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Bioeconomy – science and technology policy for agricultural development and food security

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Abstract

This paper reviews the fast move by many countries into bioeconomy strategies and related R&D investments and public science policy. It assesses the driving forces of these developments and the implications for international agricultural change and food security. The future of humankind will much depend on a secure and safe availability of food, energy, water, and industrial raw material, and these should be more and more based on renewable resources. This puts the bioeconomy - the emerging cross-cutting economic sector that produces, transforms, and uses bio-based materials and products – at the center of sustainable economic strategies. In a bioeconomy new competitions for biomass are generated, and complementarities are evolving too. The former may adversely impact food security, while the latter may enhance economic efficiency and environmental sustainability. The paper takes a holistic view to identify the synergies between technologies, creation of new links in and between value chains (e.g. production of bio-chemicals alongside production of biofuels, use for waste products of other biobased products in chemical and building material industries). Bioeconomy means 'biologisation' of the economy as an economy-wide and industrial strategy. The paper concludes that the risks of the bioeconomy for food security should be addressed by increased S&T investment, including for biotechnologies, and development of markets in which emerging economies can join.

Note: illustrations are in an accompanying power point presentation and will be integrated later

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The emerging bioeconomy

In the past five years numerous countries – mostly high income countries and some emerging economies - have designed and adopted bioeconomy strategies and included them prominently into their science policy agendas (Table 1). Some developing countries have taken note of this trend and are also considering bioeconomy strategies. What are the drivers of this new strategic trend? And what are opportunities and risks for development and food and nutrition security? The answers to these questions in brief are:

- The bioeconomy is driven by changed factor price structures and related price expectations, technological opportunities, and changed preferences.
- Opportunities within the bioeconomy relate to income and job opportunities and investment incentives for agriculture worldwide on the one hand, while risks relate to accelerated scarcity of biomass as biomass-based products may compete with food availability and adversely impact on the poor, unless new technologies are over-compensating the potential scarcities, or social protection measures are expanded.

These issues shall be elaborated in this paper, and in particular a science policy shall be considered that enhances the opportunities and prevents the risks of the bioeconomy for the poor.

Table 1: Bioeconomy Age: new science and policy initiatives 2009-13

Australia	Bioenergy – Strategic Plan 2012–2015
Brasil	Biotechnology Development Policy (2007)
Danmark	Agreement on Green Growth (2009)
Germany	Nationale Forschungsstrategie BioÖkonomie 2030 (2010)
EU-Commission	A Bioeconomy for Europe (2012)
Finnland	National Resource Strategy and Sust. Bio-Economy (2011)
Ireland	Delivering our Green Potential (2012)
Canada	Biorefining Conversions Network (2009)
Malaysia	Bioeconomy Initiative and National Biomass Strategy (2011)
Netherlands	Biobased Economy 2010–2015
Russia	Bioindustry and Bioresources – BioTech 2030 (2012)
Sweden	Research and Innovation Strategy for Bio-based Econ. (2011)
UK	UK Bioenergy Strategy (2011)
USA	National Bioeconomy Blueprint (2012)

Definitions of "bioeconomy"

The term bioeconomy was probably first defined by Juan Enriquez-Cabot and Rodrigo Martinez in 1997 (Enriquez 1998). [2] The concept had its breakthrough during a broad EU consultation held in 2005: Experts from academia and industry were invited to contribute to a paper which outlines the perspectives of a bioeconomy within the next 20 years. The resulting so-called 'Cologne Paper' was published on 30 May 2007 in Cologne at the conference 'En Route to the Knowledge-Based Bio-Economy' hosted by the German Presidency of the Council of the European Union.[3]

Being a new concept, it should not be surprising that no generally accepted definition of "bioeconomy" emerged right away. The Bioeconomy Council of the German Government adopted a rather broad definition, stating "Bioeconomy is the knowledge-based production and use of biological resources to provide products, processes and services in all economic sectors within the frame of a sustainable economic system." (Bioeconomy Council 2013). This definition of bioeconomy does not refer exclusively to biological resources acting as substitutes for other resources, but entails new products and processes as well. The European Commission (2012) defined it as, 'The bioeconomy encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products[4] and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries. Its sectors have a strong innovation potential due to their use of a wide range of sciences (life sciences, agronomy, ecology, food science and social sciences), enabling and industrial technologies (biotechnology, nanotechnology, information and communication technologies (ICT), and engineering), and local and tacit knowledge.' This definition allows for an ecosystem-driven green economic and industrial vision of bioeconomy, i.e. in which fossil fuels are replaced by bio-based substitutes, not only for energy, but also for material, clothing, plastic, and chemical applications and non-market services. The transition towards a bioeconomy in this perspective entails transition towards a sustainable use of waste and by-products, contributing to new opportunities of the concerned sectors, reducing the potential harm to the environment and taking into account the value of non-market services (Smeets et.al. 2013).

