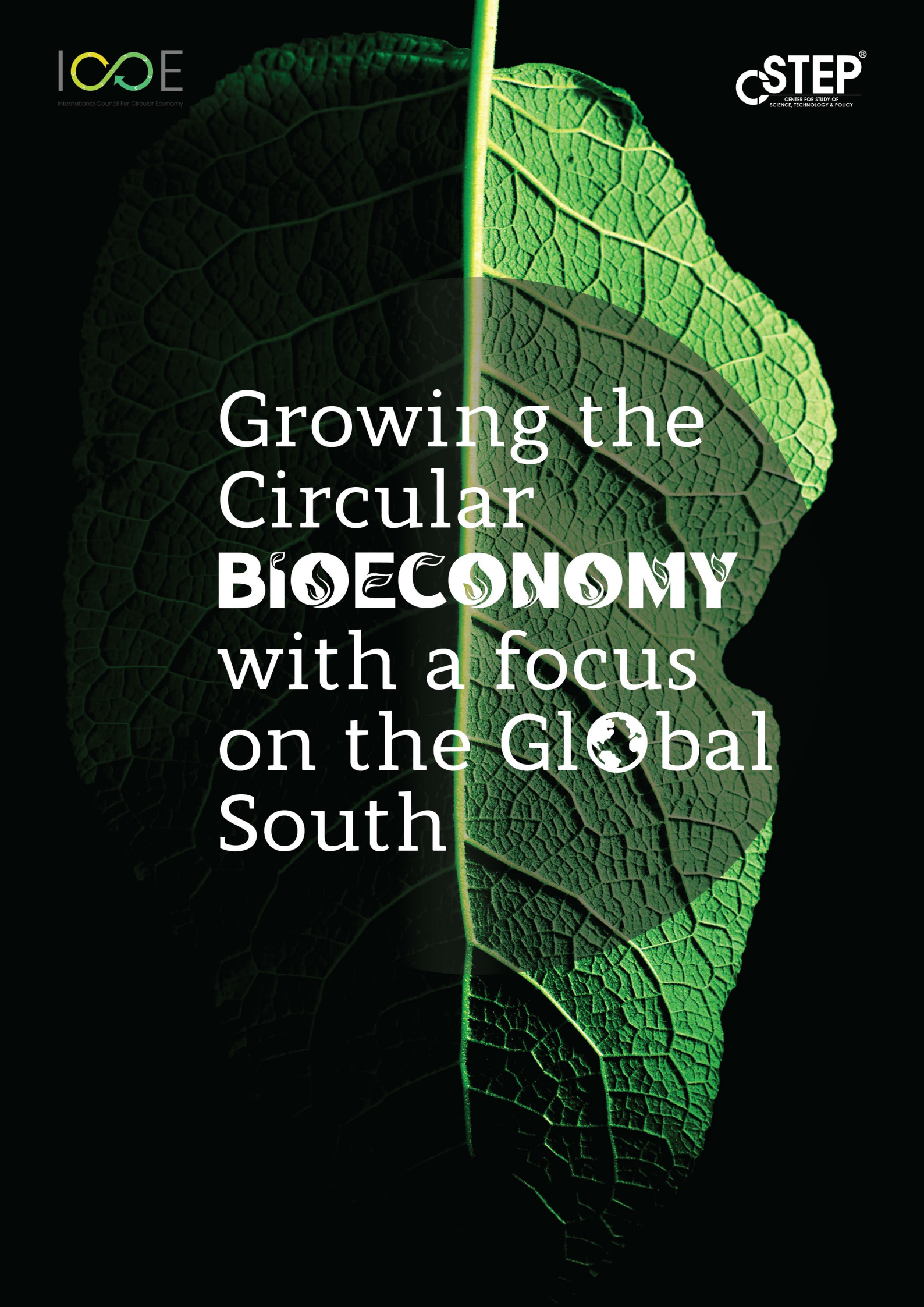
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Growing the Circular BIOECONOMY with a focus on the Global South

Growing the circular bioeconomy, with a focus on the Global South

White Paper

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Preface

The 28th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP28), concluded in Dubai last year, was a stark reality check of the present state of global climate concerns. The world today, especially countries in the Global South, are experiencing the adverse impacts of ecological collapses, water shortages, and degradation of natural assets. The production, consumption, and disposal of products in an economy have now become fundamental questions surrounding the preservation of the ecology and environment.

This White Paper titled 'Growing the circular bioeconomy, with a focus on the Global South' aims to stimulate dialogue and help enable a transformational shift towards a circular bioeconomy as a means of tackling the climate crises. A **circular bioeconomy** can play an instrumental role in reducing carbon emissions, increasing resilience to extreme weather, maintaining air and water quality, and safeguarding biodiversity. It also has a high economic potential, with the World Business Council for Sustainable Development estimating the global economic opportunity of bio-based products for food, feed waste products and energy to the tune of USD 7.7 trillion by 2030.

The paper begins by defining the concept of a bioeconomy and explains its need and potential. It also underscores the multiple ways and means to attenuate the adverse impacts of climate change through a circular and regenerative bioeconomy. It explains the importance of putting circularity at the core of climate action to reduce the risks and optimise the benefits. **The White Paper emphasises that the focus must be on growing a circular bioeconomy that is regenerative in nature to maximise the multiple 'wins', which could otherwise be missed.**

The global stocktake of bioeconomy strategies mentioned in the paper highlights the key features of the measures implemented in some Western and developing economies. *Section 3* underlines the strategies adopted in different parts of the world, indicating that a national or regional strategy on bioeconomy is now in place across countries, with similar visions but varying activities and initiatives. Section 4 delineates the extent of a circular bioeconomy and its growth potential in different areas, highlighting the key opportunities and their related benefits that could be leveraged in the Global South.

Section 5 mentions the barriers to expanding a circular bioeconomy and their potential solutions. The interventions needed for systems change are categorised under four main building blocks to ensure a steady and well-informed change: **robust policy frameworks; partnerships and collaborations; awareness generation, capacity building, and skills development; and technological innovation**. Considering these four building blocks, *Section 6* puts forth a four-stage bioeconomy roadmap for its effective end-to-end implementation through the following steps: gathering evidence, including understanding the strengths and needs of a bioeconomy in a country or region; being strategic by setting targets and goals; embedding change through effective policies, funding support, and research and development; and monitoring and reviewing the outcomes.

We hope that this White Paper will provide us the opportunity to engage with different economies as well as stakeholders to promote initiatives for achieving a circular bioeconomy.

Dr Anjali Taneja
Senior Policy Specialist and Group Head (Sustainability)
Center for Study of Science, Technology and Policy

Foreword

India is on its way to becoming a global powerhouse. At the same time, the country is grappling with some of the challenges around the application of science, technology, and innovation. The Center for Study of Science, Technology and Policy (CSTEP), a research and policy-based think tank, founded by (Late) Dr V S Arunachalam, has been playing a significant role in examining evidence-based solutions to address these issues. CSTEP is working towards addressing the key grand challenges of our time—clean energy transition, clean air for all, and a secure and sustainable future—through the adoption of cutting-edge digital technologies in all its work to devise effective solutions and drive policy decisions.

To ensure a sustainable and secure future, an integral part of our work is to examine the opportunities for a circular economy. This involves addressing the issues around a bioeconomy. It is heartening to note that a regenerative bioeconomy can help achieve the goals of climate mitigation and resilience while contributing towards greater food security, income generation, and employment opportunities. A shift from a linear to a circular bioeconomy will be essential for countries in the Global South, some of which face acute instances of poverty and malnutrition, food insecurities, high unemployment rates coupled with rapid biodiversity loss, ocean acidification, and increasing land and soil degradation.

In India, the scope of transforming towards a circular and regenerative bioeconomy is steadily rising. With agriculture and allied services being the primary source of livelihood for nearly 55% of India's population, the use of bio-based products such as bio-stimulants, bio-fertilisers, and biopesticides, in agriculture could foster repurposing, recycling, and reuse of agro-wastes, in turn contributing towards sustainable agricultural practices. It is interesting to note that significant policy developments underway in India in the fields of biotechnology, biofuels, and biomanufacturing could supplement its efforts to achieve a robust bioeconomy in the near future. In this context, the *building blocks* delineated in this White Paper are thought-provoking and useful for those interested in this topic.

These ideas will aid in making a 'transformational shift' from the existing linear practices to a more circular bioeconomic future. Driving this change will require the right evidence-based research and policy support. CSTEP will continue to drive its efforts and initiatives towards creating an ecosystem where such changes could be seamlessly implemented.

I am sure that this White Paper will prove to be informative, enlightening, and useful to the readers.

Dr Jai Asundi
Executive Director
Center for Study of Science, Technology and Policy (CSTEP)

Acknowledgements

We take this opportunity to thank our collaborators, experts, and colleagues for their continued support and guidance, without which this White Paper could not have been put together.

To begin with, we express our sincere gratitude to our external reviewers—Mr Axel Darut (Advisor, International Council for Circular Economy [ICCE]) and Mr Piotr Barczak (Advisor, ICCE, and Circular Economy Program Manager, African Circular Economy Network Foundation).

We are also extremely grateful to the experts and thought leaders from international organisations and the Indian industry, who shared their valuable insights as part of the information-gathering process carried out for this White Paper. A special thanks to Ms Laura Ombelet and Ms Ramona Liberoff (Platform for Accelerating the Circular Economy [PACE]), Mr Neil Scotland (Foreign and Commonwealth Development Office, UK), Dr Nafees Meah (formerly at International Rice Research Institute), Ms Reboni Saha (Mozaic Design, India), and Ms Gabriella D'Cruz (The Good Ocean, India).

We would also like to thank our colleague Ms Khushboo Garg for her contribution. Further, we thank the Communications and Policy Engagement team at CSTEP for the editorial and graphic design support, particularly Ms Shayantani Chatterjee, Ms Bhawna Welturkar, and Mr Alok Kumar Saha.

Last but not the least, we express our deep gratitude to the CSTEP leadership, specifically Dr Jai Asundi (Executive Director, CSTEP), for their constant support and guidance throughout the project.

Special Address

Our planet, our future: Exploring bioeconomy solutions for the Global South

The world faces an unprecedented challenge. The triple threat of climate change, biodiversity loss, and pollution places the very foundation of our planet at risk. Our current economic model, heavily reliant on unsustainable resource extraction, is pushing us towards a tipping point.

The ever-increasing consumption of natural resources, projected to rise by 60% by 2060, demands a fundamental shift in our approach. The environmental cost of resource extraction is already staggering, contributing significantly to global warming, air pollution, water stress, and biodiversity loss. Further, regions in the Global South face the challenge of balancing economic development and environmental protection.

This study examines the potential of a bioeconomy to address the challenges faced by the Global South. Recognising the importance of healthy ecosystems, the publication explores how a bioeconomy, combined with circular economy principles, can create a more inclusive and sustainable future for these countries.

