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Angaben zur Veröffentlichung / Publication details:

Backhouse, Maria, and Kristina Lorenzen. 2021. "Knowledge production and land relations in the bioeconomy: a case study on the Brazilian sugar-bioenergy sector." Sustainability 13 (8): 4525. https://doi.org/10.3390/su13084525.

sustainability

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Knowledge Production and Land Relations in the Bioeconomy. A Case Study on the Brazilian Sugar-Bioenergy Sector

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Abstract: National bioeconomy strategies aim for a comprehensive transition from a fossil-based to a biomass-based economy. One common feature of the strategies is the optimistic reliance on technology as main tool in order to overcome the socio-ecological crisis. From the critical perspectives of political ecology and the political economy of research and innovation, technologies and technological innovations are not neutral solutions to the problem; they are generally socially embedded. Against this backdrop, we contextualise the technological innovations that support a more climate-friendly production of ethanol on a sugarcane basis, building on a field research in the more recently developed cultivation areas in Mato Grosso do Sul, Brazil. In doing so, we explore the co-production of the green framing of the sector in combination with technologies for a more climate-friendly agriculture and the political economy of land. Our investigation shows that the bioeconomy in the sugar-ethanol sector perpetuates the socio-ecological problems associated with the agricultural sector. These socio-ecological problems range from the increasing concentration of landownership to the negative impact of agrotoxins.

Keywords: bioeconomy; bioenergy; agrofuels; ethanol; land access; Brazil

Citation: Backhouse, M.; Lorenzen, K. Knowledge Production and Land Relations in the Bioeconomy. A Case Study on the Brazilian Sugar-Bioenergy Sector. *Sustainability* **2021**, *13*, 4525. https://doi.org/10.3390/su13084525

Academic Editor: Idiano D'Adamo

Received: 19 February 2021
Accepted: 9 April 2021
Published: 19 April 2021

1. Introduction

Ever since the OECD (Organisation for Economic Co-operation and Development) presented the very first bioeconomy strategy [1], various countries all over the world have adopted corresponding strategies for the implementation of a bioeconomy [2]. At the heart of these strategies is a comprehensive transition from fossil to renewable resources via technological innovation. Bioenergies (power, heat and fuel generation based on biomass) are part of all bioeconomy strategy papers, while their significance and the extent of their funding varies in relation to the respective national or regional degrees of specialisation [3,4].

In this context, agrofuels are being reconceived as a subarea of bioenergy. Agrofuels comprise ethanol made from plant starch or diesel made from plant oil. The term "agrofuel" conveys a critical stance vis-à-vis the worldwide proliferation of funding policies for so-called biofuels. The reason is that the term "biofuel" is misleading because the prefix "bio" suggests an ecological or "green" production, what it is not necessarily. Agrofuels as a substitute for fossil fuels came under fire due to the negative socio-ecological impacts of the expanding agro-industrial cultivation of corn, palm oil or soybean for energy production. Socio-ecological impacts included, among others, land grabbing, the destruction of primary forests or the rise in food prices. In the context of the bioeconomy, the discussion has gradually shifted towards the question of how to ensure sustainable, climate-friendly agrofuels production. On the one hand, there are efforts to develop second-generation agrofuels based on recycling and waste materials such as plant fibre, in contrast to first-generation fuels made from plant components which are also relevant to the food industry. From this perspective, first-generation agrofuels serve as a mere bridge technology to be replaced in the near future. The second generation agrofuels are hoped to facilitate a cascading use, in the sense of a "maximum material use of biomass, i.e., as long, as often and as efficiently as possible, with subsequent energy use at the end of the product life cycle" [5]. In this context, bioenergy would also contribute to the circular economy and thus would strengthen the link between the bioeconomy and circular economy [6]. Geissdoerfer et al. "define the circular economy as a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling." [7] In the EU the bioeconomy is considered as "renewable segment of the circular economy" and therefore should contribute to its sustainability goals as, for instance, climate neutral production [6]. On the other hand, the agricultural production of biomass is to be made more efficient through technological innovation, thereby reducing carbon output e.g., [1,6]. In this regard, we refer to "new green" technologies because these technologies are indeed explicitly in line with climate targets and correspondingly politically legitimised.

However, studies already emphasized that bioeconomy strategies and policies do not automatically lead to more sustainability [8,9]. The overall socio-economic and ecological performance of the bioeconomy is still difficult to assess due to the diversity of this new field and missing indicators [10,11]. Bioeconomy indicators have been proposed but only for the European Union or single European countries [10,12]. A study on biomass trade relations also indicates that a growing biomass demand in the Northern countries could lead to decreased sustainability in biomass exporting countries of the Global South [13].

Critical researchers from political ecology as well as science and technology studies (STS) attribute the possible lack of sustainability of the bioeconomy to the technology optimism of this new version of ecological modernisation e.g., [14–16]. According to Kleinschmitt et al., the bioeconomy "has its roots in the discourse of ecological modernization arguing that economic growth and development can be aligned with environmental protection" [17,18]. From the critical point of view, every form of (technological) knowledge production is situated in social structures and contexts, which are permeated by power relations. Thus, without a social contextualization of technologies, there is a danger that socio-ecological problems will be exacerbated (ibid.). Countless policy analyses demonstrate that the bioeconomy strategies mainly promote technological innovations in the conventional areas of agriculture e.g., [4,14,19,20]. Against this background, critical researchers and NGOs (nongovernmental organisations) fear that the bioeconomy could worsen the socio-ecological problems such as diminishing biodiversity or land grabbing e.g., [14–16,21].

