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The knowledge-based bioeconomy in the semi-periphery

A case study on second-generation ethanol in Brazil

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The knowledge-based bioeconomy in the semi-periphery. A case study on second-generation ethanol in Brazil

Abstract

The promotion of a global bioeconomy is supposed to contribute – through technological innovation – to a societal transition towards a more environmentally and climate-friendly economy. Simultaneously, think tanks like the OECD hope that this transformation will enhance the role of the semi-peripheral countries as raw material suppliers, enabling them to also contribute to global innovation and knowledge production. Although Brazil has not adopted a national bioeconomy strategy until now, the country represents a promising example as starting point for the emerging bioeconomy as it is the second-largest producer of ethanol worldwide and holds longstanding technological expertise in this field. Based on the developments of second-generation ethanol (E2G), this paper discusses the extent to which the Brazilian sugarcane-based ethanol sector is successfully asserting itself – through homegrown innovation and technologies – in the global race for leadership in E2G technology. The aim of this working paper is to contribute to the question whether the bioeconomy will reproduce the global imbalance in knowledge production between centres and (semi-)peripheries or engender a multipolar world of knowledge production. Therefore, I evaluate the historical context of the sugarcane-ethanol sector and analyse studies and data on the state of technological innovations as well as about the public and private investments in E2G research. Given the fact that the proportion of E2G in gasoline blends has been marginal so far, the global competition for E2G technology still remains widely open. This explorative study based on literature reviews shows that technology development in the Brazilian sugarcane-ethanol sector focuses on the less complex optimisation of agro-industrial production, while the dependence on technology imports from Western European or North American knowledge centres to produce E2G in refineries continues. Yet, even though this may signal a partial continuity of unequal global knowledge production, the trajectory does not indicate a mere reproduction of a simple centre-periphery dichotomy. The state-funded knowledge production of this powerful Brazilian sector allows for the co-production of new knowledge centres in Brazil, e.g. in the field of genetically modified sugarcane ("cana energia"). Moreover, it strengthens the narrative of Brazilian ethanol as a climate protection strategy which serves as a basis for the sector to intervene in the global debates about policies on climate and bioeconomy.

Biographical Note

Maria Backhouse is professor of sociology and director of the Junior Research Group "Bioeconomy and Inequalities" funded by the German Federal Ministry of Education and Research (BMBF). Her current research engages with political ecology, knowledge and technology, social-ecological inequalities, bioenergy with a regional focus on Brazil.

Keywords: bioeconomy in Brazil, second generation ethanol (E2G), knowledge production in the semi-periphery, bioenergy, biofuels.

Maria Backhouse

Die wissensbasierte Bioökonomie in der Semi-Peripherie. Eine Fallstudie zu Ethanol der zweiten Generation in Brasilien

