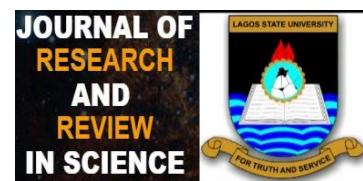


ORIGINAL RESEARCH

Stimulating Diffusion of Bio-based Products: The Role of Responsible Research and Innovation (RRI) Approach

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Abstract:

Introduction: Escalating environmental challenges have necessitated the adoption of bio-based products. The social interface between these products with low environmental impacts and the society is a dynamic site where different stakeholders, forms of knowledge, interests and powers interplay. Scientists must navigate these factors for bio-based products to become acceptable in the society.

Aims: This review explores the suitability of responsible research and innovation (RRI) as an inclusive approach to research and innovation to support the adoption and diffusion of bio-based products in the society.

Method: The study was essentially based on a desk review of relevant academic papers on bio-based products, bio-based economy, bioeconomy and, responsible research and innovation (RRI) from year 2012 - 2018, with reference to other publicly accessible documents and publications.

Results: The review shows that despite their potentials for contributing to greener environment and sustainability, bio-based products remain controversial. Results also show that embedding RRI dimensions in development of bio-based products "from lab to market" will help build trust among stakeholders in the relevant value chain, which is a pre-requisite for the diffusion of these products in the society.

Conclusion: The main conclusion of this paper is that identifying and engaging stakeholders, the publics and their concerns when developing bio-based products will ensure the products are relatively uncontested and will diffuse better throughout the society.

Keywords: bio-based product, bio-based economy, bioeconomy, responsible research and innovation

All co-authors agreed to have their names listed as authors.

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1. INTRODUCTION

Increasing depletion of earth's finite resources, climate change and environmental concerns, cutting-edge biotechnological advancements, economic considerations, changing demographics and quest for sustainable development have converged to project bio-based economy or bioeconomy (henceforth, bio-based economy) as a more sustainable alternative way to live. The concept of bio-based economy has continued to gain traction both in science and policy. It is the production of renewable biological resources and the conversion of these resources, residues, by-products and side streams into value added products such as food, feed, bioenergy and other bio-based products [1]. Adoption and diffusion of these bio-based products in the society is crucial for sustainable bio-based economy.

According to the European Standard (EN 16575:2014), bio-based products are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilized. Bio-based products are categorized into products originating directly from biomass, products made from building blocks originating from biomass, and products produced by microorganisms [2].

Responsible Research and Innovation (RRI) has been increasingly used among policy makers and academics to ensure science and scientists proceed in socially responsible ways [3]. The assumption behind RRI is that if innovations are developed with participation of multiple stakeholders in the research and development process, an eye for social and ethical concerns, and with the objective of better aligning the outcomes of the values, needs and expectations of society, they will be (relatively) uncontested and will therefore diffuse better throughout society [4]. RRI is an approach that includes relevant stakeholders "from lab to market", anticipating potential implications, reflecting and responding to the needs and values of society [5]. Focusing on these stakeholders is of paramount importance for deepening our knowledge of the main social aspects that may influence the diffusion of bio-based products, which is currently still limited.

The rest of the paper is organized as follows: Section 2 frames the context of analysis and presents the research questions. Section 3 describes the methodology. Section 4 presents categories of bio-based products, relevant studies starting from the controversial nature of bio-based products, and RRI in the context of bio-based products. Section 5 contains a discussion of the results. Finally, Section 6 concludes and states the contributions of the study to literature.

2. THE CONTEXT OF ANALYSIS AND RESEARCH QUESTIONS

An innovation is defined as "an idea, practice, or object that is perceived as new by an individual or other unit

of adoption" [6]. The definition shows that an innovation can take various forms or appearances. It may be a tangible product but may also be intangible — a service or a behavioral pattern. A product is only an innovation if it is perceived as new. Bio-based products meet these criteria; they are tangible and relatively new phenomena. In addition to these two criteria, they are a departure from current/existing products, therefore also meeting the 'radicalness' or 'discontinuity' criterion of innovation.

