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Value chain transformations in the transition to a sustainable bioeconomy

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Abstract

The adoption of new bio-based technologies that reduce our reliance on fossil fuels is presented as a path to reduce greenhouse gas emissions while creating new business opportunities. Such a transition towards a bio-based economy will require substantial investments in technological innovations that will likely affect how value chains are structured and which actors benefit from this transformation. Yet, previous studies on the bioeconomy have largely ignored the relationship between the structure of value chains and the rate of technological innovation. In this article, we analyze the link between technological innovation, value chain structures, and welfare distribution in the transition to a bioeconomy. We find that an acceleration in the rate of bioeconomy innovation is associated with shorter and more vertically coordinated value chains, bigger firms with higher market shares, increasing knowledge-sharing among value chain members, and a leading role by firms with core research capabilities. Finally, we argue that while bio-based innovation can potentially achieve environmental sustainability, it creates risks for the weakest value chain actors. Thus, we propose some lines of thought regarding the potential distributional effects of bio-based innovation. From a policy perspective, this debate is relevant to safeguarding social sustainability in the transition to a bioeconomy.

Keywords: bioeconomy, innovation, upgrading, value chains, welfare

1. Introduction

Global warming is pushing the biophysical environment towards a sustainability threshold and at the same time deepening economic inequalities (Diffenbaugh and Burke, 2019; Steffen et al., 2018). Greenhouse gases (GHG) emissions from the production of food, consumer goods, and industrial materials are the main driving forces of climate change (Crippa et al., 2021; Meinrenken et al., 2020). A transition towards a bioeconomy – an economic system based on biological principles and the efficient use of sustainably produced renewable resources – is often seen as a promising strategy to reduce our reliance on fossil-based resources while promoting economic growth and striving to achieve the Sustainable Development Goals (SDGs) (Biber-Freudenberger et al., 2020; Stark et al., 2022).

This transition will require a change in the role that biomass plays in our economic system. This means moving from traditional bio-based applications that use high-volume and low-value biomass (e.g. using raw biomass to produce animal feed) to industries built upon advanced technologies that use low-volume biomass and create economic value-added while minimizing negative consequences for the environment (Bröring et al., 2020a; Kircher, 2021). We call this process a bioeconomy upgrading. This implies a paradigm shift in the way production takes place. We have experienced different waves of industrial change in the past, from the first steam power revolution to the current fourth industrial revolution, based on artificial intelligence and digitalization (Maynard, 2015). However, this time environmental concerns have become the main drivers of change. Many of the most promising technologies in the bioeconomy, that apply engineering principles to life sciences, confront us with the possibility of a fifth industrial revolution (Peccoud, 2016).

However, shifts in production paradigms also imply institutional and social changes (Dosi, 1982). Some value chain members could see their livelihoods affected, since technological changes may be biased towards specific production factors and create welfare redistribution (Acemoglu, 2002). In general terms, technical change implies that more value is added by a combination of capital and high-skilled labor, and this creates challenges, especially for low-income economies (Rodrik, 2018; Timmer et al., 2014). The introduction of a new technology can also affect the organizational structure of value chains. For example, the introduction of genetically modified organisms (GMOs) has led to a reorganization of the global seed industry and a growing market concentration. This could result in higher prices for these technologies, thus affecting farmers' adoption and production costs (Deconinck, 2020). Thus, for some members of the value chains, innovations and structural changes can bring benefits, such as price premiums, reduced costs, or new market opportunities, while other value chain members may be displaced and lose their position. This holds not only for changes in physical technology but also for institutional innovations, such as certification schemes (Meemken et al., 2021).

Although there is a growing number of studies on transition pathways towards a bio-based economy, this literature has largely ignored the role of value chains in fostering this process of bioeconomy upgrading. The existing analyses of the bioeconomy from a value chain perspective have focused mainly on the convergence between specific value chains and sectors (Carraresi et al., 2018; Golembiewski et al., 2015) and the emergence of new value webs around certain biomass sources (Lin et al., 2019; Loos et al., 2018). However, these studies do not discuss how the organizational characteristics of these value chains relate to the technological innovations associated with the transition to a bioeconomy.

An explicit focus on this relationship is important because the way in which value chains are organized has a significant potential to drive technological innovations for more sustainable production systems (Swinnen and Kuijpers, 2019) and at the same time, they affect welfare distribution along the value chain (Minten et al., 2018). Hence, our main research questions in this paper are: (1) Which value chain features may be more conducive to a process of intensified innovation in the bioeconomy? and (2) In what way do the organizational characteristics of these new value chains may affect welfare distribution among actors in the transition to a bio-based economy?

To answer these questions, we start by explaining how innovation takes place in the bio-based economy. We follow by doing a narrative review of the literature on the mutual dependency between value chain characteristics and processes of innovation to identify our main categories of analysis. Then, using insights from the literature on value chain management and industrial organization, we present conceptual models that describe the organization of value chains across the different stages of the process of bioeconomy upgrading. Lastly, we relate these models to specific technological innovations and to several empirical examples from consolidated and emerging companies and discuss how the characteristics of these value chains might affect welfare distribution.

Our study contributes to the rich body of literature that analyzes how technological and institutional innovations can shape market structures and the organization of value chains (Barrett et al., n.d.; Reardon and Timmer, 2012; Swinnen et al., 2015). Our study is also complementary to the work by Zilberman et al. (2019), who present a conceptual framework to discuss how innovations used to transform feedstock from agricultural production into consumer products might affect the strategic decisions of an agribusiness firm. Here we propose an overarching framework to analyze the link between technological innovation, value chain structures, and welfare in the transition to a bioeconomy, covering not only agribusiness firms who engage in complementary bio-based market opportunities (e.g. a livestock processor who uses residues for produce animal feed) but also emerging high-tech companies that rely on low-volume and high-value biomass.

The remainder of this paper is structured as follows: In section 2, we describe the idea of a bioeconomy upgrading in further detail. In section 3, we present evidence on the nexus between value chains and innovation, based on previous literature. In section 4 we present a typology of value chain models in the bioeconomy and analyze how they contribute to a bioeconomy upgrading. Finally, in section 5 we propose some hypotheses on how some of the value chain attributes identified in the previous section may lead to different welfare effects in the transition to a bio-based economy.

2. The process of bioeconomy upgrading

The bioeconomy has become a popular concept among public and private actors[1]. In the public sphere, many governments have presented bioeconomy strategies in the last decade (Biber-Freudenberger et al., 2018). In the private sphere, many companies have been seeking to reduce the environmental impact of their operations, a process that is known as environmental upgrading (Navarrete et al., 2020), which could be achieved by increasing the use of bio-based feedstocks in their industrial processes.

But simply replacing industrial products from the fossil economy with bio-based products is not sustainable *per se*. In fact, at a large scale, it could mask further environmental degradation, especially (but not limited to) due to the utilization of first-generation feedstocks. Concerns over environmental sustainability have been raised for many products often associated with the bioeconomy, such as bioplastics (Escobar et al., 2018), biochemicals (Nong et al., 2020), and biofuels (Jeswani et al., 2020). Increased demand for these first-generation technologies can create increases in food prices that affect the poorest, direct and indirect land-use change, biodiversity loss, and other environmental side effects such as acidification and eutrophication.

Bioeconomy upgrading is a long-term process that requires technological innovations and changes in how biomass is used to increase economic value-added while minimizing environmental impacts (Figure 1). In its initial stages, a bioeconomy upgrading is characterized by attempts to substitute fossil-based inputs by using first-generation technologies, often using high-volume and low-value agricultural feedstock. Advanced stages involve the use of higher generation feedstocks, the adoption of circularity principles, and the design of new biosynthetic compounds. Eventually, a fully upgraded bioeconomy could simultaneously reduce the amount of biomass needed and rely on the use of less land-intensive biomass, therefore contributing to reducing the trade-off between economic growth and environmental sustainability.

Such a transformation can be reached through different paths that are not mutually exclusive: increasing the efficiency of biomass production (more output per unit of land or more value-added per ton of output), introducing new biomass inputs that do not compete with food or require less land to be produced (such as 2nd, 3rd, 4th generation feedstocks), maximizing the re-utilization of waste in multi-product biorefineries, and relying on technologies that are less dependent on biomass (i.e., high-value and low-volume applications) (Escobar and Laibach, 2021; Jiménez-Sánchez and Philp, 2015).

A sustainable bioeconomy is not only about replacing feedstocks. It also requires a comprehensive technological transition in which radical innovations that are initially used in

[1] Although there is no single widely accepted definition of bioeconomy, the idea of sustainably produced biomass coupled with the use of biotechnologies is often prominent across definitions and plays a central role in this study.

niche markets gradually become the new technical regime (Geels, 2002). This requires the emergence of a conducive business ecosystem that fosters the conversion of scientific knowledge into innovative applications.

Market adoption takes time, but in an upgraded bioeconomy we may experience a massive adoption of technological processes and products based on more complex and sustainable feedstocks, thus increasing economic value-added while reducing environmental impacts. We have already observed examples across several industries, such as biosimilars for human health, bio-inputs for agriculture, next generation of antibiotics and vaccines, new seed traits, animal-free recombinant proteins, bioplastics from waste, lignocellulosic biofuels, and algae applications (among many others).

However, it is important to note that the transition towards an upgraded bioeconomy might be especially challenging in some sectors, such as aviation, shipping, and long-distance trucking, which are responsible for around 20% of all GHG emissions from global food systems (Li et al., 2022). Adopting advanced biofuels to reduce emissions in these sectors would be contingent upon large cost reductions to ensure that these biofuels are competitive with fossil fuels. Furthermore, a fully upgraded bioeconomy in which we have a decarbonized economic system that contributes to improved social equality will require a fast and large-scale adoption of these innovations to capitalize on the synergies and co-benefits (Hawken et al., 2017).