By accelerating this transition, we must acknowledge the potential for unintended consequences such as problem displacement and rebound effects. A comprehensive understanding of these challenges is crucial for designing effective policies combining bioeconomy and circular economy, tailored to the specific needs and resources of the Global South regions.

Therefore, this study serves as a guide for leaders across all sectors, governments, businesses, and civil society. By leveraging the potential of a bioeconomy, grounded in the utilisation of renewable resources and biodiversity-friendly practices, we can create a future where economic prosperity and environmental well-being go hand in hand.

The future is at stake. We must seize this moment to create a brighter path for generations ahead.

Axel Darut
Advisor
International Council for Circular Economy (ICCE)

Special Address

In the dynamic landscape of global development, the concept of a bioeconomy has emerged as a beacon of hope, offering a pathway towards sustainable growth, resilience, and inclusivity. This publication marks a crucial milestone in our collective journey towards unlocking the vast potential of the bioeconomy, particularly in the Global South.

As we navigate the challenges posed by climate change, resource depletion, and socioeconomic disparities, the bioeconomy presents itself as a multifaceted solution. By harnessing the power of biological resources and innovative technologies, we can not only meet the needs of a growing population but also mitigate environmental degradation and foster economic empowerment.

However, realising the full promise of the bioeconomy in the Global South is not without its hurdles. Structural inequalities, limited access to technology and finance, and regulatory complexities pose significant obstacles that require concerted efforts and strategic interventions. Moreover, the bioeconomy intersects with various sectors, including agriculture, healthcare, energy, and manufacturing, necessitating a holistic and integrated approach to policy formulation and implementation.

In this context, this publication serves as a vital resource for policymakers, researchers, and stakeholders alike. Through comprehensive analysis, insightful case studies, and actionable recommendations, it offers a roadmap for leveraging the bioeconomy to drive sustainable development and foster inclusive prosperity in the Global South.

Furthermore, it underscores the urgent need for international collaboration and solidarity in supporting the transition towards a bio-based economy. By fostering partnerships, sharing best practices, and mobilising resources, we can collectively address the complex challenges and seize the immense opportunities presented by the bioeconomy.

As we embark on this transformative journey, let us remain steadfast in our commitment to building a more equitable, resilient, and sustainable world. Together, we can harness the power of the bioeconomy to create a brighter future for all.

Piotr Barczak
Advisor, International Council for Circular Economy (ICCE)
Circular Economy Program Manager, African Circular Economy Network (ACEN) Foundation

Executive Summary

Growing the bioeconomy in the Global South in a circular, sustainable way offers direct economic and environmental benefits, with the **potential to capture the economic opportunity of bio-based products of bio-based products for food, feed waste products and energy estimated at USD 7.7 trillion** (WBCSD 2020)**.**

At the 28th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP28), the global stocktake recognised the need to accelerate action across all areas of climate change including mitigation and resilience, while ensuring financial and technological support for the transition.

The bioeconomy can help achieve climate mitigation and resilience goals and attenuate the effects of climate change, while increasing food security, income generation capacity and jobs, and safeguarding the wider economic and social well-being of the population. Importantly, it aids in climate mitigation through carbon storage in a wide range of materials, which is of increasing importance in the Global South, as levels of carbon emissions begin to overtake those in the Global North. In addition, this can help achieve resilience to heat, floods, and coastal erosion, as bio-based products can be designed to be biodegradable and valorisation of organic wastes reduces water, soil, and air pollution. It can reduce biogeochemical flows of nitrogen and phosphorous that can harm ecosystems and biodiversity, land-system changes, and freshwater use. Thus, growing the bioeconomy is relevant to addressing multiple environmental issues.

However, there are potential trade-offs between growing the bioeconomy and carbon mitigation, biodiversity loss, and social well-being considerations like food security. This makes ensuring the circularity and sustainability of the approach imperative.

In this White Paper, we defined bioeconomy widely, in alignment with the definition provided by the Food and Agriculture Organization (FAO, 2020): 'the production, utilization, conservation, and regeneration of biological resources, including related knowledge, science, technology and innovation, to provide sustainable solutions (information, products, processes and services) within and across all economic sectors and enable a transformation to a sustainable economy.' It involves the optimisation of the use of bioresources and addition of value beyond the standard systems of agriculture, within the constraints of a sustainable circular economy.

Countries across the globe have already begun to adopt bioeconomy strategies and plans, with the European Union (EU) adopting its first Bioeconomy Strategy in 2012 (updated in 2019). EU member states and Norway have developed their bioeconomy strategies. Latin American countries including Columbia and the states of Brazil have introduced bioeconomy plans, with a greater emphasis on increasing the income generation of rural populations to reduce the pressure to deforest the invaluable Amazonian forest. East Africa has also developed a comprehensive regional strategy. Other countries may not have strategies in place currently but often support elements of a bioeconomy, whether through agriculture and forestry ministries or industry and technology ministries.

The opportunities available are extensive, particularly in terms of the potential of biomimicry in relation to processes as well as the materials that can be derived from plants and animals. In this paper, the activities are categorised in relation to primary material production, including food, fodder, and forestry products from farming, forestry/agro-forestry, and aquaculture; biomaterial production including textiles and construction materials; bio-refining to produce chemicals, pharmaceuticals, and polymers; biological processes including those used for synthesising new protein products and enzymes; nutrient recycling to produce fertilisers; and the production of

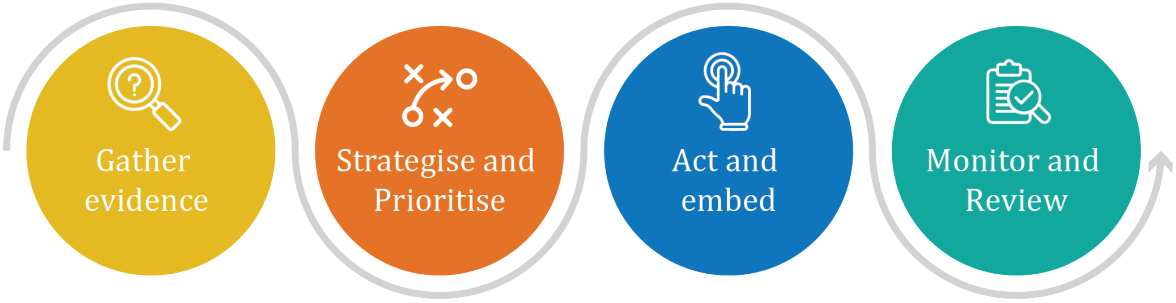
biofuels. Some examples of the innovative activities already underway in these areas and their impact have been provided in the text. The high-impact areas identified are as follows:

1. Valorise the use of agro-wastes/by-products
2. Make full use of the multiple outputs from 'super-plants' like hemp and bamboo
3. Bring forest products like fruit, nuts, and timber to market
4. Expand aquaculture and related products, e.g. seagrass
5. Establish biorefineries to produce chemicals, enzymes, and polymers
6. Grow high-protein foodstuffs, e.g. mycoproteins
7. Make fertilisers and feed from food waste and sewage sludge
8. Generate sustainable biofuels from secondary materials such as food wastes and agro-wastes

Achieving this shift will involve addressing a series of obstacles, including technology development needs, insufficient skilled workers, absence of mechanisms to ensure certainty of supply, high logistics costs and capital costs, limited consumer awareness and negative perceptions, and misaligned regulations.

A smooth transition requires a co-ordinated systems approach to accomplish the change because of the number of players involved, from primary producers to those managing logistics as well as research institutes. To help achieve this, we have created a framework, which involves four building blocks: policy framework, partnerships and collaborations, skills and social attitudes, and technological and process innovation.

The paper also describes a roadmap for informed decision-making and action. The first step is research, not only into technology but also into the social context, i.e. identifying specific needs that can be addressed through the bioeconomy and relevant community/industry strengths. The second step of the roadmap underlines the development of a strategy, establishing collaborative structures and understanding how the strategy can support economic and landscape resilience. The third step emphasises implementation. Actions and impacts should be reviewed at specific intervals, and the process should be followed-up as the situation evolves.



Embedding this strategy into a broader net-zero plan is critical and requires measuring the impacts using life cycle approaches. This is the right time to execute the strategy for ensuring that national or regional plans to decarbonise economies, while supporting growth in per capita incomes, take into consideration cost-effective bioeconomy solutions.

1. Introduction

The global stocktake completed at the 28th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP28) identified that the progress was slow-paced across all areas of climate change mitigation and resilience and in ensuring financial and technological support for the transition. A decision was made to accelerate action across all these areas by 2030[1]. This paper explores the growth of bioeconomy with circularity at its core as a means of accelerating climate action in the Global South.

Bioeconomy is 'the production, utilization, conservation, and regeneration of biological resources, including related knowledge, science, technology and innovation, to provide sustainable solutions (information, products, processes and services) within and across all economic sectors and enable a transformation to a sustainable economy' (Food and Agriculture Organisation of the United Nations, 2020)[2].

There are many related definitions in the literature[3], including

- Optimising the use of resources: the efficient and sustainable management of biomass, biodiversity, and ecosystem services for the generation of products and processes with high added value (Columbia Bioeconomy Strategy[4])
- Adding value beyond agriculture that can include a biotechnology vision, deriving chemicals and pharmaceuticals as well as new foods and fibres (Circular Bio-Economy, Venkatesh & others[5])
- Relating to a transition to a sustainable low carbon economy, combined with an emphasis on ecological processes as a means of safeguarding resources (Circular Bioeconomy Alliance[6]).

While there is a view that bioeconomy could partially replace today's economy (largely based on the use of fossil fuels, petrochemicals, minerals, and metals), simply shifting from fossil fuels to bio-derived materials and fuels is not the solution[7]. This is because, for instance, land-use change driven by agriculture is one of the key drivers of carbon emissions, ecosystem loss, and pressure on water resources[8]. For this reason, the European Union (EU) green taxonomy references to 'sustainably sourced bio-based materials'[9].

It is, therefore, important to address the trade-offs by making the system truly 'circular'[10]. This would reduce the demand for primary resources, thereby minimising the pressure for land-use change and reducing the risk of air and water pollution due to burning or effluent discharge of biowastes. Furthermore, the system can be designed to be regenerative so that materials and resources are returned to use or to the soil, sustaining further cycles of growth and production rather than depleting natural assets like soil and groundwater.

In essence, to address the trade-offs and bring about a win–win situation, sustainability and circularity criteria must be embedded in bioeconomy frameworks. An illustration of a circular bioeconomy that is regenerative in nature has been provided in Figure 1.

