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Bio-based resources, bioprocesses and bioproducts in value creation architectures for bioeconomy markets and beyond – What really matters

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ABSTRACT

Value is created by anthropogenic and natural bioprocesses in numerous ways. A common feature of optimized bioprocesses is the efficient utilization of resources, robust flow of products and reliable removal of byproducts or waste causing damages. Resource efficiency is related to molecular and engineering aspects at different scales of space and time. In a biological context, the micro-perspective is key for the creation and preservation of value by adequate functioning of bioprocesses, which is not only relevant for viable production but also for vital functions in human health. Restoring after loss of function, caused for example by inherited or acquired diseases, is therefore of key importance in avoiding the loss of value. Even more challenging are symbiotic biological consortia and ecosystems. In an economic context, the micro-perspective is the prerequisite for the success of any undertaking, from small businesses financed by microcredits to large multinational corporations owned by shareholders.

Introduction

Desirable growth directions in a limited space and time require increased attention in the 21st century in view of a sustainable management of resources and waste, with its non-negligible impact on a growing world population, health, safety and environment ((Costanza et al., 1997); (Rockström et al., 2009)). Looking at the planet earth from a geological time scale, the growing influence of humans on the environment and resource exploitation has long been known. The changing interactions of humans over the past centuries with their environment and the planetary system earth have led to the suggestion by Paul Crutzen of the new geological epoch of the Anthropocene (Crutzen, 2002;(Crutzen and Stoermer, 2000)(Steffen et al., 2007)). The scaling of the historic perspective on the Anthropocene Epoch (Christian, 2019) in space and time provides an inspiring approach for not only looking back in time in the Big History of David Christian (Christian, 2011), but also to view the numerous challenges of the present and the future in a commonly understandable and inclusive narrative.

The impacts of urbanization, anthropogenic sources, transport and transformations on ecosystems and geochemical processes are highly important for managing not only the world's freshwater systems (Kaushal et al., 2020), but also all the other systems which are relevant for the maintenance of life and the biosphere. Connecting the very large scale with the very small scale is the matter which makes up everything and which requires precise decriptions of the elements it is composed of and in which forms these elements are present. Among the most significant scientific achievements have been the discovery, creation of a universal language and increased understanding of the elements making up matter on our planet and in the universe. The 150-year anniversary of the arrangement of elements in the periodic system by Dmitri Mendeleev has been celebrated two years ago (Sekeris et al., 2019). Although essential elements for life are abundant on our planet and are part of a universe of compounds and materials, the growth of global, regional, national and local economies depends also on less abundant and rare elements. The accumulation and distribution of waste, for example from raw material preparation to final product manufacturing, after-use product disposal, or normal use of the product, creates negative health and safety effects on humans and the environment. Therefore, increasing the overall resource efficiency and the recycling of elements from waste towards suitable and reusable raw materials, from carbon dioxide and rare metals to phosphorus and nitrogen, key elements for life, become a strategic necessity. The biogeochemical flows of phosphorus and nitrogen are beyond the zone of uncertainty in the high-risk category of planetary boundaries, which includes other global key cate-

Abbreviations: GDP, Gross Domestic Product; BNB, Bonheur National Brut; PNB, Produit National Brut; PDB, Protein Data Bank; STRENDA, Standards for Reporting Enzymology Data; M-CSA, Mechanism and Catalytic Site Atlas; KBBE, Knowledge-Based Bio-Economy; BMBF, Bundesministerium für Bildung und Forschung (D); BMEL, Bundesministeriums für Ernährung und Landwirtschaft (D).

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gories like the change of climate and biodiversity loss in the integrity of the biosphere (Steffen et al., 2015). While identification of planetary boundaries is extremely important in creating awareness and a sense of urgency at the global level, the complexity and scale of the boundaries at the planetary scale make it also necessary to scale down this approach to smaller dimensions to simplify the setting of clear, measurable and actionable goals. The European Union and several countries, including Finland, Germany, The Netherlands, Sweden and New Zealand, have used this system framework approach and translated the planetary boundaries to national boundaries (Andersen et al., 2020).

From the art of managing a household to the complex and globally interconnected agricultural and industrial organizations of today (Tirole, 1988), the availability and management of the required raw materials, knowledge and experience, human and financial resources are fundamental for providing the goods needed by a growing household, organization or global human population. Planning and decision-making by private and public economic actors (Tirole, 2017) in today's market economy is however constrained by limited information and therefore data have become precious resources for economic growth in the digital economy. Although the market economy provides effective mechanisms for resource allocation and prices, market failures and limitations have been investigated from various angles (Sandel, 2012). The influence of rewards and punishment threats and the evolution of egoistic or altruistic human behaviour in groups, organisations and societies are important topics in the development of human activities towards individual benefits and/or collective benefits (Fehr and Schmidt, 1999; Fehr and Gächter, 2002; Fehr and Fischbach, 2003). The topic of growth, with its many facets and limits, has attracted increasing interest by the work and numerous reports of the Club of Rome since its foundation more than half a century ago (Meadows et al., 1972; Randers, 2012; (Von Weizsäcker and Wijkman, 2018)). Integrated perspectives of economy and ecology and life have also been approached early on by Herman Daly (Daly, 1968), who viewed economy as a subsystem of a finite ecosphere (Daly, 1990, (Daly, 2015)), and more recently by Kate Raworth, who integrated the social and ecological boundaries in the model of Doughnut Economics ((Raworth, 2017a); (Raworth, 2017b)).