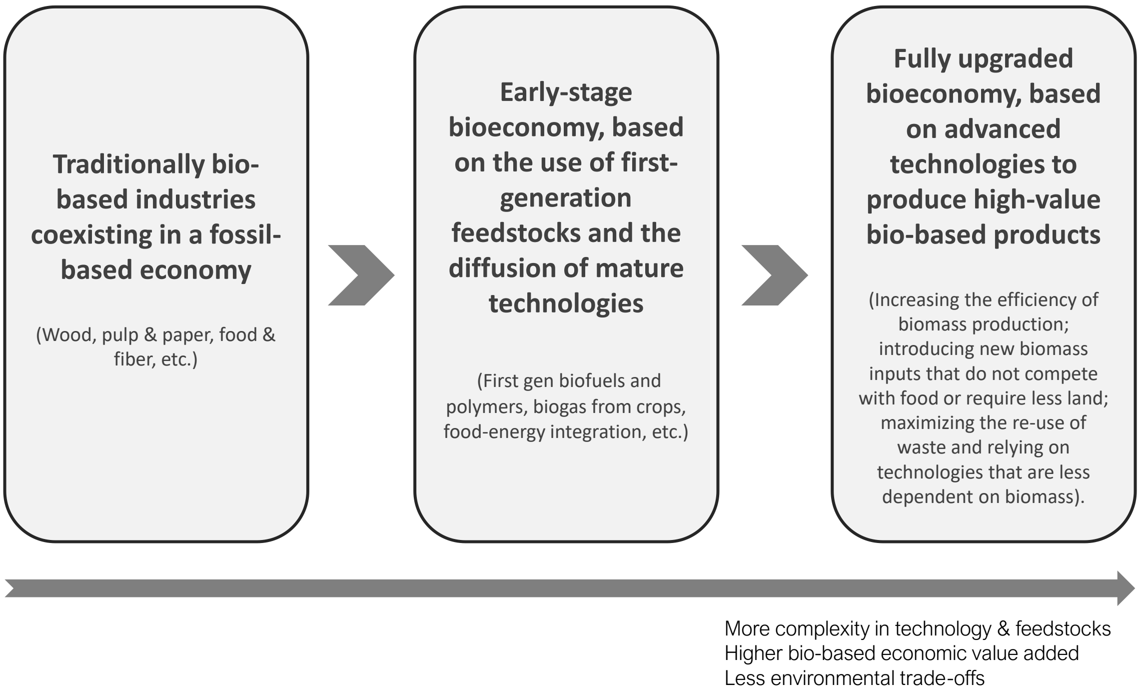

Figure 1: Main stages in a bioeconomy upgrading.

3. The nexus between value chains and innovation

The literature on the drivers of technological innovation and value chain formation suggests that there is codetermination between the organizational structure of value chains and the type of technological innovation that is adopted inside the value chain. On the one hand, the rise of a new technology in an industry may affect the characteristics of a value chain, as managers might need to change how their businesses are organized to incorporate new processes or inputs. On the other hand, some value chain features are more conducive to fostering an endogenous process of innovation. We explore both ideas in more detail in the following paragraphs.

3.1. New technologies contribute to shaping value chains.

The emergence of a new technology in an industry might lead to a reorganization of its associated value chains. This happens mainly for three reasons. First, innovators face many risks when dealing with new technologies. Regardless of whether these innovations were driven by government regulations, consumer preferences, or entrepreneurial initiatives, risks exist both from the supply side (i.e., final output, quality of feedstocks) and the demand side (i.e., commercial failure). Thus, companies might look for alternatives to organize their value chains to reduce and control part of these risks. Upstream, this affects the decision to produce feedstocks in-house or acquire them through contracts or market mechanisms (Du et al., 2016). Downstream, this affects how distribution channels and marketing activities are handled. Likewise, many innovations show specificities that create hold-up opportunism. In this case, the right contractual schemes need to be created for successful technology transfer (Kuijpers and Swinnen, 2016; Swinnen and Kuijpers, 2019).

Second, many novel technologies show increasing returns of scale. It means that substantial investments are needed in the development phase, but marginal costs are low when the technology scales up and becomes viable (Zilberman et al., 2012). This takes special relevance in the presence of market failures, since entrepreneurs may have limited access to funds (Zilberman et al., 2019). In such a context, companies need either to develop partnerships with research and development firms or associate with similar companies to scale up and facilitate investments. In the long run, these increasing returns of scale may result in value chains comprised of bigger firms, which are the ones that can overcome credit and scale barriers.

Third, many innovations are intrinsically systemic. This means that different members of the value chain need to adapt for the technology to succeed. In this case, companies may choose governance structures that give them more control over the full process (Bröring, 2008). Moreover, systemic innovations often require platform leaders that promote collaboration along the value chain (Gawer and Cusumano, 2014; von Pechmann et al., 2015). A recent example can be seen in the widespread adoption of e-commerce solutions during the Covid-19 pandemic, where we observed, for example, firms in the food industry, their suppliers, and intermediaries change their operations to adapt to make efficient use of these new technologies (Reardon et al., 2021).

3.2. The morphology of value chains affects the rate of innovation.

The organizational structure of value chains can influence technology transfer and how likely it is that technological innovation will be fostered endogenously. First, the prevailing governance schemes shape the way in which knowledge is shared and learning takes place along the value chain: while in arm's-length arrangements learning happens mostly through knowledge spillovers or imitation, in contract-intensive value chains more structured learning mechanisms prevail, such manuals of procedures, production standards or in-person training (Pietrobelli and Rabellotti, 2011). Value chains with poor contract enforceability may see technology transfer affected and require specific safeguards (Kuijpers and Swinnen, 2016).

Second, value chains comprised of firms with strong innovative capabilities, or with a tradition of innovation, are more likely to produce further innovations. Horbach (2008) finds that the technological capabilities developed by a firm affect its level of environmental innovation. Something similar happens with industries that have clear market leaders with core research capabilities, which can push innovations and engage many upstream and downstream value chain actors. Mazzucato and Robinson (2018) describe the key role that NASA has played in promoting innovations among private-sector contractors in the aerospace industry, many of which had spillovers toward other industries. In a similar line, Allal-Chérif et al. (2022) study how a leading firm in the aeronautics industry, like Airbus, is collaborating with suppliers to develop innovations that reduce the carbon footprint of its operations.

Third, value chains that operate in collaborative environments, not only among firms but also between the private sector and research institutions, are more likely to foster innovation, especially in the environmental field for which private incentives are weak (Bossle et al., 2016). The role of collaboration is especially clear in knowledge-intensive industries in which proximity among firms fosters open innovation, like in pharma (Demirel and Mazzucato, 2010) or biotechnology (Quintana-García and Benavides-Velasco, 2004).

Overall, we observe codetermination between the process of innovation (i.e., intensity and main characteristics) and the structure and morphology of a value chain. This codetermination implies that the value chain structure is endogenous to the type of innovations and the technologies adopted, but at the same time, different value chain features may foster innovations. From the articles reviewed, we identified and selected eight relevant categories of analysis that help us describe the innovation process and the features of value chains. These inductive categories are presented in Table 1. In the next section, we will present a comprehensive typology of bioeconomy value chains and apply these categories to describe them.

Table 1: Main categories of analysis.

Characteristics of the innovation process		Value chain features	
Risks and uncertainties associated with the technologies	The novelty of the technology. Degree of specificity. Potential hold-up risks. Need to develop markets. Need to protect intellectual property.	**Value chain governance**	Ways of interaction among members of a value chain (market, contracts, hierarchy). Rule-setting mechanisms.
Level of investments and capital required	Initial investments that are needed to bring a new technology to the market. Potential increasing returns of scale. Sunk costs.	**Predominant industry structure**	Size and number of firms. Level of sales and market shares. Length of the value chain (short value chains with few stages or long value chains with many stages).
Intensity of innovation in the value chain	The speed at which new products and services come out. Innovative profile of the firms. Rate of adoption and transfer of technology.	**Collaboration among firms**	Alliances and partnerships among firms. Knowledge sharing. Convergence and inter-industry collaboration. Joint ventures.
Systemic characteristics of the technologies	Technologies that require adaptations by different members of the value chain. Platform technologies. Potential network externalities.	**Core innovation capabilities**	Presence of firms that promote innovation and engage other value chain members. Research capacities among firms. The tradition of innovation in the value chain.

4. Typology of value chains in the bioeconomy

4.1 Conceptual models

A value chain is comprised of a group of actors that perform a set of value-adding activities and several strategic interactions among them (Donovan et al., 2015). Each value chain has vertical boundaries (i.e., a start and an end) and horizontal boundaries (products, markets, and activities that belong to the value chain). However, there is no rule of thumb to set these limits, which are defined according to the research goals in each specific situation. Value chain mapping is a tool that helps to reduce complexity by depicting functions, actors, and their relationships in a simple and visual-friendly way (Springer-Heinze, 2018).

To build the six value chain maps presented in Figure 2 we constrained ourselves to typify activities and their vertical links exclusively in the context of the bioeconomy. These activities include:

i. biomass production (considering not only crops but also waste and other types of bio-based feedstocks).

ii. bio-based processing (transformation of biomass into bio-based products).

iii. industrial application (use of a bio-based product as an input for an existing industry).

iv. Biotech support or research and development (R&D) services (development of novel technologies for bio-based processing or supporting activities for industrial companies).

v. Final consumption (the role of final users, such as farmers, consumers of food products, medical patients, etc.).

By mapping activities rather than actors, we ensure that our conceptual models are as broad as possible. Functions tend to be more comprehensive and rather invariable, while the actors that perform those functions may be case-specific and change according to different governance decisions. For the sake of simplicity, we excluded activities such as logistics, marketing, provision of other non-biobased inputs, financial services, and many others that should be included in a more detailed value chain mapping. We decided to keep the final users in the conceptual models because this helps to understand the orientation of the value chain and also contributes to our subsequent discussion about welfare distribution.

Based on the categories presented in **Error! Reference source not found.**, we briefly describe these models in the remainder of this section. In Table 2 we summarize how each value chain model relates to the process of bioeconomy upgrading, both from the economic and environmental perspectives. However, it is important to note that environmental impacts are only indirectly associated with the structure of these value chains. Impacts on the environment will ultimately depend on the exact type of technology being discussed. The models presented below are conceptual depictions of the industries and technologies that we currently observe empirically. But as low-impact technologies mature and biomass gets “commodified” (e.g. algae or switchgrass technologies), we might observe associated value chains to adapt and get closer to organizational structures that we currently associate with industries that use low-value and high-volume mature technologies, such as biofuels.

Model 1: low-value, high-volume biomass

This first model represents the earliest developments in the bioeconomy, in which bio-processing companies procure feedstocks from biomass producers through market mechanisms, and the bio-based product then becomes the input of an industrial process. Currently, this structure is commonly observed in first-generation biofuels or biogas from edible crops. The Argentine oilseeds crushing industry can be cited as an example. The country has one of the biggest soybean crushing clusters in the world, and after the biofuels law was passed in 2006, many companies built plants to convert soybean oil into biodiesel (Calzada and Molina, 2017). Crushers buy soybean through market mechanisms and then sell the biodiesel to refineries that blend it with oil. A similar structure was seen in the ethanol industry in Brazil, after the implementation of the *proalcool* program in the 1970s. Farmers sold their output to sugarcane mills and ethanol plants, which later distributed ethanol to different energy segments (Neves et al., 2010). There are other oilseeds value chains, such as oil palm in South East Asia, that can be in this same model (Ceres, 2018).

