2 "Global Shifting Agriculture" and Bioeconomy: Challenges for the Sustainable Use of Global Land Resources

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Abstract

For decades, introductory lectures in agricultural sciences begin by confronting students with the historical and projected future development of global population numbers. Depending on scenario assumptions, a world in 2100 may have to feed between 7 and 17 billion people. Lecturers use these demographic projections mainly to convince students that they made the right career choice: agricultural sciences will have to play a major role in developing technologies that boost primary sector productivity; allegedly the first-best strategy for the provision of sufficient food at affordable prices, while minimizing global cropland expansion.

This essay does not deny the need to develop crop varieties that produce higher and more reliable crop yields. It will argue, however, that technological innovation in agriculture is not enough to enable transformation towards a globally sustainable bioeconomy. This view is supported by the academic debate around the Sustainable Development Goals (SDGs), which highlights numerous synergies, but also tradeoffs between the multidimensional global agenda for 2030. We proceed in three steps: First, we revisit the theoretical foundations of the idea put forward by Nobel laureate Norman Borlaug, that productivity increases in agriculture reduce the demand for new farmland. Second, we synthesize recent empirical research supporting the view that Borlaug's hypothesis is a necessary, but not a sufficient condition for a sustainable global bioeconomy. And third, we highlight potential ingredients of a science and policy strategy that provides the necessary social and environmental safeguards for more sustainable innovation in agriculture.

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1 Background

For decades, introductory lectures in agricultural sciences begin by confronting students with the historical and projected future development of global population numbers. Depending on scenario assumptions, a world in 2100 may have to feed between 7 and 17 billion people. Lecturers use these demographic projections mainly to convince students that they made the right career choice: agricultural sciences will have to play a major role in developing technologies that boost primary sector productivity; allegedly the first-best strategy for the provision of sufficient food at affordable prices, while minimizing global cropland expansion.

This essay does not deny the need to develop crop varieties that produce higher and more reliable crop yields. It will argue, however, that technological innovation in agriculture is not enough to enable transformation towards a globally sustainable bioeconomy.[1] This view is supported by the academic debate around the Sustainable Development Goals (SDGs), which highlights numerous synergies, but also tradeoffs between the multidimensional global agenda for 2030.[2] We proceed in three steps: First, we revisit the theoretical foundations of the idea put forward by Nobel laureate Norman Borlaug, that productivity increases in agriculture reduce the demand for new farmland. Second, we synthesize recent empirical research supporting the view that Borlaug's hypothesis is a necessary, but not a sufficient condition for a sustainable global bioeconomy. And third, we highlight potential ingredients of a science and policy strategy that provides the necessary social and environmental safeguards for more sustainable innovation in agriculture.

2 Agricultural Technology Change and "Global Shifting Agriculture"

Borlaug's intuition goes as follows: if new agricultural technologies boost per hectare crop productivity, more can be produced on the same or even a smaller amount of land. Higher crop yields increase the supply on agricultural output markets, where prices drop and thus reduce the incentives for cropland expansion. Already in the nineteenth century, British economist William Jevons challenged the

[1] We define bioeconomy, inspired by the German Bioeconomy Council, as the production and utilization of biological resources (including knowledge) to provide products, processes, and services across sectors of an economy. Defining bioeconomy in this way allows for both sustainable and unsustainable transformation outcomes.

[2] Cf. Timko et al. (2018) and Biber-Freudenberger et al. (2018).

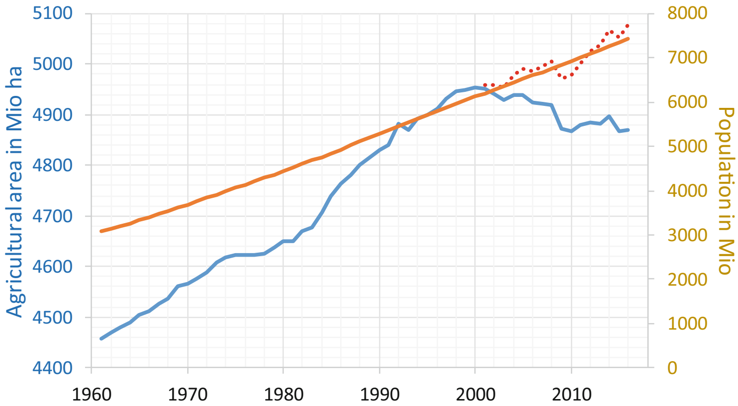

Fig. 2.1 Global growth in net-agricultural area (blue) and population (orange). The dotted red line adds cumulative net tree cover loss between 2001 and 2016 to net-agricultural area. Sources: World Bank, FAOTAT, University of Maryland