Considering the planet earth from an element and material perspective as a closed system (see fig. 1), understanding the relevant element and material boundary conditions limiting growth, sustaining life and preventing disasters becomes highly important. Linear modes of economic actions, whereby non-renewable materials are extracted, refined and reassembled into complex final products, which after their use end up in waste, together with all the waste produced along the whole chain, lead to specific elemental resource depletion and waste accumulation. It is therefore very encouraging that circular modes of economic actions have been started and have been recognized as a necessity from the environment perspective but also in order to prevent certain elements and materials becoming limiting factors for whole industry sectors (European Commission, 2020; Brudermüller, 2020). Although essential elements for life are abundant on our planet, they are not unlimited. Their finiteness raises questions on the value of biochemically important elements, nutrients and raw materials versus the value of other raw materials and precious elements like gold and silver, which have been traditionally linked with value of modern currency systems. Elements such as carbon, oxygen, nitrogen and phosphorus and compounds like water, which are required for keeping living systems alive, from microorganisms, plants, animals to humans, are system-relevant. They need to be made available in a suitable quality. Questions become important on how value is created along the manufacturing or purification chain, how it is distributed by this growth and how negative effects on health and environment can be avoided.

This requires more in-depth knowledge of the global biogeochemical flows of key elements, a mission-oriented approach (Mazzucato, 2018a) (Mazzucato, 2021) and new incentives for resource efficiency and the recycling of waste. One key element for all living organisms is phosphorus, the global cycle of which has been altered. Among the influencing factors are the continuous mining of the rocks containing phosphate due to increasing phosphorus demands from agriculture, aquaculture, nutrition and industry and the continuous phosphorus accumulation in waste, wastewater and the distribution in the environment (Wohlgemuth, 2021c).

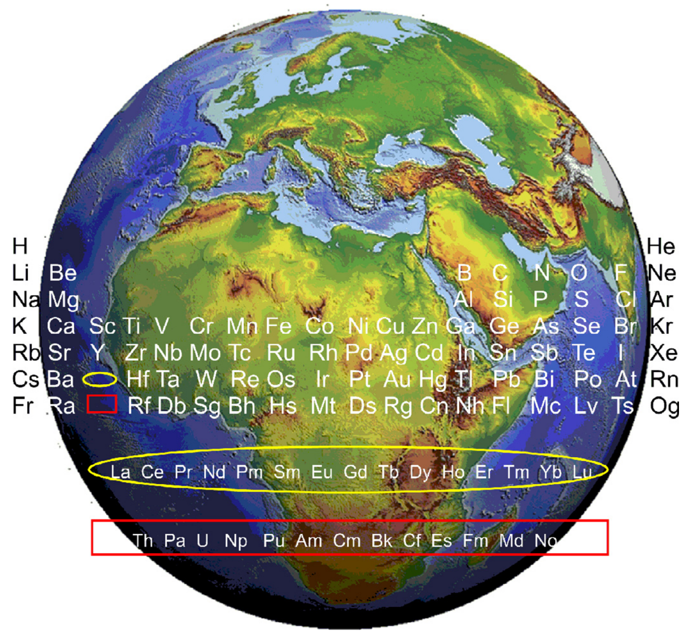

Fig. 1. The material planetary boundaries are illustrated by the finiteness of all the 118 elements of the Periodic Table, which points to the importance of the planetary cycles of key elements. Examples of key elements for sustaining life are phosphorus and nitrogen, where biogeochemical flows have already been identified as planetary boundaries. Strategic goals are essential for these elemental cycles and flows towards increasing the overall resource efficiency and new technologies are needed for the recycling of finite elements of the Periodic Table from waste towards suitable and reusable raw materials.

The current COVID-19 pandemy and its enormous consequences for patients experiencing breathing problems has brought the attention to the obvious benefits often taken for granted of the free availability of the element oxygen in the air, as well as a number of non-compensated interdepencies. This is of course nothing new and these non-compensated interdepencies, which can be positive or negative, have been described as externalities and have already been considered and further developed for more than 100 years ((Pigou, 1920); Meade, 1952; Kehone, Levine, Romer, 1992; (Maskin, 1994); Cornes and Sandler, 1996; Beeks and Ziko, 2018; Nordhaus, 2019; Splash, 2021). The pandemy has highlighted the importance of positive and negative interdependencies affecting human health and the value assigned to them, which may help to take a fresh look on other externalities, such as economic, social and environmental externalities, which are important for sustainable development (Aguilar et al., 2018) (Aguilar et al., 2019) and a healthy planet.