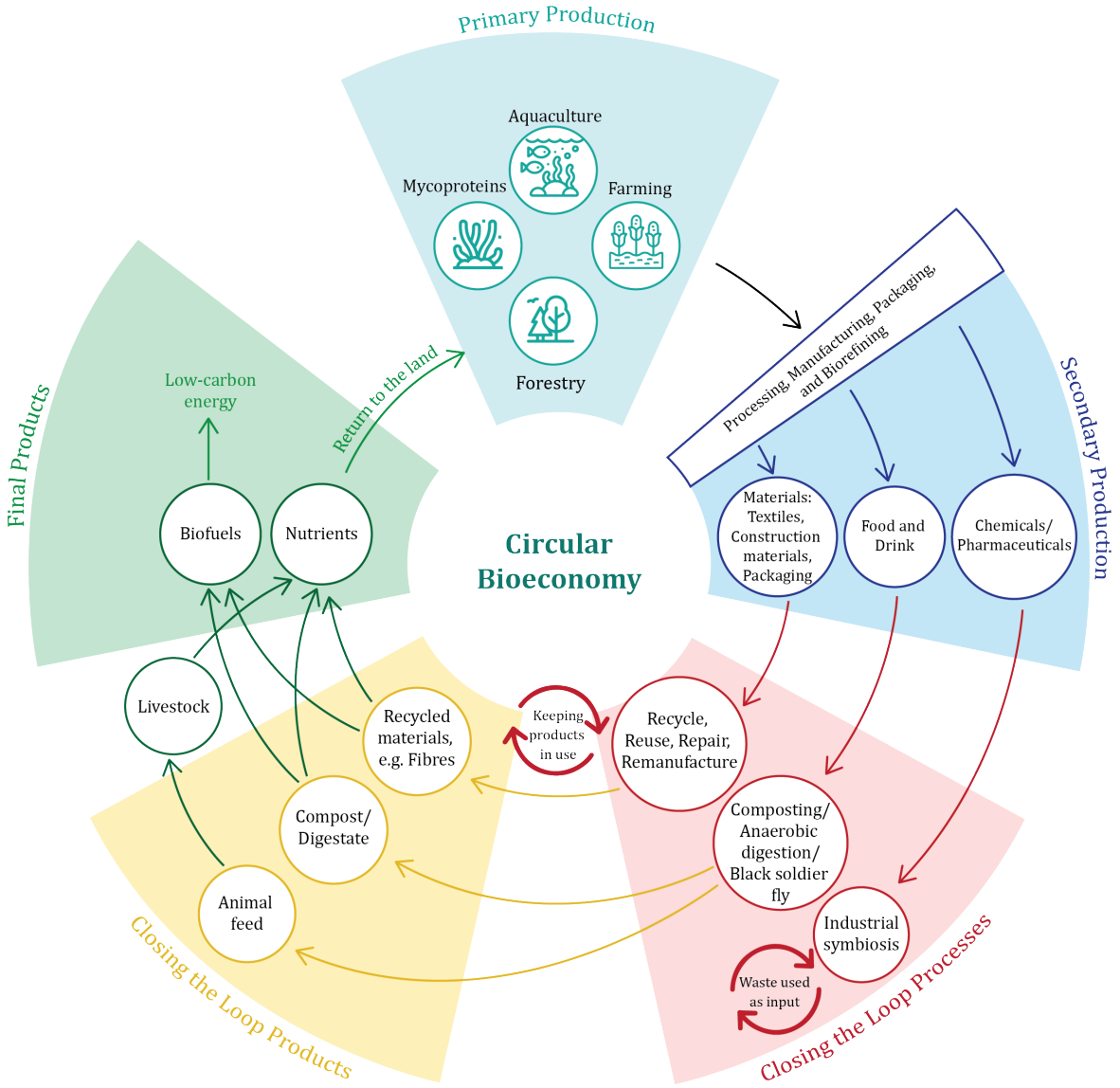


Figure 1: A circular regenerative bioeconomy

Keeping these aspects in mind, the focus of this paper is to address the following questions:

1. What is the rationale for promoting a circular bioeconomy?
2. What are the opportunities of the bioeconomy and how can its benefits be maximised in the Global South?
3. What are the win–win strategies or interventions to promote a circular regenerative bioeconomy in the Global South?

In this effort to present 'a circular bioeconomy', we discuss key aspects pertaining to (i) the optimisation of the use of biological resources to derive multiple environmental benefits, including reduced carbon emissions, increased climate resilience, and revitalised natural capital including soil and water; (ii) the valorisation of wastes/by-products and generation of economic opportunity; and (iii) the sustainability of systems within the constraints of the goals of climate mitigation, resilience, and biodiversity.

2. Why Circular Bioeconomy?

The world is facing multiple crises today and is at a risk of overshooting or moving dangerously close to a number of planetary boundaries[11]. Global carbon emissions have risen to the highest ever estimate[12] of 36.8 billion tonnes in 2023, of which a large share of emissions from fossil fuels (coal, oil, and natural gas) originate from the Global South[13].

In terms of ecosystems, the world is witnessing a high species extinction rate, driven largely by habitat loss—10,000 times greater than the rate experienced in the past. Studies suggest that we are close to a point of possible ecosystem collapse[14], including coral reefs and rainforests[15]. Impacts of land and soil degradation are severe[16].

In addition, the world is likely facing a 40% shortfall in freshwater supply by 2030, with severe water shortages in water-constrained regions (Global Commission on the Economics of Water, 2023)[17]. Water bodies are suffering from eutrophication at increasing rates owing to nitrogen and phosphate contamination[18].

At a local level, cities and rural areas around the world face air pollution due to several causes including burning of agro-waste and forest fires[19], soil degradation as a result of erosion and compaction, and water pollution due to various contaminating sources including biowastes entering waterbodies.

According to the Global Environment Outlook 6 (2019), a considerable proportion of carbon emissions can be attributed to the production of food and other commodities[20], including extraction. The recently published Global Resources Outlook 2024 shows a greater than 3-fold increase in the use of these materials since 1970, with multiple adverse impacts including global heating, air pollution, water stress, and biodiversity loss[21].

Global South faces various social challenges such as scarcity of rural jobs; high inflation rates due to drought and currency depreciation; and a shortage of decent urban housing with adequate water and power supply and sanitation.

Further, according to the report 'The State of Food Security and Nutrition in the World' (2023) by the Food and Agriculture Organization (FAO) of the United Nations (UN)[22], basic food security is an increasing problem in some regions hit hard by drought, such as East Africa. In some countries such as Kenya (East Africa), inflationary pressures have been partly driven by climate pressures[23]. Extricating themselves from this situation is made more difficult by the cost of finance in the Global South, which means limited funding for infrastructure, research and development (R&D), and skill development[24].

Thus, as reflected in the Doughnut Economics diagram in Figure 2 (Kate Raworth, 2017)[25], the challenge at hand is to avoid overshooting the boundaries related to the environment and entering the red zone shown in the figure, whilst also maximising social and economic welfare. This could be avoided by undertaking sustainability measures that keep us within the environmental boundaries. Addressing these multiple goals is the rationale for growing a circular bioeconomy.

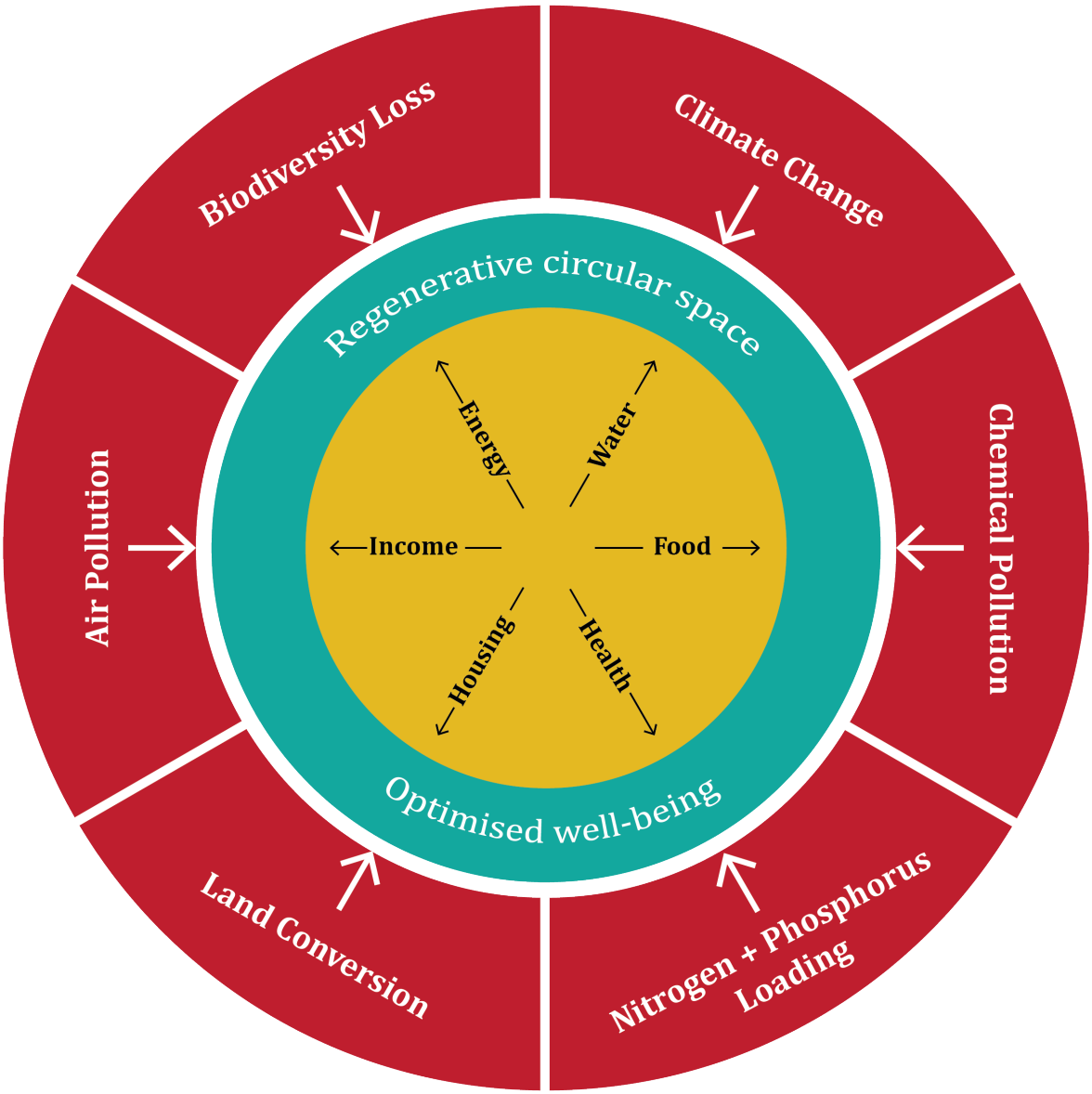


Figure 2: The challenge—maximising social benefits within planetary boundaries

In the next section, we explore global strategies already in place and describe practical opportunities and overall benefits, followed by the potential approaches to achieve this shift.