general validity of this calculus as he witnessed how technologies that enabled a more efficient use of coal triggered tremendous growth, as opposed to savings, in fossil fuel consumption during his lifetime. Clearly, fuel scarcity may have been a driver of technological innovation in the first place. Yet, over time, growth in the consumption of manufacturing goods from more fuel-efficient industries has arguably outpaced the effect of initial fuel savings on total fossil resource use. This so-called "rebound effect" is context specific and has since been observed in many other settings.[3]

In defense of Borlaug's vision, we may contend that people can only consume so much food, such that rebound effects are less likely to be mediated via food markets compared to other commodity groups due to market saturation. As we illustrate below, however, food and energy consumption patterns, especially in industrialized countries, as well as the current generation of bioeconomy strategies around the world suggest otherwise. New processing technologies increasingly allow for a variety of non-food biomass uses that could boost future demand for cropland and pastures.

Moreover, Borlaug's calculus implicitly assumes that more efficient agricultural technologies will be applied on the world's current and most productive croplands. This turns out to be a strong assumption if we consider that agricultural land markets and environmental policies in many world regions fail to effectively allocate land to its most valuable use for society.[4] As a result, we often find large tracts of agricultural land abandoned in one region, while it expands into natural ecosystems elsewhere.[5] Figure 2.1 shows that standard cropland accounting procedures grossly

[3]Cf. Herring and Roy (2007), Berbel and Mateos (2014) and Smeets et al. (2014).

[4]Cf. Deininger and Feder (2001) and Miranda et al. (2019).

[5]Cf. Schierhorn et al. (2019).

understate the actual space needed for agricultural production globally since 2001. The apparent decoupling of global population growth and agricultural area expansion after the year 2000 vanishes if we account for global net tree cover loss between 2001 and 2016.

In other words, the lion's share of global cropland and pastures is continuously used, but a considerable share shifts geographically subject to interannual dynamics of expansion and abandonment that are mediated by economic and political factors, but also through the emergence of technologies that enable agricultural production on previously unused land.[6] This global form of "shifting agriculture" has no agronomic rationale. It is not required to maintain soil productivity as in many traditional agricultural systems still practiced around the world. Instead, it leads to avoidable, often irreversible, environmental damage and not seldom provokes the displacement of traditional and indigenous populations and smallholders.[7]

Constraining the development of productivity-enhancing agricultural technologies altogether would be a poor response, nonetheless. According to Nelson Villoria, for example, additional 125 million hectares of land would have been needed to satisfy global food demand between 2001 and 2010 in the absence of technological innovation in agriculture.[8] In the context of the global food system, the Borlaug versus Jevons debate instead suggests that the opportunities of future technological change come with increasing international governance needs.[9] Failing to address these challenges may ultimately jeopardize ecosystem functions that maintain agricultural production, such as regional climate regulation, and support our ability to develop more sustainable production systems, such as genetic and species diversity.

3 Lessons from the South American Soy Boom

Land use change is an expression of societies' production and consumption patterns. The rise of the soybean economy in South America will serve us to illustrate some of the mechanisms that drive the expansion and abandonment of agricultural land. Soybeans and their derivatives are the most traded agricultural commodity worldwide. According to FAOSTAT, almost 350 million tons of soy were produced on close to 125 million hectares globally in 2018. The South American share in global soybean production has increased from roughly 25% in the 1980s to over 50% since 2010.

[6] Cf. Angelsen and Kaimowitz (2001) and Villoria (2019).

[7] Cf. Baccini et al. (2012), Obidzinski et al. (2012) and Barlow et al. (2016).

[8] Cf. Villoria (2019).

[9] Cf. Carrasco et al. (2014).

Beyond food uses, other bioeconomy sectors, such as biofuel and animal production in various world regions, were major demand side drivers of this boost in output.[10] Why did it happen in South America and what were the impacts locally?

