Agricultural waste management and valorisation in the context of the circular bioeconomy: Exploring the potential of biomass value webs

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Abstract

In this paper we discuss relocating the topic of waste management in the wider issue of circular Bioeconomy, with a special focus on the emerging concept of value webs. We do so by reviewing the literature on biomass value webs. Based on this, we discuss the potential role of this conceptual development for food waste management. The main result of the review is that the concept of value webs, though theoretically very interesting, has actually found little application to waste and by-products until now. In spite of this, it may be expected that the concept will expand to this area in the future. This will require advances in terms of data and attention to circularity, but also a better economic conceptualisation allowing more rigorous quantitative applications in support of policy decisions.

1. Introduction and objective

Waste management and valorisation through treatment, recycling and/or reuse has taken a paramount importance in recent years in the agriculture and food sectors (Duque-Acevedo *et al.*, 2020). The focus on recycling of organic materials has been growing in parallel to the wider development of the bioeconomy and of the general concept of circular economy (Viaggi, 2018). These two concepts, in turn, tend to be now merged in the idea of circular bioeconomy (Brandão et al. 2021). Much of the literature addresses the topic looking at narrow parts of the system, e.g. an individual recycling process/technology, an individual waste value chain or a specific territorial area (Duque-Acevedo *et al.*, 2020; Koul et *al.*, 2022; Do *et al.*, 2021).

Key growing features of the Bioeconomy are the increased separability of processes and, partly as an effect of this, the increased interconnection among different value chains. The latter is closely connected to the topic of flexibility and resilience. Also, especially in a context of globalised economy, scale, from local to global, affects the degree of performance with respect to the concept above, e.g. degree of circularity or the degree of flexibility (Viaggi et *al.*, 2021).

In this paper, we address the issue of relocating the topic of agricultural waste management in the wider issue of circular bioeconomy, with a special focus on the emerging concept of biomass value webs. Biomass value webs can be defined as "complex systems of interlinked value chains in which biomass products and by-products are produced, processed, traded, and consumed" (Callo-Concha *et al.*, 2020). We first perform a review of the literature on biomass value webs. Based on this, we discuss the potential role of biomass value webs for agriculture and food waste management. While being aware that there are different definitions for agriculture and food waste, we decided (on purpose) to avoid referring to a specific one, in order to keep the topic at a more general level.

The structure of the paper is the following. In section 2 we briefly illustrate the methodology for the review and selection of the relevant literature. In section 3 we illustrate the results, i.e. the main focus and gaps in the literature on value webs applied to the Bioeconomy. In section 4 we provide a discussion about the potential for the future applications of the concept in relation to agriculture and food wastes in the context of the Bioeconomy. The conclusions of the author are presented in section 5.

2. Methodology

The methodology used in this paper is that of a systematic literature review inspired by the PRISMA approach and based on the Scopus database. Scopus was searched using two sets of keywords. First, the expression "value web" was searched yielding 141 results. Note that the option of searching for "value" AND "web" was explored and it provided more than 53,000 papers, but these papers resulted totally unfocused with respect to the objectives of this paper, where "value web" has a specific meaning. The results were then filtered with the keyword "Bioeconomy", yielding 11 results. In a second step the above results were filtered by selecting papers in the categories of "Economics, econometrics and finance" or "Social sciences" or Business, management and accounting", which yielded again 11 results.

In order to make sure complementary papers and potential word variations were accounted for, a second search was performed using the term "Value network". This yielded 1589 results, that were then filtered with the keyword "Bioeconomy", yielding 6 documents. In a second step the above results were filtered by selecting papers in the categories of "Economics, econometrics and finance" or "Social sciences" or Business, management and accounting", selecting 5 documents, of which 4 relate to forestry or wood economy. Here the 6 papers were retained for the analysis. One additional paper, found among cited papers in one of those identified from the search, was added to the group.

The papers from the two groups were basically overlapping and we retained 12 papers for the analysis. In the following, given the small number of papers, we preferred to avoid further selection and classification and we moved straight to reading and analysis of contents.

Web of Science was also searched to cross-check the outcome of Scopus. This yielded a lower number (9) of papers, all of which overlapping with the Scopus search except for one, that was excluded because it was not pertinent for this study, in spite of the use of the term value web.