Zusammenfassung

Mit der Förderung einer globalen Bioökonomie soll über technologische Innovationen eine gesellschaftliche Transformation zu einer umwelt- und klimafreundlicheren Ökonomie angestoßen werden. Gleichzeitig verbinden Think Tanks wie die OECD damit die Hoffnung, dass im Kontext dieser Transformation die Rolle der semiperipheren Länder als Rohstofflieferanten aufgewertet wird, indem sie auch zur globalen Innovations- und Wissensproduktion beitragen. Brasilien hat zwar bis heute keine nationale Bioökonomie-Strategie verabschiedet, gilt aber als zweitgrößter Ethanolproduzent weltweit mit eigener langjähriger technologischer Expertise in diesem Bereich als vielversprechendes Beispiel. Anhand der Entwicklungen von Ethanol der zweiten Generation (E2G) wird deshalb im vorliegenden Working Paper der Frage nachgegangen, inwieweit es dem brasilianischen Zucker-Ethanolsektor gelingt, sich mit eigenen Innovationen und Technologien in diesem globalen Wettlauf um die technologische Vorreiterschaft der E2G-Technologie zu positionieren. Damit soll ein Beitrag zu der Frage geleistet werden, inwieweit die globalen Asymmetrien in der Wissensproduktion zwischen (Semi-)Peripherien und Zentren fortgesetzt werden oder durch eine neue Multipolarität der globalen Wissensproduktion aufgelöst werden. Dafür werden neben der historischen Kontextualisierung des Zuckerohr-Ethanol-Sektors Studien und Daten zum Stand der technologischen Entwicklungen sowie zu öffentlichen und privaten Investitionen in die Forschung ausgewertet. Bisher ist der Anteil von E2G an der Benzinbeimischung marginal, d.h. der globale Wettlauf um E2G ist noch nicht entschieden. Die explorative Studie auf der Basis einer Literaturauswertung zeigt, dass sich die Technologieentwicklungen im brasilianischen Zuckerrohr-Ethanol-Sektor auf die weniger komplexe Optimierung der agrarindustriellen Produktion konzentriert, während sich die Abhängigkeit von Technologieimporten aus den westeuropäischen oder nordamerikanischen Wissenszentren zur Herstellung von E2G in den Raffinerien fortsetzt. Doch auch wenn sich darin partiell Kontinuitäten der ungleichen globalen Wissensproduktion andeuten, handelt es sich nicht einfach um die Reproduktion einer Zentrum-Peripherie-Dichotomie. Denn die staatlich geförderte Wissensproduktion dieses mächtigen brasilianischen Sektors ermöglicht die Ko-Produktion neuer Wissenszentren in Brasilien etwa zu genmodifiziertem Zuckerrohr („Cana Energia“) und stärkt darüber das Narrativ vom brasilianischen Ethanol als Klimaschutzstrategie, mit dem der Sektor in die globalen Debatten um Klimaschutz und Bioökonomie interveniert.

Kurzbiographie

Maria Backhouse ist Juniorprofessorin für Soziologie und Leiterin der BMBF-Nachwuchsgruppe „Bioökonomie und soziale Ungleichheiten“. Ihre aktuellen Forschungsthemen umfassen unter anderem Politische Ökologie, Wissens- und Technologieforschung, sozial-ökologische Ungleichheitsforschung und Bioenergieforschung mit einem regionalen Fokus auf Brasilien.

Schlagworte: Bioökonomie in Brasilien, Ethanol der zweiten Generation (E2G), Wissensproduktion in der Semiperipherie, Bioenergie, Biokraftstoffe.

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1 Introduction[1]

There is no common definition of the term bioeconomy (Backhouse et al., 2017), but only the consensus that bioeconomy "…[is] the knowledge-based production and utilization of biological resources, innovative biological processes and principles to sustainably provide goods and services across all economic sectors […]." (Global Bioeconomy Summit, 2015, p. 4) What unites the various national and supra-national strategy papers is their insistence upon the fact that knowledge and innovation act as drivers of the emerging global bioeconomy. The term knowledge-based bioeconomy captures the notion that the social-ecological crisis could be overcome in the context of the fight against climate change, if economic growth was to be decoupled from the overutilization of resources through (bio-)technological innovation.

The technical leadership in the implementation of the bioeconomy is located – at least according to the corresponding papers issued by the OECD (OECD, 2009) and the EU (EU Commission, 2018) – in the "old" capitalist centres, particularly the United States and Europe. Although the (semi-)peripheral countries are considered to play an important role in the bioeconomy, they are seen to adopt the role of raw material suppliers, as markets for biotechnologies in the area of primary production (such as agriculture, forestry and fishing) and as fields of action introduced by development organizations from the countries of the centre. Exceptions from this basic idea are the emerging countries, particularly China, India and Brazil, which have, in some cases, been investing in research and development in the relevant fields of bioeconomy for several decades (ibid.). These semi-peripheral countries could therefore assume a more influential role in the bioeconomy, including in the development of technologies and innovation. Against this backdrop, the question arises what effect the emerging bioeconomy may have on existing asymmetries of (bio-)technological knowledge production. Will the bioeconomy engender a multipolar world of knowledge production, or will the global imbalance in knowledge production be reproduced?