So far, the mentioned policy analyses as well as studies on technological knowledge production e.g., [22,23] in the context of the bioeconomy have mostly focused on the global North. While studies on the bioeconomy in the global South usually focus only on land relations e.g., [24] However, the production of knowledge and the changes in land relations must be considered together in order to do justice to the holistic sustainability goals of the bioeconomy which include creation of employment opportunities, food security and the mitigation of climate change e.g., [6].

Therefore, in this paper we go beyond these research lacunae and focus on the following research question: How do land and working relations change in interrelation with technological innovations? Our aim is twofold: on the one hand, to clarify whether the bioeconomy continues the socio-ecological problems of agrofuels; on the other hand, we aim to provide an empirical contribution to the study of the social embedding of technological knowledge production by relating green innovations to the political economy of land relations in recently established cultivation areas.

We built on critical perspectives from political ecology and the political economy of research and innovation (PERI) and adopted a case study approach choosing the sugarcane sector in Brazil as a case we will further elaborate in Section 2. In Section 3, we contextualise the Brazilian sugarcane sector, its green framing and respective green technologies. Section 4 assesses recent changes in rural land relations in the new sugarcane expansion area of the federal state of Mato Grosso do Sul. In Section 5, we summarise our findings and draw conclusions for the bioeconomy in general.

2. Methodology and Case Selection

We proceed from approaches developed by the political economy of research and innovation (PERI) and political ecology. Both are fields of research rather than theories. They have in common a power-critical and a radically contextualising perspective of investigation. For radical contextualism, context is not only the framework of social practices. Rather, context and social practices are inseparably interrelated [25,26]. The aim is to reconstruct the relationship as thoroughly as possible.

Building on an insight from PERI, we contend that the generation of knowledge is generally situated in social relations and therefore linked to political economies [27]. While especially academic knowledge production is often seen as objective and neutral, PERI points out that it is pervaded by power relations, which means on the one hand that different groups participate unequally in the definition process of the problem and its technological solution. On the other hand, they are affected unequally by these approaches. Besides the investigation on how knowledge and political economies are co-constituted in specific contexts [27,28], its discursive framing is also highlighted [27]. Following this perspective, to understand how knowledge production is interrelated with land relations, we first investigate the context in which the bioeconomic knowledge emerges. This includes the following questions. What is defined as green practice and green technology by the Brazilian agricultural-bioenergy sector? How are green technologies implemented?

From the viewpoint of our second analytical perspective political ecology, the concept land relations encompasses land access and use [29]. Land access describes the possibility to benefit from land which may or may not include land ownership [30]. Land use includes agricultural practices and working relations. Land relations may well be influenced by natural materialities such as soil quality and climate or natural disasters but are not determined by them [29–32]. However, the way in which people pursue agricultural activities and deal with ecological crises is essentially shaped by complex social, political-economic, and cultural relations of power and land access, which may have evolved over centuries. Land relations are structured—always according to the specific context—by colonial continuities, global trade relations, (technological) knowledge and categories of inequality such as class, gender, or ethnicity [33]. Thus, land relations are not determined by technologies or the economy; rather, they all interrelate. Against this backdrop, we will study how land use and land access are shaped by the green framing of a specific agricultural sector, the implementation of green technologies as well as economic developments of the respective sector. The following questions are to be answered: How does the green framing of a respective sector in correspondence with specific technological innovations materialise on the local level? How is land access and use organized and reshaped by these changes? How is land access and use linked to different groups in the countryside? How are they affected?

By exploring these questions, we aim to contribute to the overarching research question of how land and working conditions changed in interrelation with technological innovations.

We adopt a case study approach using a single case design for our research [34]. This allows us to gain in-depth knowledge about the complex relationship of real-life dynamics. Furthermore, the case study approach gives the possibility to assess research questions for which no (sufficient) quantitative data is available. Case studies are often criticized for being single case examples, and results cannot be generalized. However, case studies aim to reach analytical instead of statistical generalization. The objective of a case study is not to propose a theory that is universally valid but to arrive at conclusions that are valid for the set of propositions [35].

The expansion of the Brazilian sugarcane-ethanol sector in the Brazilian federal state Mato Grosso do Sul is selected as the single unit of analysis [34]. As stated in the introduction, there is a research lacuna in looking at technological knowledge production in the bioeconomy in the Global South. The Brazilian sugarcane-ethanol sector is particularly suited for our investigation because Brazil has been producing sugarcane-based ethanol since the 1970s in order to partially replace conventional fossil fuels in the transport sector [24,36,37]. Over the past two decades, Brazil has increasingly invested in the development of a wide range of new, more climate-friendly technologies in the sugarcane-ethanol sector. The federal state of Mato Grosso do Sul was selected because it presented the most pronounced expansion dynamics within the green reframing of the sugarcane-ethanol sector in the beginning of the millennium [24,37–39].

The Brazilian bioeconomy policies are elaborated in the Research Plan and Bioeconomy Action Plan of the Ministry of Science and Technology (MCTIC—Ministério da Ciência, Tecnologia, Inovações e Comunicações). In these documents, the Brazilian bioeconomy focuses on agrofuels production and generally on the industrial use of biomass as well as on the extended biotechnological usage of biodiversity resources. Unlike the EU (European Union) and countries such as Germany, there is no explicit focus on a circular economy [40,41].

The case study comprises the period from 2000 to 2018. Nevertheless, to assure a sufficient understanding of the context, a short historical overview of the Brazilian sugarcane sector is given in chapter three. The conclusions also contain important insights on the current political situation after 2018 and possible effects on land and labour relations.