Bioeconomy is on the one hand very ancient and traditional (bread baking, beer brewing, food conservation, char coal production), and on the other hand new and innovative (novel biomaterials, biopharmaceuticals, biological food, feed and cosmetic ingredients). Bioeconomy comprises the above mentioned classical sectors as well as industrial biotechnology. It is merely a large cluster of activities in any economy, actually the largest even in some industrial economies in terms of share in GDP and employment. New technology intervenes in bioeconomy advancements in all of the above sectors. The largest element of the bio-economy, in terms of total output, employment etc, is typically agricultural and food production and processing. Bioeconomy based on new biology cuts across sectors and can be compared with ICT's penetration of the whole economy. While

[2] New Perspectives on the Knowledge-Based Bio-Economy, Conference Report, European Commission, Brussels 2005

[3] It presents the findings of six workshops which were held between January and March 2007. The participants discussed the following aspects: 1. Framework 2. Food 3. Biomaterials and Bioprocesses 4. Bioenergy , 5. Biomedicine and 6. New Concepts and Emerging Technologies

[4] Bio-based products are products that are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilised.

bioeconomy draws on traditional biomass as a basic resource, biomass generation and refinement for instance in industrial biotechnology is a critical part of bioeconomy, too. It is therefore not just a new mega value chain drawing on biomass.

Theory of bioeconomy and conceptual issues

The theoretical underpinnings of bioeconomy can be explored through a lens of economics of induced innovation (Hayami and Ruttan 1970) where innovation results from factor scarcities and related (expected) price changes (i.e. prices of land, water, CO2, energy). A normative approach would derive needed bioeconomy policy actions and investments from unsustainable resource use conditions, and identify cost minimal solutions incl. related opportunities of technical change. Taking a political economy perspective as theoretical base would pinpoint demand for and supply of bioeconomy in political markets, incl. rent seeking. A conceptual framework would be helpful, that could guide toward economic analysis of bioeconomy impacts assessment; separately it would also be useful to gain insights in actors' behavior and political realities of allocation of innovation funding.

Four analytical approaches may be promising:

First, an **economy-wide approach:** Bioeconomy is not well captured simply as a sector of the economy. It rather penetrates a host of sectors, especially agriculture, forestry, foods, energy, chemical industries, pharmaceuticals, textiles, etc. While economic theory of bioeconomy can draw on economy wide modeling concepts, its characteristic of cutting across sectors, however, poses practical and conceptual problems. There are difficulties to analyze the bioeconomy in established sector-disaggregated CGE models, and related attempts so far were of limited use (ISI 2007). Reasons are lack of data on the many newly created subsectors changed by bioeconomy, depicting process innovations and recycling efficiencies, and technical change in production functions, and new intermediary and end products. Still, it would be useful to embed bioeconomy in new economy-wide models after making an effort to tackle the data and conceptual complexities.

Second, via **tracking returns to investment in bioeconomy science and technology**, it would be productive to assess impacts on growth and distributional effects for sets of innovation examples of bioeconomy. This can for instance follow **partial equilibrium studies** or traditional rate of return studies, enriched by careful inclusion of environmental externalities.

Third, starting from **firms as strategic agents** is a useful unit of bioeconomy analysis. The implications for market performance are outcomes of critical interest. Yet that would require highly disaggregating supply and demand, and unless production processes are captured explicitly, a key aspect of efficiency gains would be neglected. Promising in that respect - also in view of considerable involvement of government initiatives and new inter-linkages among industries in competitive structures - may be a combination of partial equilibrium studies with **industrial organization (IO)** approaches, to guide business strategy and public policy (Schmalensee 1989). The traditional Structure-Conduct-Performance paradigm of IO (Joe Bain 1959) can be point of departure, where performance refers to the economic outcomes that result from the market structure and the firms' conduct. Joint innovation efforts across firms in the pulp and paper industry seem to be a case in point (The Economist, Dec. 1, 2013). To be relevant, the traditional concept would, however, need adaptation regarding market boundaries, the basic assumptions that structure (concentration) is exogenous, and consideration of many differences between industries. To actually evaluate bioeconomic change for an industry's performance the usual criteria apply, i.e. allocation efficiency, production efficiency, equity, and technological advancement.