3. Global Strategies and Approaches to a Circular Bioeconomy

Over the past decade, we have seen increasing interest in bioeconomy, driven in part by the demand for shifting to a low-carbon economy. The EU's first Bioeconomy Strategy[26], published in 2012 following the Copenhagen Declaration[27], highlighted multiple ecological benefits and economic potential, especially in the agricultural domain. The FAO provides information on the opportunities in different areas to achieve a sustainable bioeconomy[28]. Other key players in this field include the Centre for International Forestry Research and World Agroforestry (CIFOR-ICRAF), the global research institute on agroforestry; the UN-backed International Resource Panel; and the Circular Bioeconomy Alliance, a business-led body.

A large number of countries within the EU now have a bioeconomy strategy[29], similar to many Latin American countries and a few countries in Africa and Asia. For example, East Africa has developed a Regional Bioeconomy Strategy[30]. Table 1 reflects various regional and country-specific strategies on a bioeconomy[a].

[a] These bioeconomy strategies are generally distinct from regional agricultural strategies and waste management plans, such as the EU Farm to Folk Strategy or the Circular Economy Action Plan. A substantial alignment among such strategies could strengthen the momentum to promote a circular and regenerative bioeconomy.

Table 1: Overview of region/country-specific strategies on bioeconomy

	EU Bioeconomy Strategy (2019 updated)	Germany Bioeconomy Strategy (2020)	Norway Bioeconomy Strategy (2016)	Columbia National Bioeconomy Strategy (2020)	East Africa Regional Bioeconomy Strategy (2021)
Mission	The European bioeconomy needs to have sustainability and circularity at its heart. This will drive the renewal of industries, the modernisation of primary production systems, and the protection of the environment and will enhance biodiversity.	Combine economy and ecology to ensure a more sustainable use of resources	Targets the production, extraction, and use of renewable biological resources (food, animal feed, health products, energy, materials, chemicals, paper, textiles, and numerous other products) in a sustainable, effective, and profitable manner	Economy transformed for the sustainable use of biomass, biodiversity, and ecosystem services	Sustainable economic growth and job creation, making use of the region's bioresources to develop products in the areas of food and nutrition, health, bio-based industrial products, and bioenergy, while contributing to an improved environment and climate change mitigation
Aims of the strategy	1) Strengthen and scale-up bio-based sectors and unlock investments and markets 2) Deploy local bio-economies rapidly across Europe	1) Bioeconomy solutions for Agenda 2030 2) Harness the potential within ecological boundaries 3) Enhance and apply biological knowledge 4) Establish a sustainable raw material base 5) Promote Germany as a leader in innovation	1) Cooperation across sectors, industries, and thematic areas 2) Identification of markets for renewable bio-based products 3) Efficient use and profitable processing of renewable	1) Exported products and processes to improve in quality and become more diverse 2) Value chains from biodiversity to produce more added value and obtain a regional focus	1) Regional and international collaboration 2) Promoting regional markets for trade 3) Harmonised regional approach to create structures for innovation and deployment of technologies

	EU Bioeconomy Strategy (2019 updated)	Germany Bioeconomy Strategy (2020)	Norway Bioeconomy Strategy (2016)	Columbia National Bioeconomy Strategy (2020)	East Africa Regional Bioeconomy Strategy (2021)
	3) Understand the ecological boundaries of the bioeconomy	6) Involve society and strengthen international collaboration	biological resources 4) Sustainable production and extraction of renewable biological resources	3) Productivity and competitiveness to be improved in the traditional sectors of the economy such as agriculture 4) Biomass to be used for the new generation of products, processes, services, and bioenergy 5) Education and training to be strengthened across various sectors 6) New jobs to be created throughout the country for different skill levels 7) Identify additional strategies for rural-centric development	4) Development of national bioeconomy strategies and policy agendas 5) Joint monitoring and information sharing

	EU Bioeconomy Strategy (2019 updated)	Germany Bioeconomy Strategy (2020)	Norway Bioeconomy Strategy (2016)	Columbia National Bioeconomy Strategy (2020)	East Africa Regional Bioeconomy Strategy (2021)
				8) New interdisciplinary technologies to be developed and established 9) Local and traditional knowledge to be drawn on and evaluated 10) New companies to be created and existing ones to be strengthened in the biotechnology field	
Key Actions	1) Governance: cross-departmental 2) Maximising co-benefits	R & D: innovation focussed	Four priority areas: co-operation, markets, profitable processing, and sustainable production	1) Six priority areas: (new) materials, green chemistry, health and wellness, fuels and bioenergy, and cosmetics and pharmaceuticals 2) Different strategies in different regions	Four priority areas: food security, health & well-being, bio-based industrial development; energy

	EU Bioeconomy Strategy (2019 updated)	Germany Bioeconomy Strategy (2020)	Norway Bioeconomy Strategy (2016)	Columbia National Bioeconomy Strategy (2020)	East Africa Regional Bioeconomy Strategy (2021)
Policies	1) Scale-up research and demonstration projects Investment funds Enablers and blockers Establish biorefineries and measure size Mobilise players along value chains 2) Local bioeconomy strategic deployment agenda Pilots Policy support facility Education and training 3) Understanding ecological boundaries	Reduce the pressure on land Sustainable production and supply of biogenic raw materials Establish bioeconomy supply chains and networks Market launch and development of bio-based products, processes, and services Leverage the potential interest in the bioeconomy for the development of rural areas Leverage the potential for digitisation to achieve the bioeconomy Coherence needed across different policies pertaining to the industry and sectors such as energy, agriculture, and climate and environment	1) Networking and clustering activity: co-ordinating project support along the value chain from research and development (R&D) to innovation and market co-ordination R&D co-operation, including cross-sectoral 2) Markets -knowledge and information - standards, labelling, and certification Know-how of climate effects - new investment company - allowing investors to invest in unlisted companies - innovation loan scheme - bio-energy initiative	Concrete ideas in some areas: 1) New varieties of crops, precision agriculture, and digitalisation 2) Nature tourism expanded 3) Pricing of ecosystem services 4) Chemistry: use of enzymes 5) Research fields listed: novel biochemical compounds 6) Incubators, finance, and innovation fund	Broad, high-level ideas: 1) Enabling policy environment - Harmonising legislation, policy, and standards in the region 2) Governance policy and strategies 3) enhancing the innovation system 4) R&D and entrepreneur links; credit facilities, incubation services, risk sharing systems, business-to-business collaboration 5) Capacity development: human and infrastructural capacity

	EU Bioeconomy Strategy (2019 updated)	Germany Bioeconomy Strategy (2020)	Norway Bioeconomy Strategy (2016)	Columbia National Bioeconomy Strategy (2020)	East Africa Regional Bioeconomy Strategy (2021)
	Knowledge observation and integration into agriculture: agro-ecology	Early stage policy measures include -_ establishment of an advisory body - national–regional–international collaboration - capacity building - monitoring the progress and implementation of strategies and initiatives	- public procurement and role model - scaling-up the turnover of renewable biofuel - International co-operation - Trade tariffs 3) efficient use and profitability - test and demonstration facilities - funding research councils - promote industrial processing - deal with bottlenecks such as transport - white paper: waste policy and circular economy including fisheries waste - use of life cycle assessment -Revised fertiliser regulations - increase the use of wastes	7) Subsidies and public procurement	6) Co-ordination: partnerships and collaboration

	EU Bioeconomy Strategy (2019 updated)	Germany Bioeconomy Strategy (2020)	Norway Bioeconomy Strategy (2016)	Columbia National Bioeconomy Strategy (2020)	East Africa Regional Bioeconomy Strategy (2021)
			- evaluate relevant regulations 4) Sustainable production and extraction - carbon storage - active reforestation - regulatory framework for areas such as algae - increase know-how and area planning - develop insights to keep impacts within sustainable boundaries - upgrading skills - mapping old forests		

4. Potential Opportunities and Benefits

Learning from some of the global examples presented in Table 1, in this section, we discuss potential opportunities and benefits in expanding the bioeconomy in the Global South.

'From an economic perspective, a transformation toward a circular bioeconomy makes business sense. Expected growth is particularly high within non-food industries, such as products and energy, where growth from 2018 to 2030 is expected to be 3.3% per annum, leading to USD $5.5 trillion by 2030. This growth is based on an increase in the use of biomaterials within different product industries, the main ones being pharmaceutical, textiles, building materials, and packaging.' (Circular Bioeconomy, WBCSD, 2020)

Table 2 below shows the range of processes and outputs as well as inputs that relate to a bioeconomy, illustrating the potential breadth of a comprehensive bioeconomy strategy.

Table 2: Components of a circular bioeconomy

Inputs	Process	Outputs	Outcomes
Tree/forestry crops Multi-purpose crops, e.g. hemp Agro-waste/crop residues Food- and drink-processing waste Post-consumer food waste Wastewater/sewage sludge Aquaculture	Primary production: including food, seaweeds, forestry nuts, and timber (limited processing) Biomaterial production: may involve compression, moulding, and weaving Laboratory processes ('biorefining'): including extraction of molecules and polymer synthesis Biological processes: including the growth and fermentation of plant-based protein products Nutrient recycling: biodegradation Biofuel generation: producing biodiesel from waste cooking oil	Agri-food and fodder Fodder and substrata for mushrooms Biomaterials Textiles Construction materials Materials for manufacturing consumer goods, e.g. mattresses and plastic products Oils Enzymes Chemicals New foodstuffs Plastic polymers Pharmaceutical products and cosmetics Bio-fertilisers and fuels	Protect microclimates: local rainfall and water percolation Improve productivity Reduce air pollution Generate low-carbon products Build healthy ecosystems for plants Improve rural incomes

4.1. Opportunities

The Energy Transitions Commission (ETC) lists the uses of biomass in the order of priority in relation to sustainability[31]. To illustrate the opportunities of a bioeconomy in detail, some examples are provided below, indicating how the use of these materials or resources can be optimised. We considered the hierarchy of priorities, as explained by the ETC[32], for choosing the following examples:

A. Agro-wastes/by-products: Valorising the by-products of rice production offers a substantial opportunity for a bioeconomy, considering the huge scale of production. Annual worldwide production of rice accounts for 750 million tonnes of grain and 150 million tonnes of husk[33]. The by-products of rice include rice husk, rice straw, and rice bran.

Burning of straw is a common practice in many countries and has health implications. For example, in the Mekong Delta, 80% of 25 million tonnes of rice straw is burnt (estimated to be worth RMB 19.65 billion per annum in China)[34]. Given rice production is water- and land-intensive, identifying methods to fully utilise the output in multiple ways is important.

- In China, straw bales, which sequester carbon, are used for construction and have good insulating properties. In addition, recent research has shown the potential use of straw to make concrete[35].
- In Vietnam, rice straw is used as fodder. Moreover, rice straw is used as a substrate for mushroom production and as a feedstock for anaerobic digestion and generation of biogas and digestate in Vietnam, Cambodia, and the Philippines.
- Similarly, rice husk has positive properties. In Japan, research has shown its potential use as a construction material[36], owing to its non-combustible and insulating properties. In this case, the husk is used as an alternative material to silica stone and as a fuel.
- Rice bran can also be used as a compost and for biochar production, as part of a regenerative approach, although some studies state that more research is needed[37].

