

# Biotechnology, Bioeconomy, and Sustainable Life on Land

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## 1. Introduction

Sustainable Life on Land depends on what people want. Some people have a preference for food products labelled as “organic”, while others pay more attention to food attributes (e.g., freshness, country of origin, regionality). Yet for others, food itself is less important than the social aspects of food consumption. Moreover, the cares and concerns that people have are not limited to food. They also care about their family and friends, their work, their social life, and their leisure activities, among many other aspects of life. Their wants and choices are shaped by cultural factors, income, and available time, as well as by the places in which they are raised and choose to live. Their preferences are also influenced by local, regional, national, and international policies, over which they are also willing and able to exercise a certain level of influence (Banerjee and Duflo 2019). All of these factors have an impact on the allocation of aggregate-level natural resources—including land—over time and space. These allocations are not static, and they are likely to change in response to changes in relative prices resulting from new information, as is the case with technological changes generating new information induced by knowledge and ideas generated at home and abroad. The reallocation of natural resources over time and space can be understood as a stochastic process with variations around a trend, with new information inducing changes in both trends and the variations surrounding them. The net present value of this process expresses the value of natural resources by assigning a state-dependent and time-dependent price measured by the owner’s opportunity costs for each resource (Zilberman et al. 2018). This can also be calculated at an aggregate level for a sector. An increase in net present value is generally understood to improve sustainability (Arrow et al. 2012) and hence, contribute to the sustainable use of terrestrial ecosystems (SDG 15), but also to SDG 2 (End hunger, achieve food security and improved nutrition and promote sustainable agriculture). El-Chichakli et al. (2016) have pointed out the importance of innovation in the bioeconomy for reaching SDG 15 and in particular, from advancements in plant breeding. The approach also indicates that a positive contribution will not necessarily always be the case. As opportunity costs need to be considered, tradeoffs—but also

synergies—with other SDGs are possible. Ronzon and Sanjuán (2020) assessed the EU Bioeconomy Strategy and already identified a number of potential links with 53 targets distributed over 12 of the 17 SDGs. A positive synergy has been identified with respect to SDG 7, SDG 11, and SDG 15, while a negative one has with SDG 2, SDG 8, and SDG 12.

The generation of new ideas can have an important effect on the allocation of resources, and thus, on trends and variations around them. The importance of these effects has increased when responding to climate change (SDG 13), population growth (Jatana and Currie 2020), and the associated increase in the demand for food, all of which pose challenges to the sustainability of continuing “business as usual”. It has been estimated that the agricultural sector alone contributes about 37% to current greenhouse gas emissions, and this contribution is expected to increase to between 47% and 60% by 2050 (SAPEA 2020). Based on projected population growth through to 2050, an increase of about 35% in agricultural production is expected to be needed in order to maintain current consumption levels. Some estimates are even higher (SAPEA 2020).

Achieving such an increase in productivity will pose a challenge in light of climate change and in reaching SDG 15. Cost-effective compliance with the objective of the Paris Agreement (a warming limit of 1.5 °C) will require large-scale land-based mitigation strategies involving bioenergy production and afforestation, which will result in higher food prices (VanMeijl et al. 2018). Compensating for the increase in food prices will require either further increases in productivity and/or a reduction in meat consumption (Doelman et al. 2019). The magnitude of the changes in agricultural productivity and meat consumption that will be required differs widely, depending on the model used and the assumptions made (Rosenzweig et al. 2014; VanMeijl et al. 2018).

In this contribution, we review and discuss recent technical changes in the field of biotechnology from an economic perspective and how they can help to cope with increasing food demand while also contributing to the sustainability of life on land. We pay particular attention to the ways in which these technical changes will be affected by policies at the national and international level.

In the next section, we provide a brief overview of recent historical developments in the political economy of biotechnology and discuss recent major developments and their implications for sustainable life on land. This is followed by Section 3, which focuses on the importance of supply-chain design, and then by Section 4, which addresses the policy dimension. We conclude (Section 5) by mentioning options for policy changes that could enhance the sustainability of life on land.