This question has thus far received little attention in social science debates on bioeconomy, as the regional focus of investigation is usually confined to Western Europe and North America. Hence, the question cannot be answered conclusively in this paper, at least not regarding the global dimension. The intention is rather to present an initial contribution to this debate by placing the focus on the technological development of second-generation ethanol in Brazil. Brazil has not yet presented a concrete national bioeconomy strategy, nevertheless it is regarded as a "high-potential country

[1] I would like to thank Andrey Rocha for his support in conducting research for this paper and for helping to establish contact with experts on the Brazilian sugarcane- ethanol sector. The responsibility for the interpretation of these data is, of course, entirely my own.

due to comparative advantages, biodiversity, competitive costs of biomass – especially sugarcane and advanced tropical agriculture anchored in science and technology." (Araújo, 2016, p. 2) Brazil is the largest producer of sugarcane and the second-largest producer of first-generation ethanol (E1G) after the US.[2] This paper focuses on second-generation ethanol (E2G) due to the fact that it represents an important research area of the Brazilian bioenergy sector. Furthermore, although it may not yet be market-ready due to the high production costs, it is a technology on which decision makers pin great hopes in the context of the bioeconomy: second-generation biofuels are supposed to replace first-generation biofuels, which have increasingly been criticised for competing with land for food production, destroying biodiversity and displacing smallholder producers. E2G, by contrast, can be extracted from organic waste such as fibres from sugarcane, sugarcane bagasse or waste wood and, according to a press release by the National Federation of Industries of Sugar-based Biofuels, CEISE (*Centro Nacional das Indústrias do Setor Sucroenergético e Biocombustíveis*), has the potential to boost Brazilian ethanol production by 50 per cent without increasing the required acreage (Emy, 2017). E2G would, moreover, have a better carbon footprint than E1G given that its production would release only 1/15th of CO_2 emissions. CEISE goes on to claim that Brazil would master all stages of E2G production and that the nation undoubtedly has the potential to become a global leader in this sector (ibid.).

2 Analytical approach and structure of the study

The explorative study at hand is guided by a political-economic perspective on knowledge and innovation, which is distinct from two essential credos of mainstream economics regarding knowledge:

> "[…] first, that 'knowledge' is a familiar beast, namely the (growing) body of factual, normatively neutral truths that enables people to serve their needs and desires; and, secondly, that it is therefore obvious and axiomatic that, when it comes to the question of the production of knowledge, more knowledge always leads to economic growth and societal benefit. In short, more knowledge is always better." (Tyfield et al., 2017, emphasis in the original, pp. 2–3)

Furthermore, research in this field refutes the notion that innovation represents a linear process of development "which starts with the invention of something new and ends

[2] First-generation biofuels (biodiesel or bioethanol) are based on liquid (vegetable oil or sugar) or gaseous (biogas) fuels mainly for the transport sector. They are added to gasoline or biodiesel in line with certain blending quotas. Second- or third-generation biofuels are extracted from waste, straw, cellulose or algae.

with the commercialization of a 'new good on the market'." (Godin, 2015; Birch, 2017, pp. 3–4)

Following the approach of *Science and Technology Studies* (STS), the generation of knowledge is generally conceived as situated and socially produced. Simultaneously, however, this study goes beyond the micro-perspective of STS and investigates the co-production of knowledge, economy, culture and politics (Tyfield et al. 2017a). In line with the *Political Economy of Research and Innovation* (PERI), I argue that all knowledge generation is related to social relations. This puts the social contestation around knowledge and innovation at the centre stage of the analysis (Tyfield, Thorpe, Lave, & Randalls, 2017). Further, it brings the question how the generation of knowledge forms distinct political economies and, conversely, how it is formed by the latter, to the heart of the epistemological interest (ibid.).

