of agro-biomass valorization. Currently, except for the industrialized countries, the agricultural sector is used mainly for food production. Opportunities and incentives for the valorization of waste biomass to produce valuable products are scarce owing to limited infrastructure. Thus, infrastructure and innovation become driving forces for extracting benefits from agro-biomass valorization. Another

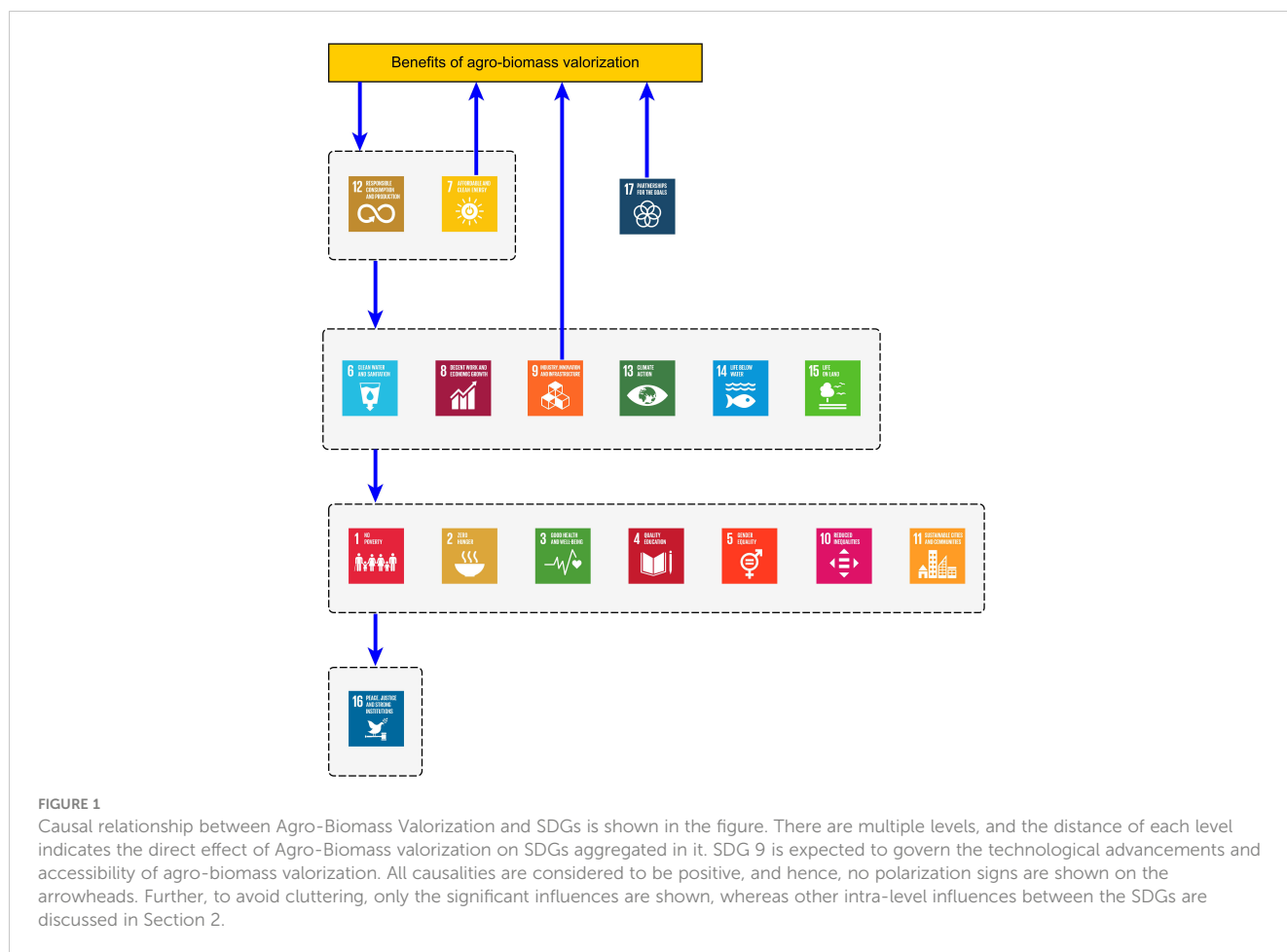
essential factor is the energy supply. There has been extensive research examining the role of energy in agriculture. Interested readers may refer to the works of Markussen et al. (2015); Pimentel (2019); Krupnik et al. (2022); Walston et al. (2022) for better insights. Agro-biomass valorization would require additional energy, and hence, by extension, a sustainable energy supply becomes a necessity. Thus, SDG 7 is also critical for extracting the benefits of agro-biomass valorization. Apart from these technically influential SDGs, monetary and institutional support is also necessary for the successful implementation of any policy, idea, or project. SDG 17 deals with these aspects and hence, would be indispensable for agro-biomass valorization.