Value Concepts

The concepts of a value and its plural form of values have accompanied mankind throughout history, from the invention of agriculture, cultivation of plants and animals enabling humans to settle down at suitable sites on the planet instead of living as nomadic hunters and gatherers up to the present time. Using, exchanging and storing value are important functions of economic value and its description in monetary terms are present in all kinds of human activity areas. As we are at a turning point of big history (Christian, 2011, 2019), it is important in this context to also keep in mind the numerous other dimensions of value (see fig. 2), such as intrinsic and extrinsic, public and private, absolute and compar-

Fig. 2. A limited selection of type representations of material economic value which are considered to be of high interest by humans to be gained or acquired and to be securely stored in order to avoid loss of value over time, to be used or exchanged. Additional dimensions of value include intrinsic and extrinsic, public and private, absolute and comparative, cultural, sociological, linguistic and philosophical value concepts.

ative value, as well as the concepts of value in the cultural, sociological, linguistic and philosophical perspectives (Perry, 1914; Moeran, 2009; (Mazzucato, 2018b). The assignment of a value to goods, services and anything which can bear value is closely connected with human history back to ancient civilizations. Human labor, ingenuity, innovation and cooperation, despite competition, have enabled numerous milestones in creating lasting value, which present and future generations can benefit from and enjoy. Increasing fragmentation and specialization of work in human societies, progress in transport and information flow as well as changing human perceptions about the value of goods and services have contributed to the need for value measures and monetary systems. In the division of labor among specialized organisational units producing goods and providing services the customer orientation continues to be a key success factor for increasing its value by the producer/provider. The different types and degrees of value, their resilience and stability have thereby been important in the development of standard numerical units for measuring the value of use or exchange of goods and services in a market economy, where also competition plays a decisive role.

The core concepts of a competitive strategy have been introduced by Michael Porter, including concepts such as value chain and competitive advantage, differentiation, technology and competitive advantage, industry segmentation and competitive advantage, substitution, interrelationships among business units, complementary products and competitive advantage (Porter, 1985). The value chain is regarded as tool for analyzing competitive advantage and for searching ways to enhance it, for example by looking at how the value chain can be influenced by the scope of activities (Porter, 1985). Cliff Bowman and Véronique Ambrosini have focussed on the creation and capture of value in real world situations, whereby they have differentiated two forms of values (Bowman and Ambrosini, 2000), "the perceived use value that is subjectively assessed by the customer who uses consumer surplus as the criterion in making purchase decisions, and the exchange value, that is the price paid for the use value created, which is realized when the sale takes place."

Margaret Peteraf and Jay Barney have suggested to link the competitive advantage with the economic value of a good or service generated by an enterprise and with the demand side ((Peteraf and Barney, 2003)). They defined the economic value created as "... the difference between the perceived benefits gained by the purchasers of the good and the economic cost to the enterprise" ((Peteraf and Barney, 2003)).

A widely used indicator for economic activity and value creation in a country or region is the Gross Domestic Product (GDP), which describes the total gross value for the goods and services produced in the corresponding country or region during a given time period. Although this enables to compare countries by using GDP per capita and comparisons over time by measuring GDP at constant price, the GDP has a narrow focus on the economic efficiency in providing goods and services. Numerous factors which contribute to the well-being of the humans living in that nation, such as distribution, education, health, resource depletion, environmental degradation, security and trust, are disconnected from GDP levels and growth, as they are not taken into account, but are nevertheless of key importance to avoid mismeasuring value creation ((Stiglitz et al., 2009)(Sen et al., 2010)Stiglitz et al., 2010; Stiglitz et al., 2019; Alvaredo et al., 2020). Other approaches for better measures than GDP have however also found criticism. Sicco Mansholt, who served as the 4th President of the European Commission, suggested already in 1972 a new measure, which was called in French "Bonheur National Brut (BNB)", as a replacement of the "produit national brut (PNB)" and a European Development Plan with a new (clean and recycling) production system (Commission européenne, 2014). This suggestion experienced however significant objections and was rejected in the European Commission, while in Bhutan King Jigme Singye Wangchuck introduced a commission and index on the Gross National Happiness (Ura and Penjore, 2017). The question of value and what should matter in economy and society has also been discussed in ecological economics (Pirgmaier, 2021).

As with all large-scale global changes this takes time and has not been going on without challenges. Active interactions between different scientific disciplines, industries and statistical institutions are important for defining a limited set of key parameters to measure the sustainable development of economies in a standardized and timely way (Stiglitz et al., 2018).

The concept of creating shared value suggests companies to take the perspective of shared value in their decision-making ((Porter and Kramer, 2019)) and opportunities for creating shared value leading to new approaches are thereby envisioned. These can come from fresh looks at products and markets, productivity and local cluster development, which have been predicted to generate increased company innovation and growth as well as greater societal benefits ((Porter and Kramer, 2019)).