From a critical perspective on the social production of knowledge and innovation, the technocratic orientation of the bioeconomy has been criticised for several years. Some researchers claim that there is no space for alternative conceptions of a bioeconomy – as developed, for example, by agroecology – beyond conventional agriculture and biotechnologies (Birch & Tyfield, 2013; Levidow, Birch & Papaioannou, 2012; Moreno, 2017). Thus, they point to social contestation and the exclusion of different actors regarding knowledge production. In terms of global inequalities, the question arises how the production of knowledge is linked to global asymmetries in knowledge production and distribution or co-produces centres and (semi-)peripheries in the context of the emerging bioeconomy. A study of global knowledge production from a world-system perspective reveals contradictory developments: In their study of the impact of the globalisation of science on the centre-periphery configuration, Pierre Delvenne and Pablo Kreimer show that the old science centres may have ceased to exert overwhelming dominance in all fields of research, mainly due to the increasing research and development activities in China.[3] That said, however, these shifts ought not to be mistaken for a general development towards a new global multipolarity of science production. These shifts are, according to the authors, mainly related to an increase in scientific production in China, which, is confined to certain disciplines such as the *nanosciences*. In other, more "traditional" areas of research like biomedicine, the long process of accumulation remains a crucial prerequisite, which is why the "old" Western European and North American centres have managed to retain their leading position (Delvenne & Kreimer, 2017, p. 393). Specialisations in knowledge production and the unequal distribution of knowledge are hardly altered at a global level. The authors

[3] During the 1990s, the US accounted for some 37 per cent and Europe for 35 per cent of scientific production (number of publications). A similar picture emerges in terms of citations (US: 52 per cent; Europe: 35 per cent). Between 2010 and 2012, a shift could be observed: scientific production from the US decreased to 24.3 per cent, while newcomers, particularly China at 11 per cent, displayed a substantial increase. Brazil's share in global publications rose slightly, from 0.84 to 2 per cent. Hence, by this measure, it is on a par with the Netherlands. For more details, see Delvenne & Kreimer (2017, pp. 392–393).

assert that the multipolarity rather consists in the fact that some semi-peripheral countries like Brazil are more heavily oriented towards China (ibid., p. 399). Semi-peripheral countries like Brazil, Argentina or Mexico may operate research programmes in key disciplines but are nevertheless weakly represented in the area of "high technology fields" in a global comparison. Contrary to the widespread neoliberal rhetoric about the expansion of private investment in research and innovation, state-funded research remains the dominant mode in these countries (Delvenne & Kreimer, 2017, p. 394). Similarly, the emergence of transnational research networks based on international research funding programmes such as the EU's HORIZON programme (which also finances research for the bioeconomy) has only rarely led to a shift in the division of labour between centre and (semi-)peripheries: At closer inspection, researchers and research centres in the Western European and North American centres are usually in charge of these transnational research networks, while scholars from the (semi-)peripheries act as assistants and contribute only around 10 per cent of theory formation (Delvenne & Kreimer, 2017, p. 394).

This study proceeds from these insights and investigates the extent to which they apply to the Brazilian sugarcane-ethanol sector as a sector that has created its own homegrown knowledge centres. The sector does not depend on exports, but on national blending quotas and the domestic market. Moreover, this study emphasises the fact that a simplified centre-periphery perspective would be inadequate, despite continuing global inequalities in knowledge production. Rather, the specific historical and political contexts of nationally grounded knowledge production must be taken into account, while inquiring into the ways in which multiple centres and peripheries are co-produced – both within and beyond the (semi-)peripheral countries (Delvenne & Kreimer, 2017).

In the remainder of this paper I sketch the Brazilian E2G sector and outline the inner-sectoral debate about the possibilities, limitations and challenges in the development of technologies and innovation. I embed the knowledge production related to E2G in the Brazilian sugar(cane)-energy sector, which emerged out of the conflict(s) that arose as a result of the government's funding of the crisis-prone sugarcane sector, its dependence on the price of oil, its national energy and climate policy and, since the mid-2000s, the global dispute surrounding the CO2 balance of Brazilian sugarcane. In a closing discussion I analyse the empirical material against the backdrop of the co-production of knowledge, the political economy of Brazilian ethanol and unequal centre-periphery constellations. I conclude that the "old" asymmetries are reproduced, but simultaneously new centres and peripheries within the semi-periphery are evolving. Further, I describe further research lacunae as well as implications for the shape of the emerging bioeconomy.