## 2. Brief History of Modern Biotechnology, Including Recent Developments

The field of modern biotechnology originated with the development of dDNA technology in the mid-1970s. Early applications were made in various fields, including the pharmaceutical and food-processing sectors. Applications with direct land-use implications began with the development of seeds for plants that can express toxins to protect themselves against pests, as well as for plants that were resistant to broadband herbicides. These traits have since been introduced into major crops, including corn, cotton, canola, soybeans, and sugar beet (ISAAA 2018). These crops are cultivated primarily in the United States and Canada, Brazil and Argentina, China, India, and a few other countries (Brookes and Barfoot 2020b). In recent years, insect-resistant eggplants have been introduced in Bangladesh. Another noteworthy application involves the cultivation of papayas that are resistant to ringspot virus in Hawaii. These crops are often summarized under the term “genetically modified organisms” (GMOs), a legal term used in the European Union (Eriksson et al. 2019).

Several meta-studies have pointed to an average increase in yield, a substantial reduction in the use of herbicides and pesticides, and a substantial reduction in greenhouse gas emissions (Brookes and Barfoot 2020a, 2020b; Klümper and Qaim 2014; Finger et al. 2011; Barrows et al. 2014a, 2014b). The increase in the productivity of land has reduced the pressure on land use. Other countries (e.g., Brazil, Argentina) have also experienced an increase in double-cropping (Zallesa et al. 2019; Trigo and Cap 2006). Brookes and Barfoot (2020a) report an aggregate reduction of 775.4 million kg in pesticide use and a reduction of 2.456 million tons CO<sub>2</sub> emissions over the period from 1996 to 2018, due to decreases in fuel consumption. These figures do not include reductions in greenhouse gas emissions resulting from changes in land use through the adoption of reduced-tillage systems, which can also be substantial. As reported by Smyth et al. (2011), emission savings from the adoption of reduced-tillage systems in Canada’s production system for herbicide-resistant canola amounted to about 381,000 to 434,000 additional tons in 2006.

Recent progress in molecular biology has provided opportunities for increasing the scope of plant breeding. New plant-breeding technologies (NPBTs) reduce the time and costs required to develop new plants with traits that protect them against a number of abiotic and biotic stressors, including drought tolerance, pest and disease resistance, and increased efficiency in the use of plant nutrients (Nationale Akademie der Wissenschaften Leopoldina, Deutsche Forschungsgemeinschaft und Union der deutschen Akademien der Wissenschaften 2019). An overview of applications in plant breeding is provided in Table 1. Many more are under development. Such developments can be expected to generate further increases

in land productivity, to enhance preparations to counteract the adverse effects of climate change, and to reduce the quantity of pesticides and inorganic fertilizer applied. Taken together, these developments will increase the sustainability of agriculture production and land use by reducing emissions and the pressure on terrestrial ecosystems (Barrows et al. 2014a). Nevertheless, the judgment of the Court of Justice of the European Union (CJEU) in 2018 on the legal treatment of crops developed by using mutagenesis has been interpreted as subjecting crops developed by new plant breeding technologies to the specific EU regulations on GMOs (Purnhagen 2019). This implies that crops developed by those technologies have to follow a lengthy, costly, and unpredictable approval process (Purnhagen and Wesseler 2019; Smart et al. 2017).

New developments in modern biotechnology are not limited to plant production. They have implications for food consumption in general (Tilman and Clark 2014). Advances in biotechnology are being used to grow meat, not only by raising farm animals, but also by growing meat from stem cells in laboratories—a procedure known as “cultured meat” or “clean meat” (Dance 2017). The expectation is that fewer inputs will be needed to grow meat from cell cultures. This is a reasonable expectation, given that the energy needed to keep an animal alive (e.g., for growing a heart, liver, and other body parts) will not be needed, and less land will be required for producing the energy (e.g., in the form of feed and fodder). While the energy use per 1000 kg of cultured meat is comparable to that of beef, the land use and greenhouse gas emissions are more than 10 times less (Dance 2017). Several companies have invested in these technologies, and progress has been made, but it will be many years before the results will reach the market (Thorrez and Vandenburg 2019). They are nevertheless quite promising from the perspective of both sustainable land use and animal welfare.