Circular Design of Bioprocesses from Biobased Resources to Bioproducts and vice-versa

Linear process designs already accumulate significant amounts of waste, as shown in fig. 3, from resources to final products, which after

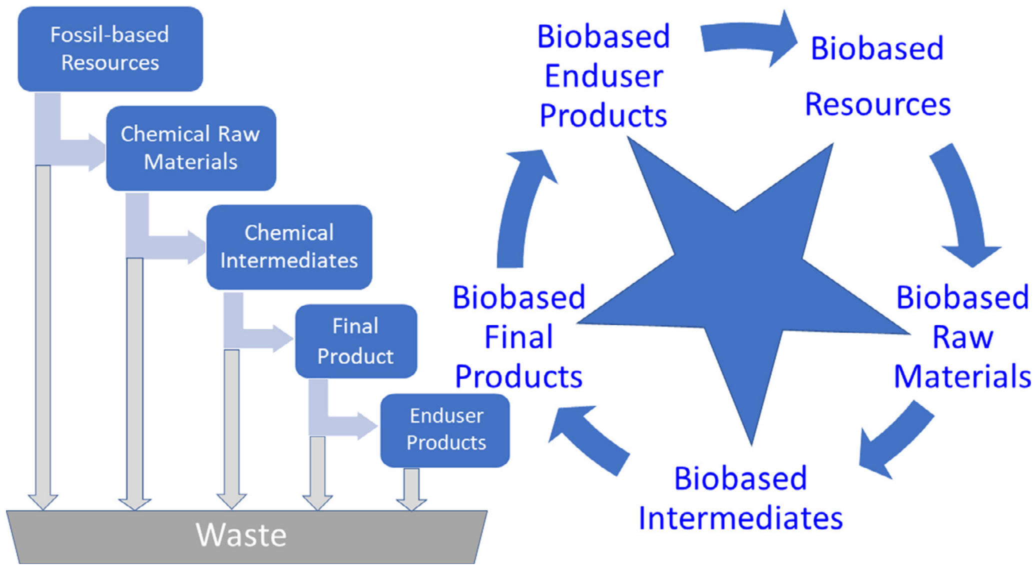

Fig. 3. Linear design of processes to enduser products from fossil-based resources with concomitant waste generation and circular design of bioprocesses from biobased resources to bioproducts and back

their disposal contribute to a further increase of the amount of waste. This line of development is leading to imbalances with increasing pressure of the accumulated, non-recycled and non-biodegradable waste on the safety, health and environment of the human population as well as natural ecosystems.

Economic growth using linear process designs is leading to increasing accumulation of waste and depletion of important non-renewable resources, which are finite on our planet. The product classes of the chlorofluorohydrocarbons, plastics and fuels derived from fossil resources exemplify this for the element carbon. These incompatibiles of simple linear process designs with the sustainable development goals require better process designs.

The transition to circular designs is a common global task of the 21st century and requires not just end-of-the pipe solutions but also fundamental innovation, new system approaches and reengineering of business models (Kershaw et al., 2021). Going from linear to circular process design is necessary but not sufficient, since running the cycle requires work and having a performance of work which lasts forever without any cost is incompatible with the laws of thermodynamics. Limits to sustainable growth and recycling have been identified and a framework for identifying targets and indicators for implementation of a circular economy has been mentioned as lacking (Giampietro, 2019). In addition, the way how the circular process is operated matters, for example if the technology used in the processes is responsible for human diseases, environmental deterioration or biodiversity loss. Therefore, it is not enough to have circular processes, which also need energy and materials input, but it is also essential to reengineer the resource efficiency of the underlying technologies (Wohlgemuth, 2019). Bioprocesses can thereby contribute to the design of smart frameworks with sustainable processes (Sreeharsha and Venkata Mohan, 2021). Great inspiration for such circular designs is provided by nature, where bioprocesses make use of the locally available inorganic and organic resources to prepare the biochemical intermediates, bioproducts and biopolymers needed for sustaining life. The metabolic pathways of the biosphere ensure also the utilization and biodegradation of the biochemical intermediates, bioproducts and biopolymers.

A systems approach is valuable for a full understanding of elemental cycles in nature and for designing resource efficient, safe and environment-friendly bioprocesses from biobased resources to bioproducts which can be fully recycled ((Lee et al., 2012); Fessner, 2015; Wohlgemuth, 2018). The circular design of bioprocesses can be approached from different starting points, such as replacing nonrenewable fossil-based raw materials by biobased resources, developing new bioprocesses for improving the resource efficiency to existing products, recycling existing products and waste using new bioprocesses to valuable raw materials and intermediates, replacing existing products by novel bioproducts with improved functionalities and reducing the elemental footprint by completely new bioprocesses. Depending on the starting point for the design, different methodologies have been useful for the development. When the goal is to produce a new bioproduct and the task is to find the most suitable synthetic route, a backward-going line of thought, which is called retrosynthetic analysis or retrobiosynthetic analysis, has been attracting much interest and promising new tools have been developed ((Hadadi and Hatzimanikatis, 2015); De Souza et al., 2017; Hönig et al., 2017; Turner and Humphreys, 2018; Delépine, 2018; Finnigan et al., 2021).