Therefore, the single-case design includes the national and local contextualisation of green innovations and the in-depth assessment of the case in the recent established areas of sugarcane production in the state of Mato Grosso do Sul. The contextualisation in chapter three is based on statistical data, the scientific and grey literature. We assessed the data and documents using three main categories: first, market characteristics and expansion dynamics of the Brazilian sugarcane sector; second, the technologies which are being funded in the context of the Brazilian sugarcane-ethanol sector; third, the green framing of the Brazilian sugarcane-based ethanol as a mean for climate protection and green development.

The assessment of the changes in land relations are based on thorough field research conducted by Kristina Lorenzen in April 2017, between November and December 2017, and between April and June 2018. Methods such as explorative and semi-structured interviews, informal conversations and group discussions were complemented and contrasted with quantitative data and insights from a literature review. This approach has the advantage to compensate for potential distortions and disadvantages of one of the research methods through the use of a variety of methods [42,43]. Furthermore, a cross-perspective approach was used, meaning that a diverse group of individuals from civil society (social movements, nongovernmental organizations, labour unions and peasants), academia, the state and the private sector was interviewed (see Table 1 for the List of Interviews; see [44]). During the field research, the first analysis was performed using open coding, memo writing and reflection in a research diary [42,43]. More detailed coding was carried out after the field trips and were condensed into the two main categories land access and land use. Land use contains the topics of working conditions and agrochemicals.

Table 1. Interviews.

No.	Sector	Position/Organization	Date
1	State	Two prosecutors of the Public Prosecution for Labor Rights (MPT)	16 March 2017 13 June 2018
2	State	Group discussion with different researchers of the State Agricultural Research Authority *Embrapa Centroeste*	7 June 2018
3	Private	Representative of the regional sugarcane federation *Biosul*	29 May 2018 6 June 2018
4	Private	Big landowner, who used to grow sugarcane, but now grows soybean	7 May 2018
5	Private	Big landowner, who used to grow sugarcane, but now grows soybean	7 May 2018
6	Private	Big landowner, who used to grow sugarcane, but now grows soybean	7 May 2018
7	State	Representative of a Municipal Secretary for Economic Development	7 May 2018
8	Civil Society	Representative of the Pastoral Land Commission *(CPT)*	28 May 2018
9	Union	Representatives of a labour union for rural workers	24 November 2017
10	Civil Society	Members of a landless movement	12 May 2018
11	State	Representative of the regional agrarian reform authority *INCRA*	22 May 2018
12	Private	Big landowner who has land which partly lies on identified Indigenous Land	23 November 2017
13	State	Federal prosecutor of the public prosecution *(MPF)*	11 June 2018
14	Union	Representative of an industrial labour union	9 May 2018
15	Union	Representative of an industrial labour union	20 June 2018
16	Civil Society	Person of an organic agriculture association	3 May 2018
17	Civil Society	Sericulturist	3 May 2018
18	State	Prosecutor of the state public prosecution (MPF)	21 May 2018
19	State	Researcher of the agrarian research authority *Embrapa Pantanal*	19 April 2018
20	Civil Society	Indigenous person on occupied land	9 June 2018
21	Civil Society	Peasant in an Agrarian Reform Settlement	19 May 2018

3. Context: Technological Innovation for Climate Protection in the Brazilian Sugarcane Sector

3.1. The Brazilian Sugarcane-Ethanol Sector in Numbers

Producing 35.5 billion litres, Brazil is the second-largest producer of ethanol after the United States (US), and it is the biggest sugarcane producer worldwide (Figure 1) [45].

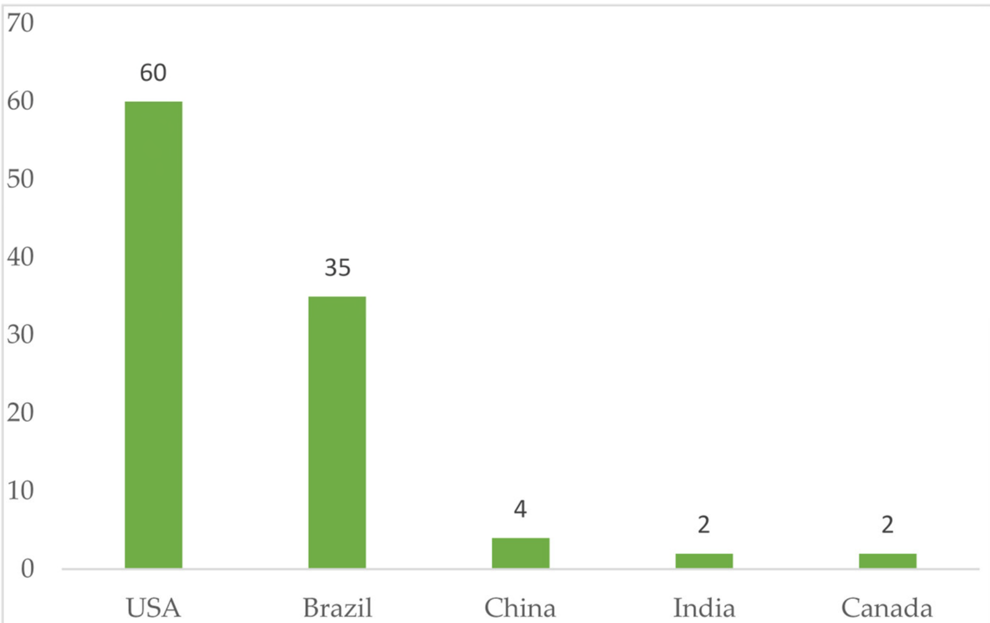

Figure 1. Global ethanol production by top producers (in billion liter).

In contrast to sugar, 75 per cent of which is exported to more than 100 countries around the globe, the bulk of the ethanol produced in Brazil remains in the domestic market [46].