While processing companies are always looking for new uses for their byproducts (e.g., crude glycerine in the case of biodiesel), the main processing technologies are at a mature stage and involve low technical risks. Thus, innovation intensity is low in this value chain model. Investments in fixed assets, technical efficiency, and logistics are key success factors, and there are no systemic adaptations involved. For these reasons, the procurement of feedstock often happens in arm's length transactions that are governed by market mechanisms. Some companies might prefer to secure contracts with their suppliers, but these are not strictly necessary given the non-specificity of feedstocks. There are not many incentives for firms to collaborate and develop new technologies because these industries rely on mature technologies.

Currently, this type of value chain represents industrial processes characterized as low-value and high-volume, mainly aimed at the substitution of fossil-based products. There are potential GHG emissions savings, but there are also risks of land-use change that can create further environmental impacts such as biodiversity loss, eutrophication, or acidification. In the long run, these side effects can outperform gains from reduced emissions (Jeswani et al., 2020).

Models 2-3: adoption of cascading and circular principles

The next two models are closely linked, as they introduce some degree of vertical integration and horizontal cooperation in the bioeconomy[2]. In the second model, biomass production and

[2] Dotted boxes and arrows in Figure 2 reflect the fact that biomass flows might not come from market transactions but take place within a hierarchical or coordinated governance structure.

bio-based processing are integrated. It is usually biomass producers (i.e., farmers) who forward integrate towards the bio-based processing stage, seeking to increase the value-added of their output. This is done mainly through local biorefineries, which can later incorporate additional processes and cascading uses. The emergence of cooperatives in the U.S. corn ethanol industry works as an example. Despite transaction costs, Midwest farmers decided to organize themselves in cooperatives after the 1978 Energy Tax Act, mainly in response to the absence of local corporate buyers. This also happened even in the presence of private corporations, in counties with a tradition of cooperative culture (Boone and Özcan, 2014). Model 2 also depicts a type of organization that has become common in many European countries: small farmers' associations for converting manure or crop residues from their farming operations into biogas via anaerobic digestion, obtaining bio fertilizer as a by-product (Carrosio, 2013).

In the third model, an agro-industrial company (or maybe a large-scale farm) installs a biorefinery to add new cascading uses to its biomass. This is a typical structure in the production of biogas and bioenergy from industrial waste, crop residues, or animal manure (FAO, 2020). Residual biomass employed in model 3 is bulky and has low or no market value. Thus, these new bio-based processes should be carried out in local biorefineries which can be supplied entirely from the company's own feedstocks or may require external sourcing to reach a minimum operative level (FAO, 2020). These residues can be used either to (i) produce biogas that will later be upgraded into biomethane, (ii) produce biogas that will later be converted into electricity, or (iii) cogenerate heat and electricity (Scarlat et al., 2018). The company can choose the optimum mix of in-house use and external sale of the bioenergy generated.

As specific examples, we can mention dairy farms using cow manure for anaerobic digestion (Vida and Tedesco, 2017) or farmers joining forces to use residues from hog production (Skovsgaard and Jensen, 2018). There are also food companies producing bioenergy from fruit peels (Raimondo et al., 2018) or peanut shells (Streetz, 2021). This is also a common scheme for timber companies using dry residues (mainly wood chips) to cogenerate heat and electricity (Olemberg et al., 2020). The production of electricity from bagasse, which is a common practice among sugarcane mills in Brazil, also fits into this value chain model (Chaddad, 2010).

Since these are biomass-intensive models and transport costs might be prohibitive, in-place processing and geographical coordination is crucial for success. The technologies involved, such as biodigesters or distilling facilities, are mature and can even be bought as turnkey solutions, entailing a low level of systemic adaptations. The bioeconomy at this stage is more about the diffusion of known technologies rather than the development of new ones.

The main challenges in these two models come from organizational rather than technological aspects. Both vertical integration and horizontal cooperation pose additional management challenges for the ones involved. No advanced research activities are required, so there is no need for a highly-skilled innovative leader. However, some players do need to take the lead to promote and coordinate these initiatives on a local basis. Some specific forms of governance, such as collection agreements, might be needed in the case of waste.

The main economic value added in models 2 and 3 is still related to the substitution of fossil-based products (i.e., biofuels, biogas, electricity, and biofertilizers are all examples of possible outputs in these models). However, those ventures in models 2 and 3 that rely on the circular use of waste are in a better place for mitigating the environmental externalities posed by the use of first-generation feedstocks. In the long run, this requires what Bröring et al. (2020b) define as behavioral innovation in the bioeconomy. The emergence of small-scale biorefineries may also create new jobs and motorize economic activity at a local level.

Model 4: higher-generation feedstocks and advanced technologies

This model has a similar structure to model 1 but we observe here an additional function: R&D and biotech support. Using higher generation feedstocks and getting advanced products from first-generation feedstocks require more complex processing techniques. These are not turnkey technology platforms, so the company in charge of processing the biomass often works closely with a high-skilled technological partner.

The first example of this value chain model comes from the bioplastics industry, in which chemical or petrochemical companies have been associating with biotech companies. For example, the petrochemical company Total joined forces with the biotech company Corbion to produce polylactic acid (PLA) polymer resins from sugarcane (Kees, 2017). We can also mention the company Synvina, originally developed as a joint venture between Avantium – a technology company that develops chemicals based on renewable resources – and the chemicals company Basf to produce bio-based furandicarboxylic acid (FDCA), which can be used for the production of green chemicals[3] (de Jong, 2018).

This type of value chain structure is also common in industries that rely on second-generation technologies. For instance, Poet (ethanol company) and Royal DSM (science-based company) created a joint venture to produce cellulosic bioethanol in Iowa. A comparable experience took place in Italy with a cellulosic ethanol plant in Cresecentino, that originally came up from a partnership between the chemical Mossi & Ghisolfi and the industrial enzyme leader Novozymes[4] (Wydra, 2019). Similarly, Avantium promoted a consortium including many other industrial partners to build a pilot biorefinery in Delfizjl to produce sugars and lignin from woodchips (Vels, 2021). In Brazil, there are two second-generation ethanol plants using sugarcane bagasse and straw as main inputs. One is an association between GranBio and Beta Renewables, and the other one is a joint project between Raízen and Iogen Energy, in cooperation with Novozymes (Karp et al., 2021).

[3] In 2019 Avantium acquired all of BASF's shares.
[4] The plant now belongs to Versalis (subsidiary of Eni group).

Finally, this model is also seen in ventures based on molecular farming, which is a technology that employs transgenic plants to create new industrial proteins, especially for food and pharmaceutical uses (Buyel, 2019). Thus, it requires a combination of both industrial and biotechnological expertise. We can mention two specific examples to illustrate this. The first is the case of the Argentine AGBM, a joint venture between the distiller Porta Hermanos and the biotech company Bioceres, to produce chymosin (an enzyme used in the dairy industry) from transgenic safflower (Rodríguez et al., 2018). A second example comes from the pharmaceutical industry, in which pharmaceutical and biotechnology companies are joining forces for the development of a vaccine against covid-19 from the plant *nicotiana benthamiana* (Maharjan and Choe, 2021).

Unlike models 1 to 3, investments in fixed assets are not enough: funds for research and development are needed as well. This may be expensive (especially in the early stages) and necessarily implies a learning curve. This model is close to what Biber-Freudenberger et al. (2020) define as the manufacturing sector in the bioeconomy (high-volume biomass sector). Companies need to profit from economies of scope in multi-product biorefineries to make the business economically viable.

Given that the specificity of feedstocks increases, upstream systemic adaptations are needed, and thus contracts may be preferable. Contracting allows the bio-processing company to secure feedstock procurement while guaranteeing the farmers a selling channel for a highly specific output. Since 2nd, 3rd and 4th generation feedstocks may have few alternative uses in a specific region, some monopsony power may be created. Collaboration between technology developers and industrial clients seems a core task in this model.

In model 4, the use of biomass is still intensive, but the value-added of the output is higher compared to models 1-3. This model also seeks to depict the adoption of more sophisticated feedstocks which require less arable land or do not compete with food, so there is a higher potential to mitigate environmental externalities.

Model 5: low-volume, high-value biomass

Synthetic biology, one of the workhorses of an upgraded bioeconomy, uses genomic techniques to develop new synthetic compounds that are currently sourced from Nature (El Karoui et al., 2019). Model 5 represents a value chain structure that reflects what might be happening soon in the field of synthetic biology. The promise behind these ventures is twofold. First, new synthetic compounds can replace substances that are either rare and very hard to obtain or whose extraction creates undesirable environmental impacts (e.g. synthetic nootkatone, used as insect repellent, or synthetic artemisinin, used for malaria treatment). Second, synthetic biology can (partially) replace animal proteins, therefore reducing land needs, mitigating GHG emissions from land use change, and improving animal welfare (Lv et al., 2021). Here, a highly-skilled biotech company applies genome editing to engineer new living cells and requires biomass to replicate them through fermentation. The synthetic compounds obtained from these processes then become the input of existing industries.

The most common applications in this field are nutraceuticals, flavor and fragrances, and cosmetics (Wydra, 2019). Many companies are using synthetic biology to produce ingredients such as sweeteners (Amyris), or milk whey (Perfect Day), all based on engineered yeast (Voigt, 2020). In the last five years, we have seen the rise of many startups in the non-animal food ingredients industry. For instance, The Good Food Institute (2021) reports more than 50 companies developing alternative proteins, such as animal-free eggs (Clara Foods), meat (Motif), or dairy (Cultivated), just to mention a few. While some products in this field have already reached a commercial scale (mainly pharma and cosmetics), others are still working on a low scale or in a pilot phase (especially those related to food substitutes).

Some of these technologies require edible feedstocks (sugar or starch), while many other projects base their applications on second-generation biomass (residues or non-edible feedstocks). Moreover, fermentation not only takes place through biomass but is also based on microbial hosts, a process defined as precision fermentation (The Good Food Institute, 2021). In any case, the precision techniques that are used increase fermentation efficiency so we may see a decrease in biomass flows compared to the previous four models, therefore reducing land use requirements and GHG emissions[5]. From an economic standpoint, this value chain model can be considered a low-volume and high-value transformation pathway (Dietz et al., 2018). This implies bringing to the market new products and biochemical processes, most of which do not exist in the fossil-based economy.