A great arsenal of new tools has been discovered for designing and evolving enzymes with improved or novel properties for the catalysis of reactions, from known to new-to-nature reactions, using new resources, making new chemical bonds and adapted to given process conditions (Arnold, 2019; Reetz, 2001; Bornscheuer, 2017; Lutz and Bornscheuer, 2012; (Renata et al., 2015); (Reetz, 2016)Chen and Arnold, 2020; Siegel et al., 2010)

The universe of enzymes in nature has provided value to humans in everyday life for thousands of years by catalyzing transformations for preserving food and beverages.

The knowledge about the structure, function and mechanisms of enzymes has grown tremendously and has thus shown the importance of guidelines for reporting (Gardossi et al., 2010). Information and communication technologies have been developed for facilitating the workflow, standardization, and storage of the tremendous amount of enzyme data generated about structures (PDB; Berman et al., 2000), functions (STRENDA Database; Swainston et al., 2018), mechanisms and catalytic sites (M-CSA; Ribeiro et al., 2020).

Whatever the starting point is for bioprocess design, biocatalysis plays a key role in bioprocess design as a highly selective, safe, healthy and environment-friendly technology in science and technology areas like industrial biotechnology and organic synthesis (Reetz, 2013; (Sheldon and Pereira, 2017); (Sheldon and Woodley, 2018); Wohlgemuth, 2010). Biocatalysis has become increasingly important in a large number of industrial bioeconomy sectors, such as food and beverage industries, agroindustry, chemical, pharmaceutical and biotech industries, flavor and fragrance industries and the biomedical domain (Wu et al., 2021; Fryszkowska and Devine, 2020; Ghisalba et al., 2010; (Jimenez-Gonzalez et al., 2011) Meyer et al., 2013; Hanlon et al., 2018; Adams et al., 2019; Wohlgemuth, 2021b). While bioprocesses are prevalent in some industrial sectors, the replacement of fossil-based resources by biobased resources, the introduction of bioprocesses and bioproducts with new/improved functionalities require fundamental innovations and changes at multiple levels.

The growing knowledge about the structure, function and application of biocatalysts in various bioeconomy sectors has broadened the bioprocesses from one-step biocatalytic reactions, to multistep biocatalytic reactions and total biocatalytic synthesis (Wohlgemuth, 2021b).

Value Creation Architectures for Bioeconomy Markets

Architectures for the creation of goods and services in industrial ecosystems can vary widely from simple value creation chains to complex value creation networks, resembling an industrial analogy to the metabolic pathways of living organisms and their interactions in a natural ecosystem.

The value chain architecture (Kaplinsky and Morris, 2000) has been providing a concept for understanding how cost behavior, differentiation sources and technology can be used to determine competitive advantage and how it can be considered for designing organisational structures (Porter, 1985). Fragmentation of production processes across our planet has been influenced by various factors such as costs, knowledge and experience, resources, markets or trade policies (De Backer and Miroudot, 2013). The economic actors and organisations on our planet are connected by complex interactions, such as extraction of resources, production, trade, consumption and waste disposal. Amid the changes in the operational environment of industries and the evolving complexity of value chains from raw materials to final products, creating value and keeping cost under control have remained key objectives. The extensive experience in value creation of the chemical industry in general and of some key segments has shown key success factors for selecting new activities and opportunities as well as for managing challenges and risks (Budde et al., 2006; (Miller, 2015)).

The original value chain concept has been extended with the introduction of alternative value creation architectures (Stabell and Fjeldstad, 1998). The tools of the value shop and the value network are also of great interest for bioeconomy markets. The four bioeconomy-specific innovation types of product substitution, new biobased process development, new biobased product introduction, and behavioral innovation have been conceptualized (Bröring et al., 2020) and allow to structure technology portfolios, to allocate commercialization challenges and to check its sustainability performance.

The utilization of the unique benefits of biobased resources and bioprocesses, such as high selectivity, renewability, novel and improved functions, molecular economy, sustainability and inherent circularity, for closing cycles has over the past decades been the direction of research and innovation in the European Union Framework Programmes, which together with the concept of Knowledge-Based Bio-Economy (KBBE) evolved to actions of ever increasing ambition (Patermann and Aguilar, 2018; Bell et al., 2018; European Commission, 2020). Global thinking, foresight, courage and a long-term perspective of the decision-makers have been key success factors for establishing not only the European Bioeconomy Strategy (European Commission, 2012,(European Commission, 2018a)(European Commission, 2018b)), but also regional and national bioeconomy strategies around the world (BMBF and BMEL, 2020; Aguilar et al., 2019; Wohlgemuth et al., 2021a). Biodiplomacy has also been considered for a global approach in sustainably managing resources in the interest of human population (Aguilar and Patermann, 2020). Although the different approaches towards public bioeconomy strategies, private initiatives in distinct bioeconomy sectors and cooperation between public and private institutions ((Mengal et al., 2018)(Sierra et al., 2021)) vary considerably, the global exchange of best practices (Boldt et al. 2020) provides inspiration to continuous process improvement. Innovation can also be derived from new circular value creation architectures (Hansen and Revellio, 2020) and new thinking across value chains which traditionally have nothing in common. Creating awareness of bioeconomy activities in a country can also be beneficial for possible coordination of bottom-up initiatives of various bioeconomy sectors (National Academies of Sciences, Engineering, and Medicine, 2020; (Hecht et al., 2020)).