Fourth, a **system analysis approach** could be helpful, in which drivers of the bioeconomy would be related to change in systems components, and impacts on growth, distribution and ecology be derived in the context of policy interventions, incl. investments. Competition among goals and complementarities of instruments should be explicitly modeled, and futures scenarios could be developed. Such an approach would best include lifecycle analyses of inputs and outputs. However, the usual limitations of systems modeling apply, for instance, selective capture of causal relations, difficulties of systems boundary definition, and dynamics of technological change. Still, a systems approach to bioeconomy assessment may be appropriate compared to a more rigorous framework, such as the first option mentioned above, which constrains the desired flexibility and inter-sectoral linkages.

Combining all of the four approaches mentioned above with **innovation-storylines** may provide insights into the opportunities of the bioeconomy and highlight externalities (resource use, food security). In order to build the needed data base for a flexible analytical approach, the EU is currently establishing a "bioeconomy observatory" with information on bioeconomy's sector components, technology innovations, research, and industry and processing elements (European Commission. 2012).

Strategic relevance of bioeconomy

Bioeconomy means making virtue out of necessity, i.e. use more of what can sustainably grow on soils, with seed, sun and water, or in ponds and inputs and use those a lot more efficiently and more innovatively, and it entails producing bio-based materials even independent of soils. Bioeconomy understood as 'biologisation' of the economy is a societal and economic strategy involving producers and consumers. It addresses both the efficient use of biological routes in the production of materials in substitute for chemical reactions and the use of biological raw material instead of fossil carbon sources for industrial processes. It addresses concerns about the exploitative use of biological and other natural resources, especially water and soils.

Competitiveness in such a system will increasingly depend on innovations around bio-based products and processing technologies. They will be in demand worldwide if they are competitive in the market, and also perceived as better than non-bio-based products by consumers. This puts the bioeconomy at the center of a new industrial strategy. While offering prospects of economic growth, the development of the bio-economy is expected to play an increasing role in addressing some of the big challenges faced by society:

- Growing population and higher living standards, leading to increased demand for food, animal feed, fibre for clothing, material for housing, water, energy, health services, etc.
- Declining resources - e.g. degraded ecosystems and loss of ecosystem services, including land degradation and unsustainable ocean fisheries, declining biodiversity – due to unsustainable management practices, and the effects of climate change on resources,
- Adapting to limitation in fossil resources by providing a meaningful substitution of the consumption of such finite resources by the use of bio-based renewable resources;

- The needs to move from production systems that entail waste that may be recycled, toward prevention of waste in the first place, i.e. a zero waste strategy where “waste” is designed to act as bio-resource for further biological processes in cascading relations.

A caveat, however, is, what are the consequences for the poor and their food security? Could an ill-designed strategic drive toward bioeconomy - as a strategy by the rich for the rich - accelerate scarcity of food?

Drivers of bioeconomy

Historically biomass was the main primary energy source. Also, for instance in Ethiopia today, biomass is still by far the dominant energy source, providing about 90 per cent of primary energy. Here the challenge is to make better use of biomass with new technologies, that is to say, a leapfrogging into a knowledge-based bioeconomy could be explored. The use of fossil fuels was fundamental to economic growth and development since the industrial revolution. The fast growth in world biofuel production in recent years was initially driven by price expectations of fossil fuels and expectations of (low) raw material prices. Policy in support of and subsidies for this particular line of bioenergy production has so far not dealt with its negative side effects for food security and landuse. Ill designed biofuels policies teach that sound policy impact analyses need to precede hasty bioeconomy actions.

The fundamental drivers of bioeconomy are (expected) resource scarcity, new technology opportunities, and changed preferences, the latter especially in rich countries.