Risk and uncertainties associated with the innovation process are considerable since companies face high risks of failure. The techniques applied by the companies in this model are tailor-made and imply a continuous interaction between scientists and entrepreneurs. There are systemic characteristics and collaboration needs that become evident in the stage of product development.

Firms need to control the value chain, both upstream and downstream. Upstream, it is unlike that biomass used in a fermentation process will be sourced through pure market mechanisms, since the control over its quality needs to be strict. Downstream, developing selling channels for synthetic products is challenging, and often requires commercial partnerships with companies that are established already. Currently, many startups are deploying synthetic biology applications: small science-based ventures can develop the initial stages of a specific technology and then sell it or associate with bigger partners to scale it up. However, in the long run, increasing returns of scale might lead to the presence of companies with a size that allows them to undertake the level of investments needed.

[5] Alternatively, we could hypothesize that, as fermentation efficiency increases, prices could drastically decrease, thus greatly increasing demand. Such rebound effect could further increase biomass flows and pressure on land.

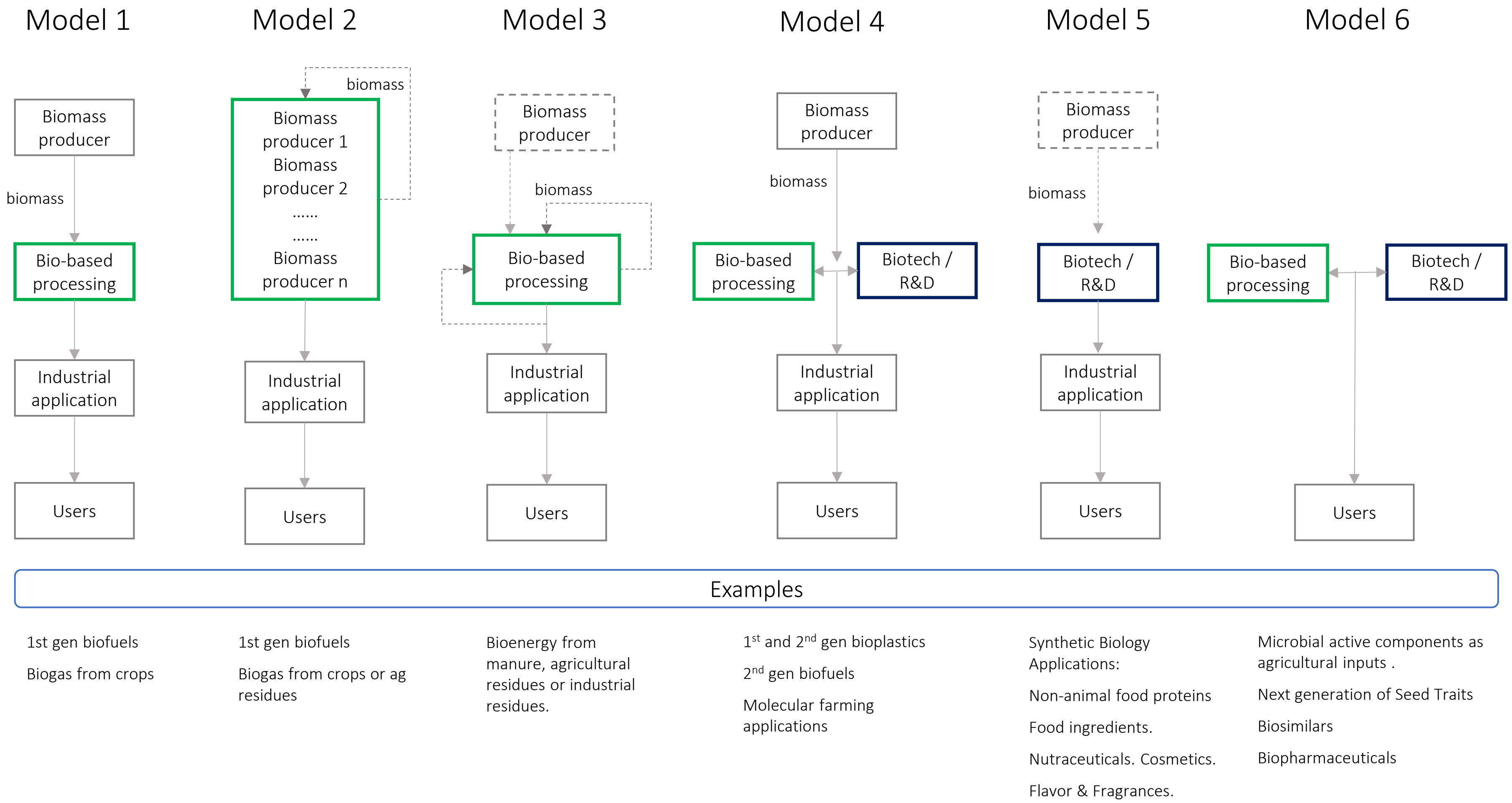

Figure 2. Typology of value chains in the bioeconomy.

Model 6: biomass-free biotechnologies

The combination of biomass and biotechnology is often highlighted by different bioeconomy definitions. However, there are products and services in the bioeconomy that are almost exclusively based on biotechnology research and do not necessarily involve biomass flow. Model 6 depicts these types of initiatives. In this value chain structure, there is no bio-based processing as such, but rather a convergence of companies that hold specific industry knowledge with companies that provide biotechnological research platforms. This convergence can take many forms, from completely structured joint ventures to more informal partnerships or alliances. Many of these ventures are focused on microbial platforms, metabolic engineering, and genome editing, which have been identified among the most advanced key enabling technologies for the future of the bioeconomy (Laibach et al., 2019).

We can mention two examples to illustrate this model. A first example is the development of microbial active bio-inputs for the agricultural sector, for which traditional agricultural input companies are associating with biotech companies (e.g. Syngenta and AgBiome, Bayer and Gingko Bioworks). A second example comes from the health care industry, in which we observe partnerships between pharmaceuticals and biotech companies to develop biosimilars (e.g., Amgen-Allegran Kanjinti and Mylan-Biocon Ogivri, both Herceptin biosimilars) and a new generation of biopharmaceuticals (e.g., Gingko Bioworks-Roche for the development of advanced antibiotics). The joint initiatives between Cellscript-Moderna and Pfizer-BioNtech for the development of mRNA Covid-19 vaccines is another example of this model that comes from the pharmaceutical industry (Gaviria and Kilic, 2021). As we can see from these examples, we have complementary companies joining forces to bring new low-bulk and high-value applications to the market.

As was previously described, many of these platforms are not strictly based on biomass processing. Thus, in this case, the risk of environmental impacts seems low. However, caution is necessary; as in model 5, the use of new genetic techniques and the application of engineering principles to life sciences might also bring some concerns in terms of potential biosecurity hazards to human health and biodiversity (Li et al., 2021).

As in model 5, companies face high risks of failure in the product development stage. Regulation is an issue, especially in human health products. The need for managing and protecting intellectual property leads companies to gain more control of their value chain by getting involved in different stages. Since it is unlikely that one individual company can hold the complete set of skills needed for this type of complex process, inter-industrial collaboration, platform sharing, and research interaction are unavoidable.

4.2 The rate of innovation in the bioeconomy

As we detailed in this section, the six bioeconomy value chain models presented in Figure 2 involve different levels of scientific research and biotechnology skills. In Schumpeterian terms, models 1 to 3 are characterized by the diffusion of mature and turnkey technologies, while models 4 to 6 rely on the transition from invention to innovation, in which either new technologies are developed or known technologies are used to create new bio-based products. At the same time, models 1 to 3, and partially model 4, rely critically on biomass availability, for which logistics and handling efficiency are key to success. Models 5-6, on the other hand, belong to a low-volume and high-value transformation pathway in which biomass handling is not essentially a success factor.

Thus, when we go from left to right in Figure 2 we observe that risks and uncertainties increase, higher capital requirements are needed, the rate of innovation intensifies (both in products and processes) and systemic characteristics and network effects become more evident. In Table 3 we summarize for each model the dimensions of the innovation process and the technologies involved. We acknowledge that the models as they were presented reflect more a static than a dynamic approach. The concept of technological trajectories (Dosi, 1982) implies that technologies mature in time, so they get cheaper and more accessible. Thus, models 4-6 might probably reflect some of the characteristics of models 1-3 in the future. However, the main bio-based technologies that we see rising now (i.e., synthetic biology or gene editing) have substantial disruptive potential, and we cannot yet foresee how the trajectory will take place for them.

In section **Error! Reference source not found.** we discussed the codetermination between value chains and innovation. How does this apply to a process of bioeconomy upgrading? On the one hand, we will likely observe changes in the morphology of value chains as the biotechnology intensity increases. On the other hand, some value chains show features that could be more favorable to innovation and accelerate the rate at which new technologies are developed and adopted. In Table 4 we present a summary of the main value chain features of each model.

Each of the value chain models that were presented will play a role in the process of bioeconomy upgrading as we showed in Table 2. All of them have the potential to contribute to environmental sustainability and create business opportunities. However, the last models seem to hold fewer risks of undesired environmental externalities. This is because they are either based on more space-efficient feedstocks and waste or because they rely less on biomass and more on biotechnology. From an economic perspective, products and services in the last models hold higher value-added per unit and are closer to final users (we move from biofuels, bioenergy, or biofertilizers to biopharmaceuticals, biocosmetics, and food products, just to mention a few examples).

Table 2. Typology of value chains in the bioeconomy. Role in a bioeconomy upgrading.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Environmental externalities	Mainstream use of first-generation technologies. High risk of environmental impacts in the long run due to land-use change.	There are risks associated with the use of first-generation technologies. However, in the case of waste, there is a higher GHG mitigation potential. Adoption of circular economy practices.	There are risks associated with the use of first-generation technologies. However, in the case of waste, there is a higher GHG mitigation potential. Adoption of circular economy practices.	The palette of feedstocks used is wide. The risk of externalities is mitigated when more efficient feedstocks are used (2nd, 3rd, and 4th gen).	Less intensity in terms of biomass processing. This reduces the risks of land-use change and GHG emissions.	The technological processes are not strictly based on biomass processing. Low risk of environmental impacts.
Economic Value Added	Substitution of fossil-based products. High volume-low value.	Substitution of fossil-based products. High volume-low value. Space for local biorefineries and new employment opportunities in rural areas.	Substitution of fossil-based products. High volume-low value. Space for local biorefineries and new employment opportunities in rural areas.	Substitution of fossil-based products. The use of biomass is still intensive, but value-added is higher compared to models 1-3.	Low volume/High Value. New products and processes.	Low volume/High Value. New products and processes.