3 Possibilities for and limitations to E2G production in Brazil

3.1 Some figures

In 2017, the Brazilian energy mix contained a 43 per cent share of renewable energies, earning the country the title of "low carbon economy" (IEA Bioenergy, 2018, p. 2). In comparison, the global average is about 13.7 per cent and the OECD average 10.2 per cent (Empresa de Pesquisa Energética, 2018). Particularly significant in the case of Brazil is electricity generation from hydropower, which in 2017 accounted for 64.4 per cent of Brazil's total electricity production. Likewise, Bioenergy represents a major source of energy: some 9 per cent of electricity production is based on biomass, which in turn is made up of 77 per cent sugarcane and 21.45 per cent wood (UNICA, 2018). In the transport sector, Brazil has established blending quotas: biodiesel (of which 80 per cent are soy-based) has a blending quota of 10 per cent, while for (sugarcane-based) ethanol, the ratio is at 27 per cent (USDA 2018). Demand has been stabilised since 2003, not least through the introduction of flexible fuel vehicles (so-called "flex cars"), whose engines run on any given mixture of gasoline and hydrous ethanol and whose owners can thereby react flexibly to oil and ethanol price fluctuations. In 2018, some 90 per cent of newly registered cars were equipped with these flexible engines (UNICA, 2018).

Global production of ethanol totalled 105.5 billion litres in 2017. At 60 billion litres (produced from corn), the United States is both the largest producer and consumer of ethanol worldwide. Brazil, with a total output of 28.5 billion litres, is the second-largest producer of ethanol and the largest producer of sugarcane. Together, the two countries account for 85 per cent of ethanol produced worldwide (REN 21, 2018, p. 73). Unlike sugar, which is exported to a large extent, the bulk of Brazilian ethanol is reserved for the country's domestic market. In 2018, about 1.2 billion litres were exported – primarily to the US, South Korea and Japan – while around 2 billion litres were imported – mainly from the US – in order to satisfy demand (USDA, 2018).

The production of sugarcane in Brazil has continually risen over the past decade, albeit slowly and with some fluctuations between 2005 and 2017: from 423 million tons in 2005 to 768.6 million tons in 2016, with a minor slump to 758.6 million tons in 2017. The industry produces either sugar or ethanol, depending on current global sugar market prices. During periods of economic stability, around half of the sugarcane produced is used for ethanol production. Due to improved yields, land consumption has not grown at the same rate. In 2017, about 10 million hectares of land were used for sugarcane cultivation in Brazil (by comparison, soy accounted for more than 30 million hectares). Most of this land is concentrated in central Brazil, that is the federal state of São Paulo and neighbouring states – the centre of the Brazilian sugarcane-ethanol sector.

The history of sugarcane is inextricably linked to colonialism, the slave trade and the emergence of capitalism (Mintz, 1986). The sugar(cane)-ethanol sector as we know it today, has been the product of government subsidies and support policies from its very outset, initially shaped by the major sugar barons and subsequently by the entire sector – a trend that continues to this day. The subsidisation of ethanol and funding of corresponding research began as early as the 1920s and followed the stated goal of finding a market for the surplus production of the collapsing sugarcane sector (Lorenzi, 2018, p. 45). A broader introduction of ethanol as a substitute for gasoline occurred in 1973/74 in the context of the "Programa Nacional do Alcool – PROALCOOL", which, on the one hand, was a reaction to the oil crisis and an attempt to provide an alternative to fossil petroleum. On the other hand, it served to support the sugarcane sector, which had once again found itself in a crisis as a result of the drop in sugar prices (Lorenzi, 2018, p. 58). A study from the 1980s shows that the PROALCOOL programme was a bad investment in economic terms. The competitiveness of alcohol on the domestic market could only be ensured through considerable government subsidies (Borges et al., 1984, p. 206). According to the authors' estimates, some 1.7 billion US dollars in tax revenue and tax breaks flowed into PROALCCOL-related subsidies in 1982. This was compounded by the fact that ethanol only very marginally mitigated its dependence on oil, as it represented a mere 2.8 per cent of the national energy supply (ibid.). Subsequently, the sector experienced a renewed boost following the introduction of flexible fuel cars and the green framing of ethanol as a climate protection strategy.