The conception of this study is that bio-based products are wholly or partly derived from materials of biological origins, such as plants, trees or animals, the biomass may have undergone physical, chemical or biological treatment, but excludes materials embedded in geological formations and/or fossilized. Also excluded are traditional bio-based products, such as pulp and paper, and wood products, and bio-mass as an energy source.

Diffusion is "the process by which an innovation is communicated through certain channels over time among the members of a social system"[7]. Accordingly, the success of an innovation depends crucially on the social system. Diffusion theory focuses on how quickly and to what degree a social system accepts an innovation. Although adoption and diffusion are two different processes, they are highly interrelated. Adoption decisions drive every diffusion process. The major difference between adoption and diffusion is the aggregation level at which the processes are studied: adoption theory is concerned with adoption decisions of individual units (at a disaggregate level), whereas diffusion theory is concerned with dissemination on an aggregate level [8]. Li and Jin noted that the essence of a new product's diffusion process is the product information exchanged by which one individual communicates a new product to one or several others [9].

This paper adopts Stahl's working definition of responsible research and innovation (RRI) as a higher level responsibility or meta-responsibility that aims to shape, maintain, develop, coordinate and align existing and novel research and innovation-related processes, actors and responsibilities with a view to ensuring desirable and acceptable research outcomes [10]. This definition is consistent with established views that RRI should incorporate social concerns and democratic accountability into research and innovation to ensure mutual responsiveness of stakeholders and establish principles of anticipatory governance of research and innovation.

While the phenomena of individual adoption of a new product and its diffusion through a population have received much attention, research within the diffusion paradigm that explicitly considers the importance of the RRI approach in diffusion of bio-based products is very limited. In applying diffusion theory, we seek to establish how RRI approach will help bio-based products get accepted within in the society.

Accordingly, this paper will seek to answer the following research questions:

RQ1: Is the RRI approach ideal for engaging relevant stakeholders to ensure diffusion of bio-based products?

RQ2: How are RRI dimensions applicable to relevant stakeholders in bio-based products?

3. METHODOLOGY

The scope of our analysis ranges from scientific journals and official published documents (e.g., conference proceedings and books) to the so-called "grey literature" (reports). The publication date covered was 2012 -2018.

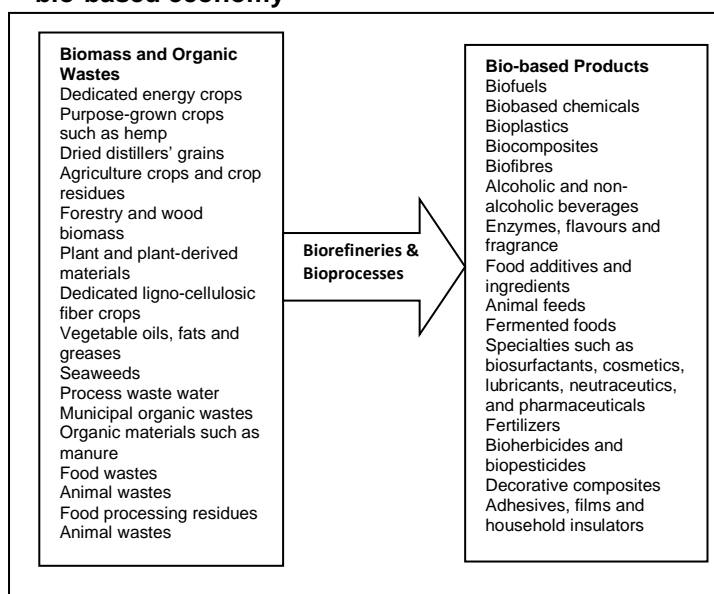
Following Fink [11] and Pfau,Hagens, Dankbaar & Smits [12] there was selection of key search terms - bio-based products, bio-based economy, bioeconomy and, responsible research and innovation (RRI), followed by application of screening criteria to identify relevant literature using Google Scholar search engine and other academic communities – Academia, ResearchGate and the Social Science Research Network (SSRN). The relevant papers were reviewed and the findings collated.