Table 3. Typology of value chains in the bioeconomy. Characteristics of the innovation process and the technologies involved.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Risks and Uncertainty	Mature, turnkey technologies. Biomass intensive. Efficiency and logistics are key to success.	Mature, turnkey technologies. Biomass intensive. In-place processing.	Mature, turnkey technologies. Biomass intensive. In-place processing.	Application of known technologies to new processes. Technologies are not fully mature (may still be expensive). Steep learning curve.	New conversion pathways. High risks of failure. Tailor-made technologies.	New conversion pathways. High risks of failure. Tailor-made technologies.
Investments and Capital Requirements	Investment in fixed assets. Decreasing returns to scale.	Investment in fixed assets. Decreasing returns to scale.	Investment in fixed assets. Decreasing returns to scale.	Investment in fixed assets but also in R&D. Need to develop and protect IP.	High R&D Costs. Increasing return of scale. Regulation is an issue. Need to develop and protect IP.	High R&D Costs. Increasing return of scale. Regulation is an issue. Need to develop and protect IP.
Intensity of innovation	Diffusion of known technologies.	Diffusion of known technologies. Changes in behavior (circular approach).	Diffusion of known technologies. Changes in behavior (circular approach).	Invention-Innovation	Invention-Innovation	Invention-Innovation
Systemic characteristics	Low	Low	Low	Medium	High	High

Table 4. Typology of value chains in the bioeconomy. Value chain features.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Governance	Procurement of biomass follows market prices. Supply contracts can exist (but not necessarily).	Horizontal and vertical (forward) integration. Need for contracting schemes. Collection agreements (in the case of waste).	Vertical integration. Collection agreements (in the case of waste).	Contracts for biomass supply (especially for higher generation feedstocks).	Lead firms need to control the value chain. Supply contracts and vertical integration are preferred over market mechanisms.	Lead firms need to control the value chain.
Structure	Many firms. Geographical concentration.	Many firms. Geographical concentration.	Many firms. Geographical concentration.	Big Players. In the case of 2nd, 3rd, and 4th gen of feedstocks, some monopsony power may be created.	Big players with developed capabilities. Place for start-ups to develop and "carry" new developments. Shorter value chains.	Big players with developed capabilities. Place for start-ups to develop and "carry" new developments. Shorter value chains.
Collaboration among firms	Low	Horizontal cooperation among biomass producers.	Low	Partnerships between technology developers and industrial clients. Research capabilities are needed.	Partnerships between technology developers and industrial clients. Research capabilities are needed.	Inter-industry collaboration.
Leadership & firm Capabilities	Low	Low	Low	High	High	High

5. Welfare implications of bioeconomy innovation

The value chain features associated with each of the models in a bioeconomy upgrading are nontrivial from a welfare perspective. While innovation is crucial to safeguard environmental sustainability in the bioeconomy (or at least minimizing environmental impacts), social sustainability aspects should not be thrust aside, given that costs and benefits from an intensified rate of innovation may be redistributed among value chain actors.

The distribution of the value-added created in a bioeconomy upgrading poses many questions. The cost of new bio-based products may be prohibitive to some consumers (Timmermann, 2020). Will every consumer have access to these new bio-based products at a reasonable price? In the case of farmers, they might have to bear extra costs to comply with additional value chain requirements (Ponte, 2020). But are small farmers going to be able to participate in upgraded value chains and get a fair share of the new market opportunities? And what about midstream actors? Many of them contribute to the creation and diffusion of innovations (Reardon, 2015). To what extent this will happen in bio-based value chains is not yet clear.

We do not have today substantial evidence on the distributional effects produced by core bioeconomy innovations, since many of them are yet far from commercial viability. However, based on the available literature on value chains, we can propose some hypotheses.

5.1 Governance Schemes

In section 0 we saw that augmented bioeconomy innovation is associated with shorter and vertically coordinated value chains. Value chains become tighter when specific research activities are required. There are two main reasons behind this. First, markets for some bio-based products are not yet developed. Downstream, innovators need to develop distribution channels and deal with consumer acceptance. Upstream, higher generation feedstocks (e.g., energy crops, algae, molecular farming) tend to be transaction-specific, so innovators need to offer farmers a secure selling channel, which is normally done through contracts. Even collection agreements may be needed for residual biomass. The second reason is related to the systemic nature of innovations in the bioeconomy, which compels firms to engage in many steps of the value chain to improve control. The need to protect intellectual property rights (IPRs) while transferring technology demands more vertical integration (Lee, 2018). This holds especially in contexts lacking strong institutions that safeguard IPRs. However, where such institutions exist and are well-functioning, firms might be more willing to use licensing (Deconinck, 2020).

In this context, the first question here is related to the inclusion of small farmers in upgraded bioeconomy value chains. Previous experiences show that while different forms of inclusion are possible (Maertens and Swinnen, 2009), there are also risks of exclusion when small and large farms coexist (Reardon et al., 2009). Smaller farms probably lack the scale, capital requirements, and non-land assets to supply big processing companies. This may favor contracts with larger farms to secure feedstocks procurement.

Another discussion is related to potential costs created by new environmental compliance requirements. These additional costs could be pushed upstream to farmers (Ponte, 2020). Also, smallholders might be forced to make upgrading investments if they want to keep selling, as has happened with private standards in the past (Lee et al., 2012).

Finally, the effects of vertical coordination on farmers' welfare are still under debate. Despite contracts being considered a way to improve farmers' livelihoods, these benefits are context and product-specific (Meemken and Bellemare, 2020; Ruml and Qaim, 2020). Many of the studies in this field lack external (and in some cases, internal) validity (Bellemare and Bloem, 2018). Thus, it is better to be cautious rather than conclusive on this issue.

5.2 Industry structure

An acceleration in bio-based innovation could potentially increase market shares and concentration. Moving from first-generation to advanced feedstocks requires expensive investments in research and development. And these investments are not always a clear shot: risks of failure bring sunk costs into the cost equation. Moreover, biological organisms are not completely controllable, so there is a steep learning curve and periods of trial and error. Thus, bigger companies are in a better position to deal with all these issues, at least until these technologies are mature and more accessible.

Moreover, innovation naturally creates monopoly rents and there might be winner-takes-all situations. This is the case when a certain platform becomes the dominant technology (Schilling, 2009). Also, the stronger role of IPRs may lead to different forms of concentration, especially in downstream activities (Lee, 2019). This is especially relevant in models 4 to 6 since in models 1 to 3 it is easier for smaller actors to get involved.

There is mixed evidence of welfare effects from the augmented buyer and seller market power in agricultural value chains (Swinnen and Vandeplas, 2010). However, in the case of the bioeconomy, we can expect big players from buyer-driven value chains to take the lead, especially in consumer-oriented applications (i.e., cosmetics, nutraceuticals, food). This holds implications for the international division of labor: if developed countries are the ones who own the patents and focus on R&D and downstream activities, then developing countries will be constrained only to the supply of raw materials (Gries et al., 2018; Reis et al., 2020). If this is the case, additional benefits from bioeconomy innovation will likely stay in developed countries. However, benefit sharing will ultimately depend on the type of technology being discussed: research has suggested that most welfare benefits from GM soybeans in the USA have been reaped by farmers and not the seed companies (Ciliberto et al., 2019).

There are two immediate concerns about market power: prices and investments in R&D. The effect is not clear in the case of prices. For instance, while the increased concentration in low R&D industries, such as the fertilizer industry, has raised input prices, the overall effect on prices from concentration in the seed and biotech industries is still disputed (Deconinck, 2020). Evidence is divided for R&D investments as well. The belief is that higher market shares allow firms to allocate money for risky ventures. But while some authors support this (Chassagnon and Haned, 2015; Smolny, 2003), others state that the effects of concentration on innovation are unclear (del Río et al., 2016; Horbach, 2008). Nonetheless, it is important to note that despite the growing role of private R&D in developing technologies for the agri-food sector, public investments are still relevant and often complementary to private R&D (Pray and Fuglie, 2015).

5.3 Collaboration among firms

In the long run, a bioeconomy upgrading calls for higher levels of collaboration and cooperation among companies in value chains. This can take many forms, such as alliances, partnerships, or joint ventures. As we saw in section 4, moving from turnkey to tailor-made technologies (models 4-6) naturally leads to sharing knowledge, since one single firm cannot have all the skills required and need to rely on capacities developed by others.

An accelerated rate of innovation in the bioeconomy increases the relative weight of biotechnology compared to biomass. This opens a gap for startups and small tech firms to assume risks by becoming early-stage developers of new technologies (Tsvetanova et al., 2021), and then scale up in association with other firms. Inter-organizational collaboration is crucial to foster innovation among SMEs (Radziwon and Bogers, 2019), and developing countries can promote new hi-tech startups and support the creation of local innovation ecosystems. These SMEs can benefit smallholders even in a non-contract environment, by transferring knowledge and technology to them (Liverpool-Tasie et al., 2020).

But are small firms going to be able to survive? Or big firms will end up taking them over? While small startups can be the first movers and develop their own technologies, in the long run additional research funds and scale become crucial for survival (Lee, 2019). When small firms run out of funds, the take-over opportunity emerges for the big ones. Also, there are risks of new forms of exclusion created by cross-licensing practices, if the access to specific technologies is limited to a specific circle of incumbent firms (Deconinck, 2020).

5.4 Leadership and firm capabilities

Lead firms will have an important role in fostering technological innovation and bringing other value chain members into the process. In the case of mature technologies that do not require research activities, lead actors that promote associative practices and organizational changes are needed (this is especially relevant for models 2-3). In a high-value-low-volume transformation pathway, in which knowledge becomes the key success factor, highly skilled firms are naturally the ones that can create, protect, and capture value from intellectual property and may become key facilitators of a bioeconomy upgrading.