In the transport sector, Brazil has established blending quotas for agrofuels: in 2020, the blending quota for biodiesel was 12 per cent, while the quota for ethanol was at 27 per cent [47,48]. Demand has been stabilised since 2003, not least through the introduction of flexible fuel vehicles (known as "flex cars") whose engines run on any given mixture of gasoline and ethanol and whose owners can thereby react flexibly to oil and ethanol price fluctuations.

Bio-electricity based on bagasse has become the third most important product in the sector besides sugar and ethanol. Bagasse consists of the plant fibers that remain after sugarcane is crushed. Some 46 per cent of producers use it for their own energy supply, and 54 per cent feed electricity into the national grid, thereby contributing to a further diversification of the Brazilian energy mix [49].

3.2. The Green Reframing of Brazilian Sugarcane-Ethanol Sector

The introduction of ethanol as a substitute for petroleum occurred in 1973–1974 in the context of the government funding programme *Programa Nacional do Alcool* (PROALCOOL). On the one hand, this was a reaction to the oil crisis and an attempt to provide an alternative to fossil petroleum. On the other hand, the programme served to support the sugarcane sector, which was facing a crisis as a result of the drop in sugar prices. At the same time, and in connection with these measures, the government began funding research on ethanol use in energy production and improved cultivation methods [50]. During the period from 1985–2000, however, PROALCOOL was increasingly regarded as a failure, and the sector was once again thrown into crisis due to low oil prices, high sugar prices, and Brazil's general economic crisis [51,52].

It was not until 2003 that the sector received a renewed boost as a result of the introduction of "flex cars" and the establishment of blending quotas. The most important technological innovations included new sugarcane varieties, production facilities which could produce both sugar and ethanol, and the use of bagasse for power generation [39]. At the same time, ethanol production was promoted as a climate protection measure. Given its low CO_2 (carbon dioxide) footprint—a reduction of 85–90 per cent compared to petroleum—Brazilian ethanol was regarded as almost climate neutral and, moreover, economically more competitive because of its enormous productivity and low production and transport costs [53]. In the wake of the biofuel policies introduced primarily in the US and the EU as a way of reducing CO_2 emissions, major sales markets seemed to emerge in Brazil. However, the positive carbon footprint of Brazilian ethanol was soon called into question [37,54], which underscores how contested the quantification of the carbon footprint is. So far, the hopes for new markets for bioethanol have not materialised [55].

Correspondingly, the sector continues to try to establish and maintain its green image as an implementor of climate protection measures [36]. Besides emphasising the climate-friendly cultivation methods and modern production and refinement facilities, one central narrative conveys that ethanol production consumes far less land (around 10 million hectares in 2018, UNICA: https://observatoriodacana.com.br/, accessed on 18 January 2021) compared to soybean cultivation (almost 37 million hectares in the harvest year 2019–20, Embrapa: Dados econômicos: https://www.embrapa.br/soja/cultivos/soja1/dados-economicos, accessed on 4 November 2020) or cattle farming (around 160 million hectares in 2019, see [56]). Another narrative implies that the plantations are expanding in central Brazil and not, like the cattle pastures and soy fields, in the Amazon region. This means that they do not contribute to the CO_2-intensive destruction of primary forests. One initial success for the sector has been that Brazil is able to export first-generation ethanol to the US as an "advanced biofuel" because the US largely acknowledges ethanol's favourable carbon footprint [57]. That said, total exports to the US during the harvest year of 2019–20 constituted only three per cent of Brazil's total ethanol production According to UNICA, some 35,595,000,000 litres of ethanol were produced in the harvest year of 2019–20, of which 1,141,743,000 litres were exported to the US (https://observatoriodacana.com.br/, accessed on 18 January 2021).

Given the emergence of new crises, such as the drop in oil prices and poor harvests [58], the reframing of the sector in terms of climate protection is more than just an image campaign; in fact, it increasingly serves as a political-economic crisis management strategy. The aim is to open up new export markets for Brazilian ethanol and technology while simultaneously achieving the country's climate targets. In the context of the Paris Climate Agreement, Brazil has agreed to reduce its emissions by 37 per cent by 2025, compared to 2005 levels [59]. Government funding of the sector is therefore increasingly tied to Brazil's pledge to reduce national CO_2 emissions.

This includes, firstly, the international platform Biofuture, which was founded by Brazil's Ministry of Foreign Affairs (Itamaraty) in order to foster the sector's international relations and thereby gain access to new sales markets. In this context, the platform advertises ethanol made in Brazil as the ideal fuel to reduce CO_2 emissions. Some 20 countries are members of this platform, among them the US and Argentina; Germany is not affiliated (Biofuture: http://www.biofutureplatform.org/, accessed on 15 January 2021).

Secondly, the RenovaBio programme, which promotes the trade in CO_2 emissions certificates, has been in effect since 2020. It is hoped that this will enable production facilities to generate additional income and provide incentives for new investments [57]. By the end of September 2020, around ten million CO_2 certificates had been issued. At the time, Brazil's energy agency (*Agência Nacional do Petróleo, Gás Natural e Biocombustíveis*—ANP) was confident that the target of 14.9 million certificates in 2020 would still be reached (ANP: www.anp.gov.br/noticias/5991-renovabio-chega-a-10-milhoes-de-cbios-emitidos, accessed on 4 November 2020.).