4. RESULTS

4.1 Bio-based Products

While much of the focus on the bio-based economy has been on biobased fuels and energy sources [13], there are several other bio-based products. These include manufactured goods such as biobased chemicals, bioplastics, biopolymers, biocomposites, alcoholic and non-alcoholic beverages, fermented foods, food additives and ingredients, feed, and specialties such as biosurfactants, lubricants, and pharmaceuticals and nutraceuticals.

Figure 1. Bio-based products in the emerging bio-based economy



4.2 Relevant Stakeholders in Bio-based Products Innovation and Diffusion

Diffusion of the bio-based products depends on the engagement of a range of stakeholders and publics. Publics represents groups who lack the direct connection to bio-based product innovation that stakeholders have and also differ from stakeholder groups in terms of their level of organization and visibility, but nonetheless have interests, concerns, hopes, fears, and values that can contribute to democratic decision making [14,15,16].

Stakeholders involved in bio-based products innovation and diffusion are individual researchers, research organizations (both publicly and privately funded), research ethics committees and their members, funding agencies, policy makers at different levels, farmers, fishermen, agribusinesses, food processors, waste handlers, manufacturers, civil societies and nongovernmental organizations, business associations, professional bodies, legislators, educational organizations (e.g. schools and universities) and public bodies (from local authorities to regional structures) [10,17,18].

4.3 Bio-based Products are Emerging and Controversial

Our literature review shows that the concept of bio-based economy and bio-based products is still emerging [19,20,21], controversial [22,23,24,25,26,27] and conceived rather differently from various stakeholder perspectives [28,29].

The diverse perspectives on bio-based products include appropriate sustainability criteria, food vs biofuel debate, arguments for and against GMOs, and the ethics of innovation. The vision upon which national bio-economy policy is based will also dictate the legal frameworks of the bio-based products. Bugge et al. listed three visions of bio-based economy to include the bio-technology vision, the bio-resource vision, and the bio-ecology vision [28].

4.4 RRI in the Context of Novel Bio-based Products

Elster called for the promotion of responsible research and innovation (RRI) in respect to biosciences research to create a shared understanding of the appropriate roles of those who have a stake in the processes and products of science and technology, scientists, as well as educators and the general public [30]. This opinion was supported by Yu that RRI will help realize public benefit objective and obtain the optimal social and economic values from biomedical research [31]. This is more important in bio-based economy which requires changes in the social structures embedding the bio-economy. RRI will help to handle socially sensitive issues involved that need to be addressed to prevent social resistance [24].

Asveld, Ganzevles, & Osseweijer proposed a responsible research and innovation (RRI) approach to stimulate the development and diffusion of bio-based products [32]. The authors believed that for the further development and diffusion of the bio-based products, trust among actors in the relevant value-chain is a prerequisite and that RRI can play a pivotal part in the bio-based economy by providing conditions for trustworthiness of actors and by enhancing trusting relationships. van Lancker, Wauters, & van Huylenbroeck had earlier submitted that the inherent characteristics of RRI make it an appropriate framework to stimulate the development and diffusion of bio-based products [33].

4.5 Applying RRI Dimensions to Bio-based Products Diffusion

Table 1 enumerates how RRI could be used to incorporate the concerns of a broad array of actors into bio-based products research and development to ensure their diffusion in the society.