'The Platform for Accelerating the Circular Economy (PACE) is working to identify scalable solutions for circular food systems. Initial research has demonstrated there is potential to make more use of biomaterials derived from food loss and waste. Having explored the potential uses of rice or paddy-derived materials in depth, PACE sees significant potential to utilize rice straw and rice husk. The potential for these byproducts to partially replace hard-to-abate building materials, such as concrete, is especially promising.' (Laura Ombelet, PACE)

B. Non-timber forest products: Forests and forestry products offer opportunities to increase the income of rural populations while retaining the carbon and biodiversity advantages of existing ecosystems. These materials are not only a source of economic well-being but also provide multiple social and environmental benefits.

The examples below draw from the work of Partnerships for Forests (P4F)[38] on the utilisation of forestry products such as fruits and nuts. One initiative involves the scaling-up of juice production in Peru from native trees. A second project is related to rubber production in the Amazon Rainforest, Brazil, wherein a shoe manufacturer/brand is working to strengthen the native rubber supply chain. A third project is related to the production of nuts from a tree in Kalimantan, Indonesia, which can generate up to 800 kg of nuts per harvest season and live for more than 100

years. All these initiatives have increased the incomes of local forest dwellers, in addition to having positive environmental outcomes. For example, in case of rubber production, the incomes increased by 71%. These initiatives have bolstered the interest of villagers in retaining forests, with some even registering their villages as 'Village Forests', such as those in case of the Kalimantan initiative[39].

The potential for valorising forests and forestry products is augmented by the carbon credit market and possible payments for ecosystem services. For example, in case of rubber production in Brazil, the buyer also made payments for social and environmental services.

'Foreign, Commonwealth & Development Office (FCDO) supports a wide range of work on the bioeconomy and related concepts, such as regenerative forest businesses and the development of agroforestry and non-timber forest products. These are important and innovative ways of delivering benefits for communities, as well as for climate and nature, creating sustainable jobs and livelihoods while protecting and restoring the natural assets that underpin life on earth. The FCDO's work in this field has shown that these are important win-win activities, increasing the incomes of vulnerable groups and reducing the pressure to clear forest rich in biodiversity.' (Neil Scotland, International Forests Unit, FCDO, UK)

C. New materials (multi-purpose crops): A number of crops have considerable potential for providing low-carbon sustainable products while being resilient and even regenerative. One of these resources is hemp (Cannabis sativa L), which is suitable for optimising the use of bioresources. Studies have shown its potential use as a food and medicinal crop as well as an oil crop and the suitability of its long fibres for producing textile and construction materials[40]. It is also resilient because it is less water-intensive than cotton and has a lower chance of crop failure than flax. Further, it has soil improvement properties, in line with the regenerative principle[41].

A recent report by the United Nations Conference on Trade and Development (UNCTAD)[42] indicates that the global market for hemp could hit USD 18.6 billion by 2027. The potential of using all parts of the plant and avoiding waste creation reduces the risk of burning, which is common for other crops. Thus, a circular economy dimension is embedded in the use of this crop. In other words, materials like hemp have the potential to replace carbon-intensive materials in the built environment while offering more comfort, as it a breathable material and good insulator, with the co-benefits of reduced air pollution. To ensure full circularity, other factors such as the process of manufacturing the fabric to ensure ease of recycling and degradation at the end of life should be considered.

D. Bio-refining (chemicals and polymers): Pharmaceutical products or chemicals have been commonly produced from biological resources. However, going beyond biotechnology to a 'circular bioeconomy' that is also regenerative requires some additional strategies, as explained below.

The EU has reported the top 20 products from which a large number of bio-materials can be derived[43]. Some best-known examples include bioplastics that are still under research[44] and recycled plastics[45]. Other examples include substances such as chemicals[46], some of which are produced using waste materials like agricultural residues. Pharmaceutical manufacturing is another example wherein chemicals derived from nature are utilised and valorised.

Embedding circularity involves designing these substances to be recyclable and ultimately bio-degradable. The use of life cycle assessment (LCA), i.e. considering the total system emissions including supply chain logistics and material collection in decision-making, can help in achieving a substantial reduction in carbon emissions.

Germany's Bioeconomy Strategy[47], which focusses on bio-innovation for climate-neutral development and use of biogenic raw materials for a sustainable circular economy, flags the potential for bio-based materials to be circular and displace carbon-intensive materials. An example drawn from the implementation of Germany's Bioeconomy Research Programme includes making bio-based polyurethane building blocks from vegetable oil using a chemical catalytic route[48] developed through a collaboration between Bielefeld University and an industry partner. Another example involves manufacturing fragrances from non-fossil fuel inputs. The programme has also supported the development of products such as enzymes that can breakdown polyurethanes, resulting in the generation of biocatalysts that assist in their recycling process.

E. Marine and aquaculture products: A wide range of products can be derived from this sector. New products that have circular economy and optimisation of resources at their core are under development.

As per our literature review, the three aspects of a circular bioeconomy for this sector include utilising waste materials from existing products, making more products with multiple benefits, and operating existing aquaculture systems in a regenerative circular way. Drawing from the East Africa Bioeconomy Strategy with a section on coastal and freshwater resources for the bioeconomy, many possibilities of using shells, crabs, seagrasses, seaweed, algae, and shrimps as resources are evident.

An example in terms of materials produced from wastes or by-products is fish skin leather, which is now being used in East Africa to make leather products for export. About 70 tonnes of fish skin wastes, estimated at a value of USD 140 million per annum, are generated weekly on the shores of Lake Victoria. A similar idea is the use of prawn shells for plastic manufacturing, for which research has been undertaken but production is yet to begin.

Operating aquaculture businesses in a circular, sustainable way is also a fundamental part of a circular regenerative bioeconomy. Tanzania in East Africa is one such country with organisations working towards replenishing aquatic resources through community-driven conservation and sustainable aquaculture.

F. Nutrient recycling (food wastes and wastewater/sewage sludge): A circular approach that valorises food wastes and sewage sludge is of high impact. If disposed in landfills, these materials can produce methane, a potent greenhouse gas. Further, when sewage sludge is discharged into water bodies, it can cause eutrophication and lead to bacterial infections due to *Escherichia coli*.

Some possible approaches for processing sewage sludge are as follows[49]:

- the use of anaerobic digestion to produce a digestate used as a fertiliser and biogas,
- pyrolysis to produce biochar, and
- a broader sewage sludge refinery approach that aims to valorise this material to the maximum extent.

Anaerobic digestion is widely used in Europe, including the UK, by water and sewerage companies and is gaining attention in developing countries[50]. Ghana's Circular Economy Bio-

innovation Hub is an example of an institution that has been set up successfully to share knowledge and expertise on this front[51].

Other than anaerobic digestion, there are different solutions for processing food wastes with lower capital costs, including black soldier fly (BSF) composting. Unlike the conventional composting process, which takes 8–24 weeks, BSF-assisted composting has been found to take only 5 weeks to convert organic wastes into mature and stable organic fertiliser. This has been successfully tested and tried in Kenya using brewery wastes, supported by the International Centre of Insect Physiology and Ecology[52]. To progress on this front, the challenges of capital costs and knowledge-sharing should be mitigated.

These examples show that there is considerable opportunity to utilise biomimicry or the field of biomimetics to learn from natural processes as well as materials. For example, we can use natural cycles such as the decomposition of organic matter for producing fertiliser and feed as well as materials like prawn shells to produce bio-plastics. Making the most of these opportunities involves leveraging potential learnings from biomimetics, an inter-disciplinary approach to enable the transfer of knowledge from biological systems to emerging technology and processes.

4.2. Potential Benefits

A shift from a linear approach to a circular bioeconomy has many benefits.

BOX ITEM 1: Expected returns from a circular bioeconomy

According to the World Business Council for Sustainable Development[53],

- The estimated economic opportunity for bio-based products to complement or even substitute conventional ones will be worth USD 7.7 trillion by 2030 for food and feed waste (excluding food and feed end-use) products (with pharma, textiles/apparel, and building materials having the greatest potential) and energy, generated across 10 industries (pharma, textiles/apparel, building materials/construction, packaging, vehicles, other forest products, electronics and electricals products, machinery, biomass energy and biofuels).
- The growth in non-food industries such as products and energy is expected to be nearly 3.3% per annum, leading to a generation of USD 5.4 trillion by 2030[54].

According to the World Economic Forum[55],

- Productive and regenerative agriculture could address the challenges of land degradation, considering that nearly 20% of vegetated surfaces are showing signs of decline in productivity.
- Coastal communities in Vietnam witnessed an increase in incomes between 200% and 800% from aquaculture products such as shells and oysters following the restoration of critical mangroves[56].
- A promising solution to many of these challenges is to expand seaweed and mollusc farming that provides food and biomaterials in a regenerative way—requiring no freshwater, land, or fertiliser input and sequestering carbon while growing[57].

The Centre for International Forestry Research (CIFOR)[58] has reported that economic opportunities worth approximately USD 3.5 trillion, having the potential to generate nearly 87 million more jobs, are expected to be generated from a circular bioeconomy.

The European Union Bioeconomy Strategy (2012)[59] has reported that a circular bioeconomy can create nearly 1 million green jobs by 2030. Moreover, replacing materials with more bio-based products could lead to significant reduction in environmental emissions. For example, using 1 tonne of wood instead of 1 tonne of concrete could lead to a drop in 2.1 tonnes of CO_2 emissions. Similarly, avoiding food waste and its negligent disposal could save up to EUR 143 billion annually.

The potential to generate greater value addition from a circular bioeconomy has also been reported in the Global South economies. For example, in Brazil[60], an expanded bioeconomy can generate nearly USD 284 billion per annum by 2050. In India, the estimated bioeconomy potential is around USD 137 billion, which is expected to rise to USD 300 billion by 2030.

There is scope for climate mitigation through carbon storage[61], which can be implemented at a low cost, using bio-based products such as bamboo and hempcrete, reducing high embodied emissions in construction materials. In addition, it is possible to reduce methane generated from biodegradable wastes by utilising such bio-based products. According to the European Environment Agency[62], with an increase in demand, petrochemical plastics can be displaced with biodegradable materials produced using food waste.

'The bio-based circular carbon economy, in particular, stresses capturing atmospheric carbon via photosynthesis and exploiting this unique feature to the fullest extent possible.' (Tan & Lamers, 2021)

Climate resilience can be improved through forestry and agro-forestry, which can safeguard microclimates[63] and reduce soil erosion[64]. Plants such as seagrasses and mangroves can reduce wave strength and reduce erosion in coastal areas[65].