Thirdly, this also includes the funding of Research and Development (R&D). Apart from the versatile use of sugarcane for power generation, efficiency increases and the development of particularly fertile and resistant varieties of sugarcane, it is above all the development of harvesting machines that represents an important step forward in terms of climate policy [36]. The mechanized harvest eliminates the need to burn the fields before harvest and thus improve ethanol's carbon footprint [60]. Similarly, the research on second-generation ethanol (E2G) has received funding from the Brazilian development bank—BNDES (*Banco Nacional do Desenvolvimento*) and the government agency for research funding—FINEP (*Financiadora de Estudos e Projetos*) since 2011. However, the likelihood of E2G being rolled out on the market anytime soon is rather slim given the high production costs and technological challenges [61], and this in fact applies to all such efforts worldwide [59,62]. For most enterprises, the shift to E2G therefore makes little sense, especially because they have only adjusted their machinery to generate electricity from bagasse. Furthermore, E2G and the power generation sector compete for the same raw materials (i.e., waste materials), while E2G is more expensive and has no guaranteed sales market [63]. RenovaBio is equally unable to remedy this situation because the high production costs for E2G cannot be compensated through the sales of emission certificates [64]. This shows that there are competing claims on waste material for cascading use which is not infinitely available. First-generation ethanol (E1G) is certainly not what could be called a bridge technology that will be replaced by climate-friendly E2G in the foreseeable future.

4. The New "Green" Sugarcane-Ethanol Sector in Mato Grosso do Sul

The green reframing of the sector and the prospect of a global ethanol market was accompanied by the expansion of the sector in the early 2000s. This expansion was not a purely territorial extension of the sugarcane cultivation area and production facilities but a restructuring of the entire sector that involved new actors and new technologies.

This restructuring primarily meant that the prices for land in the main cultivation area, the federal state of São Paulo, rose and the sugarcane industry moved to the neighbouring states of Minas Gerais, Goiás, and Mato Grosso do Sul. Among the states with the most dynamic expansion was Mato Grosso do Sul [24,37–39].

During the period of the PROALCOOL programme, Mato Grosso do Sul was already home to eight production facilities (Portuguese: *usinas*) for ethanol and to some extent also for sugar [65]. These production facilities were of a low technological standard and were all Brazilian (family) enterprises. Similarly, the farming and harvesting of the sugarcane also occurred in a nonmechanised process, performed mainly by Indigenous workers (Authors' own research, based on [65]; websites of Novacana, Biosul, UDOP and sugarcane enterprises; and interview 1).

Between 2001 and 2012, another 14 production facilities were set up in Mato Grosso do Sul [65]. Due to increasing internationalisation and concentration, the stakeholder structure in the sector changed entirely. New actors were for the most part corporate holdings, such as Odebrecht (Atvos), Adecoagro, Luis Dreyfuss (Biosev), Raízen (Shell/Cosan) and Bunge. These new actors invested in new enterprises or bought out smaller companies that were struggling at the time [58]. New, more modern production facilities were put into operation, many of which produced not only sugar and ethanol but also electricity based on sugarcane bagasse (Authors' own research, based on [65]; websites of Novacana, Biosul, UDOP and sugarcane enterprises).

The new actors provided the capital needed for the mechanisation of the agricultural segments of the sector (interviews 1 and 2).

The process of ethanol production itself, however, did not undergo much innovation. As a result, the production of first-generation ethanol made from sugarcane juice continued. The production of second-generation ethanol was not implemented in Mato Grosso do Sul due to high production costs and technological challenges even though the regional sugarcane federation Biosul considered this technology to be one of the most promising for the future of the sector (interview 3).

The agricultural research agency in the region, *Embrapa Agropecuária Oeste* (*Empresa Brasileira de Pesquisa Agropecuária*), was keen to advance technological development in the sugarcane sector. One central theme is so-called vertical growth, which aims for yield increases per hectare (ha) instead of the expansion of the cultivation area. In this context, 100 tons/ha is an important target figure, and in Mato Grosso do Sul, according to Embrapa representatives, the average was at 89 tons/ha (interview 2). Despite this, the cultivation area for sugarcane rose from 120,534 ha in 2003 to 680,611 ha by 2018, which amounts to a 464 per cent increase (Figure 2, UNICA: https://observatoriodacana.com.br/, accessed on 18 January 2021).

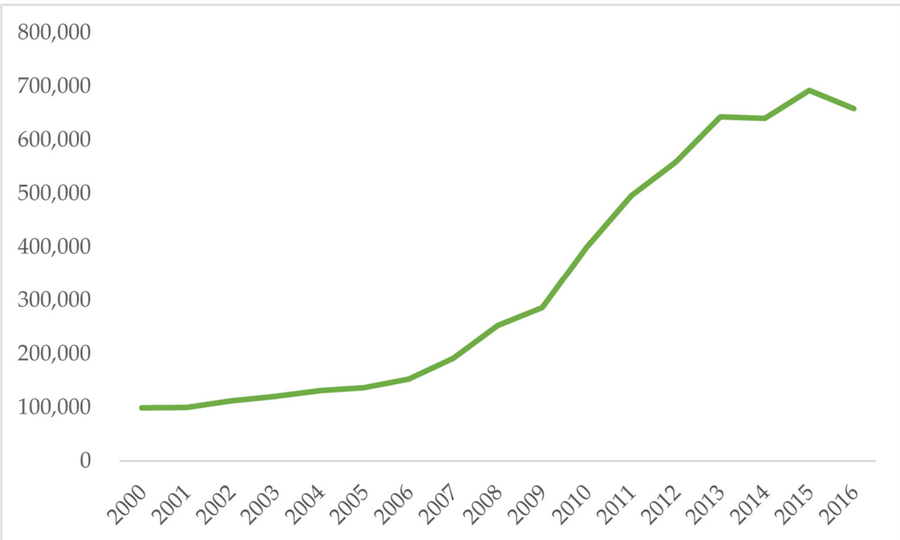

Figure 2. Sugarcane area in Mato Grosso do Sul, 2000–2016 (in ha).