The complexity of value creation architectures for a selected bioeconomy sector and its markets is analogous to the interconnections of metabolic pathways of living organisms in an ecosystem. Smart interactions between global, national, regional and local industrial ecosystems, as schematically illustrated in fig. 4, with reliable material flows and connections of local value creation chains, can provide competitive advantages with respect to added value, resilience of supply chains, circularity and sustainability.

Value Creation Architectures Beyond Bioeconomy Markets

While existing and emerging bioeconomy markets provide promising prospects, there are in addition also opportunities to create value beyond markets. In a detailed and thorough analysis Thomas Piketty came to the following conclusion regarding income and wealth (Piketty, 2014): "a market economy based on private property, if left to itself, contains powerful forces of convergence, associated in particular with the diffusion of knowledge and skills; but it also contains powerful forces of divergence, which are potentially threatening to democratic societies and to the values of social justice on which they are based." The "inequality that r, the private return on capital, can be significantly higher for long periods of time than g, the rate of growth of income and output," represents according to Thomas Piketty a fundamental logical contradiction (Piketty, 2014). Building broadly distributed private property and sustainably investing capital is therefore highly relevant (Schoenmaker and Schramade, 2019) for directing the creation of value networks beyond bioeconomy markets, which support the sustainable development goals (United Nations, 2015a); (United Nations, 2015b). It can be even more secure and in the longer term bring more private return on investment than the promises of seemingly highly profitable investments into non-sustainable activities. It is therefore very good that the sustainable investing assets in the five major markets have increased by 34% in two years to 30.7 trillion US dollars at the beginning of 2018 (Global Sustainable Investment Alliance, 2018).

Long-term investments into biobanks may not seem attractive at first sight, but bioresources have been key throughout human history, providing unique value to many stakeholders, from individuals, farms, breweries and seed companies to the food industry, pharmaceutical industry and biotech industry. The information on billions of genes, isolated from natural sources or manufactured by gene synthesis, is rapidly increasing due to decreasing costs of sequencing and synthesis. Ambitious biodiversity initiatives aiming at sequencing, cataloguing and characterizing genomes of living organisms in the Earth Microbiome Project (https:// earthmicrobiome.org; Thompson et al., 2017), the Earth BioGenome Project (https://www.earthbiogenome.org; (Lewin et al., 2018)), Bioscan from 2019–2026

(https://ibol.org/programs/bioscan), and its successor, the Planetary Biodiversity Mission from 2026-2045, utilize high-throughput gene sequencing for understanding biodiversity, species interactions, ecosystems and the planet's biosphere. Global information exchange on genomic samples is facilitated by the Global Genome Biodiversity Network Data Standard (Droege et al., 2016), which provides also best practices in managing compliance with the international guidelines on access and benefit sharing of the Nagoya Protocol (Convention on Biological Diversity, 2011), which just celebrated its 10-year anniversary in 2020. As the value generated depends however on the knowledge about the applications and functions of the gene products (Gerlt, 2017)(Zallot et al.,