Moreover, the use of agricultural residues to produce useful items can reduce air pollution caused by post-harvest stubble burning of rice and wheat crops. Similarly, utilising organic matter from food- and drink-processing plants as well as 'resources' from wastewater systems (otherwise discharged into water bodies) can help maintain healthy waterbodies. Further, some bio-based products are less polluting. For example, in Scotland, an alcohol-making industry produces bio-based chemicals (such as acetone, butanol, and ethanol) from by-products such as benzene. Economic benefits are derived from utilising waste streams to maximise the benefits from specific crops, shifting from lower-value outputs to higher-value outputs. For example, the use of harvested seaweed as a food crop attracts a higher price than its use as a hydrocolloid (gel). Making the most of new opportunities, e.g. bioplastics, also has potential. Similarly, the use of new food technology systems enables the production of nutrient-rich products with low land and water demand, addressing some of the other challenges in the Global South[66].

According to Nature Imperative (EMF 2022), circularity diminishes the pressure from utilising these resources on the natural environment[68]. Circular economy actions that reduce the extraction of materials by optimising their usage lower the pressure on biodiversity[69]. Therefore, ensuring that the growing bioeconomy is circular is essential to minimise the potential trade-offs.

With the cost of finance to the Global South, the need for win–win solutions to address multiple challenges, as reflected in the global Sustainable Development Goals[67], is increasingly apparent. Moreover, to achieve such a systems transition, a shared understanding of the problem, rationale, and approach to address any trade-offs is needed.


UKRAINE
SPAIN
ITALY
GREECE
TURKEY
TUNISIA
ALGERIA
LIBYA
EGYPT
SAUDI ARABIA
MAURITANIA
NIGER
CHAD
SUDAN
NIGERIA
ETHIOPIA
KENYA
UGANDA
TANZANIA
D.R. OF CONGO
ANGOLA
ZAMBIA
ZIMBABWE
BOTSWANA
MOZAMBIQUE
MADAGASCAR
COMOROS
SEYCHELLES
INDIAN OCEAN
ARABIAN SEA
YEMEN
OMAN
IRAN
IRAQ
AFGHANISTAN
PAKISTAN
SWAZILAND

5. Expanding the Bioeconomy in the Global South

5.1 Barriers and Enablers

Based on the regional and country-specific strategies, examples explored above, and findings from previous studies, the barriers and potential solutions to expanding a bioeconomy are presented in Table 3. The Table also lists specific challenges to the expansion in the Global South, supported by findings of a study conducted on 18 countries globally[70]. Some of the overarching barriers highlighted by previous research in the Global South are related to technology availability, capital/finance, and competitiveness. These studies have also identified the need for value chain collaboration as a vital component for building demand and enabling scale up[71].

Table 3: Barriers and enablers

S no.	Barriers	Solutions: Enablers and specific policies
	Supply side	
1.	***Technology:*** Needs development, in relation to materials, processes, and use of data and the identification of appropriate approaches in specific climatic zones	Industry and academia research partnerships[72] Business: academia platforms Examples: - Germany's Bioeconomy Research Programme[73] - The UK's National Interdisciplinary Circular Economy Programme[74] and UK Catapults Programme Innovative solutions for redesigning to avoid over-production
2.	***Logistics:*** - High cost and the need for co-ordination in case of reverse logistics - Logistics of sourcing inputs from smallholdings	Co-location of industry and city-rural plans[75] Provision of producer responsibility schemes relevant to waste processing: meet the costs of reverse logistics in industries such as paper and textiles Data on what is being produced and the sources
3.	***Infrastructure and storage:*** - Materials often degrade easily - Feedstock is seasonal	Public infrastructure or subsidies for storage Research into storage and preserving systems
4.	***Externalities:*** Multiple *wins* from the suggested solutions are externalities not priced	Carbon credits: robust schemes related to accredited projects

S no.	Barriers	Solutions: Enablers and specific policies
	into the market, including nature, carbon, and pollution	Payment for ecosystem services, beyond carbon sequestration Extended producer responsibility (EPR) schemes
5.	***Skills:*** Absence of skills ranging from entrepreneurial to technical and operational skills	Capacity building workshops and training Multi-stakeholder partnerships across the value chain to ensure that all personnel develop skills and gain awareness
6.	***Certainty of supply:*** Difficulty in accessing sufficient inputs, especially from smallholders, for example, forestry products	Appropriate contractual arrangements with suppliers or producers, including the establishment of relevant institutions, e.g. co-operatives for sale of produce
7.	***Capital:*** Borrowing is unaffordable and particularly problematic for some processes	International finance solutions for dealing with risk Incubator and accelerator funds Green taxonomies that highlight circular economy to attract impact investment
Demand side		
8.	***Consumer preference and information:*** - May not appreciate variable quality - Negative perception regarding bio-based products - Concern that bioeconomy is not sustainable—displacing other land uses - Limited trust in new products	Labels and certification: schemes such as Forest Stewardship Council (FSC) and Marine Stewardship Council (MSC) Use of regional promotional policies, including protected geographic indicators[b], to get higher prices and build consumer loyalty Promote life cycle assessment Promote agro-ecology and standards for sustainable sourcing to address consumer concerns Public procurement to kick-start demand
9.	**Cost/price competitiveness:** - Externalities not priced in - Cycle of low demand, not being able to scale up	Review agricultural subsidies and channel appropriately Tax benefits (e.g. Goods and Services Tax [GST]/Value-added tax [VAT]) Taxes on fossil-fuel derived products, e.g. EU tax regime (European Union Emissions

[b] Why geographical indicators for least developed countries (UNCTAD) https://unctad.org/system/files/official-document/aldc2015d4_en.pdf p.4

S no.	Barriers	Solutions: Enablers and specific policies
		Trading System (EU ETS) and Carbon Border Adjustment Mechanism [CBAMS]) Eco-design and bans (including a ban on agro-waste burning) *EPR schemes (can be used to factor in variations in environmental impacts [modulated fee structures])*
Existing policies		
11	***Misaligned regulations:*** Some of the existing regulations (laws, policies, legislation, etc) might not be aligned properly to promote the shift to a circular bioeconomy. For example, forestry law may excessively restrict the harvesting of fruits or timber.	Review the existing regulations pertaining to bio-waste management and align those with the overall circular bioeconomy objectives
12	***Economic reporting:*** - Bioeconomy development not measured in a consistent manner - Variable definitions (e.g. in the Indian context, the definition includes a large part of the pharma sector)[76]	Agreed metrics and reporting convention Develop a shared understanding of the concept (not only bioeconomy but circular bioeconomy)

Drawing from UNCTAD's findings and recommendations for hemp[77], which are also relevant for other new products, some of our key findings include the need to address information failures regarding product uses and prices, ensure favourable regulatory requirements to reflect sustainability benefits, and adopt a supportive industrial policy. The advantage of regional cooperation can be emphasised based on the potential inter-regional benefits; for example, Malawi can benefit from South Africa's research capacity while making the most of its own capacity for action at scale.

Barriers vary across sub-sectors. In terms of biorefining, further research is needed on the production processes of chemicals and polymers. This is in part to ensure that the substances derived are circular, degrading at end of life, or having low toxicity to avoid contamination of water bodies[78].

Forestry products may not be fully utilised because of poor access to markets and difficulties in maintaining a steady supply. Irregular harvests and markets controlled by factories and big traders, along with the resulting low prices, may make it more attractive for locals to engage in other activities like the extraction and sale of timber. Developing logistics, which may include digital sourcing applications, and supplier associations are important. For some materials, barriers include a lack of research to show how the by-products will function in a hot and humid climate.

Further, some challenges are related to farming systems. In India, for example, the overall rice value chain poses a few challenges to transition to a bioeconomy, partly because of the short period of time between the harvest of the monsoon and winter crops. Ploughing rice straw back into the land, as promoted under India's Happy Seeder programme, reinforces the idea of a bio-regenerative approach through which materials can help protect and enhance soil quality. Understanding intermediate technologies available for straw baling might also help enable change. Other barriers are common to larger environmental goals, including the lack of payment for ecosystem services and inaccessibility of affordable finance.

On the demand side, mechanisms to scale up activities, including tapping into regional markets and building partnerships with businesses that will buy the products, are helpful. The public sector can also provide active support to strengthen demand.

5.2 Building Blocks

Recognising that interventions to achieve a circular regenerative economy will require a systems approach, we have compiled the **interventions needed for systems change**, categorised under four main building blocks. Internalising the analysis of barriers and solutions, we further explored policies and fundamental elements needed for achieving the change, including partnerships and collaboration.

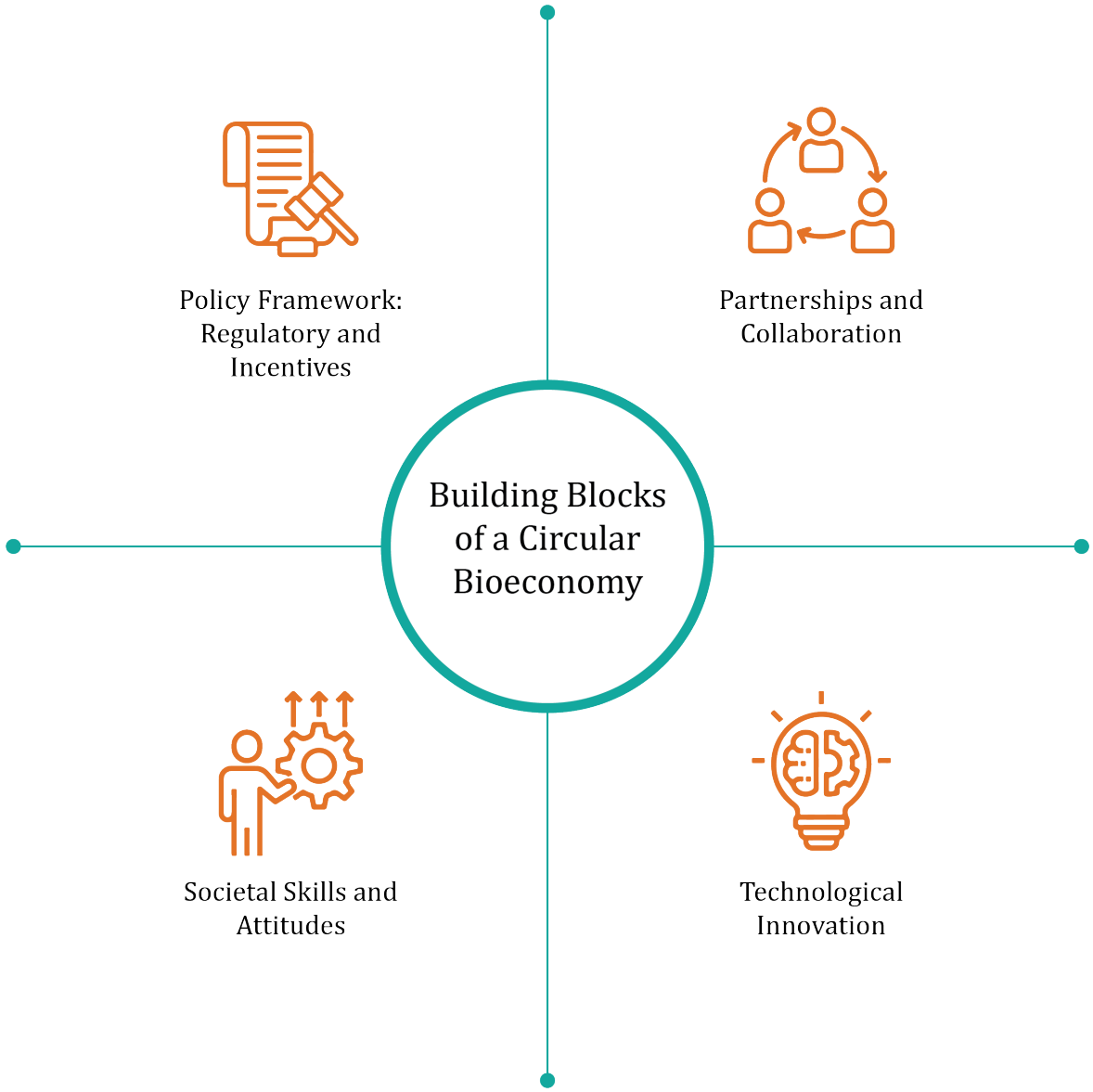


Figure 3: The building blocks of a circular bioeconomy

A. Policy Framework: Regulatory and Incentives

A well-developed policy framework should comprehensively assess the scope for a bioeconomy and use the set of levers that are at the government's disposal, such as material taxes, tariffs, extended producer responsibility schemes, carbon trading and other market mechanisms, eco-design standards, and labelling. These policies may need to be supplemented with innovation support and skill development. Additionally, international collaboration may be needed, especially on standards,