Now, let us look at the propagation of benefits of agro-biomass valorization. SDG 7 and 12 are influenced directly. The importance of SDG 7, which highlights the need to ensure the supply of sustainable energy, is already discussed earlier. SDG 12 refers to sustainable production and consumption. It is an umbrella of objectives that intend to overhaul the entire production and consumption systems of the present global economy. One of the tenets of this SDG is the circular economy. Agro-biomass valorization is a shining example of the circular economy, which retains the value of materials that are already produced rather than disposing of them. It is clear that SDG 7 and 12 would get a significant boost because of agro-biomass valorization.

Progress in SDGs 7 and 12 can have significant benefits in the SDGs pertaining to two domains, the environmental and the industry related. Industry-related SDGs include SDG 8 and SDG 9. SDG 8.4 targets to improve resource efficiency, which is indirectly benefitted by the agro-biomass valorization *via* progress in SDG 12. Processes of building, operating, maintaining, and updating the infrastructure are energy-intensive in nature. Hence, SDG 9, which focuses on infrastructure, is expected to be benefitted from the availability of sustainable energy (SDG 7). Other SDGs, namely, 6 (water quality), 13 (climate action), 14 (ocean acidification), and 15 (water ecosystem), benefit because of reduced consumption of fossil-based energy sources and avoided emissions and pollution.

Development in the environmental and industry SDGs propagates into the social SDGs. Better economic opportunities lead to poverty reduction and, subsequently, hunger reduction, better education, and expenses towards a healthy life. Other aspects related to equality also get positively affected by higher affluence. Lower pollution and a better environment mean better health. Lastly, better infrastructure and innovation can contribute towards sustainable communities. Thus, SDGs 1, 2, 3, 4, 5, 10, and 11 can be benefitted. Lastly, progress in all other SDGs is expected to be a stepping stone toward a peaceful and just world (SDG 16).

One example of impact propagation is discussed here. Implementation of agro-biomass valorization will reduce the material footprint of fuel production (Indicator 12.2.1). Lower material footprint means lower greenhouse gas (GHG) emissions (Indicator 13.2.2). Climate change is expected to affect agricultural productivity, thus, lower GHG emissions mean lower intensity of climate change and hence, relatively higher productivity (Indicator 2.3.1). In a similar way, influencing linkages to other indicators, whether direct or indirect, can be determined. However,



development of the complete causal loop diagram and its calibration with real world data is part of a larger project and is beyond the scope of the present work.

3 Impact evaluation and techno-economical-environmental aspects

We propose that the direct impact of agro-biomass valorization to be quantified using an impact detection index κ_i defined as the ratio of fractional change in a particular indicator ΔX for a country to the weighted average of increment in valorized farm area ΔA_v , normalized with total agricultural area A_{total} in that country, as shown in Equation 1.

$$\kappa_i = \frac{\Delta X_i}{(\Delta A_v / A_{total})} \tag{1}$$

Impact propagation through the SDG targets can be similarly quantified by Equation 2

$$\psi_{ij} = \frac{\Delta X_j}{\Delta X_i} \tag{2}$$

Where, i and j are the SDGs closer and farther from the agro-biomass valorization influence and ψ_{ij} is the indirect influence of

agro-biomass valorization on SDG j via SDG i . This method can be used for impact propagation of any policy decisions on the SDGs.