Given the small number of papers, an inspection of the related literature was performed (cited papers, citing papers), with specific attention to the papers included in the special issue summarised in Callo-Concha et *al*. (2020). There is indeed a high number of papers addressing different aspects of biomass production, however their inclusion was inconsistent with the aim to investigate specifically the use of the concept of value web in relation to the bioeconomy. For this reason, no additional paper has been added to the selection explained above.

3. Results: Biomass web and biomass networks

A preliminary inspection of the papers selected in this way shows that both value webs and value networks in Bioeconomy are totally focused on social sciences and economics. Bioeconomy covers a relatively high share of the concept for value webs (around 10%) while it is negligible for value networks. All selected papers have been published from 2018 to 2021, with the exception of two papers under the keywords "value web" published in 2016. In this section, we illustrate the contents of these papers based on three main features: presence of empirical analyses; methodology; role given to wastes.

The systematic collection of studies selected in this paper as addressing value webs and the Bioeconomy is reported in table 1, which highlights the role that wastes and by-products have in each paper.

Table 1 – Selected studies on value webs and the role of wastes and by-products

Reference	Case study	Approach	Waste & circularity
Korhonen *et al.*, 2021	Three value networks on forest economy in Finland	Expert-based	Side streams of wood –related industries; focus on the need of more

			flexible regulation about the use of wood streams
Callo-Concha *et al.*, 2020	N/A; Overview of papers from a special issue focusing on biomass production in Sub-Saharian Africa	Review	Use of several waste streams for the production of valuable products; need of public expenditure and training to empower actors towards these new options; comparison with Northern countries
Naah, 2020	Biomass value web in six rural communities in Ghana	Interview to 180 local actors (120 smallholder farmers and 60 local commercial intermediaries); cognitive salience index to quantify importance	Poor use and lack of cascading approach to by-products
Anderson *et al.*, 2019	Biomass-based value webs of selected crops in Ghana, Nigeria, and Ethiopia	Modeling using systems analysis software iMODELER and participatory stakeholder workshops	Not considered
Adeyemo *et al.*, 2019	Cassava system in Nigeria	Intensity of cassava utilisation and its determinants on sample of 541 households, through cluster analysis and ordered probit regression	Higher level of intensity of utilisation seen as a strategy for waste reduction
Lin *et al.*, 2019	Bamboo value web in Injibara township (Ethiopia)	Semi-structured interviews and informal focus group discussions with key stakeholders	Not considered
Loos *et al.*, 2018	Plantain Residues in Ghana	Expert interviews, and group discussions	Market potential for fiber rich plantain pseudostems that usually remain in the field. Also some knowledge and stakeholders structures exist that could establish a market. However, market is not activated. Pilot initiatives and technology transfer needed.
Poku et *al*., 2018	Cassava in Ghana	Physical mapping, actor's mapping and interviews; net-map tool	Problem of high quantity of wasted product; zero-waste potential.
Devaney and Henchion, 2018	Irish bioeconomy	Delphi panel of experts	Waste reduction and use in bioenergy/biomaterials important;