**Table 1.** Current and Potential Applications of new plant-breeding technologies (NPBTs) in Agriculture (Examples).

Plant	Trait
<i>Improved food and feed quality</i>	
Alfalfa	Reduced lignin content
Camelina	Improved fatty-acid composition
Lettuce	Increased Vitamin C content
Potato	Reduced acrylamide formation
Oilseed rape	Improved fatty-acid composition
Soybean	Improved fatty-acid composition
Wheat	Low gluten content
	Improved fiber content
<i>Improved agronomic properties</i>	
Banana	Fungus resistance
Cassava	Virus resistance
Cherry	Virus resistance
Cocoa	Fungus resistance
Flax	Herbicide tolerance
Corn	Drought tolerance
	Fungus resistance
Oilseed Rape	Disease tolerance
	Herbicide tolerance
	Shatter tolerance
Rice	Fungus resistances
	Herbicide tolerance
	Salt tolerance
Soybean	Drought tolerance
Tomato	Bacterial resistance
Wheat	Fungus resistance

Source: adopted from Purnhagen and Wesseler (2020).

Similarly, a number of plant-based meat alternatives are under development, and some have already reached the market. This reduces the amount of land required for final consumer products by substituting plant-based consumer goods for animal-based products by a factor of four or more (STATISTA 2020a). As reported by Curtain and Grafenauer (2019), more than 4400 meat-substitute products were registered worldwide as of 2015, and the market is approaching a value of several billion dollars (King and Lawrence 2019). In addition to its potential to reduce greenhouse gas emissions relative to equivalent meat products (STATISTA 2020b), meat alternatives are expected to enhance human health by reducing the over-consumption of meat (Willett et al. 2019).

Another development involves the production of insect-based protein. This is accomplished either by raising insects directly for human consumption or by converting maggots into protein—either for human consumption or for use as a protein for animal feed (Pippinato et al. 2020). Insects have a much higher conversion rate. Some can be raised on food waste, thereby increasing the circularity of the food system. The production of protein from insects requires less land, as maggots can grow in chambers, requiring much less space per unit of protein. As reported by Akhtar and Isman (2018), compared to the amount of resources required to produce one kilogram of protein from mealworms, beef protein requires more than 100 times more land, more than 150 times more energy, and more than 110 times more water, in addition to producing at least 50 times more emissions of greenhouse gases. The major markets for insect-based protein production are in the Asia Pacific regions, with an expected value of USD 476.9 million for 2018, followed by Europe, with a market value of USD 216.5 million. The insect protein market in the United States is exhibiting the largest compound annual growth rate—about 28% for 2018–2023—followed closely by Europe, with an annual growth of 26% (STATISTA 2020c).

A fourth development that is increasing the sustainable intensity of agriculture per unit of land is the indoor production of vegetables through closed systems or indoor farming. These techniques also enhance the efficiency of water usage, in addition to requiring almost no pesticides and nearly eliminating nutrient emissions into the environment. Indoor vegetable farming increases yields by a factor of 10, relative to outdoor farming (STATISTA 2020b). The use of LED technology to resolve one of the greatest challenges associated with indoor farming is expected to increase both yield and the adoption of the technology (Tibbetts 2019). The worldwide market is expected to increase by a factor of four, from about USD 4.4 billion in 2019 to about USD 15.7 billion in 2025 (STATISTA 2020b).

In yet another development, aquaculture production is increasingly shifting to closed production systems, thereby reducing pressure on coastal regions (e.g., mangrove forests) (Romano and Sinha 2020). Closed and semi-closed aquaculture systems, including recirculating aquaculture systems (RAS), are often combined with closed vegetable-production systems in “aquaponic systems”. Although the market is still developing, further growth is expected to be strong in response to the “lighting revolution”. The forecasted worldwide market value for 2022 is about USD 870.6 million (STATISTA 2020c). Overall, aquaculture production is expected to exceed capture-fishery production in quantitative terms by 2024 (OECD/FAO 2020), also supported by the recent developments in genetically engineered salmon (Van Eenennaam et al. 2021).