3.2 New hopes for "advanced biofuels"

Biofuels based on cultivated biomass have faced some challenges in the last years. First, they are heavily dependent on the oil price. Second, they have been object of debates in the context of the "food vs. fuel" controversy in Europe and the US, i.e. the contested use of biomass for fuels instead of food. In this regard, first-generation biofuels have been framed as a bridging technology, which is finally to be replaced by second-generation biofuels, charged with many yet unfulfilled hopes.[4] According to the OECD and FAO's projections, "advanced biofuels" will not play any significant role even by 2027 due to a lack of investment in research and development (OECD-FAO Agricultural Outlook 2018-2027, 2018, p. 194). The US issued a "cellulosic mandate" in 2017, which, however, the industry has thus far been unable to meet (ibid.: 192). Meanwhile, the production of first-generation biofuels in the transport sector is constantly

[4] Second-generation biofuels are produced from cellulose, hemicellulose and lignin. E2G is distinct from E1G only regarding the production process, while the final product is the same and can be blended with gasoline. For more details, see UNCTAD (2016, p. 18).

increasing[5] and due to further expand future developments will continue to be reliant on the extent of government incentives and funding policies (ibid., p. 192).

According to *United Nations Conference on Trade and Development* (UNCTAD), there are more than a hundred refineries and pilot plants to produce advanced biofuels worldwide, although the biofuel market remains strongly fragmented (UNCTAD, 2016, p. 18). The number of facilities dedicated to E2G production was still rather negligible in 2016, as the table below shows. In a global comparison, Brazil ranks fourth behind the US, China and Canada. Inside the EU, E2G plants are distributed among Germany, Sweden, Spain, Italy, Finland, the United Kingdom and Denmark (UNCTAD, 2016, p. 30, p. 53-54).

Countries	**Plants in operation (million litres)**	**Plants in construction (million litres)**	**Planned plants (million litres)**
USA	26 (346)	3 (144)	10 (890)
China	12 (360)		
Canada	9 (303)		
EU	26 (346)		10 (792)
Brazil	3 (126)		

Source: Milanez et al. (2017, p. 117) based on data from UNCTAD (2016).

Initial attempts to produce E2G in Brazil date back to the 1970s (Lorenzi, 2018, pp. 132–133). Targeted research, however, only gathered pace after interest in advanced biofuels increased in Europe and North America, with hopes running high that this technology would contribute to developing new export markets for Brazilian ethanol (UNCTAD, 2016, p. 31). The establishment of three E2G plants in Brazil from 2011 onward was funded by the Brazilian development bank BNDES and the government authority for research funding FINEP (*Financiadora de Estudos e Projetos*) within the framework of the Plan for the Support of Innovation in the Sugar-Energy and Sugar-Chemical Sectors PAISS (*Apoio à Inovação dos Sectores Sucroenergético e Sucroquimico*). The actual trigger was a study which criticised that the Brazilian sector was too fragmented compared to that of the US and required concerted coordination measures as well as increased funding of research and innovation in order to be able to compete in the global race for leadership in E2G technology development (Nyko et al., 2010). The objective of PAISS (phases 1 and 2) is the funding of private corporate research and innovation. The three facilities comprise two commercial plants, GranBio and Raizen,

[5] According to REN 21, in 2017 the production of ethanol and biodiesel rose by 2.5 per cent compared to the previous year (see REN 21, 2018, p. 22).

as well as one pilot facility for research purposes run by the centre for sugarcane technologies CTC (*Centro de Tecnologia Canaviera*) (Lorenzi, 2018, p. 120).