The amount of land and water that is presently used for agricultural purposes cannot be substantially increased, as either cultivation makes no economic sense due to low potential yields, or expansion would negatively impact the environment and climate. The preferred way of increasing productivity is, therefore, to intensify farming sustainably on the land that is already used for agriculture where in many cases water is the restricting parameter.

The competitiveness of the bioeconomy in general and its various lines of production are determined by the expectations regarding long term prices. Food and other biomass related prices have been increasing to higher levels over the past six years. Yet, prices do not need to be taken as given. In the long run it mainly depends on the investments in innovation, not just on short term supply and demand, how prices may evolve. R&D will be very important in helping reduce future shortages of biomass, and will thereby influence price developments. Tapping the potentials of bioeconomy further depends on infrastructure and trade. Much of the biomass production potentials in the developing countries are in remote areas, where access to markets is impaired by limited infrastructure. The new price incentives for biomass production and utilization do not reach out there and that limits efficiency in the global bioeconomy. Processing facilities (incl. bio-refineries) may be best located close to biomass production bases.

It is one of the main tasks of a sustainable bioeconomy to create the conditions in which the global provision of foodstuffs can be guaranteed. This includes further advances in crop varieties by breeding techniques as well as measures and technologies to reduce the considerable loss of produce from harvest to market observed today. Social and socio-economic behavior must also be taken into consideration here, to restrict excess consumption of biomass. But the bioeconomy will not deliver its potential benefits quickly. It will probably move as slowly as agricultural research did in the past. Varietal crop innovations take typically a decade in plant breeding and the various bioeconomy innovations will hardly be faster.

The change in preferences for bio-based products is wide-spread in global middle classes, not just in rich countries. It probably relates to risk considerations and lifestyle perspectives. The externalities of these preferences for the poor and food security are so far not much studied. In case of bioeconomy externalities they may be going significantly beyond the classical externalities of preferences, such as excessive animal product consumption and adverse attitudes of genetically modified crops in rich countries, the latter in Europe in particular. Change in preferences tends to lead to more demand for bioeconomy products, but there are externalities. Hence the magnitude of preferences' impact on the advent of bioeconomy is difficult to predict.

Bioeconomy innovations and food security

Bioeconomy changes the world food equation on both the supply and demand side, and thereby may impact on food security. Food and nutrition security depends upon the availability of food (through production and trade), access to food due to purchasing power, and the utilization of that food by people's nutrition. Stability of the food system, especially of production and related markets, cuts across these three pillars of food and nutrition security. These concepts, however, need to be viewed in a dynamic context, where food and nutrition insecurity undermines the resilience of poor people and low-income countries and thus can erode both societal cohesion and the natural resource base of countries. The potential tradeoff between bioeconomy-based sustainable economic growth and food security could raise ethical issues, if a tradeoff between the two should occur (see Pinstrup-Andersen 2007 on such ethical issues).

Governments play important roles in shaping markets and the food systems (Pinstrup-Andersen 2011). Strategies for food and nutrition security need to take note of the fundamental changes that re-position food and nutrition in the context of the global and national bioeconomy. To the extent food security partly depends on the availability of food, which is part of biomass production and affected by new competitive uses of biomass for energy and industrial raw materials, new challenges will require a systemic approach identifying:

- the consequences of substituting the consumption of finite resources by using biomass and other renewable resources; and
- production systems that rely more on recycling, on more efficient use of limited resources and on an increased deployment of renewable resources.

The pros and cons of bioeconomy for food security need to be identified from at least two angles, first, competition in joint markets and related price formation, and secondly, synergies resulting from technology serving income generation among the poor due to bioeconomy and related food security effects.

Other fundamental forces around bioeconomy relate to consumption, to climate change, and to land. World food consumption trends entail more products that are rather biomass intensive, i.e. animal products. A comprehensive integration of animal production into efficient value chains is an essential part of the bioeconomy. Climate change provides powerful incentives for investment in the bioeconomy in three ways: first, there is the need to establish a different energy base, including biomass; second, there exists the threat of declining crop productivity and production risks; and third, the emerging GHG mitigation markets are increasing the incentives for biomass stocks (rather than food production) for sequestration and re-carbonizing the biosphere (Wheeler, von Braun 2013). The biofuels – food security linkages do not just work via raw material markets, but also via land (and water) markets: rapid expansion of investment in land acquisition to grow biofuels reflects the strong demand for biomass that has become an international issue. The often unregulated land markets in which power rather than efficiency rules, the investment ventures need more policy attention to protect rights of poor land users, especially small farmers and pastoralists.