The five developments discussed above are moving food production closer to urban and peri-urban areas, with greater density per unit of land and less release of pollutants into the environment, including the emission of greenhouse gases. Each of these developments has the potential to achieve sustainable increases in food productivity. An overview of expected market values is provided in Table 2.

**Table 2.** Forecasted market values of sustainable intensification of food production systems.

Production System	Forecasted Market Value (in USD Million)	Year
Cultured meat <sup>1</sup>	214.00–593.00	2027–2032
Plant-based meat substitutes <sup>2</sup>	17,540.00	2022
Edible insects <sup>2</sup>	954.44	2022
Vertical farming <sup>2</sup>	15,700.00	2025
Aquaponic <sup>2</sup>	870.60	2022

Source: <sup>1</sup> MarketsandMarkets (2019), <sup>2</sup> STATISTA (2020a, 2020b, 2020c, 2020d, 2020e).

New developments are also relevant to parts of the bioeconomy that are involved with activities other than processing biomass into food and feed (as discussed above). The bioeconomy is viewed as part of a strategy aimed at sustainable development in general and, in particular, decarbonization and the transition from an economy that relies on non-renewable resources to one that relies heavily on renewable resources (EC 2018). The broad adoption of modern biotechnological solutions combined with taking advantage of new information technologies and applying precision agricultural techniques is expected to increase the input use

efficiency of agriculture, in addition to enabling the farming of fine chemicals and biofuels (Zilberman 2014). Many countries have developed bioeconomic strategies involving such conversions, including the production of bioenergy (e.g., biofuels), the extraction of biopolymers for bio-based products (e.g., food wrappings), and the production of textiles and clothing, enzymes for detergents, and many more examples (Wesseler and von Braun 2017). The main expectation is that these developments will reduce the extraction of carbohydrates from fossil resources and contribute to the reduction of greenhouse gas emissions through product substitution. This strategy has received considerable attention in the European Union. Under the new green deal, the EU plans to mobilize investments amounting to about EUR one trillion to develop the EU bioeconomy (EC 2020). Several large biorefineries are under development for the production of bioenergy, bio-based chemicals, and enzymes. A report by Parisi (2018) lists 803 biorefineries, 507 of which produce bio-based chemicals, 363 produce liquid biofuels, and 141 bio-based composites and fibers (multi-product facilities are counted more than once). Germany has the highest number of small-scale biorefineries producing energy in the EU in the form of biogas. Further increases are expected for investments in biorefineries. The economic success of many biorefineries depends in large part on government support. The rise in biogas facilities in Germany was driven primarily by the fixed feed-in tariffs for transferring energy into the grid system, resulting in a substantial reduction in price uncertainty. The future development of smaller and larger scale biorefineries critically depends on government policies (Theuerl et al. 2019) and in particular, on access to advances in biotechnology (Purnhagen and Wesseler 2019).

The United States and Brazil have engaged in a massive effort to produce ethanol as a biofuel. These efforts include the production of ethanol from feed stocks (e.g., corn and sugar cane), as well as the production of second-generation biofuels from grasses (e.g., miscanthus and switchgrass), corn stover and bagasse, and various trees. The production of corn ethanol in the US originally caused a significant rise in food prices and required substantial subsidies. Learning by doing and economies of scale eventually reduced the costs of producing corn ethanol by 45% between 1983 and 2010, while the cost of producing sugar-cane ethanol declined by 75% between 1975 and 2010, thus making these biofuels much more competitive with fossil fuels. The fuel-blend restriction in the US limits the ethanol content of gasoline to 10%, while ethanol provides 30% of the fuel for gasoline cars in Brazil. Corn ethanol production has had less of an impact on land use than was feared. In particular, in 2014, the total crop acreage in the US was only 0.5% higher than it had been in 2008 (Khanna et al. 2021). Furthermore, the introduction of corn ethanol led to