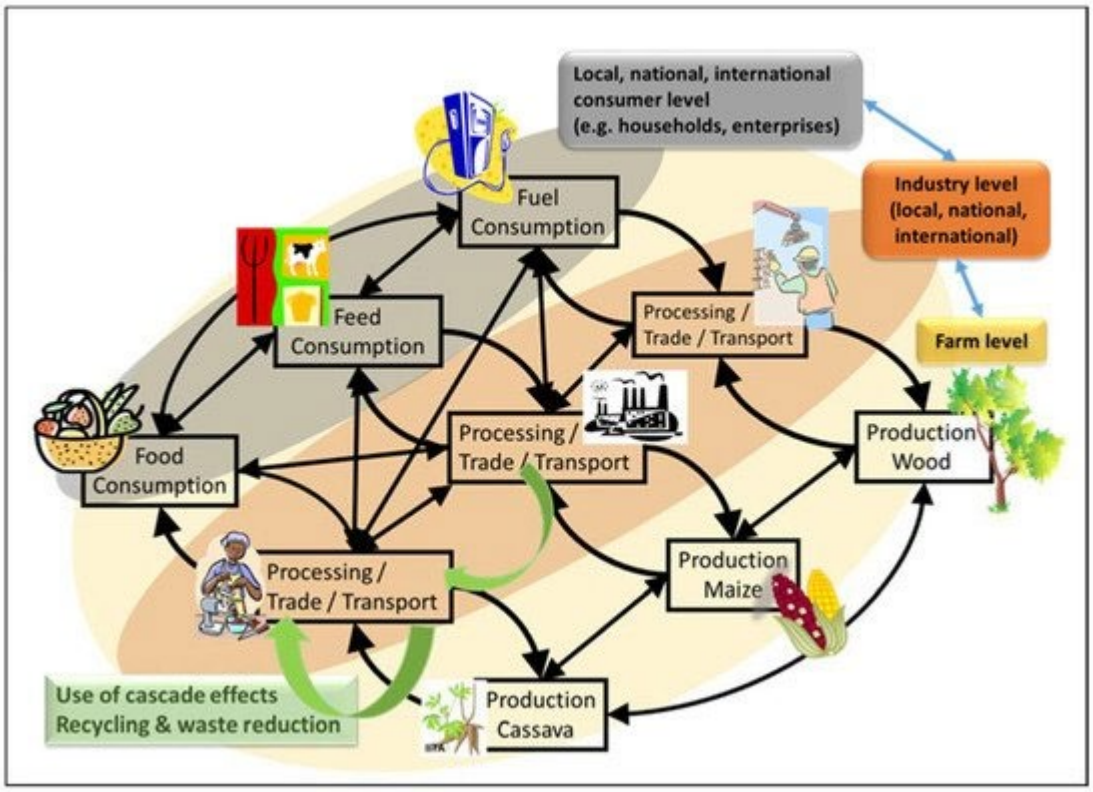
			value web approach advocated but poorly implemented
Scheiterle *et al.*, 2018	Sugar cane in Brazil	Physical mapping, actor's mapping and interviews; net-map tool	Extension of the value chain approach to include the utilization of by-products as well as the inclusion of cascading use of biomass
Borras *et al.*, 2016	N/A; discussion on importance of value webs in relation to flexibility and changing power relationships in the bioeconomy	Review	Discussion of importance of by-products
Virchow *et al.*, 2016	N/A, discussion of African Bioeconomy potential including need of shift to value web concept	Review	Potential of by-products; need to reduce waste/zero-waste objective

One fourth of the papers is a review or commentary, with only 9 papers providing empirical analyses. Biomass value webs are mostly framed as an answer to the emerging trends in the Bioeconomy, of which the prevailing one relates to the need of representing the Bioeconomy as a complex system. The concept of value web aims to go beyond the narrow vision of value chains, properly accounting for inter-chain relationships. Biomass value webs are proposed as an improved support to the understanding of evolving Bioeconomy systems, also in terms of power relationships and social concerns.

Only 7 papers try to describe value webs empirically. These are all located in the Global South, either Africa or Brasil (e.g. Callo-Concha *et al.*, 2020; Naah, 2020; Virchow *et al.*, 2016). Most of the empirical applications offer an expansion of the value chains approach into value web approaches focusing on marketable products, so do not consider ecosystem services. From a methodological point of view, empirical exercises are mostly based on interviews. The biomass value flows are mostly described qualitatively as links among activities/processes, without quantification of flows or economic parameters, while functional relationships are described qualitatively. This can be easily explained with the lack of statistical information fitting with the approach (i.e. at the appropriate level of disaggregation).

An example of value web representation is given in Figure 1.

Figure 1 – An example of value web representation



Source: Virchow et al. (2016)

While the description of biomass flows is important for the analysis, the most interesting side of the approach is in the actual economic conceptualisation, by representing value flows and their relationships. In this respect, most papers do not go beyond the mention of value chains as a conceptual background. One exception is Poku et *al*., 2018 that uses the Porter' diamond model of national competitive advantage as a background theoretical approach.

Anderson *et al.*, 2019 provide a modelling representation of biomass-based value webs of selected crops in Ghana, Nigeria, and Ethiopia, which is still somehow unique in trying to use the value web concept in simulating impact pathways in the bioeconomy. The authors use a system dynamics approach to identify supporting and hindering factors allowing contributing to food security. While emphasising the need to connect value chains through a value web approach, the author find that linkages among value chains are, in practice, still below expectations.