Problems with productivity on the sugarcane plantations arose in Mato Grosso do Sul because the expansion during the early 2000s had occurred at such rapid pace that the establishment of new cultivation areas often lacked sufficient availability of the appropriate sugarcane variety. As a result, other less suitable but readily available variants were used.

Adding to this, the sugarcane sector came into crisis in 2010–2011, which led plantations to postpone regeneration efforts, resulting in the same plants being used for ten years or longer instead of the ideal six to seven years. Similarly, the mechanisation did in fact lead to a reduction in CO_2 emissions, but the compaction of the soils caused by the heavy harvesting machines also led to productivity problems on the sugarcane fields. The same issues applied to the subsequent mechanised collection of the sugarcane straw used for electric power generation (interviews 2 and 3).

At the time of the case study, the new market-based funding programme RenovaBio offered the greatest hope for the recovery of the sector and new investment, according to the regional federation Biosul (interview 3).

The new technologies failed to live up to the expectations they had raised. Despite yield increases, territorial expansion was pursued, leading to a rise in conflicts over land, as the following two sections illustrate. Moreover, even though mechanisation did bring about some reduction in CO_2 emissions, the greater soil compaction led to a loss in productivity. In addition, the mechanisation also had social consequences, another aspect that is addressed in the following sections.

4.1. Changes in Land Relations in Mato Grosso do Sul

Ever since its creation in 1977, Mato Grosso do Sul has had an agrarian structure characterised by large estates [66–68]. Even what is defined as small-scale agriculture often occupies relatively large portions of land on which soybean is cultivated. Brazilian statistical data do not contain a “smallholding peasants” category; instead they include one for “family-based agriculture”. This category is defined by a maximum size of landholding and the predominant employment of family members for all necessary labour according to law no. 11.326, 24 July 2006. In Mato Grosso do Sul, the maximum size of an estate that still falls into this category varies according to the respective municipality, ranging from 60 to 380 ha (INCRA: http://www.incra.gov.br/tabela-modulo-fiscal, accessed on 22 October 2018). Smallholder families with less than 100 ha of land occupy only 3.2 per cent of the surface area in Mato Grosso do Sul (IBGE. Censo Agropecuário 2017: https://sidra.ibge.gov.br/pesquisa/censo-agropecuario/censo-agropecuario-2017, accessed on 18 January 2021.).

Initially, the expansion of sugarcane displaced soybean cultivation in Mato Grosso do Sul. The world market price for soybean was quite low at the time, and the major landowners seized the opportunity to lease their land to the sugarcane sector (interviews 4, 5, 6 and 7). At first, between 2006 and 2012, the cultivation area for soybean declined. In the subsequent years, then, both sugarcane and soybean expanded to former pasture land (SEMAGRO, BDEWeb: http://bdeweb.semade.ms.gov.br/bdeweb/, accessed on 18 January 2021) [69].

The rise in demand for land led to rising land prices in Mato Grosso do Sul, as had previously been the case in São Paulo. Increasing land prices generally make redistributive land policies more difficult [70]. In Brazil, there is a land reform process, which stipulates that any land that is unproductive and, thus, does not fulfil its social function is transferred to the government, which then redistributes it. In this context, we use the term unproductive in the sense of the Brazilian land reform authority INCRA (*Instituto Nacional de Colonização e Reforma Agrária*): “INCRA considers rural property to be unproductive in those cases in which agricultural land is not or only partially used” (INCRA: http://www.incra.gov.br/pt/educacao/2-uncategorised/233-imovel-rural-improdutivo.html, accessed on 30 November 2020, translation KL). This is the right that smallholders and landless movements invoke when they occupy large estates [71]. Up until the sugarcane expansion, there were large areas of extensive cattle farming (i.e., a small number of cattle per ha) in Mato Grosso do Sul and thus large swathes of land which, as unproductive land, would have technically been subject to land reform (interviews 8, 9 and 10).

The higher prices for land and the increasing productivity of former pastures rendered expropriations in the context of land reform projects increasingly unlikely. From 2008 onward, the land reform process slowed down, evidenced by the smaller number of agrarian reform settlements (ARS) being established. Between 2011 and 2018, only two new settlements were created, but in neither of the two instances was land actually expropriated. Instead, the landowners sold their land to the land reform authority at market price [72] (interviews 10 and 11). Of course, the land reform process coming to an almost complete standstill is not exclusively the result of the sugarcane expansion. There are also political reasons such as the neglect of the needs of smallholding farmers and the abandonment of the land reform plans, as well as the government's promotion of an export-oriented agro-industry [73]. That said, the rise in land prices, caused mainly by the sugarcane expansion, certainly complicates the land reform process.

Thus, the relations of land access that had already been unequal were exacerbated as a result of the incentives for ethanol production as a climate protection measure. Large estates remained large-scale land holdings, and the prospect of a redistributive land policy diminished. Land use first shifted from soybean to sugarcane cultivation, and subsequently from extensive to intensive pasture farming, as well as sugarcane and soybean cultivation. In Mato Grosso do Sul, "green" bio-ethanol has led to the expansion of an agro-industrial model which has aggravated land conflicts with the landless movements ever since the 1970s [66,67] and which impedes alternative agricultural land use practices and related knowledge production.