While South American soy producers became more productive over the years, the main contribution to the observed increase in total production was a massive cropland expansion. Between 1980 and 2018, average soy yields in the region increased less than twofold, whereas harvested area increased by a factor of five to 57 Mha (FAOSTAT). Direct planting technology in combination with roundup-ready soybean varieties adapted to various South American climate zones have played a major role as push factors in bringing soy to the region's agricultural frontiers.[11] As a result, soybean production has become a major driver of the environmentally costly conversion of South America's natural and biodiverse dry and tropical forests.[12]

Potential for further agricultural expansion is considerable. According to Frey et al., Brazil's Amazon region alone holds sufficiently well-suited land to accommodate over six times more soy than the roughly 2.3 Mha planted in that region in 2014.[13] Whether or not soy can expand on these lands depends mainly on transport infrastructure investments and the effectiveness of environmental policies that legally restrict the conversion of forests to agriculture. Road and fluvial transport infrastructure improvements reduce transport costs and thus literally pave the way for farmers and processing industries to unlock the agricultural potential of remote forest zones. The effect of soy production on deforestation may not always be direct, however. Research has repeatedly produced evidence for indirect land use change, where soy producers rent or buy extensively used pastures, while cattle production expands elsewhere via both legal and illegal deforestation.[14] While most South American countries have formulated environmental policies to control illegal land cover change, lack of implementation capacities or fluctuations in political priorities limit their effectiveness.[15]

Indirect land use change can happen at local, regional, and global scale and represents one of the mechanisms through which "global shifting agriculture" occurs. While cause-effect relationships are chronically hard to establish, the environmental impacts of displacing agricultural land across the globe are sizeable. Schierhorn et al., for example, estimate that cropland abandonment in the former Soviet Union led to greenhouse gas emission savings of over 7 Gt (approximately the amount emitted by the USA in 1 year) between 1991 and 2011.[16] From the perspective of global agricultural land accounting, the abandonment roughly offset

[10] Cf. Bruckner et al. (2019) and Pendrill et al. (2019).

[11] Cf. Grau et al. (2005) and Trigo et al. (2009).

[12] Cf. Gasparri et al. (2013).

[13] Cf. Frey et al. (2018).

[14] Cf. Richards et al. (2014) and Gasparri and Le Waroux (2015).

[15] Cf. Nolte et al. (2017).

[16] Cf. Schierhorn et al. (2019).

the increase in cropland and pastures in South America over the same period. According to Schierhorn et al., however, emissions from land cover change in South America exceeded savings by factor four, while net biodiversity loss was not assessed.

Key lessons from the South American soy boom and the broader debate on indirect land use change can be summarized as follows: Despite the obvious economic benefits of trade in agricultural commodities, increasingly complex global value chains allow for shifts in consumption and production patterns to more effectively propagate and thus amplify regional patterns of land abandonment and expansion. Profitable technological innovations can reinforce processes of land expansion at agricultural frontiers, especially where public and private infrastructure investments improve access to land and when land use regulations and property rights are poorly enforced.

As such, the environmental and social costs of "global shifting agriculture" can be considered a collective externality of the trade system that links consumers and producers of agricultural and forestry commodities across the globe. As usual, liability and responsibility for these costs are difficult to establish, but in the absence of internationally negotiated and locally enforced land use regulations, productivity-enhancing agricultural technologies are part of the problem.

4 Bioeconomy and Global Land Resources

In line with our definition of bioeconomy, "global shifting agriculture" is inherently a bioeconomic phenomenon. As more and more countries around the world develop strategies to promote their bioeconomies, an intriguing question is whether future generations will look back at bioeconomic transformation as a Borlaugian symphony or a Jevonsian cacophony. Answers are so far speculative by nature and thus often rely on modeling studies. Escobar et al., for example, simulated alternative scenarios of policy support to increase the reliance on biomass as opposed to fossil fuels for the production of bioplastics.[17] Assuming the current state of biomass conversion technologies, they find that bio-based plastics will only pay off in terms of carbon emission savings after more than 20 years due to indirect land use change. Earlier, Hertel et al. had demonstrated similar limitations of attempts to promote the use of bio-based fuels.[18]

Beyond substituting bio-based for fossil resources, visions of future bioeconomies also embrace circular economy principles and arguably land neutral technologies, such as the use of enzymatic instead of chemical conversion processes.[19] Here it can help to differentiate between more efficient biomass uses, which, despite their potential benefits, may produce rebound effects and the

[17] Cf. Escobar et al. (2018).