A.1. Country-wide strategy: This is a good starting point, and many countries have built such strategies or plans, as discussed in Section 3. Such strategies can help in the following ways:

A.1.1. Provide clarity on the vision and mission, including the constraints discussed above. Without clarity on constraints, there is a risk that an optimised approach ensuring the full use of materials and delivery to achieve the goals will not be achieved.

A.1.2. Prioritise sectors that can help channel research funds to areas of strength and enable aligned action by government, academia, and industry. In deciding which activities to prioritise, relevant considerations for countries include not only goals but also needs. An example includes prioritising initiatives or strategies to reduce stubble burning or safeguarding forests.

A.1.3. Minimise ambiguity by setting a clear pathway and targets that could help existing industries adjust and align.

A.1.4. Ensure a clear flow of knowledge and information, for example, in utilising indigenous knowledge that can help identify new products.

A.2. Address externalities: Carbon pricing to ensure that climate externalities are priced in is becoming part of the standard policy framework and carbon border tax adjustment mechanisms, which means that tariffs on carbon-intensive products are being introduced, as in the EU. Extended producer responsibility schemes could also be explored to address the environmental costs of the product.

A.2.1. Devise payment mechanisms for ecosystem services: Carbon credits and nature credits can provide an ongoing source of funding for some aspects of a circular regenerative bioeconomy. Farming subsidies can be redesigned to support circular regenerative bioeconomy approaches.

A.2.2. Review existing regulatory frameworks: Regulations designed to address hazards from waste and protect forests need to be reviewed to ensure alignment with the bioeconomy. For example, it may be necessary to allow harvesting of fruits and nuts from forests.

A.2.3. Establish eco-design standards and assurance: To give biomaterials the recognition and market acceptance needed for building consumer trust (business-to-business or business-to-consumer), government standards will need to be set and assurance schemes need to be implemented to certify products. Products that do not meet those standards could be barred from entering or being sold in the market, e.g. non-biodegradable plastics.

A.2.4. Focus on regional approaches: The right products and materials in a region should be brought into focus, creating local markets, because transport costs can be high[79]. Different areas may have very different potential: the Western Ghats or the Himalayas in India may benefit from a forestry product/agro-forestry focus, whereas urban metropolitan areas may benefit from a biotechnology/refinery-type expansion. As the scale is important for efficient production, regional collaboration on both supply chains and the demand side and markets is critical. Regional action can also support clusters of industries, as stated in Norway's bioeconomy strategy.

B. Partnerships and Collaborations

Considering the interdisciplinary nature of a bioeconomy and how it cuts across sectors and departments such as agriculture, forestry, industry, tourism, energy, and waste, a good starting point would be to create the right internal government structures and wider stakeholder groups.

B.1. Creation of government cross-departmental forums to ensure that policies are not hindering development and to channel collective efforts into priority areas[80]

B.2. Collaboration among academia, agricultural bodies, and industries to develop materials; for example, Germany's Bioeconomy R&D efforts and Bioinnovate Africa[81] in the Global South

B.3. Cross-boundary collaboration at a regional level, such as that in East Africa[82], to scale up markets and enhance symbiotic relationships and at an international level to develop a shared understanding of materials, e.g. bioplastics, and develop labels and standards including embodied carbon benchmarks for materials

B.4. Formation of business-led forums: This can ensure that businesses take the lead and influence policies needed to support change. The Circular BioEconomy Alliance[83] operates at a global scale and can be supplemented by national or regional groups. They can help aggregate demand for new products and materials and support improved logistics and supply chain efficiency.

B.5. Creation of forums or platforms for industries to connect with global funding agencies, including accessing funds like the Asia Climate-Smart Landscape Fund[84] and acquiring funds from multilateral development banks such as Asian Development Bank and World Bank

B.6. Creation of village-level cooperatives and other supply-focussed groups to help ensure a stable supply of inputs

C. Awareness Generation, Capacity Building, and Skill Development

Capacity building includes skill development and enables consumers to make choices through awareness and information.

The following specific actions are needed:

C.1. Skill development and capacity building to include entrepreneurial skills and increase knowledge-sharing of solutions, and embedding this knowledge in professional training and skills programmes

C.2. Recognition of indigenous knowledge[85], as established in the new Biodiversity Agreement (2022)[86], in identifying forestry products, making packaging products from grasses and palms, and utilising biomaterials in construction. However, as shown in the Indonesian example, traditional methods can be improved.

C.3. Conduct interdisciplinary courses and professional training exercises that bring biomimetics into the mainstream and devise strategies for its adoption

C. 4. Increase awareness of the benefits. It may be necessary to tackle a perception that newer technologies are best and to increase the recognition of the value of older materials[87].

D. Technological Innovation

Efforts to grow the bioeconomy in a circular regenerative manner are at an early stage. Most countries are still at the strategy/action plan stage with a focus on R&D. The challenges are already apparent. These include not only the constraints but also considerations of scale, cost, and sourcing, especially where production is dispersed across smallholdings. Research and academic institutions have a key role to play in expanding R&D in the field, taking part in and running knowledge exchange events, and participating in interdisciplinary research programmes such as the UK's National Interdisciplinary Circular Economy Programme88 and the UK Catapults Programme.

D.1. Academic and research solutions including the development of new products, materials, and processes from intermediate technology to complex chemistry research on new materials.
The following actions are important to support these solutions:

D.1.1. Public funding to support basic research, develop prototypes, and bring research closer to commercialisation

D.1.2. Publicly funded materials testing facilities, such as that in Germany, to support start-ups

D.1.3. Voluntary business initiatives to promote the bioeconomy such as the Circular Bioeconomy Alliance89

D.2. Finance in the form of incubator and accelerator funds to help develop prototypes, fund start-ups, and allow scaling up of businesses or initiatives

D.3. Building the evidence base regarding trade-offs and synergies to help industries identify actions with multiple benefits or those with minimal adverse impacts

BOX ITEM 2: Example of a business-led initiative: the Circular Bioeconomy Alliance

This was established in 2020 as a knowledge-support organisation facilitating learning and networking by connecting key players. It includes investors, companies, governmental and non-governmental organisations, and local communities, connecting them to advance the circular bioeconomy while also restoring biodiversity. It seeks to put nature at the centre of the economy, recognising the value of the bioeconomy.

Key projects:

a) a series of 'Living Labs' to test and trial solutions
b) cost–benefit analysis on a forest-based bioeconomy
c) a study of the potential for a forest-based bioeconomy in specific African countries
d) exploration of wildfire-resilient landscapes
e) participation in nature finance dialogues

It aims to create a consensus and support collective action, which has led to the generation of principles for regenerative landscapes and a 10-point action plan[90] for a circular bioeconomy of well-being.

6. A Bioeconomy Roadmap for the Global South

Considering the four building blocks of a circular bioeconomy, we propose the following roadmap for further discussion:

Figure 4: A roadmap to achieve a circular bioeconomy

This roadmap is explained in more detail below:

Step 1: Gather evidence

This involves collecting evidence in relation to the relevant aspects of the national and regional economy to ensure the establishment of a well-informed strategy/plan and policy framework:

- Develop a good understanding of the materials produced in the local economy, including what may be regarded as wastes or by-products
- Explore what they are used for and investigate whether there may be alternative high-value uses
- Understand the social context, considering the potential of increasing the incomes of individuals forced to adopt adverse environmental practices such as deforestation and stubble burning
- Explore how to tap into national and local strengths, such as indigenous knowledge and levels of biodiversity
- Identify pressing needs, such as addressing urban air pollution or maintaining micro-climates for rainfall purposes
- Consider rural–urban symbiotic opportunities, such as production of materials that could be used to replace current carbon-intensive building materials

Step 2: Strategise and prioritise

This stage is focussed on achieving a clarity of direction and an understanding of systems that may be needed to implement a circular economy.

- Develop clear priorities that consider the above findings, involving governmental and non-governmental stakeholders
- Establish cross-departmental structures to facilitate a co-ordinated approach
- Co-create a vision that provides clarity on the goal to obtain collective support
- Set targets and goals to measure progress over the short term and keep up momentum
- Build governance and stakeholder forums to enable the exchange of ideas and feedback on how actions are impacting on ground
- Develop knowledge-sharing systems that involve key players including industry and academia

Step 3: Act and embed

This stage involves taking forward a strategy or plan. It may, however, be helpful to establish some pilots while developing the strategy.