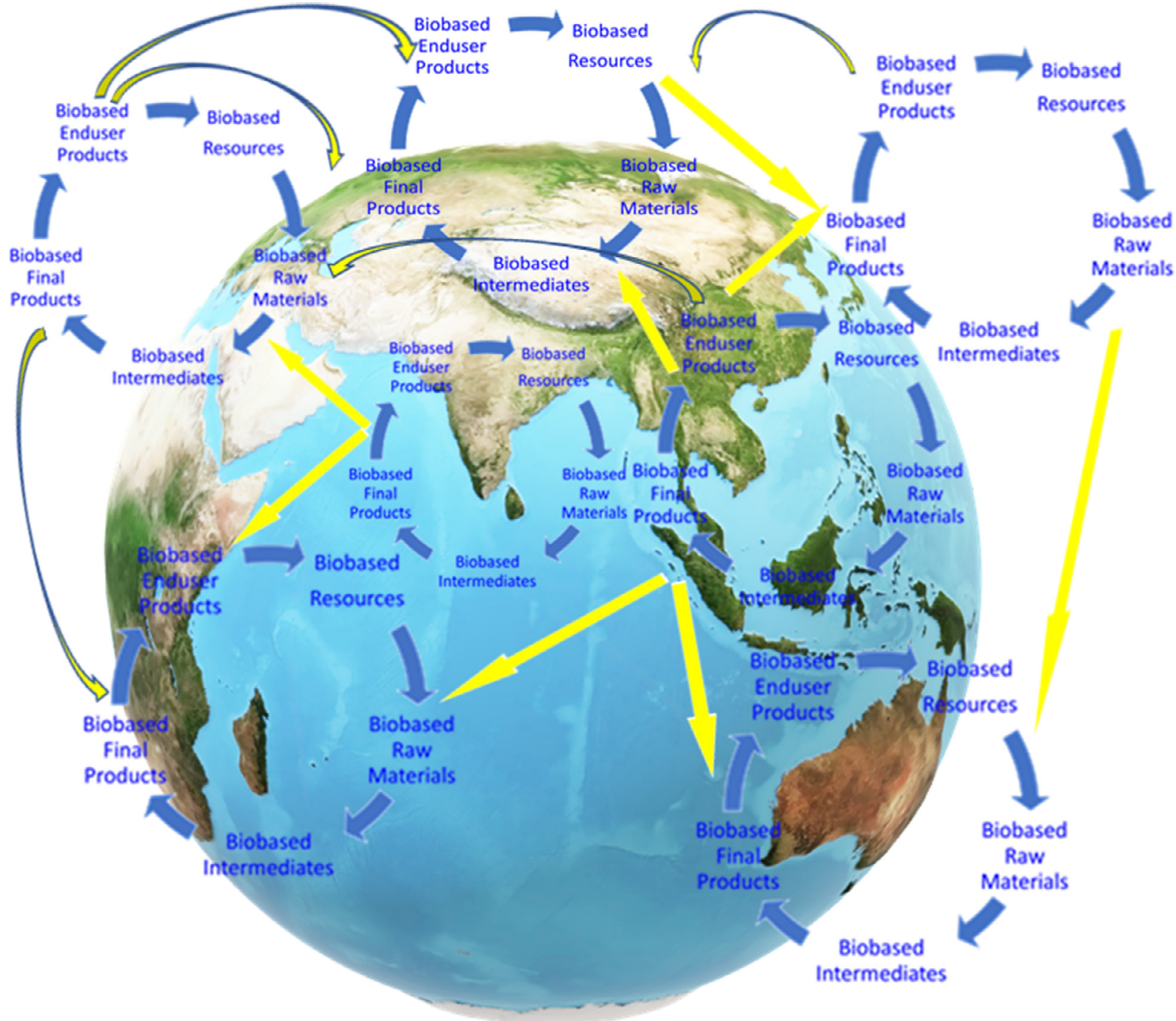

Fig. 4. For a selected bioeconomy market the global value creation architecture can be composed of national, regional and local industrial ecosystems in which smart and reliable connection of local value creation chains can provide competitive advantages with respect to added value, resilience of supply chains, circularity and sustainability.

2021), the question comes up whether and how the benefits of the generated value can be distributed within value creation networks. While a clear separation of different approaches for genes isolated from natural ecosystems and synthetic genes may be difficult in practice, a consensus between science, industry and society on effective solutions is desirable and useful for a sustainable bioeconomy. The long-term objectives of biobanks, the maintenance and the reliable long-term preservation of bioresources, both in biobanks as well as natural ecosystems, are in the interest of all involved stakeholders from science, industry and society, although stable and continuing funding can be challenging. Research, maintenance and preservation of the biodiversity in natural ecosystems is however essential for addressing the planetary boundary of biodiversity loss. Furthermore, it is important for various system-relevant areas, such as for example the crop diversity of plant resources for the security of food and feed production under changing environmental conditions (Crop Trust, 2015).

Outlook

In big and small human history, crises have been chances for the improvement of the conditions leading to crises, for imagination of novel paths not gone before and for making it a reality, whatever it takes. Bioeconomy is moving forward step by step (Wohlgemuth et al., 2021a) with bottom-up and top-down initiatives and by continuous interactions between science, industry and society stakeholders, as schematically shown in figure 5.

It is great that at this turning point numerous bottom-up and top-down bioeconomy actions and initiatives have been started at different levels, involving people of all generations at multiple levels (Aguilar et al., 2021; Boldt et al., 2020; BMBF and BMEL, 2020; European Commission, 2020). The projected growth of the world population (United Nations, 2019) to around 10 billions in 2050, which would be about four times as much as in 1950, will make bioeconomy-related education, empowerment and inspiration to people around the world essential tasks.

Therefore, it is important to build consensus on what really matters in the transition ((Fritsche et al., 2020); (Garrity, 2018) (Lewandowski, 2018)) to biobased resources, bioprocesses and bioproducts and to take action now, fast and at scale in designing value creation architectures (Mazzucato, 2016) (Mazzucato et al., 2020) for bioeconomy markets and beyond. The original considerations on selected bioeconomy topics and conclusions on what really matters which