4.2. The Double Exclusion of the Guarani-Kaiowá

The state of Mato Grosso do Sul is home to the second-largest Indigenous population in Brazil, the largest ethnic group being the Guarani-Kaiowá (FUNAI: http://funai.gov.br/index.php/comunicacao/noticias/1069-entre-1991-e-2010-populacao-indigena-se-expandiu-de-34-5-para-80-5-dos-municipios-do-pais, accessed on 5 September 2018; Museu das Culturas Dom Bosco: http://www.mcdb.org.br/materias.php?subcategoriaId=23, accessed on 5 September 2018). According to Brazil's constitution, Indigenous peoples are entitled to their traditional territories, and there is indeed an ongoing process of demarcation which is supposed to identify indigenous land and return it to the respective groups [74]. Major landowners and farmers living on this land are expropriated by the government without any entitlement to compensation, except for the *benfeitorias*, i.e., the assets and property built on this land.

When the price of land exceeded that of the *benfeitorias* in Mato Grosso do Sul due to the rise in land prices, the chances of Indigenous land being demarcated diminished. The large landowners in particular are up in arms about the demarcation processes, and they launch legal battles whenever a demarcation is announced. These legal proceedings, on the one hand, have led to the demarcation process being stalled for years on end (interviews 12 and 13). The last indigenous land was demarcated in 2004 (Terras Indígenas: https://terrasindigenas.org.br/pt-br#pesquisa, accessed on 25 September 2018). On the other hand, the landowners have actually managed, through their legal tactics, to reverse some of the demarcation [75,76]. The Indigenous activists, for their part, continue to fight against the delayed or reversed demarcations through land occupations [77]. Here, again, large landowners resort to legal means and call on the military police to have the Indigenous activists evicted from the land by force (e.g., http://www.ihu.unisinos.br/78-noticias/582206-policia-militar-do-ms-retira-a-forca-guarani-kaiowa-de-retomada-em-caarapo, accessed on 22 October 2020).

This is particularly dramatic given that the Indigenous population lack any alternative basis of existence. Up until 2012, the Guarani-Kaiowá provided the bulk of the workforce for manual sugarcane harvesting. Owing to the continuous mechanisation of sugarcane harvesting to avoid the CO_2-intensive burning of the fields, however, a single machine now replaces up to 100 workers (interview 1, a list of interviews can be found in Table 1). For jobs as machine operators, preference is given to non-Indigenous farmers and skilled specialists who, according to the trade unions, usually have an officially recognised qualification of some sort (interviews 14 and 15). Abolishing this agricultural labour—the precarious and slave-like conditions human rights organisations frequently drew attention to [78]—has contributed to the social exclusion of Indigenous people.

In sum, green technological innovations in the sugarcane sector have had a severe impact on the Guarani-Kaiowá. They are cut off from income opportunities in two ways. Firstly, their access to land is further restricted, which once again exacerbates a historic conflict that dates back to colonial times. Secondly, they are effectively left without any opportunities to pursue wage labour.

4.3. Social-Ecological Impacts of Pesticides and Herbicides

The Brazilian Agricultural Research Autority Embrapa conducts research on the more efficient use of pesticides and herbicides (Embrapa Agropecuária Oeste: https://www.embrapa.br/agropecuaria-oeste/pesquisa-e-desenvolvimento, accessed on 12 January 2021). However, this research has so far failed to prevent the expansion of a monocultural form of land use such as sugarcane cultivation from exacerbating another line of conflict. Smallholding farmers and Indigenous peoples denounce the contamination of plants and water as well as serious health effects caused by pesticides and herbicides that are sprayed on the sugarcane fields by planes.

In 2018, for the first time ever, there was official confirmation of the negative impacts of agrochemicals by the government's agricultural research agency. In the municipality of Glória de Dourados, Embrapa analysed silkworms and their feed (mulberry leaves) after sericulturists had complained about large-scale production losses. Lab studies found that the leaves and worms showed evidence of residue of the chemicals that had been sprayed over the neighbouring sugarcane fields. Moreover, Embrapa was able to verify a chemical spray drift of up to 4 km (interviews 2, 13, 16, 17 and 18). Various smallholders in existing agrarian reform settlements as well as Indigenous activists living on occupied land near sugarcane plantations reported dying plants or plants with retarded growth after planes had sprayed chemicals on the fields (interviews 20 and 21). However, there is no proof in these cases that the agrochemicals caused the loss of plants. That said, it is a widely known fact that sugarcane is treated with desiccants prior to the harvest to allow the plant to dry out and shed its leaves, which accelerates the ripening process and makes mechanical harvesting more economical. In the case of sugarcane, the most commonly applied desiccant is glyphosate. International studies have shown that glyphosate can damage or even demolish neighbouring crops [79–81]. Furthermore, it is assumed that the agrochemicals and the vinasse, a waste product from ethanol production that is used as a fertiliser for sugarcane fields, are the cause of water contamination. Here, we can distinguish another field of conflict related to the negative impacts of this monocultural production type on the rural population. What is revealed at the same time is a profound knowledge gap in the bioeconomy discourse as a whole regarding the damage caused by the use of fossil agrochemicals in the bioeconomy.

5. Conclusions and Outlook

This paper addressed the research question, how do land and working conditions change in interrelations with technological innovations? An analytical framework of PERI and political ecology was presented to show the importance of contextualisation for bringing together the two complex topics of technological knowledge production and land relations. A qualitative case study approach was used to investigate in-depth the relationship between green technologies in the Brazilian sugarcane-ethanol sector and land relations in the federal state Mato Grosso do Sul. The contextualisation of the Brazilian sugarcane sector and its technological innovations since the 1970s showed the green reframing of the sector. Sector policies and technological innovations were reframed as "green" solutions to the climate crisis. While those new green technologies had some positive effects such as the reduction in CO_2 emissions of sugarcane harvest, detrimental effects were observed in regard to land access for both agrarian reform peasants and

Indigenous peoples. Furthermore, negative socio-ecological impacts of agrochemicals used in sugarcane cultivation were officially proofed by state authorities.