- Establish R&D programmes that bring industry, agriculture, and academic stakeholders together, enabling action-focussed research
- Bring LCA into this research to ensure that the policies and supporting activities are impactful in terms of carbon mitigation
- Introduce a robust policy framework that helps remove barriers to the circular economy and introduces incentives to support circularity, while ensuring that proper monitoring mechanisms are in place
- Introduce systems for leveraging carbon and nature offset resources, which appear to be of increasing importance
- Ensure grant finance and private incubator and accelerator finance and provide clarity through a green taxonomy on the circular bioeconomy to encourage investment by institutional and impact investors
- Introduce demand-side measures including public procurement and tax incentives

- Implement skill development measures
- Explore programmes to influence consumer behaviour, addressing unfounded perceptions such as those on product quality and a lack of awareness of the natural environment and carbon benefits of (sustainable, circular) bio-based products
- Conduct pilots to test concepts and build a business case for action
- Establish knowledge-sharing systems using private partners as necessary

'For Cocoa Landscape Investment Facility activities to be truly effective, it is vital to ensure a positive business case and positive impact that involves assessing the financial viability and potential economic benefits of the project. A demonstration project can effectively ensure the business case and positive impact of a reforestation or conservation project in various ways. Demonstrating successful outcomes and tangible environmental benefits in a controlled setting builds confidence among potential investors and stakeholders, encouraging further financial support for expansion.' (Partnerships for Forests, Lessons Learned from the Cocoa Landscape Investment Facility - Valorising Natural Capital, 2023)

Step 4: Monitor and review

After a few years (e.g. about 3–5 years), it is imperative to check the progress and review the measures in place, as follows:

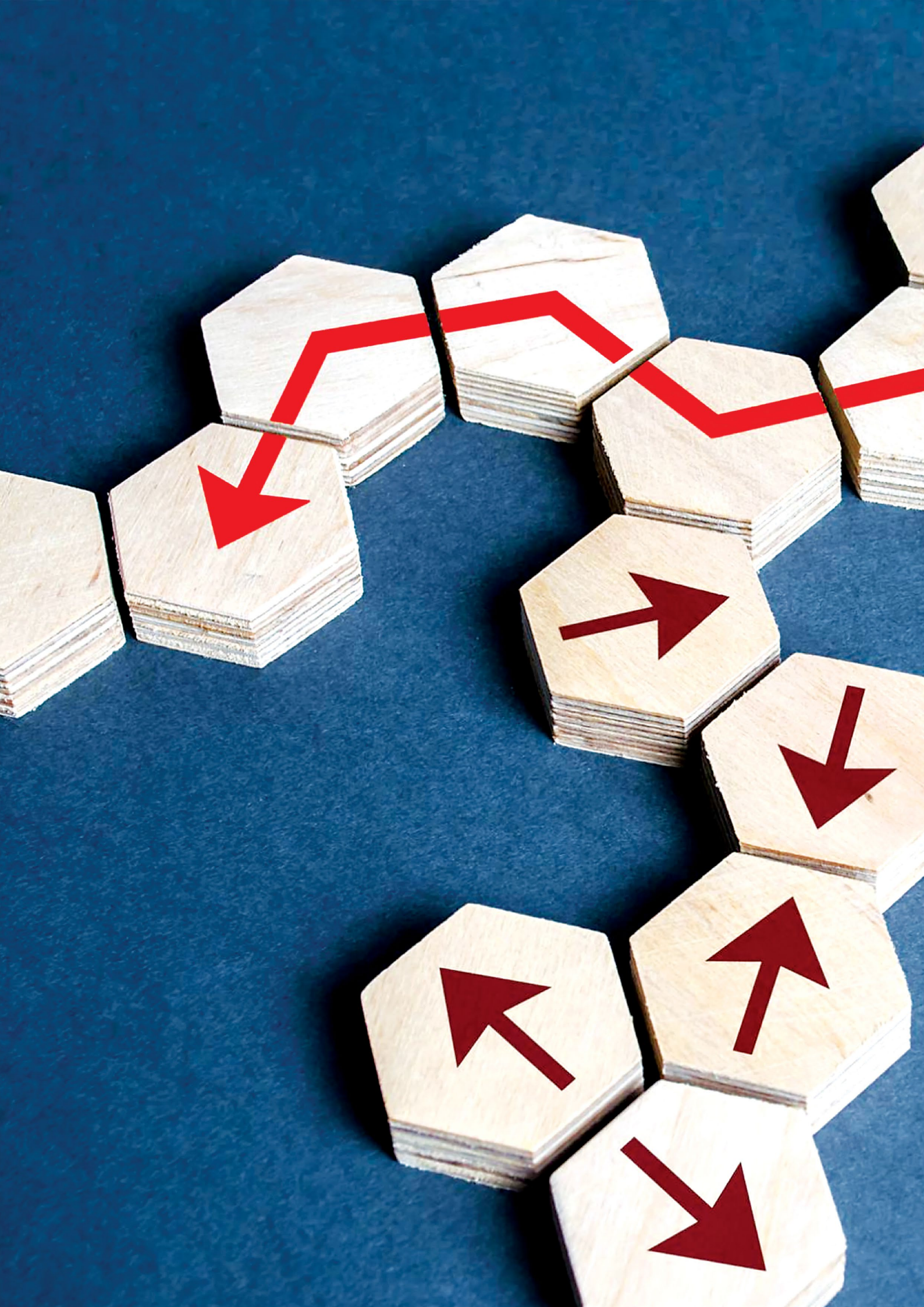
- the use of metrics to assess progress and share findings with stakeholders and
- the consideration of how to refine policies,
- how to ensure capital flows, and how well skills and influencing programmes worked.

In case of India, the bioeconomy market at present is estimated to be worth approximately USD 137 billion[91] and is expected to grow up to USD 300 billion by 2030[92]. Although there is no overarching strategy for a low-carbon, circular and regenerative bioeconomy, progress is being reported across the country, as multiple measures are underway by different government departments.

The Department of Biotechnology is exploring waste-to-energy technologies and biofuels. The focus is on biofuels and biotechnology including pharmaceuticals, with the industry size estimated to be about USD 137 billion in 2023[93].

- The Ministry of Agriculture and Farmers Welfare has developed an agro-forestry plan[94].
- The National Institution for Transforming India (NITI) Aayog has explored the potential to harness bamboo wealth.
- India has been instrumental in establishing the Global Biofuel Alliance, which is a multi-stakeholder alliance, bringing together governments, international organisations, and industries to increase the use of sustainable biofuels and contribute to the growth and development of the country.

Going forward, inter-departmental collaborations, various stakeholder forums, financing avenues for start-up projects, and a data repository of inputs and outputs could be actively explored to accomplish the target potential.



7. Conclusion

The multiple challenges faced by countries across the globe, especially the Global South, bring into sharp focus the need for a circular bioeconomy that is regenerative. Countries are facing climate change-related impacts including extreme heat, drought, and coastal flooding. Knock-on effects, such as high inflation, malnutrition, air and water pollution, and land degradation, can be witnessed globally. In parallel, the bulge in the working-age population in the Global South necessitates the creation of jobs to ensure adequate incomes. The growth of the Global South economies indicates that emissions are beginning to outweigh the current and even historic emissions of the Global North[95], highlighting the importance of low-carbon strategies.

Affordable solutions are needed to address the challenges, taking into account the high capital costs in the Global South[96]. Growing the bioeconomy, shifting away from dependence on fossil fuels and petrochemicals to bio-based materials and resources, offers a solution or part of the solution[97] owing to its multiple benefits. Valorising agro-waste and key primary materials from timber to hemp can facilitate carbon storage, along with reduction in air pollution due to burning of agro-waste and water pollution caused by bio-effluents, while also increasing local incomes.

'Beyond immediate gains in food security, income generation, and employment, the circular bioeconomy emerges as a guardian of wider economic opportunities and social well-being. It endeavours to safeguard natural assets, from soils to water and air quality, fostering resilience against environmental challenges.' (Shalini Goyal Bhalla, International Council for Circular Economy).

However, there are trade-offs and risks. Expanding the bioeconomy may increase the pressure on land, increase carbon emissions, reduce biodiversity, and lead to groundwater depletion. For these reasons, the growth of the bioeconomy needs to be predicated on transitioning to a low-carbon, low-impact economy, i.e. a circular regenerative bioeconomy, wherein materials are used efficiently and bio-materials are cycled back onto the land to improve soil.

The examples described in the previous sections highlight that there is considerable potential to grow the bioeconomy in a circular regenerative way. Applying the ETC hierarchy[98] as well as the 'waste hierarchy', based on reducing lifecycle impacts, is a helpful rule of thumb. This means prioritising product longevity through repairing, upcycling, recycling, and ensuring that processes do not contaminate other material stocks like biowastes.

The areas with potential for win–win solutions taking into account the context explained in Section 2 are as follows:

1. Valorise the use of agro-wastes/by-products like rice straw and rice husk: It is possible to make the required construction materials with good thermal properties, reduce air pollution, and increase carbon storage.
2. Make full use of the multiple outputs from 'super plants' like hemp and bamboo: It is possible to reduce pressure on the land, reduce emissions from making products like concrete, and obtain items of medicinal value.

3. Bring forestry products like fruit, nuts, and timber to market: Timber usage increases carbon storage, and the use of these other products also increases the incomes of local people and reduces the pressure to deforest land.
4. Expand aquaculture: This offers opportunities to make use of wastes/by-products, such as fish leather and prawn shells, while supporting the regeneration of ecosystems such as coral reefs and seagrasses, which have multiple benefits.
5. Establish biorefineries to make chemicals, enzymes, and polymers: To make these processes circular and sustainable, measures to avoid contamination and the use at end of life should be considered. These processes can involve utilising wastes, such as agri-food industry wastes.
6. Grow high-protein food crops: This can include developing mycoproteins and various other foods, which require little land and other resources to grow.
7. Make fertilisers and feed from food waste and sewage sludge: Processes such as anaerobic digestion can generate biogas, while also recycling water and producing fertilisers. Treatment using BSF can also be used to rapidly convert waste into high-protein animal feed and fertilisers99. Bio-fertilisers can also be produced using agro-wastes as a carrier.
8. Generate sustainable biofuels from secondary materials like food waste and agro-wastes: The circular bioeconomy model would prioritise the use of secondary materials as well as materials at their highest value before transitioning to waste-to-energy[100].

In other words, several activities have a high win–win potential, but the adopted strategies and specifics will vary from country to country and even within the countries. For policymakers to support these initiatives in a meaningful way, a systematic process to prepare a comprehensive roadmap could help. The hallmarks of an effective roadmap are as follows:

a) Research-based: robust evidence to ensure investment in the right set of activities to
   - understand local needs and pressures
   - gather and publish data on the bioeconomy inputs that are available
   - reflect on strengths of communities and industries
   - LCA of carbon and nature impacts
b) Collaborative and partnership-driven:
   - across sectors including agriculture, industry, and finance
   - Regional and local collaboration
   - Industry–academia partnerships
c) Measuring climate, landscape, and economic resilience benefits plus climate impacts: seek to optimise and enhance
d) Comprehensive approach involving an exploration of
   - the breadth of opportunities and
   - various aspects of the bioeconomy for different regions

In the Global South, this means mobilising research, capital, and human resources into relevant materials, products, and processes, considering greater rural populations and high levels of species diversity in tropical areas and towards ensuring that the system is circular and sustainable. Without doing the latter, this shift may be self-defeating, considering the trade-offs involved. Looking at the level of research in the EU, for example (Horizon 2020), the challenge is how to develop the knowledge and know-how across this wide range of activity but with scarce capital.

Close collaboration among industry, academia, and research institutes is vital for pooling scarce R&D funding and utilising indigenous knowledge. Solutions are technological, legal, and organisational, requiring an interdisciplinary approach. Embedding this strategy into a broader net-zero plan is critical and requires measuring the impacts using life-cycle approaches.

This is the right time to accelerate action for achieving a circular and cost-effective bioeconomy that not only helps in decarbonising economies but also contributes towards higher per capita incomes and economic growth.

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