It is also worth mentioning that while biomass value webs are intended as crossing among value chains, several biomass value web papers restrict deliberately attention to one single crop or value chain (e.g. Scheiterle *et al.*, 2018; Lin *et al.*, 2019).

The role of waste and by-products in the biomass value web literature is not particularly prominent. While waste and by-products importance is widely recognised and the use of value webs is envisaged as a way to minimise wastes and improve circularity, the explicit inclusion in the biomass value web analysis is mostly absent. Only one case directly addresses the use of by-products (Loos et al., 2018) and only one explicitly attempts to use value webs to expand the value chain also to by-products (Scheiterle et al., 2018). These by-products are mostly crop losses in the field rather than wastes or by-products from industry.

4. Discussion: the way ahead in using biomass value webs to analyse agriculture waste management in the context of the bioeconomy

This paper reviews recent developments in the concept of biomass value webs applied to the Bioeconomy. The current literature is still rather narrow, with limited empirical representation of biomass value webs. Also the empirical relevance of the concept of value web seem to be below expectations due to the limited number of links among value chains. It can be expected that the concept will become much more relevant in the future with the growth of interconnections among chains, which is a clear of the Bioeconomy, though often based mainly on anecdotal evidence.

The current use of the biomass value web concept largely do not account for waste and circularity aspects. Locating these concepts in the context of the circular bioeconomy and waste management requires refinement and expansion in at least three directions.

First, the concept needs to highlight explicitly flows that can be considered as circular, or better the net harvesting of biomass from the ecosystem. Again, while this is partially considered, a proper consideration of circularity would probably need to become explicit and this would also support a straight consideration of waste and by-products.

Second, the concept needs an expansion beyond agriculture and food input and products, in order to account properly for wastes and by-products, as well as for considering explicitly the interaction with non-food and energy sectors. Indeed wastes are already considered in a few of the existing exercises, but this needs to be expanded more systematically and explicitly.

Thirds, in perspective this may go even beyond considering the full definition of Bioeconomy to expand to ecosystems management, hence better linking to ecological concepts.

These directions may require three additional advances. First, valuation exercises need to be improved taking into account non-market values. This would, among others, contribute to the progress of technologies for developing new high-value products from wastes, e.g. bioplastics (Degli Esposti *et al.*, 2021). This explicitly brings to the issue of accounting for potential benefits from research and product development in the representation of biomass value webs, that are often based just on current (market) values.

Secondly, improvements are needed about understanding the functional explanatory capacities of the value web as a whole in contrast to the current emphasis on links. Even more, a promising pathway is that of integrating the value web vision with wider systems representations, such as that of socio-ecological systems (SES) (Ostrom, 2009; de Schutter *et al.*, 2019). An even wider view, inspired to SES, but opening to value flows and technology, is that Socio-ecological-technological system value enhancing webs (SETVEW) proposed by Viaggi (2019). These interdisciplinary explorations, in particular the latter, are still under development.

Third, both the previous issues hint at the importance of dynamics. In relation to value webs, dynamics means not only changes in structure over time, e.g. due to new links across chains, but also ability to change structure continuously to adapt to economic and social pressure.

5. Final remarks

Studies on circular Bioeconomy are striving to identify appropriate concepts to take into account the complexity of the biomass flows and of the related value relationships. We claim that the process may benefit from a wider use of the concept of biomass value web. This goes beyond the vision of the value chain, accounting for the complexity of the web of relationships and biomass flows characterising the Bioeconomy and crossing different value chains. In the current literature, this concept is only in its infancy, accounting for a few papers and even fewer attempts to implement the concept empirically.

In this paper, we use this background to discuss the potential of biomass value webs to provide a better picture of the integration of waste and by-products considerations into the Bioeconomy organisation. While there is some potential, the current literature on biomass value webs accounts only marginally for wastes and by-products. However, attempts are available in this direction and it may be expected that the concept will expand more explicitly to this area in the future. This will require advances in terms of data and attention to circularity, but also a better economic conceptualisation allowing more rigorous quantitative applications in support of policy decisions. In perspective, this may go even further, considering the full definition of Bioeconomy to expand to ecosystems management and technological aspects, hence better linking to the Bioeconomy as whole.