Combining the radically contextualising perspectives of PERI and political ecology has proven conducive to clarifying the contradictions and pitfalls of the technology optimism inherent in current bioeconomy strategies. It was also possible to shed light on the reduction of climate protection to abstract, quantifiable carbon footprints. This combination of perspectives shows how the green reframing of a powerful agro-industrial sector (in terms of portraying their industry as a whole as a climate protection measure) and the related "green" technologies restructure relations of land access and land use. The differentiated study perspective was particularly helpful in discerning the complex land rights and relations of access (large landowners, smallholding peasant families, landless and indigenous actors). This way, we were able to show the contradictory effects of the mechanisation of harvesting: while new jobs and sources of income do emerge in the mechanised sector for smallholding families, the situation of the Guaraní-Kaiowá is deteriorating on two fronts, threatening their very existence. They have neither land nor jobs that could allow the population to reproduce itself even precariously. In Mato Grosso do Sul, the "new green" sugarcane to some extent exacerbates local conflict scenarios.

What remains unclear for now is how significant the "green" legitimation of Brazilian ethanol as a climate protection strategy will be in the future. Announcements by Brazilian president Jair Bolsonaro that he wants to withdraw from any climate protection agreements may well pose a problem for the sector. The green image of Brazilian ethanol could also suffer due to Bolsonaro's attempts to abolish Brazil's legally stipulated agro-ecological zoning, which prohibits sugarcane cultivation in the sensitive ecosystems of the Pantanal and the Amazon region. The Pantanal is a marsh and lakeland area in the southwest of Brazil, some parts of which are under UNESCO protection as it is the largest landlocked wetland in the world. In November 2019, President Bolsonaro issued a presidential decree suspending the legislation concerning agro-ecological zoning. In return, the draft for a legislative decree (*Projeto de Decreto Legislativo*) was put forward by parliament, which seeks to suspend the presidential decree. This draft is due for discussion in the Chamber of Deputies (https://www.camara.leg.br/propostas-legislativas/2228776, accessed on 5 November 2020). Another unknown concerns the future development of knowledge production in the Brazilian sugarcane-ethanol sector because Brazil's entire research sector has recently been subject to sweeping cuts.

Therefore, what can we draw from this case study for the international debate about the orientation of the emerging bioeconomy?

First, this paper illustrates that technologies may not determine social relations such as land access, but they do have a strong impact on them. Thus, more research on the social embeddedness of green R&D is needed.

Second, the Brazilian case study shows that the bioeconomy will continue the social-ecological problems of agrofuels if its focus is set only on the substitution of petroleum and efficiency in the agricultural sector. As a partial substitution strategy for petroleum and due to the dependence on agrochemicals and the oil price, ethanol, like most agrofuels, moreover, remains part of the fossil regime that the bioeconomy is supposed to overcome and replace. Yield increases and technological innovations for the reduction of carbon emissions and a favourable carbon footprint do not offset these contradictions.

Likewise, the technology optimism harboured by many bioeconomy strategists, according to which first-generation agrofuels are merely bridge technologies soon to be replaced by more climate-friendly second-generation agrofuels, has proven—at least for the time being—to be a misconception not only in the Brazilian ethanol sector.

Third, there is a lack of qualitative and quantitative studies to further assess the socio-economic and ecological performance of the bioeconomy or its many sectors. While there have been first proposals for a broader bioeconomy monitoring in the European Union or in single countries of the EU [9,11], more insights on the bioeconomy performance in countries of the Global South and on the impact of increased transnational biomass trade are mostly missing.

Finally, we agree with many critics all over the world that further research on alternative technological approaches is needed. The conflicts surrounding the damage caused by agrotoxins not only call the climate-friendly image of Brazilian ethanol into question. They also underscore just how incomplete the knowledge is regarding the social-ecological impacts of pesticides and herbicides. Finally, the unresolved knowledge production regarding alternative forms of agriculture and energy generation does not play any role in this context. The existing regional agro-industry, not only in the sugarcane-ethanol sector but also in the soybean and cattle ranching sectors, increasingly appears to be without any alternative. Other cultures and practices of land use by agrarian reform settlements and Indigenous communities are being marginalised and displaced. As a result, important fields of experimentation and spaces of opportunity are disappearing which may prove vital in the development of alternatives to this agro-industrial version of the bioeconomy. Thus, with regard to the imminent social contestation around the general orientation of the bioeconomy, the question arises as to which knowledge forms, technologies and infrastructures may serve to shape the bioeconomy in a way that actually contributes to a socially just ecological transformation in a global context. This requires democratic deliberation and negotiation about the direction of the bioeconomy and, on that basis, a change in research funding programmes—not only in Brazil, but all over the world.

Author Contributions: M.B. contributed as lead author and mainly wrote Sections 1–3 and 5 with contributions from K.L. K.L. mainly authored Section 4 with contributions from M.B. All authors have read and agreed to the published version of the manuscript.

Funding: The research on which the article is based was funded by the Federal Ministry of Education and Research (BMBF) as part of the junior research group "Bioeconomy and Inequalities. Transnational Entanglements and Interdependencies in the Bioenergy Sector" (funding number 031B0021). We acknowledge support by the German Research Foundation and the Open Access Publication Fund of the Thueringer Universitaets- und Landesbibliothek Jena Projekt-Nr. 433052568.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: All relevant data or references can be found in the paper itself.

Acknowledgments: The authors would like to thank five anonymous reviewers as well as the whole junior research group "Bioeconomy and Inequalities" for valuable comments on an earlier draft and Laura Mohasci for the review of the latest version. Furthermore, we are especially grateful for all interview partners and colleagues in Mato Grosso do Sul, Brazil who enabled and were part of the research.

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

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