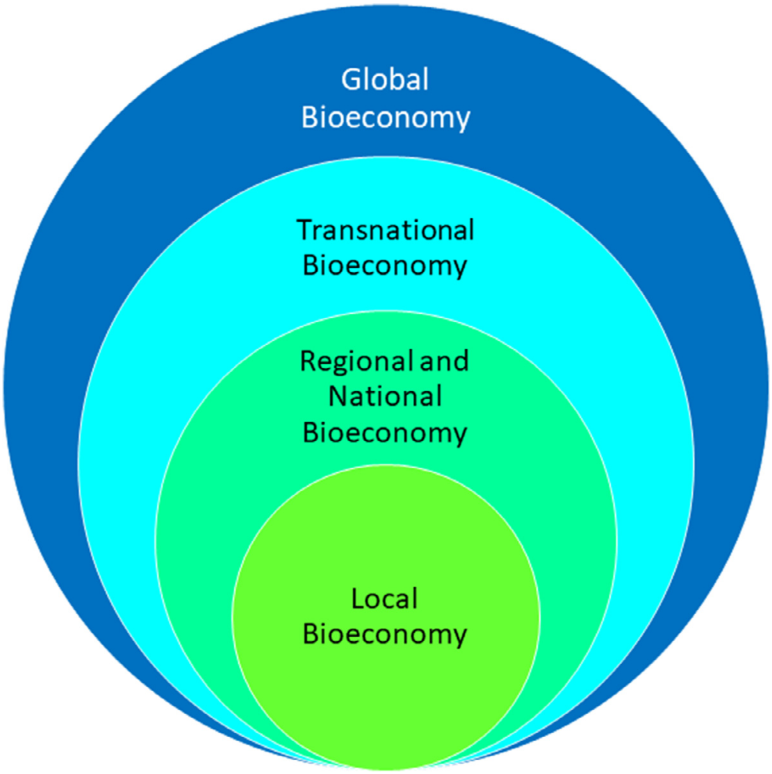

Fig. 5. Moving bioeconomy forward step by step by bottom-up and top-down initiatives and by continuous interactions between science, industry and society stakeholders at local, regional, national and global levels.

Bioeconomy Topic	What really matters - Key Considerations
Value	Finding consensus on what values really matter and how value assignment serves the sustainable development goals Defining a limited set of key parameters to measure the sustainable development of economies in a standardized and timely way
Bioresources	Increasing knowledge on all living organisms on planet earth Biochemical flows of elements essential for life, e. g. Nitrogen, Phosphorus, Carbon, Oxygen Increasing understanding of biological systems and their interactions at all levels Preservation of Biodiversity and Loss Prevention Maintenance & reliable long-term preservation of bioresources Creation and Maintenance of Biobanks
Bioprocesses	Inspirations from nature for circularity, quality, selectivity and sustainability by design Molecular economy and resource efficiency Biocatalysis as key enabling technology Interfacing biomolecular and bioengineering sciences Transforming non-sustainable processes and creating novel bioprocesses
Bioproducts	Novel bioproducts with improved functionalities Creating added stakeholder value towards health, nutrition, safety and environment Further processing, re-use or recycling schemes
Value CreationArchitectures	Linear value creation chains Circular value creation chains Complex value creation networks Local, regional, national and global value creation networks
Research & Innovation	Stable and long-term investment into research and innovation Not more of the same, but fundamentally new research Creating a continuum in the flow from basic idea to practical application Empowering individual initiatives and building mission-oriented partnerships
Bioeconomy Markets and Beyond	Creating awareness of bioeconomy activities can be beneficial for possible coordination of bottom-up initiatives of various bioeconomy sectors New circular value creation architectures and new thinking across value chains which traditionally have nothing in common can build opportunities for growth and sustainability Global exchange of best practices provides inspiration to continuous process improvement

have been put forward on value, bioresources, bioprocesses, bioproducts, value creation architectures, research and innovation, bioeconomy markets and beyond in the previous sections are highlighted in Table 1.

New cooperations, partnerships, alliances and dedicated result-oriented work will be needed to master this 21st century task to harmonize nature, business and human development (World Economic Forum 2020a, 2020b). This will however require a favorable long-term perspective by all stakeholders for sustainable investments into bioeconomy and a proper balance between the costs and benefits of debt accumulation, especially as global debt has increased to an all-time high number in the current debt wave (Kose et al. 2021). A commonly understandable and inclusive narrative is important in building consensus for a healthy planet and inspiring timely actions to not only address the numerous challenges but to shape the future of the Anthropocene Epoch ((Sachs, 2015); (Sachs et al., 2019)). Bioeconomy is building the required bridges within and between different disciplines for a systems approach and it is of much interest that for the next 30 years ecological economics has been proposed as a torchbearer of a systems economics (Hangens, 2020).

The numerous decisions taken at various levels, from government, business, industry, science and technology leaders to non-governmental organizations and individual members of civil societies, show that bioeconomy is on the move at all levels, steadily, step by step and globally. This is an encouraging and healthy outlook for human life in 2050 on planet earth within its planetary boundaries, but should not lead to complacency. An urgent call for action has been issued by the steering committee of the Nobel Prize Summit 2021 “Our Planet, Our Future”, and co-signed by Nobel Prize Laureates and experts (The National Academies of Science, Engineering, Medicine, 2021).

Author Statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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