a modest reduction in greenhouse gas emissions, as compared to the gasoline it replaced (5–15%), while sugarcane ethanol reduced greenhouse gas emissions by as much as 70% (Hochman and Zilberman 2018). Second-generation biofuels are not yet competitive, especially due to the reduction in oil prices since 2014 and the increased economic viability of electric cars that rely on solar energy. Nevertheless, second-generation biofuels continue to be developed, utilizing recent advancements in biotechnology to target air travel, in which battery use is unlikely to be feasible (Debnath et al. 2019). More could have been achieved, but the use of flex-fuel vehicles in the United States and elsewhere is limited by the E85 refueling infrastructure (Kuby 2019).

Investments in the bioeconomy have not been undisputed. There has been an intense debate about food versus fuel. The conversion of crops that could have been used for food into fuel has been seen as morally unacceptable, given the high level of poverty observed in many regions of the world. This is a somewhat narrow view of the causes of poverty. Although access to food is obviously important, reducing the debate to the provision of food ignores the importance of purchasing power (Sen 1982). It can be extremely misleading to limit the understanding of purchasing power or income to food alone, as it depends on a variety of factors (Schmitt 1989; Acemoglu and Robinson 2012).

### **3. Developing Supply Chains**

Many new technological developments in the bioeconomy require substantial investments, combined with a high level of uncertainty. The supply chains for many products are not yet developed, thus increasing the risk of an individual investor. Public–private partnerships and contracting sales along the supply chain have become important tools for developing new markets. This includes new bio-based products that are associated with positive relative carbon emissions and other environmental benefits (Rahmann et al. 2020).

The introduction of production standards and vertically integrated supply chains has created new market opportunities (Beckmann 2000). Vertical integration has allowed many farmers in Africa, Asia, and Latin America to benefit from export opportunities to the European Union and the United States. In many cases, this involves the export of high-value products, including the sourcing of aquaculture products or vegetables (Reardon and Zilberman 2018).

The development of vertically integrated supply chains has been supported by consumer demand, stakeholder groups, and government policies. The certification of timber products by the Forest Stewardship Council (FSC) has become an important

tool for supporting sustainability (Degnet et al. 2020). The Rainforest Alliance and other groups support the production of soybeans without a direct link to the deforestation of the Amazonian rain forest. Other certification schemes support other forms of agriculture (including organic agriculture), with the aim of contributing to sustainable agriculture, resulting in an overall increase in vertical integration (Wesseler 2014). Although many of these initiatives are well-intentioned, their impact on sustainability has been questioned in some cases (Ghozzi et al. 2016).

#### **4. The Political Economy of Biotechnology**

Sustainable life on land depends largely on policies and institutions. Policies can directly increase or decrease the price of goods at home and abroad, thereby affecting the allocation of natural resources. In particular, the impact of environmental and food-safety policies on the allocation of natural resources and its related implications for sustainability have been discussed by academics at the level of policy (e.g., Eriksson et al. 2019; Paarlberg 2008).

Concerns about environmental health and food safety have led to the establishment of production standards including procedures, incentives, and regulations that constrain land use (Winston 2002). In general, these measures include a combination of ex ante regulations and ex post liability rules. Ex post liability is understood as liabilities faced by producers in case they do not comply with ex ante regulations. The dependent design of safety policies affects incentives for investment in new food-production technologies. The clarity, severity, and enforcement of safety policies vary across countries. In some countries, they provide clear investment guidance, and in others, they add a layer of uncertainty, possibly curtailing investments. In recent decades, safety policies have substantially increased in importance, becoming non-tariff barriers to trade (e.g., Felbermayr and Larch 2013).