[18] Cf. Hertel et al. (2010).

[19] Cf. Meyer (2017).

application of bio-based principles in land independent sectors, such as medicine or the pharmaceutical industry. Growing this latter part of bioeconomy is unlikely to put additional pressure on global land resources.

A closer look at national bioeconomy strategies, however, reveals that most countries place strategic emphasis on technological innovation in the sectors that traditionally rely on the production, conversion, and consumption of biological resources.[20] To the extent that these strategies promote alternative biomass uses and refinement, they potentially push the limits of saturation that govern traditional food markets and led Borlaug to propose that land can be saved by boosting agricultural yields.

All this would not be a problem, if the world's remaining natural landscapes were protected by effective use regulations. Unfortunately, enabling policy measures for bioeconomy and voluntary sustainability labels feature more prominently in national bioeconomy strategies than binding environmental and sustainability safeguards.[21] All else equal, bio-based innovations and enabling policy support will thus most likely align to put additional pressure on global land resources.

5 Way Forward

Coordinating action towards internalizing the costs of globally shifting land use incentives may seem like an insurmountable "wicked problem."[22] Consumers blame farmers for unsustainable production practices, farmers bemoan exaggerated consumer expectations and costly regulations, and technology developers maintain that ill-designed policies and institutions prevent their innovations from unfolding their inherent sustainability potential. Most parties ignore or downplay their own contribution to the undesirable collective outcomes.

To turn this blame game into a constructive dialogue we need to tune up the conventional Borlaugian chant of agricultural sciences with the lessons of recent multidisciplinary research on global land use change dynamics. Based on what we have learned about the drivers of land use change in various regional contexts, improved science-based decision support can help us anticipate where and when incentive structures shift in favor of land expansion at agricultural frontiers. Evidence-based methods in combination with unprecedented access to remotely sensed data on land use change have also greatly enhanced our ability to measure the effectiveness of agricultural and environmental policies. Insights from these applied fields of research can and should inform not only policy design but also goal-oriented priority setting for basic research and technology development.

At the policy level, we need to push our leaders to move from global goals to collective deeds. Few of the land-related Sustainable Development Goals (SDGs), if

[20] Cf. Dietz et al. (2018).

[21] Cf. ibid.; Grossauer and Stoeglehner (2020).

[22] Cf. DeFries and Nagendra (2017).

any, can be achieved through uncoordinated action.[23] The transaction costs involved in negotiating binding multilateral treaties are a necessary price to pay, which will reduce as we make headway towards equally sharing the benefits and costs of economic prosperity among winners and losers. To do so, we need to acknowledge that there are limits to governing global trade in bio-based commodities via improved value chain transparency and voluntary sustainability labels. Certification schemes can complement, but not substitute for functioning national and subnational land use regulations.[24] This is because adverse selection mechanisms often exclude those segments of the producer spectrum, where changes in production practices are costly, but bring about the largest sustainability gains.

A "new deal" to govern global land resources must leverage the potential power of conditional compensation mechanisms, such as the Sustainable Development Mechanism (SDM) in the Paris Agreement or Reducing Emissions from Deforestation and Degradation (REDD+), which can be flexibly designed to target agricultural frontiers affected by global shifts in economic incentives for agricultural expansion. So far publicly funded programs have made substantial progress in preparing the ground for such compensation schemes to work more effectively, for example, by establishing land cover monitoring systems and rural land cadasters.[25] Funding remains a bottleneck to scale up international compensation schemes, be it for land-based climate change mitigation or biodiversity conservation. However, we should not forget that many of the perceived benefits of bio-based transformation are expected to accrue as positive externalities and thus may require policy support.[26] This potentially creates synergies between bioeconomic transformation and the protection of global land resources at least in the context of climate policy. Emission taxes or offset trading schemes provide incentives for climate-smart (including bio-based) innovation and at the same time generate revenues that can and should be used to compensate countries for additional efforts towards protecting globally valued land resources. Compensations offered so far represent only a fraction of the actual costs of safeguarding ecologically sensitive ecosystems around the world and thus cannot be expected to effectively curb global forest loss.

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[23] Cf. ibid.

[24] Cf. Auld et al. (2008) and DeFries et al. (2017).

[25] Cf. Ochieng et al. (2016) and Maniatis et al. (2019).

[26] Cf. Wesseler and von Braun (2017).

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