Table 1. Dimensions of RRI

Dimension	Relevance to bio-based products diffusion	Selected relevant stakeholders
Anticipation	Why should the bio-based product be developed? Will the bio-based product be socially desirable? Is the process of developing the bio-based product acceptable? To what extent can the future uses and impacts of the bio-based product be anticipated? Have we included the right stakeholders?	Individual researchers Research organizations Ethics committees Policy makers Education institutions Funding agencies
Reflexivity	Is the bio-based product controversial? Can we develop the bio-based product differently? Is there an alternative bio-based product? What might be the potential use of the bio-based product? What don't we know about? How can we ensure societal desirability?	Policy makers Civil societies NGOs Professional bodies Ethics committees Funding agencies
Inclusion	Is there a national definition of bio-based products? What are the viewpoints of a wide group of stakeholders? Is the bio-product acceptable? Who determines the bio-based product(s) to develop? Whose priority is the bio-based product?	Business associations Biomass producers Agribusinesses CSOs NGOs
Responsiveness	Who matters? What needs to be done to make bio-based products desirable? What training or enlightenment is required? Which networks are required? How do we ensure that the implied future is desirable?	Agribusiness Professional bodies Biomass producers Business associations NGOs CSOs
Sustainability	Is the bio-based product sustainability anticipated? Which environmental and social problems will the bio-based product solved? What are the bio-based product sustainability criteria? How are resources conserved during the bio-based product production? Are the bio-based products designed to be safe and ecologically sound? What is the quantity of petroleum based products been replaced?	Manufactures Waste handlers Food processors Biomass producers Agribusinesses Policy makers
Economic	What is the expected contribution to GDP, employment and foreign exchange? What is the expected return on investment? Are the investment risks covered? What are the key drivers of bio-based products market development? Are there stable, long term and supportive bioeconomy policies? How do bio-based products compared in price to other products?	Investors Shareholders Investment bankers Venture capitals

5. DISCUSSION

Our study showed availability of several RRI activities and approaches such as, scenario-building, state-gates, user-centred design, deliberate polling, niche management, socio-economic impact analysis, etc., that could be employed to reflect on the vision, motivations, processes, risks, sustainability and economic benefits of bio-based products. These activities and approaches are useful for lower and higher levels engagement with relevant stakeholders, and to instruct and educate publics that do not participate in bio-based product innovation, and to tackle this mistrust of new science and can legitimize bioscience research and bioeconomy development decisions to ensure wider societal benefit.

As previously underlined and tabulated, RRI dimensions are extensively applicable to relevant stakeholders involved in bio-based products innovation and those whose opinions and contributions are vital to the products diffusion. The dimensions are also relevant in instructing and educating publics that do not participate in bio-based product innovation, and to tackle this mistrust of new science and can legitimize bioscience research and bioeconomy development decisions to ensure wider societal benefit.

It is important to remark that the RRI will help researchers and policy makers to be aware of public understanding and expectations of bio-based products in order to advance their diffusion and by extension bio-based economy as a future economic model, away from our current unsustainable fossil economic model.

6. CONCLUSION

In this paper we have attempted to give a short overview of the relevance of RRI approach in influencing the diffusion of bio-based products in the society. It is clear that the success of sustainable bioeconomy will depend on diffusion of bio-based products. Employing RRI approach to engage with relevant stakeholders will not ensure that bio-based products are relatively uncontested but accelerate their market-uptake, leading to better diffusion through the society to help solve several societal challenges.

Our contribution to the literature on RRI is to build the connection between its dimension and diffusion of bio-based products, demonstrating how the RRI approach will accelerate market-uptake of bio-based products. The advancement of sustainable bioeconomy to solve several societal challenges required an inclusive approach; our call is for the innovation ecosystem to be built on RRI dimensions to bring all relevant stakeholders into the bio-based products innovation matrix.

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APPENDIX

Appendix 1. Bio-based co-products

Fuels	Biodiesel, Ethanol
Household furnishings	Bedding and bed linens , Towels, Tableware, Upholstery, Soy wax candles, Carpets and carpet backing, Furniture protectors, Soy - Based foam for household furniture, Computer plastics, Electronic plastics, Lignin - based printed wiring boards, Electronic acoustic foams, Wall coverings, Window coverings, Natural furniture, Biobased polyurethane refrigerator insulators, Toys, Cellulose – based batteries (in development)
Household supplies	Laundry detergents, Bathroom tub and tile cleaners, Fertilizers, Paint strippers, Hydraulic fluids, Mold and mildew removers, Lubricants, Dry erase board cleaner, Household cleaning solvents, Soy ink toner cartridges for printers, Household paints, Stainless steel and glass cleaners, Drain and septic tank cleaners, Floor cleaners, Insecticides, Wood sealant and waterproofing, Wood stains, Air fresheners
Personal care	Apparel, Textiles, Footwear, Shampoo and conditioners, Lip balms, Cosmetics, Soap bars, Pet shampoo, Deodorants, Sun care products, Shaving products, Lotions, Moisturizers, Hand cleaners, Razors
Automotive sector	Car tires, Soy - based foam for automotive seats, Acoustical products, Structural foam, Seat cushions, Sunshades, Headrests, Headliners, Armrests, Elastomers
Construction sector	Acoustic panels, Structural wall panels, Plastic lumber, Interior panels, Insulating foams, Non-food disposable containers, Concrete and asphalt release fluids, Floor strippers, Wood and concrete sealers, Household insulation, Decorative composites, Mold and trim, Adhesives, Films
Food sector	Food containers at sporting events, Food containers at restaurants, Water bottles, Other bioplastic bottles, Disposable cutlery
Pharmaceuticals and nutraceuticals	Vaccines, Drugs, Neuroprotective products, Therapeutic proteins, Antioxidants, Cholesterol-lowering agents, Salt replacements, Chiral chemicals
Specialty chemicals	Enzymes, Bulking and thickening agents, Flavours and fragrances, Bioherbicides and biopesticides