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Adeyemo, T. *et al.* (2019) 'Determinants of intensity of biomass utilization: Evidence from cassava smallholders in Nigeria', *Sustainability (Switzerland)*, 11(9). doi: 10.3390/su11092516. * Land, social capital, farming experience, and asset ownership increase the probability of intensifying cassava utilization among smallholders. The study recommends strengthening assets acquisition, improving land quality and encouraging social capital development among smallholders.

Anderson, C. C. *et al.* (2019) 'Identifying biomass-based value webs for food security in Sub-Saharan Africa: A systems modeling approach', *Sustainability (Switzerland)*, 11(10). doi: 10.3390/su11102885. ** Biomass-based value webs of selected crops in Ghana, Nigeria, and Ethiopia are modeled using the systems analysis software iMODELER. A generic model was created compiling the country models to identifyoverarching system dynamics with supporting and hindering factors impacting food security. The findings show highly complex value webs, suggesting that the predominant value chain approach may oversimplify actual structures and resource flows in real life. However, few interconnections within the value webs link the actors and flows of different crops.

Borras, S. M. *et al.* (2016) 'The rise of flex crops and commodities: implications for research', *Journal of Peasant Studies*, 43(1), pp. 93–115. doi: 10.1080/03066150.2015.1036417.

Brandão, A. S., Gonçalves, A. and Santos, J. M. R. C. A. (2021) 'Circular bioeconomy strategies: From scientific research to commercially viable products', *Journal of Cleaner Production*. Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança, Campus de Santa Apolónia, Bragança, 5300-253, Portugal, 295. doi: 10.1016/j.jclepro.2021.126407.

Callo-Concha, D. *et al.* (2020) 'Food and Non-food biomass production, processing and use in sub-Saharan Africa: Towards a regional bioeconomy', *Sustainability (Switzerland)*, 12(5). doi: 10.3390/su12052013. * The paper summarises 22 articles in a sepcial issue derived from the BiomassWeb project, aiming to underpin the bioeconomy concept by applying the 'value web' approach, which seeks to uncover complex interlinked value webs instead of linear value chains. The project also aimed to develop intervention options to strengthen and optimize the synergies and trade-offs among different value chains.

Callo-Concha, D *et al.* (2020) 'Food and Non-food biomass production, processing and use in sub-Saharan Africa: Towards a regional bioeconomy', *Sustainability (Switzerland)*. Center for Development Research (ZEF), University of Bonn, Bonn, 53113, Germany, 12(5). doi: 10.3390/su12052013.

Degli Esposti, M. *et al.* (2021) 'The role of biotechnology in the transition from plastics to bioplastics: an opportunity to reconnect global growth with sustainability', *FEBS Open Bio*. Department of Civil, Chemical, Environmental and Materials Engineering, Alma Mater Studiorum Università di Bologna, Italy, 11(4), pp. 967–983. doi: 10.1002/2211-5463.13119.

Devaney, L. and Henchion, M. (2018) 'Consensus, caveats and conditions: International learnings for

bioeconomy development', *Journal of Cleaner Production*, 174, pp. 1400–1411. doi: 10.1016/j.jclepro.2017.11.047. * The paper presents the results of an online Delphi study conducted with 75 bioeconomy experts in Ireland to assesses and prioritise value chain opportunities for the Irish bioeconomy and for the development and governance of bioeconomies worldwide. It addresses factors from supply to demand, including the scale and fragmentation of feedstock, the capital investment required at the transformation technology stage and consumer acceptance of the biobased output. The need for robust environmental sustainability assessments, clear support frameworks, adherence to cascading and circular principles and integrated value web approaches are also highlighted through this analysis.

Do, Q. *et al.* (2021) 'A systematic review of research on food loss and waste prevention and management for the circular economy', *International Journal of Production Economics*, 239. doi: 10.1016/j.ijpe.2021.108209.

Duque-Acevedo, M., Belmonte-Ureña, L. J., Cortés-García, F. J., *et al.* (2020) 'Agricultural waste: Review of the evolution, approaches and perspectives on alternative uses', *Global Ecology and Conservation*, 22. doi: 10.1016/j.gecco.2020.e00902.

Duque-Acevedo, M., Belmonte-Ureña, L. J., Yakovleva, N., *et al.* (2020) 'Analysis of the circular economic production models and their approach in agriculture and agricultural waste biomass management', *International Journal of Environmental Research and Public Health*, 17(24), pp. 1–34. doi: 10.3390/ijerph17249549.