Nevertheless, the technology that is created needs to be transferred to improve welfare. To whom will these technologies be transferred and under what conditions? Access to knowledge is needed to help least developed countries reach growth convergence. A well-designed value chain should help to transfer knowledge, but this might not take place without a minimum threshold of capabilities in the least developed countries (Gries et al., 2018; Janssen and Swinnen, 2019). Also, this could increase technological dependency in developing countries. Acemoglu (2002) suggests that technical change strongly biased towards skilled labor may increase the income gap between rich and poor countries, given that developed countries are the ones with the highest share of skilled workers.

Another welfare effect is related to low-volume and high-value trajectories in a bioeconomy upgrading. As we mentioned in the previous section, models 5, 6, and partially model 4, may reduce biomass needs. This forces midstream actors to revisit their role, especially those who are in charge of transportation and storage. Moreover, the possibility of creating food substitutes in a lab will likely affect the income of cattle and dairy farmers – albeit reducing negative environmental externalities. The final effect will depend on whether new synthetic products work as complements to traditional value chains rather than substituting them (Stephens et al., 2018). In the near future, we will likely see biomass-intensive products coexisting with their synthetic substitutes but as we approach a fully upgraded bioeconomy, we should see biomass-intensive products lose most of their market share.

6. Conclusions

A sustainable transition to a bioeconomy requires more than replacing fossil-based products. It calls for a shift in the current technological paradigm. Many promising bioeconomy innovations could lead us towards the gates of a new industrial revolution. In this paper, we proposed the concept of bioeconomy upgrading to describe trajectories that minimize negative environmental externalities and create new opportunities for adding economic value.

We consider that the original contribution of this paper lies in the systematization of an overarching typology of value chains in the highly dynamic landscape of the bio-based economy. While many of the current debates focus mainly on primary production and biomass-intensive activities, a bioeconomy upgrading implies a broader range of activities, some of them biotech-intensive. Each of the six presented models shows different characteristics in terms of the technologies involved (from mature technologies to completely new bio-based techniques) and how innovation takes place (from a diffusion process, that requires mainly organizational changes, to an invention-innovation process that demands research skills and collaboration). The acceleration of innovation rates in the bioeconomy is associated with (a) shorter and tighter value chains with an increasing degree of vertical coordination; (b) enhanced role of big and leader firms and potentially more concentration, at least until new bio-based technologies become mature; (c) more collaboration and knowledge sharing among value chain members, to move from turnkey to tailor-made technologies, and (d) a leading role of firms with core research capabilities, driving innovations and bringing other value chain members into them.

Since innovation may create environmental benefits as well as welfare changes, we also presented in this paper some lines of thought on the social dimension of a bioeconomy upgrading, for which empirical research is still limited. Future research should explicitly account for value chain organizational aspects in the bioeconomy, for a better assessment of who are the winners and losers of these innovation processes. This is critical to understand to what extent an inclusive bioeconomy is possible. For example, our models show that in the process of bioeconomy upgrading (dominated by low-volume and biotech-intensive value chains), farmers might obtain only a small share of the surplus created, as more value is added by downstream activities. However, at the same time opportunities to participate in new value chains might open for them (e.g., farmers might be able to participate in the bioplastics value chain, while they do not have a role in the industry of fossil-based plastics).

While it seems hard to change the natural course of a technological transition, policymakers should consider measures to mitigate potential harmful effects for the weakest value chain actors. In this context, it is crucial to foster policies that safeguard the interest of the weakest value chain actors, giving them access to these new bio-based technologies and ensuring that they will not be left out of the transition towards a fully upgraded bioeconomy. But while access to these technologies is crucial, another important aspect to consider is whether end consumers – be they farmers or households in urban centers – will welcome these bio-based innovations. Complexity in how to use the technologies or difficulty in perceiving its benefits can hinder adoption (Ploll et al., 2022).

We are aware that one of the main characteristics of the bioeconomy is the convergence among economic sectors and the creation of dynamic value webs (Scheiterle et al., 2018). Biomass cascading use and knowledge sharing contribute to blurring the boundaries between industries. On behalf of simplicity and generalization, all the value chain maps in Figure 2 were presented in a linear set-up, but we believe that these models still represent the highly inter-industrial setting of the bioeconomy. Each of the presented value chain maps is built by actors from different industries, and the same happens with biomass flows. For instance, in models 1-3 there are interactions between food, feed, and energy industries. In model 4 we see how traditional chemical industries get into the production of renewable energy and bio-based products. The same happens in models 5-6, where actors with complementary capacities join to launch new products to the market.

Moreover, the models presented in the typology should not be understood as separate compartments without interlinkages. Part of the more advanced products of the bioeconomy are supposed to supply to more traditional value chains in the future. For example, agricultural bio-inputs or second-generation seed traits, that are reflected in model 6, will provide inputs for biomass production for all the models. In this regard, we foresee two main debates. The first one is around adoption, and to what extent final users (i.e., farmers, consumers, patients) are willing to embrace new biotech-intensive products. The second debate is access: will all these products be available at an affordable cost for the final users who are willing to adopt them?

There are four caveats in our work. First, a systematization based on typologies normally entails a degree of simplification. It is possible that many bioeconomy initiatives and business cases do not fit perfectly under any of the models that we proposed. Second, those models should be considered complements rather than substitutes: we expect that goods and industrial processes that rely on high-volume and low-value biomass will lose their economic importance, but some of the technologies discussed may be one-to-one substitutes while others do not. The rate of innovation in bio-based initiatives will accelerate in the near future, but all the presented models will likely coexist in an upgraded bioeconomy. Third, for a bioeconomy upgrading to be sustainable, we are assuming that biomass production is input-efficient, and food has priority over the allocation of the available productive land. Sustainably produced biomass is a core principle of the bioeconomy and to uphold it we might require investments in technology as well as institutional innovations. Finally, we presented innovation as a consistent path to reducing negative environmental externalities. However, these may not be completely ruled out. Leading technologies could bring unforeseen environmental challenges in the future.

From a research perspective, there are still many opportunities to understand the causal mechanisms lying behind the interaction between value chains and innovation. Also, research efforts should be aimed at studying the welfare effects of a bioeconomy upgrading, to include social sustainability in the bioeconomy agenda. Hopefully, the conceptual framework presented in this paper will guide future empirical research in the field of the bioeconomy.

References

Acemoglu, D., 2002. Directed Technical Change. Rev. Econ. Stud. 69, 781–809.

Allal-Chérif, O., Guijarro-Garcia, M., Ulrich, K., 2022. Fostering sustainable growth in aeronautics: Open social innovation, multifunctional team management, and collaborative governance. Technol. Forecast. Soc. Change 174, 121269. https://doi.org/10.1016/j.techfore.2021.121269

Barrett, C.B., Reardon, T., Swinnen, J., Zilberman, D., n.d. Agri-food Value Chain Revolutions in Low- and Middle-Income Countries. J. Econ. Lit. https://doi.org/10.1257/jel.20201539

Bellemare, M.F., Bloem, J.R., 2018. Does contract farming improve welfare? A review. World Dev. 112, 259–271. https://doi.org/10.1016/j.worlddev.2018.08.018

Biber-Freudenberger, L., Basukala, A., Bruckner, M., Börner, J., 2018. Sustainability Performance of National Bio-Economies. Sustainability 10, 2705. https://doi.org/10.3390/su10082705

Biber-Freudenberger, L., Ergeneman, C., Förster, J.J., Dietz, T., Börner, J., 2020. Bioeconomy futures: Expectation patterns of scientists and practitioners on the sustainability of bio-based transformation. Sustain. Dev. sd.2072. https://doi.org/10.1002/sd.2072

Boone, C., Özcan, S., 2014. Why Do Cooperatives Emerge in a World Dominated by Corporations? The Diffusion of Cooperatives in the U.S. Bio-Ethanol Industry, 1978–2013. Acad. Manage. J. 57, 990–1012. https://doi.org/10.5465/amj.2012.0194

Bossle, M.B., Dutra de Barcellos, M., Vieira, L.M., Sauvée, L., 2016. The drivers for adoption of eco-innovation. J. Clean. Prod. 113, 861–872. https://doi.org/10.1016/j.jclepro.2015.11.033

Bröring, S., 2008. How systemic innovations require alterations along the entire supply chain: the case of animal-derived functional foods. J. Chain Netw. Sci. 8, 107–119. https://doi.org/10.3920/JCNS2008.x093

Bröring, S., Baum, C.M., Butkowski, O.K., Kircher, M., 2020a. Criteria for the Success of the Bioeconomy, in: Pietzsch, J. (Ed.), Bioeconomy for Beginners. Springer, Berlin, Heidelberg, pp. 159–176. https://doi.org/10.1007/978-3-662-60390-1_8

Bröring, S., Laibach, N., Wustmans, M., 2020b. Innovation types in the bioeconomy. J. Clean. Prod. 266, 121939. https://doi.org/10.1016/j.jclepro.2020.121939

Buyel, J.F., 2019. Plant Molecular Farming – Integration and Exploitation of Side Streams to Achieve Sustainable Biomanufacturing. Front. Plant Sci. 9. https://doi.org/10.3389/fpls.2018.01893

Calzada, J., Molina, C., 2017. La industria del biodiesel en Argentina (No. 1823), Informativo Semanal. Bolsa de Comercio de Rosario (BCR), Argentina.

Carraresi, L., Berg, S., Bröring, S., 2018. Emerging value chains within the bioeconomy: Structural changes in the case of phosphate recovery. J. Clean. Prod. 183, 87–101. https://doi.org/10.1016/j.jclepro.2018.02.135

Carrosio, G., 2013. Energy production from biogas in the Italian countryside: Policies and organizational models. Energy Policy 63, 3–9. https://doi.org/10.1016/j.enpol.2013.08.072

Ceres, 2018. An investor brief on impacts that drive business risks: palm oil, Engage the Chain. Ceres.

Chaddad, F.R., 2010. UNICA: Challenges to Deliver Sustainability in the Brazilian Sugarcane Industry. Int. Food Agribus. Manag. Rev. 13, 20.