Food security linkages with the bioeconomy need to consider that the **new value chain system** of bioeconomy is much more a system than a chain; actually, it is a set of interlinked chains, i.e. a "value web". For the bioeconomy to get into harmony with food security requires increased efficiency in this whole value web. Linkages to food security relate to how some of the key bioeconomy domains are actually evolving, both in terms of market development and in terms of technological progress. Here are some examples:

- Biofuels: sugar- and corn-based ethanol will not be sufficient to achieve energy/climate goals; dedicated ligno-cellulosic crops to be converted into ethanol, or others, with higher energy input/output ratio, are hoped for, but emerge slowly at best. Plant breeding in this context is crucial in terms of lignin content and composition (amount of lignin present in cell walls) and conversion technology with chemical innovations, such as catalytic conversion.
- Among fibers, cotton is most common, but there is now a need to spread the value chains covering fibers from flax and hemp. These fibers are also a means to decrease water and fertilizer use (compared to cotton). Breeding targets should aim to improve fiber quality by optimizing cell wall properties in relation to specific applications of fiber uses. Bio-based innovations in fibers include artificial spider fibers, already emerging with interesting properties for industrial uses.
- Oil crops: plant breeding to enhance use of vegetable oils in industrial applications, by introducing different fatty acid profiles in plants, in order to simplify the refining or chemical modification of the oil, or by developing plants with new specialty fatty acids, not normally present in food oil crops. Modern biotechnology is increasingly employed to achieve targets, such as reduced costs through higher seed yield, improved disease resistance and use of by-products.
- Challenges to be met in the bio-refinery sectors, i.e. the processes of transforming biomass into a wide range of value-added products (chemicals, materials, food and feed) or energy (biofuels, heat or power), which has been much less studied so far than the sector of primary biomass production, will include recycling too. For instance, recycling from microbial fermentation.
- Industrial biotechnology is on a fast expansion track, for instance with big investment in succinic acid plants currently pursued by many large chemical companies. This has the potential for establishing a changed resource base in chemical industries, without putting much pressure on scarce biomass.
- Bioeconomy does not only comprise of raw material substitution and upstream commodity processing, but very much entails new lines of end products at consumer level. These

include new bio-plastics, bio-materials for the car industry and for building construction, cosmetics products, bio-based synthetic meat, health products (e.g. biological anti-caries components in tooth paste), etc.

In sum, the emerging bioeconomy is changing the competition for food, land and water. Food security-proof bioeconomy systems require new biomass types, and cascading re-use systems, as well as end-product innovations, even unrelated to biomass. The emerging market for biomass and its agricultural underpinnings need sound institutional arrangements and codes of conduct beyond voluntary guidelines. The governance of the food system needs to pay renewed attention to property rights, especially land, including communal lands.

Science policy for reconciling food security and bioeconomy

The linkages between science, technology, innovation, and food security are strong and positive (Conway and Waage 2010; Pinstrup-Andersen 2007) but the details of impacts in a bioeconomy context are less clear. Bioeconomy is re-defining the demand for science related to agriculture and food. Essentially it calls for overcoming commodity focused research moving toward systems innovations, i.e. systems, in which value chains interact in value webs. This challenges sectoral analyses, as well as tool boxes in agricultural economics. Science policy is understood here as the design of science landscapes, institutional arrangements for science funding, implementation, and partnerships, and the setting of goals and allocation of resources to science priorities. A traditional concept of agricultural research – while of course still important - with a focus on crops and animal production, emphasizing closing of “yield gaps” is, however, not sufficient in a bioeconomy age. In view of major constraints faced by low income and emerging economies in the cluster of health, nutrition, human capital, food and agriculture, and natural resources management, the related sciences need particular attention. The context of this cluster is changing with the emerging bioeconomy, demanding a much stronger emphasis on basic science linked to applications.

Bioeconomy draws heavily on basic scientific research which is lacking in developing countries. Current science funding is extremely limited in many low income and emerging economies, and science policy strategies are often not well informed by evidence. To take advantage of opportunities, emerging economies need to invest in building their analytical strength to prioritize science and technology investments. Low income and emerging economies need to have access to basic science — which, being largely non-tradable, is hard to buy from abroad – and connect to international science and knowledge-sharing systems. Science support needs to become a much stronger component in development aid policies and rich countries need to open up access to their basic science capacities by emerging economies to facilitate domestic bioeconomy innovation.