The inputs to such evaluations are sought from national level data. For example, the progress in nationally determined contributions (NDC) can be used to assess the unit of overall progress towards SDG 13 (Climate action). Progress towards achievements of NDCs is reported by various countries. Other such similar external data can be used to evaluate SDG progress. However, Voluntary National Reviews, which is a mechanism to follow-up and track the SDG progress provides unobstructed view of the local realities. Thus, assessment of progress towards SDGs and hence, impact evaluation has minuscule scope of under or overestimation.

This work forms is the first step of a larger project of development of a complete system dynamics model to analyze impact of agro-biomass valorization on SDGs. In future, the model will be refined by calibrating it with SDG performance indicators. Then validation of the proposed view will be carried out through ex-post analysis. However, in context of the present work, verification of causal relationships can be carried out through examination of the SDG performance indicators.

As discussed by Shastri (2017), agro-biomass valorization intersects with second generation biofuels which can also be produced from energy crops, forest residues and waste from wood industry. Hence, infrastructural, techno-economic feasibility

and environmental issues of second generation biofuels map to agro-biomass valorization. In order to fully utilize the potential of the agro-biomass, integrated biorefineries are needed. Several research groups, for example, Arranz-Piera et al. (2018); Ali et al. (2019); Gojiya et al. (2019), have analyzed feasibility of these systems. The valorization process requires use of chemicals like sulfuric acid, hydrochloric acid, sodium and ammonium hydroxide, ethanol, acetone, and butanol. Hence, valorization process invokes chemical safety concerns. From pollution perspective, solid byproducts like cellulose residues, liquid byproducts like waste water containing organic compounds and alcohols may be a matter of concern. Suitable emission control technologies and waste management practices become essential to this issue. Lastly, works of several researchers such as Guerrero and Muñoz (2018); Munagala and Shastri (2020); Prasad et al. (2020); Kumar and Verma (2021) have brought out that agro-biomass valorization has benefits whether from energy security, economic as well as environmental perspective. Hence, it can be considered as an investment towards long term benefits.

4 Final considerations

“Think global act local” has become the philosophy of today’s globalized world. Sustainability in agriculture is no exception which is largely focused on progressive measures to be taken towards making agriculture more productive. These measures fall under the ambit of under Voluntary National Reviews of SDGs which help us understand the local realities. However, macro-level assessment of agricultural sustainability becomes critical in developing a holistic understanding of the agricultural sustainability. This assessment calls for “agro-biomass valorization”. The impact of agro-biomass valorization on different sustainable development goals (SDGs) can be considered in four levels. These levels have differed influence of agro-biomass valorization. The energy and circular bioeconomy are the direct beneficiaries in the first level. Second level consists of key factors governing agriculture, that is, climate, water, soil, and technology. Overall development of a society can be benchmarked by social indicators such as poverty, education, gender equality and so on. These aspects are aggregated in level three. The overall

objective of peace and just society is far away from this fulcrum on level four. The performance of agro-biomass valorization can be catalyzed through the infrastructure development, innovation in technology, access to renewable energy and support of global institutions. This inter-SDG impact can be quantified using the impact detection index proposed here. For the developed and developing countries, on a macro scale, while the causal relationship between agro-biomass valorization and SDGs remains the same, the quantum of impact propagated would differ based on local realities.

We conclude with a quote, by Thomas Jefferson, modified to suit the present work:

Agro-biomass valorization is our wisest pursuit because it will in the end contribute most to real wealth, good morals and happiness.

Author contributions

NH and NM drafted, critically revised the manuscript, and agree to be accountable for the content of the work. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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