Chassagnon, V., Haned, N., 2015. The relevance of innovation leadership for environmental benefits: A firm-level empirical analysis on French firms. Technol. Forecast. Soc. Change 91, 194–207. https://doi.org/10.1016/j.techfore.2014.02.012
Ciliberto, F., Moschini, G., Perry, E.D., 2019. Valuing product innovation: genetically engineered varieties in US corn and soybeans. RAND J. Econ. 50, 615–644. https://doi.org/10.1111/1756-2171.12290
Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N., Leip, A., 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. Nat. Food 2, 198–209. https://doi.org/10.1038/s43016-021-00225-9
de Jong, E., 2018. DAWN Technology: The future of Biorefinery.
Deconinck, K., 2020. Concentration in Seed and Biotech Markets: Extent, Causes, and Impacts. Annu. Rev. Resour. Econ. 12, 129–147. https://doi.org/10.1146/annurev-resource-102319-100751
del Río, P., Peñasco, C., Romero-Jordán, D., 2016. What drives eco-innovators? A critical review of the empirical literature based on econometric methods. J. Clean. Prod. 112, 2158–2170. https://doi.org/10.1016/j.jclepro.2015.09.009
Demirel, P., Mazzucato, M., 2010. The Evolution of Firm Growth Dynamics in the US Pharmaceutical Industry. Reg. Stud. 44, 1053–1066. https://doi.org/10.1080/00343400903241469
Dietz, T., Börner, J., Förster, J., von Braun, J., 2018. Governance of the Bioeconomy: A Global Comparative Study of National Bioeconomy Strategies. Sustainability 10, 3190. https://doi.org/10.3390/su10093190
Diffenbaugh, N.S., Burke, M., 2019. Global warming has increased global economic inequality. Proc. Natl. Acad. Sci. 116, 9808–9813. https://doi.org/10.1073/pnas.1816020116
Donovan, J., Franzel, S., Cunha, M., Gyau, A., Mithöfer, D., 2015. Guides for value chain development: a comparative review. J. Agribus. Dev. Emerg. Econ. 5, 2–23. https://doi.org/10.1108/JADEE-07-2013-0025
Dosi, G., 1982. Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. Res. Policy 11, 147–162. https://doi.org/10.1016/0048-7333(82)90016-6
Du, X., Lu, L., Reardon, T., Zilberman, D., 2016. Economics of Agricultural Supply Chain Design: A Portfolio Selection Approach. Am. J. Agric. Econ. 98, 1377–1388. https://doi.org/10.1093/ajae/aaw074
El Karoui, M., Hoyos-Flight, M., Fletcher, L., 2019. Future Trends in Synthetic Biology—A Report. Front. Bioeng. Biotechnol. 7. https://doi.org/10.3389/fbioe.2019.00175
Escobar, N., Haddad, S., Börner, J., Britz, W., 2018. Land use mediated GHG emissions and spillovers from increased consumption of bioplastics. Environ. Res. Lett. 13, 125005. https://doi.org/10.1088/1748-9326/aaeafb
Escobar, N., Laibach, N., 2021. Sustainability check for bio-based technologies: A review of process-based and life cycle approaches. Renew. Sustain. Energy Rev. 135, 110213. https://doi.org/10.1016/j.rser.2020.110213
FAO, 2020. Modelos de negocios para proyectos de energía térmica de biomasa, Colección Documentos Técnicos. FAO. https://doi.org/10.4060/ca8589es
Gaviria, M., Kilic, B., 2021. A network analysis of COVID-19 mRNA vaccine patents. Nat. Biotechnol. 39, 546–548. https://doi.org/10.1038/s41587-021-00912-9
Gawer, A., Cusumano, M.A., 2014. Industry Platforms and Ecosystem Innovation. J. Prod. Innov. Manag. 31, 417–433. https://doi.org/10.1111/jpim.12105

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy, NELSON + WINTER + 20 31, 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Golembiewski, B., Sick, N., Bröring, S., 2015. Patterns of Convergence Within the Emerging Bioeconomy — The Case of the Agricultural and Energy Sector. Int. J. Innov. Technol. Manag. 12, 1550012. https://doi.org/10.1142/S0219877015500121

Gries, T., Grundmann, R., Palnau, I., Redlin, M., 2018. Technology diffusion, international integration and participation in developing economies - a review of major concepts and findings. Int. Econ. Econ. Policy 15, 215–253. https://doi.org/10.1007/s10368-017-0373-7

Hawken, P., Frischmann, C., Bayuk, K., Mehra, M., Gouveia, J., Zame, K., Mukkavilli, s. K., 2017. Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming.

Horbach, J., 2008. Determinants of environmental innovation—New evidence from German panel data sources. Res. Policy 37, 163–173. https://doi.org/10.1016/j.respol.2007.08.006

Janssen, E., Swinnen, J., 2019. Technology adoption and value chains in developing countries: Evidence from dairy in India. Food Policy 83, 327–336. https://doi.org/10.1016/j.foodpol.2017.08.005

Jeswani, H.K., Chilvers, A., Azapagic, A., 2020. Environmental sustainability of biofuels: a review. Proc. R. Soc. Math. Phys. Eng. Sci. 476, 20200351. https://doi.org/10.1098/rspa.2020.0351

Jiménez-Sánchez, G., Philp, J., 2015. Omics and the bioeconomy. EMBO Rep. 16, 17–20. https://doi.org/10.15252/embr.201439409

Karp, S.G., Medina, J.D.C., Letti, L.A.J., Woiciechowski, A.L., de Carvalho, J.C., Schmitt, C.C., de Oliveira Penha, R., Kumlehn, G.S., Soccol, C.R., 2021. Bioeconomy and biofuels: the case of sugarcane ethanol in Brazil. Biofuels Bioprod. Biorefining 15, 899–912. https://doi.org/10.1002/bbb.2195

Kees, J., 2017. Total Corbion PLA: An innovative Joint Venture making PLA innovations a reality.

Kircher, M., 2021. Bioeconomy – present status and future needs of industrial value chains. New Biotechnol. 60, 96–104. https://doi.org/10.1016/j.nbt.2020.09.005

Kuijpers, R., Swinnen, J., 2016. Value Chains and Technology Transfer to Agriculture in Developing and Emerging Economies. Am. J. Agric. Econ. 98, 1403–1418. https://doi.org/10.1093/ajae/aaw069

Laibach, N., Börner, J., Bröring, S., 2019. Exploring the future of the bioeconomy: An expert-based scoping study examining key enabling technology fields with potential to foster the transition toward a bio-based economy. Technol. Soc. 58, 101118. https://doi.org/10.1016/j.techsoc.2019.03.001

Lee, J., Gereffi, G., Beauvais, J., 2012. Global value chains and agrifood standards: Challenges and possibilities for smallholders in developing countries. Proc. Natl. Acad. Sci. 109, 12326–12331. https://doi.org/10.1073/pnas.0913714108

Lee, P., 2019. Reconceptualizing the Role of Intellectual Property Rights in Shaping Industry Structure (SSRN Scholarly Paper No. ID 3271882). Social Science Research Network, Rochester, NY.

Lee, P., 2018. Innovation and the Firm: A New Synthesis (SSRN Scholarly Paper No. ID 3028989). Social Science Research Network, Rochester, NY.

Li, J., Zhao, H., Zheng, L., An, W., 2021. Advances in Synthetic Biology and Biosafety Governance. Front. Bioeng. Biotechnol. 9, 173. https://doi.org/10.3389/fbioe.2021.598087

Li, M., Jia, N., Lenzen, M., Malik, A., Wei, L., Jin, Y., Raubenheimer, D., 2022. Global food-miles account for nearly 20% of total food-systems emissions. Nat. Food 3, 445–453. https://doi.org/10.1038/s43016-022-00531-w

Lin, J., Gupta, S., Loos, T., Birner, R., 2019. Opportunities and Challenges in the Ethiopian Bamboo Sector: A Market Analysis of the Bamboo-Based Value Web. Sustainability 11, 1644. https://doi.org/10.3390/su11061644

Liverpool-Tasie, L.S.O., Wineman, A., Young, S., Tambo, J., Vargas, C., Reardon, T., Adjognon, G.S., Porciello, J., Gathoni, N., Bizikova, L., Galiè, A., Celestin, A., 2020. A scoping review of market links between value chain actors and small-scale producers in developing regions. Nat. Sustain. 3, 799–808. https://doi.org/10.1038/s41893-020-00621-2

Loos, T., Hoppe, M., Dzomeku, B., Scheiterle, L., 2018. The Potential of Plantain Residues for the Ghanaian Bioeconomy—Assessing the Current Fiber Value Web. Sustainability 10, 4825. https://doi.org/10.3390/su10124825

Lv, X., Wu, Y., Gong, M., Deng, J., Gu, Y., Liu, Y., Li, J., Du, G., Ledesma-Amaro, R., Liu, L., Chen, J., 2021. Synthetic biology for future food: Research progress and future directions. Future Foods 3, 100025. https://doi.org/10.1016/j.fufo.2021.100025

Maertens, M., Swinnen, J.F.M., 2009. Trade, Standards, and Poverty: Evidence from Senegal. World Dev. 37, 161–178. https://doi.org/10.1016/j.worlddev.2008.04.006

Maharjan, P.M., Choe, S., 2021. Plant-Based COVID-19 Vaccines: Current Status, Design, and Development Strategies of Candidate Vaccines. Vaccines 9, 992. https://doi.org/10.3390/vaccines9090992

Maynard, A.D., 2015. Navigating the fourth industrial revolution. Nat. Nanotechnol. 10, 1005–1006. https://doi.org/10.1038/nnano.2015.286

Mazzucato, M., Robinson, D.K.R., 2018. Co-creating and directing Innovation Ecosystems? NASA's changing approach to public-private partnerships in low-earth orbit. Technol. Forecast. Soc. Change 136, 166–177. https://doi.org/10.1016/j.techfore.2017.03.034

Meemken, E.-M., Barrett, C.B., Michelson, H.C., Qaim, M., Reardon, T., Sellare, J., 2021. Sustainability standards in global agrifood supply chains. Nat. Food 2, 758–765. https://doi.org/10.1038/s43016-021-00360-3

Meemken, E.-M., Bellemare, M.F., 2020. Smallholder farmers and contract farming in developing countries. Proc. Natl. Acad. Sci. 117, 259–264. https://doi.org/10.1073/pnas.1909501116

Meinrenken, C.J., Chen, D., Esparza, R.A., Iyer, V., Paridis, S.P., Prasad, A., Whillas, E., 2020. Carbon emissions embodied in product value chains and the role of Life Cycle Assessment in curbing them. Sci. Rep. 10, 6184. https://doi.org/10.1038/s41598-020-62030-x

Minten, B., Dereje, M., Engida, E., Tamru, S., 2018. Tracking the Quality Premium of Certified Coffee: Evidence from Ethiopia. World Dev. 101, 119–132. https://doi.org/10.1016/j.worlddev.2017.08.010