- GranBio is a biotech company based in São Paulo that was founded in 2010. It is 100 per cent in Brazilian hands and controlled by GranInvestimentos, which holds an 85 per cent majority share (Lorenzi, 2018, pp. 143–146). The GranBio refinery is located in the north-eastern state of Alagoas and has an annual capacity of 90 million litres of E2G (Milanez, Souza & Mancuso, 2017, p. 116).
- Raizen was established as a joint venture by Shell and Cosan in 2011 and is one of the largest sugarcane producers in Brazil (Lorenzi, 2018, pp. 140–144). In addition, Raizen is a major shareholder of CTC. The refinery, which has an annual capacity of 45 million litres of E2G, is located in the state of São Paulo (Milanez, Souza & Mancuso, 2017, p. 116).
- CTC was established as far back as the 1970s. Since 2011, the research enterprise has become a listed company and is forced to finance itself through the valorisation of its technologies (Lorenzi, 2018, p. 137-140). Important shareholders include Copersucar and Raizen. The pilot plant is located in the state of São Paulo and has an annual capacity of three million litres of E2G (Lorenzi, 2018, p. 140). CTC is the only company in Brazil to fully develop its own technology in E2G production, holding three relevant patents (ibid., p. 139).

The corporate structures of Raizen and CTC illustrate the high degree of internalisation that the whole sugarcane sector has undergone since the early 2000s.[6]

3.3 The future of E2G from the perspective of the Brazilian sector

Despite these efforts, E2G was still not market-ready by 2020 as the sector had hoped. In 2018, a mere 25 million litres of E2G were produced in Brazil – a rather insignificant amount (USDA, 2018). Assessments regarding the future significance of E2G varied already in 2016 (Salles-Filho et al. 2016). Experts agree that the further development of E2G will depend on major investment in R&D, which includes funding of basic research (for an overview of the corresponding debate, see Salles-Filho, 2016). Furthermore, there is a unanimous call for a coherent government funding policy, which,

[6] The early 2000s saw a boom in foreign investment by oil and chemical companies such as Shell, Dupont and BP in the sugarcane/ethanol sector and thus a far-reaching re-design of its capital structure. The transnational corporations also began investing in development and innovation in both E1G and E2G production. From 2011 onward, the sector entered a crisis caused by a drop in oil prices, production slumps and Brazil's economic crisis, from which it is slowly recovering. For more details, see Wilkinson & Herrera (2010); Wilkinson (2015); Salles-Filho, et al. (2016).

similar to the US, must provide a fixed blending quota for E2G (for more on this, see Milanez et al., 2017).

Assessments on whether Brazil will be able to become a technological pioneer in E2G production differ in their conclusions. While BNDES emphasises that E2G is on the brink of being market-ready, others remain more doubtful (Araújo, 2016; Salles-Filho et al., 2016). According to Sérgio Salles-Filho, development and innovation are primarily focused on the agricultural domain, i.e. the development of new varieties, more efficient land use, direct planting techniques, yield increases and harvest machines. The intermediate steps to produce E2G, then, are secured through imports of technologies or microorganisms, such as for instance from Denmark (ibid.). Despite its achievements in technological development, Brazil has, according to Salles-Filho, not managed to develop "proprietary technologies" and thereby determine technology paths: second-generation technologies, which are now supposed to be upscaled, are being imported to Brazil, while the US is developing them itself. That is why, the author concludes, there is much to suggest that E2G will be marketed in the US far sooner than in Brazil (Salles-Filho, 2016, p. 246).

Another limitation to the upscaling of E2G is seen in the dominance of E1G. The predominant view within the sector is that E2G complements the current sugarcane-ethanol electricity model. Some regard this as positive, as the E1G sector is thereby economically safeguarded against global price fluctuations for sugar and oil. Others, however, object that Brazil will thereby retain its focus on E1G even once E2G is introduced to the market (Cortez & Baldassin, 2016). From the latter perspective, there is a problematic path dependency in this sector which is difficult to disrupt without a targeted funding policy and the creation of a new business model.