Economic growth models which considered the importance of ideas and knowledge as engines for growth originate in the early 1990s (for instance Romer 1990; Grossman and Helpman 1994; Jones and Romer 2010). One of the message of these models is that ideas, which are typically non-rival goods (i.e. they can be shared and used by several actors simultaneously without exhausting them), are increasing as development and growth progress. Network externalities in science systems may further accelerate their impacts on development. Cluster theory (Porter 1990, 1998) argues for geographic proximity and agglomeration as being conducive for productivity, and this also can be relevant for the design of science landscapes. These models are important to consider when bioeconomy science policy priorities are set. Science policy in emerging economies may need to identify specific areas of focus for making most effective contributions to development (Ruttan 1997), but doing so without becoming overly specialized in applied research that lacks the links to the broad benefits of basic science is a challenge.

As the opportunities of bioeconomy depend upon complex science, the gap between the rich and the poor world may increase, unless improved science policy cooperation comes about. Policy needs the input from science, an input which can only take place if science is targeted at the right needs and communicated efficiently (Alberts 2010). A number of low income countries have designed suitable science policies, but failed to implement these policies for economic development. The main reason is that these policies are not well integrated into the national development plans and budgets to facilitate and ensure appropriate levels of funding for implementation. Often, the resource constraints are too severe in two dimensions, finance and human resources coming out of higher education, i.e. science spending per capita in rich countries is about 100 times what is often found in low income countries, and in addition, science capacities must draw on higher education systems (i.e. the formation of human capital), and consider the interconnectedness of innovations (Alberts 2010).

What is needed is a holistic view to identify the synergies between different technologies, creation of new links in and between different value chains (e.g. production of bio-chemicals alongside production of biofuels, use for waste products of other bio-based products). It also comprises public goods related ecosystem services that are not priced in the market and thus require regulation and protection, e.g. biodiversity, water sheds, long term soil fertility, and the GHG neutrality of production, etc.

The search for efficiency in bioeconomy that would not be in competition with, but enhances food security relates to

- the development of new types of biomass based production and new production techniques, and the creation and exploitation of synergies, for instance in fermentative production systems or bio-refineries, as well as in

- raising the resource efficiency of the newly interrelated value chains: from the production of biomass in agriculture and forestry at locations not suitable for food and feeds, to the use of "waste", to the efficiency of end products in the food sector, the energy sector, and areas of industry such as the chemical, textile, paper or pharmaceutical sectors,

- new opportunities in the bio-chemical processes that can grow from the new science of fundamental processes within plants, and microorganisms. Industrial biotechnology is a key element, i.e. developing and using enzymes and whole cells for bio-transformations and production processes, and is about to change the resource base of bio-chemical industries.

Reconciliation of food security goals and bioeconomy is thus a matter of technological and institutional innovations. Systematic research into the bio-economy is still in its infancy and should be pursued to explore its perspectives. Implementation of measures will necessitate the active participation of all stakeholders in innovation:

- Consumers as end users, because without their demand for bio-based products opportunities remain theoretical,
- Industry and enterprises will have to ensure that production and processing of materials is done using best technologies and management practices,
- Regulatory and innovation hurdles will need to be reduced and removed to allow novel products reach the market in the first place,
- Governments will need to focus on wider sustainability issues, such as managing demand, and competition between various end-uses and incentives.

Concluding remarks

Bioeconomy must ultimately be understood in a context of larger changes of societal, technological, and economic transformations toward "green growth" strategies. While many seem to understand the essence of such transformational strategies as mainly technological (new science) and behavioral (adjusted consumption), the central issue may very well be institutional, providing the frameworks and long run incentives for industry and consumers, both at national and international levels. Sharing the public goods-related new knowledge about what works in bioeconomy with developing countries would be a highly desirable global collective action. Food security, reliable availability of energy, and industrial raw materials should be based more on renewable resources. Science, open rule-based trade, and sound public policy are needed for this. This puts the bio-economy at the center of sustainable economic development. It is an opportunity and challenge for the next generations of scientists, inventors, small and large business, incl. farmers, and environmental social entrepreneurs.

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