Navarrete, S.D.S., Borini, F.M., Avrichir, I., 2020. Environmental upgrading and the United Nations Sustainable Development Goals. J. Clean. Prod. 264, 121563. https://doi.org/10.1016/j.jclepro.2020.121563

Neves, M.F., Trombin, V.G., Conejero, M.A., 2010. A method for strategic planning of food and bioenergy chains (CHAINPLAN) applied to the sugarcane chain in Brazil. J. Chain Netw. Sci. 10, 193–206. https://doi.org/10.3920/JCNS2010.x186
Nong, D., Escobar, N., Britz, W., Börner, J., 2020. Long-term impacts of bio-based innovation in the chemical sector: A dynamic global perspective. J. Clean. Prod. 272, 122738. https://doi.org/10.1016/j.jclepro.2020.122738
Olemberg, D., Egolf, P., Zaderenko, C., Lupi, A.M., Fernandez, R., Casellas, K., 2020. Economic incentives and energy production from forest biomass in Argentina, in: International Consortium on Applied Bioeconomy Research (ICABR). Virtual Conference, p. 25.
Peccoud, J., 2016. Synthetic Biology: fostering the cyber-biological revolution. Synth. Biol. 1. https://doi.org/10.1093/synbio/ysw001
Pietrobelli, C., Rabellotti, R., 2011. Global Value Chains Meet Innovation Systems: Are There Learning Opportunities for Developing Countries? World Dev., Special Section (pp. 1204-1270): Foreign Technology and Indigenous Innovation in the Emerging Economies 39, 1261–1269. https://doi.org/10.1016/j.worlddev.2010.05.013
Ploll, U., Arato, M., Börner, J., Hartmann, M., 2022. Sustainable Innovations: A Qualitative Study on Farmers’ Perceptions Driving the Diffusion of Beneficial Soil Microbes in Germany and the UK. Sustainability 14, 5749. https://doi.org/10.3390/su14105749
Ponte, S., 2020. The hidden costs of environmental upgrading in global value chains. Rev. Int. Polit. Econ. 1–26. https://doi.org/10.1080/09692290.2020.1816199
Pray, C.E., Fuglie, K.O., 2015. Agricultural Research by the Private Sector. Annu. Rev. Resour. Econ. 7, 399–424. https://doi.org/10.1146/annurev-resource-100814-125115
Quintana-García, C., Benavides-Velasco, C.A., 2004. Cooperation, competition, and innovative capability: a panel data of European dedicated biotechnology firms. Technovation 24, 927–938. https://doi.org/10.1016/S0166-4972(03)00060-9
Radziwon, A., Bogers, M., 2019. Open innovation in SMEs: Exploring inter-organizational relationships in an ecosystem. Technol. Forecast. Soc. Change 146, 573–587. https://doi.org/10.1016/j.techfore.2018.04.021
Raimondo, M., Caracciolo, F., Cembalo, L., Chinnici, G., Pecorino, B., D’Amico, M., 2018. Making Virtue Out of Necessity: Managing the Citrus Waste Supply Chain for Bioeconomy Applications. Sustainability 10, 4821. https://doi.org/10.3390/su10124821
Reardon, T., 2015. The hidden middle: the quiet revolution in the midstream of agrifood value chains in developing countries. Oxf. Rev. Econ. Policy 31, 45–63. https://doi.org/10.1093/oxrep/grv011
Reardon, T., Barrett, C.B., Berdegué, J.A., Swinnen, J.F.M., 2009. Agrifood Industry Transformation and Small Farmers in Developing Countries. World Dev., Agrifood Industry Transformation and Small Farmers in Developing Countries 37, 1717–1727. https://doi.org/10.1016/j.worlddev.2008.08.023
Reardon, T., Heiman, A., Lu, L., Nuthalapati, C.S.R., Vos, R., Zilberman, D., 2021. “Pivoting” by food industry firms to cope with COVID-19 in developing regions: E-commerce and “copivoting” delivery intermediaries. Agric. Econ. 52, 459–475. https://doi.org/10.1111/agec.12631
Reardon, T., Timmer, C.P., 2012. The Economics of the Food System Revolution. Annu. Rev. Resour. Econ. 4, 225–264. https://doi.org/10.1146/annurev.resource.050708.144147
Reis, G.G., Heidemann, M.S., Borini, F.M., Molento, C.F.M., 2020. Livestock value chain in transition: Cultivated (cell-based) meat and the need for breakthrough capabilities. Technol. Soc. 62, 101286. https://doi.org/10.1016/j.techsoc.2020.101286

Rodríguez, A., Henry, G., Trigo, E., 2018. Latin America's developing bio-economies: concept note for a regional panel discussion. Berlin.
Rodrik, D., 2018. New Technologies, Global Value Chains, and Developing Economies (Working Paper No. 25164), Working Paper Series. National Bureau of Economic Research. https://doi.org/10.3386/w25164
Ruml, A., Qaim, M., 2020. Smallholder Farmers' Dissatisfaction with Contract Schemes in Spite of Economic Benefits: Issues of Mistrust and Lack of Transparency. J. Dev. Stud.
Scarlat, N., Dallemand, J.-F., Fahl, F., 2018. Biogas: Developments and perspectives in Europe. Renew. Energy 129, 457–472. https://doi.org/10.1016/j.renene.2018.03.006
Scheiterle, L., Ulmer, A., Birner, R., Pyka, A., 2018. From commodity-based value chains to biomass-based value webs: The case of sugarcane in Brazil's bioeconomy. J. Clean. Prod. 172, 3851–3863. https://doi.org/10.1016/j.jclepro.2017.05.150
Schilling, M.A., 2009. Protecting or Diffusing a Technology Platform: Tradeoffs in Appropriability, Network Externalities, and Architectural Control, Platforms, Markets and Innovation. Edward Elgar Publishing.
Skovsgaard, L., Jensen, I.G., 2018. Recent trends in biogas value chains explained using cooperative game theory. Energy Econ. 74, 503–522. https://doi.org/10.1016/j.eneco.2018.06.021
Smolny, W., 2003. Determinants of innovation behaviour and investment estimates for west-german manufacturing firms. Econ. Innov. New Technol. 12, 449–463. https://doi.org/10.1080/1043859022000029230
Springer-Heinze, A., 2018. ValueLinks 2.0. Manual on Sustainable Value Chain Development. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.
Stark, S., Biber-Freudenberger, L., Dietz, T., Escobar, N., Förster, J.J., Henderson, J., Laibach, N., Börner, J., 2022. Sustainability implications of transformation pathways for the bioeconomy. Sustain. Prod. Consum. 29, 215–227. https://doi.org/10.1016/j.spc.2021.10.011
Steffen, W., Rockström, J., Richardson, K., Lenton, T.M., Folke, C., Liverman, D., Summerhayes, C.P., Barnosky, A.D., Cornell, S.E., Crucifix, M., Donges, J.F., Fetzer, I., Lade, S.J., Scheffer, M., Winkelmann, R., Schellnhuber, H.J., 2018. Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. 115, 8252–8259. https://doi.org/10.1073/pnas.1810141115
Stephens, N., Di Silvio, L., Dunsford, I., Ellis, M., Glencross, A., Sexton, A., 2018. Bringing cultured meat to market: Technical, socio-political, and regulatory challenges in cellular agriculture. Trends Food Sci. Technol. 78, 155–166. https://doi.org/10.1016/j.tifs.2018.04.010
Streetz, H., 2021. Peanut Shells to Power. Biomass Mag.
Swinnen, J., Deconinck, K., Vandemoortele, T., Vandeplas, A., 2015. Quality Standards, Value Chains, and International Development: Economic and Political Theory. Cambridge University Press.
Swinnen, J., Kuijpers, R., 2019. Value chain innovations for technology transfer in developing and emerging economies: Conceptual issues, typology, and policy implications. Food Policy 83, 298–309. https://doi.org/10.1016/j.foodpol.2017.07.013
Swinnen, J., Vandeplas, A., 2010. Market power and rents in global supply chains. Agric. Econ. 41, 109–120. https://doi.org/10.1111/j.1574-0862.2010.00493.x
The Good Food Institute, 2021. 2020 State of the Industry Report: Fermentation. The Good Food Institute.

Timmer, M.P., Erumban, A.A., Los, B., Stehrer, R., de Vries, G.J., 2014. Slicing Up Global Value Chains. J. Econ. Perspect. 28, 99–118. https://doi.org/10.1257/jep.28.2.99
Timmermann, C., 2020. Contributive Justice and the Importance of Inclusive Agricultural Innovation Systems, in: Timmermann, C. (Ed.), Social Justice and Agricultural Innovation, The International Library of Environmental, Agricultural and Food Ethics. Springer International Publishing, Cham, pp. 123–146. https://doi.org/10.1007/978-3-030-56193-2_6
Tsvetanova, L., Carraresi, L., Wustmans, M., Bröring, S., 2021. Actors' strategic goals in emerging technological innovation systems: evidence from the biorefinery sector in Germany. Technol. Anal. Strateg. Manag. 0, 1–14. https://doi.org/10.1080/09537325.2021.1919300
Vels, E., 2021. Construction of Avantium plant for large-scale production of bioplastics: status report. Innov. Orig.
Vida, E., Tedesco, D.E.A., 2017. The carbon footprint of integrated milk production and renewable energy systems – A case study. Sci. Total Environ. 609, 1286–1294. https://doi.org/10.1016/j.scitotenv.2017.07.271
Voigt, C.A., 2020. Synthetic biology 2020–2030: six commercially-available products that are changing our world. Nat. Commun. 11, 6379. https://doi.org/10.1038/s41467-020-20122-2
von Pechmann, F., Midler, C., Maniak, R., Charue-Duboc, F., 2015. Managing systemic and disruptive innovation: lessons from the Renault Zero Emission Initiative. Ind. Corp. Change 24, 677–695. https://doi.org/10.1093/icc/dtv018
Wydra, S., 2019. Value Chains for Industrial Biotechnology in the Bioeconomy-Innovation System Analysis. Sustainability 11, 2435. https://doi.org/10.3390/su11082435
Zilberman, D., Lu, L., Reardon, T., 2019. Innovation-induced food supply chain design. Food Policy 83, 289–297. https://doi.org/10.1016/j.foodpol.2017.03.010
Zilberman, D., Zhao, J., Heiman, A., 2012. Adoption Versus Adaptation, with Emphasis on Climate Change. Annu. Rev. Resour. Econ. 4, 27–53. https://doi.org/10.1146/annurev-resource-083110-115954