Appendix 2. Techniques for applying RRI dimensions

Anticipation dimension	Description	Anticipation is a dimension that aims at envisioning the future of bio-based products innovation. Anticipation plays an important role at the beginning of bio-based products development and in indicating the direction to take in order to achieve better and more desirable results.
	Techniques and approaches	Foresight Technology assessment Horizon scanning Scenario building Vision assessment Socio-literacy techniques
Reflexivity dimension	Description	Reflexivity is linked to public dialogue, science and public collaboration, and anticipation. Reflecting on underlying motivations, potential impacts, uncertainties, risks, areas of ignorance, assumptions, questions, and dilemmas. Connection between reflexivity and anticipation allows avoiding the risk of making wrong predictions, especially in the early stages of bio-based products development.
	Techniques and approaches	Multidisciplinary collaboration and training Embedded social scientists and ethicists in laboratories Dialogues Ethical technology assessment Codes of conduct Moratoriums
Inclusion dimension	Description	Processes of engagement and dialogue with different stakeholders in the early stages of bio-based product innovation. This enables the introduction of a wide range of perspectives to reframe issues and the early warning for areas of potential conflict.
	Techniques and approaches	Consensus conferences Consulting exercises Citizens' juries and panels Focus groups Public discussions and debate Science shops Questionnaires Deliberate polling Lay membership of expert bodies Outreaches Networks and clusters User-centered design Open innovation
Responsiveness dimension	Description	Responsiveness is linked to risk, which is the probability of an occurrence of an event multiplied by the amount of the cost of that event, which bio-based products may bring about. The risks associated with bio-based products can be – medium or long term, economic, environmental, security or societal. In this case, identification and analysis of risks as part of responsiveness is linked to the anticipation dimension. Discussions involving responsiveness were also primarily linked to ethics, risks, transparency and accessibility.
	Techniques and approaches	Constitution of grand challenges and thematic research programmes Regulation Standards Open access and other mechanisms of transparency Niche management Value-sensitive design Moratoriums Stage-gates Alternative intellectual property regimes
Sustainability dimension	Description	Sustainability is identified as a key driver of bio-based product development. Identification of the environmental aspects of business operations. Smart use of natural resources and investment in eco-efficient production processes.
	Techniques and approaches	Multiple criteria decision making Legal framework – Policies and regulations Standards and certification schemes Voluntary industry agreements and initiatives Life-cycle impact assessment ISO Standards Eco-efficiency analysis ProfiTS (Products fit to Sustainability) PPOSA – Product Sustainability Assessment
Economic dimension	Description	Concerns about the impact of bio-based products on economy and society explain growing calls for the – responsible – innovation concept, the sustainable transition of social and technical arrangements, and stronger engagement between science-driven innovation and society. Bio-based products are not developed only for the creation process but must comply with the requirements of meeting needs in terms of value creation for the scientists, company, the public and other stakeholders in the process of economic development.
	Techniques and approaches	Green public procurement Socio economic impact analysis Life cycle costing SWOT analysis PESTEL analysis Critical success factors, CSFs Income economic multipliers