As suggested by Arrow et al. (1996), cost-benefit analysis is crucial for guiding the establishment of safety guidelines. Such analyses require performing risk assessments to estimate the relationship between risks to humans, to the environment, and to human action under alternative regulations and conditions, in addition to evaluating the benefits that the regulations will have for various parties (Antle 1999). Safety regulations are based on tradeoffs. The introduction of transgenics in agriculture benefited the consumers and producers who adopted it. At the same time, it was costly to producers not adopting transgenics and to chemical manufacturers, due to reduced commodity prices. Overall, however, the introduction of transgenics increased social welfare, based on economic criteria (Hochman and Zilberman 2018). In addition to precise and efficient regulations, the implementation of effective safety

policies has required effective risk communication and management (Henson and Caswell 1999).

The use of cost–benefit analysis could potentially be constrained by the lack of data on the value of non-market benefits and the cost of regulation. An alternative approach involves the use of cost-effectiveness criteria to establish cost-minimization regulations, subject to an upper boundary of mortality risk (Lichtenberg and Zilberman 1988). The resulting regulations require evaluating statistical life gain (i.e., the value of statistical life; Aldy and Viscusi 2007). This evaluation can be compared to those implied in other regulations, thereby allowing assessment of the stringency of the risk constraint.

Herring and Paarlberg (2016) suggest that Latin American countries (e.g., Brazil, Argentina), which are large feedbox producers (like the US), have applied regulatory frameworks similar to those in the US, while African countries, which have strong ties to Europe, have adopted a strict regulatory environment for biotechnology, even though they also stand to reap significant benefits from such technology (Shao et al. 2020; Wesseler et al. 2017).

Decisions about food safety regulations are inherently political, and the welfare of different groups in society may have different weights, which may be affected by political realities (Swinnen and Vandemoortele 2009). In particular, the economic tradeoff between *ex ante* regulations and *ex post* liability (Beckmann et al. 2006, 2010) as well as the decision-making procedures (Smart et al. 2015) can have strong implications for the incentives to invest (Purnhagen and Wesseler 2019). This has been demonstrated by a number of studies that look into the approval process and related costs of biotechnologies in agriculture. Those studies show that the time lengths in approval can differ substantially between regions (Jin et al. 2019; Frederiks and Wesseler 2019; Smart et al. 2017; Smyth et al. 2017) and of course, in many cases, the approval process reaches infinity, i.e., similar to a ban.

In an analysis of the political economy of agricultural biotechnology, Graff et al. (2009) suggest that existing restrictions on the use of biotechnology in Europe reflect the political power of the coalition of a number of farm groups, environmental groups, and chemical manufacturers, as well as the unique political structure of the EU (Smart et al. 2015). The regulatory environment in the US is more receptive to biotechnology, given that many biotechnological innovations have originated in the US, with some traits having been beneficial to US farmers. Wesseler (2002), McCluskey and Swinnen (2004), and Castellari et al. (2018) further suggest that in both the US and the EU, opponents to GMOs have been able to utilize the media to affect consumer preferences, even though consumers stand to benefit from the

introduction of genetically modified varieties. Additionally, the semantics being used in the public debate as well as in books, including teaching material, has a further impact on shaping opinions (Aerni 2018). Tosun and Schaub (2017) show that in the EU, the opposition to GMOs includes more active groups and has a stronger network, while the same has also been observed for China (Jin et al. 2020).

While many safety policies are designed by national governments, several international agreements impose additional costs and uncertainty for investors. One example is the *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity*. Plant breeders and others have complained that the protocol increases the costs and related uncertainties associated with developing new plant varieties with desirable traits, including drought tolerance, pest and disease resistance, and the efficient use of nutrients and adds to the regulatory burden already caused by the *Cartagena Protocol on Biosafety to the Convention on Biological Diversity* (Deplazes-Zemp et al. 2018). While any international agreement will invoke complaints by some, agreements that increase the costs of investing in sustainable agricultural solutions are of particular concern. New technologies and the benefits associated with them must be weighed against their potential negative implications, particularly those that are irreversible. As stated in Principle 15 of the Rio Declaration on Environment and Development of 1992: "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." (United Nations 1992, p. 3 )