Korhonen, J. *et al.* (2021) 'Development of a forest-based bioeconomy in Finland: Insights on three value networks through expert views', *Journal of Cleaner Production*, 299. doi: 10.1016/j.jclepro.2021.126867.

Koul, B., Yakoob, M. and Shah, M. P. (2022) 'Agricultural waste management strategies for environmental sustainability', *Environmental Research*, 206. doi: 10.1016/j.envres.2021.112285.

Lin, J. *et al.* (2019) 'Opportunities and challenges in the Ethiopian bamboo sector: A market analysis of the bamboo-based value web', *Sustainability (Switzerland)*, 11(6). doi: 10.3390/su11061644. * The paper uses the "value web" approach to assess the potentials of different product lines that create the bamboo biomass value web. We utilize qualitative data collection methods, in particular, semi-structured interviews and informal focus group discussions with key stakeholders. The findings suggest that bamboo farmers in Injibara are constrained by a lack of local demand and market for bamboo products with high-value addition, leading to an absence of product diversification and innovation.

Loos, T. K. *et al.* (2018) 'The potential of plantain residues for the ghanaian bioeconomy-assessing the current fiber value web', *Sustainability (Switzerland)*, 10(12). doi: 10.3390/su10124825. * The paper assesses predominant plantain production structures, derives stakeholder network map and discusses the potential starting points for linking the platain supply side with the national or international fiber market. Results indicate that there is substantial interest of private enterprises but the fiber rich plantain pseudostems usually remain in the field. Key to the establishment of a sustainable plantain based fiber value web would be pilot activities, including technology transfer of suitable innovations from other countries.

Naah, J.-B. S. N. (2020) 'Community-level analysis of value webs of biomass-based resources: A case study among local actors in Ghana', *Sustainability (Switzerland)*. Center for Development Research (ZEF), University of Bonn, Genscherallee 3, Bonn, D-53113, Germany, 12(4). doi: 10.3390/su12041644. * The paper identifies value webs, challenges, and future actions for sustainable use of biomass-based resources in Ghana. The value webs of selected food biomass-based resources are not well developed and still remained simple and traditional in nature, since no cascading uses of by-products were identified. Several challenges and the future actions for managing locally produced biomass-based resources are addressed.

Ostrom, E. (2009) 'A general framework for analyzing sustainability of social-ecological systems', *Science*, 325(5939). doi: 10.1126/science.1172133.

Poku, A.-G., Birner, R. and Gupta, S. (2018) 'Is Africa ready to develop a competitive bioeconomy? The case of the cassava value web in Ghana', *Journal of Cleaner Production*, 200, pp. 134–147. doi: 10.1016/j.jclepro.2018.07.290. * The papers addresses the requisite policy and institutional environment needed to foster the development of a competitive and sustainable bioeconomy in Africa, using the case of cassava in Ghana for an empirical case study and the novel concept of biomass-based of value webs combind with Porter's Diamond model. Empirical analysis involved mapping the physical biomass flows, applying the 'Net-Map' tool to identify all the actors in the emerging value web and their linkages, as well as in-depth interviews with the identified actors. The study finds that despite the huge opportunities for cassava biomass in Ghana, there are coordination problems between farmers, processors and industrial end-users. There is also generally a lack of private sector initiatives in the development of new cassava based products.

Scheiterle, L. *et al.* (2018) 'From commodity-based value chains to biomass-based value webs: The case of sugarcane in Brazil's bioeconomy', *Journal of Cleaner Production*, 172, pp. 3851–3863. doi: 10.1016/j.jclepro.2017.05.150. * The paper combines two conceptual tools: 'biomass-based value web'and 'national innovation system'. Empirically, the study combined three methods: a mapping of the physical biomass flows in the value web, in-depth interviews with the actors involved, and the application of the 'Net-Map' tool to identify the actors in the NIS and their linkages. The findings show that the development of Brazil's international competitiveness in sugar and ethanol was based on political incentives that resulted in a strong network of institutions that focused on these two products. However, to become a front-runner in the future bioeconomy, the existing innovation network needs to be expanded by integrting national and international private sector organizations.

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