The presence of irreversible damage does not imply that a technology should be prohibited. As demonstrated by various scholars (Arrow and Fisher 1974; Henry 1974), if an irreversible effect is present, one unit of irreversible costs requires more than one unit of reversible benefits to compensate (Wesseler and Zhao 2019). Unfortunately, many assessments fail to consider the tradeoffs between irreversible damage costs, which are often uncertain, and the benefits foregone by delaying or preventing the introduction of a new technology. Previous studies have indicated that a one-unit increase in investment costs requires more than one unit in benefits to compensate for related uncertainties. For example, as demonstrated by Purnhagen and Wesseler (2019), the marginal effect of an increase in approval costs can be substantial, possibly extending beyond a factor of 10. One prominent and widely discussed example is the regulation of new plant-breeding technologies in the European Union (e.g., Nationale Akademie der Wissenschaften Leopoldina, Deutsche

Forschungsgemeinschaft und Union der deutschen Akademien der Wissenschaften 2019), which has resulted in court cases in which judges have applied an absolute interpretation of the precautionary principle (Purnhagen and Wesseler 2020).

As mentioned previously, many new developments in biotechnology have the potential to provide substantial sustainability gains. Nevertheless, they have been rejected by important stakeholder groups, which also argue that these technologies should be prohibited from entering the market, based on the perspective of sustainability. Such arguments extend beyond the absolute application of the precautionary approach, as the debate concerns the types of agriculture and land use that should be preferable. The line is drawn largely between what is and is not considered organic agriculture. Definitions differ by country and interest group. Referring to the Austrian anthroposophist Rudolph Steiner, groups including farmers market their products under the Demeter<sup>®</sup> label. While what is and is not considered organic is a policy decision (Castellari et al. 2018), policy choices that favor one over the other are questionable from a sustainable development perspective. In many cases, large-scale applications of organic agriculture as defined by policy makers result in lower yields per unit of land and reduce the total quantity of food available. While one common argument holds that organic agriculture reduces the emissions associated with fertilizers and pesticides, the application of copper sulfate has sometimes resulted in environmental pollution, and the rejection of inorganic fertilizer has led to soil mining in some cases. In other cases, the principles of organic agriculture are likely to yield better results. Policy decisions in these matters can result in a substantial misallocation of resources, thereby endangering sustainable development (World Bank 2010).

## 5. Conclusions

Modern biotechnology offers a number of possibilities for addressing challenges to sustainable life on land (SDG 15), but there is also a strong link with achieving zero hunger (SDG 2) as achieving SDG 15 depends on the expected increase in population and the related increase in food demand. In this contribution, we have listed several of the possibilities. Many more exist, and some are better developed than others. The promotion of sustainable life on land and protecting terrestrial ecosystems is thus not mainly a technical problem; the major problem is both institutional and political. This has been stressed by several authors before as well (Wesseler and von Braun 2017; El-Chichakli et al. 2016; Zilberman et al. 2018). More specifically, institutional and political environments provide both incentives and disincentives for the private and public sector to invest in the development of solutions. When the obstacles

are lower, parties in the private and public sectors are more likely to invest in the development of solutions. Obstacles can be reduced by harmonizing the standards for safety assessments. Examples include the acceptance of animal-feeding trials and nutritional studies across jurisdictions, as well as agreement on the procedures for field trials and the exchange of field trial data for environmental safety assessments. The relevance of harmonization of standards and the related benefits for all has been demonstrated by the COVID-19 pandemic recently. Hence, the positive contribution of biotechnology and the bioeconomy in general will go beyond SDG 15. This has important implications for achieving zero hunger (SDG 2), but also for reducing poverty (SDG 1), promoting sustainable growth (SDG 8), ensuring sustainable consumption and production patterns (SDG 12), and relies on fostering innovation (SDG 9). The UN Sustainable Development Goals initiative provides an opportunity for implementing important policy changes for achieving “decent lives for all on a healthy planet”.

**Author Contributions:** J.W. and D.Z. both equally contributed to conceptualization, investigation, writing—original draft preparation, writing—review and editing. Both authors have read and agreed to the published version of the manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

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