> "Brazilian success in the sugarcane industry is at the same time its main strength and its main weakness. The strength can be easily seen throughout history and particularly during the past decades …; the weakness is due to the lock-in provoked by this trajectory. The advantages of a sugar-ethanol-electricity business model are hard to beat, making the transition to E2G unlikely to happen in the short term. That is why it is better to believe in a complementarity of technological trajectories rather than in substitution." (Salles-Filho, 2016, p. 247)

Experts see one major challenge in the fact that research and innovation are almost exclusively reliant upon the government for its funding – and these funds have been dwindling since the financial crisis. The state-run development bank BNDES is the central funding institution in the E2G sector. Another important government funding institution is the federal state research foundation of São Paulo FAPESP, which funds academic research on bioenergy in universities and research institutions via the BIOEN programme (Lorenzi, 2018, p. 117). According to Lorenzi, these two institutions have collectively spent around 4,7 billion Reais (in 2018 around 1.18 billion Euros) in funding

E2G research between 2011 and 2018 (Lorenzi & Andrade, 2019, p. 6). The private sector, on the other hand, invests very little in research and innovation in the area of E2G (ibid., p. 11). Another criticised aspect is that the bulk of public support funds is used by companies to finance new machinery and equipment, while research and development remain underfunded. However, this does not seem to be a sector-specific problem and only underscores the characterisation of semi-peripheral countries put forward by Delvenne and Kreimer (2017). This is compounded by the fact that state spending for research and innovation has generally decreased since 2017. While the proportion of public funds, according to FINEP, was still around 1.3 per cent of GDP in 2014, this figure had dropped to almost less than one per cent by 2017 (FINEP, 2017). It remains to be seen how this will affect the field of research on E2G.

The question remains whether the production of E2G, in contrast to E1G, will create new export markets. Due to the EU's fixed blending quota for biofuels and its promotion of e-mobility, it has largely been written off by the Brazilian sector as a market. Yet the sector remains very optimistic that the introduction of E2G will give rise to new markets in the US and China. Given its favourable carbon footprint, E1G is already recognised as an "advanced biofuel" in the US and exported there in small quantities (Milanez et al., 2017, p. 118). E2G may further reinforce this effect. In China, ethanol plants already exist, and for a while there was reason to believe that blending quotas might be introduced which Chinese production would be unable to fully meet. However, China's energy policy is currently moving towards nuclear power and other renewables instead.[7] Hence, it is unlikely that China will open up its market for ethanol imports from Brazil (Lu, 2016).

But even if Brazil should not emerge victorious in the race to develop E2G, the entire national sugar(cane)-ethanol sector has nonetheless been strengthened through government research funding: the "old" ethanol research centre in the state of São Paulo has been modernised and expanded, and a new research centre is currently being built in the north-eastern state of Alagoas. Furthermore, according to BNDES, other innovations have been introduced at the intersection of ethanol and biotechnologies which may prove advantageous for the Brazilian sector in the global competition for new research sites. This does not only include – indirectly – improved cultivation and harvesting methods, but particularly the genetically modified sugarcane variety "Cana Energia". It is characterised, firstly, by an improved stress resistance to poor quality soils and aridity. More importantly, it is secondly twice as productive as the existing varieties and perfectly suited to the production of E2G: Cana Energia contains up to 100 per cent more fibre (*fibra*) and 300 per cent more bagasse (Milanez et al., 2017, p. 116).

[7] I owe this instructive advice to Fabricio Rodríguez.

3.4 Ethanol and global climate protection

To improve the sector's international links and thereby gain access to new markets for E1G as well as E2G, the ministry of foreign (called: *Itamaraty*) affairs set up the international platform *Biofuture* in November 2016. Some twenty countries have joined the platform so far (among them the US, Argentina and others; Germany has not joined). The aim of the platform is "to promote an advanced low carbon bioeconomy that is sustainable, innovative and scalable".[8] In this context, ethanol from Brazil is regarded as a model fuel for the reduction of CO_2.

One important government initiative for the promotion of the sector in Brazil is the RENOVABIO programme, which was launched at the end of 2017 and is due to be fully implemented by 2020. The programme's objective is to contribute to Brazil's commitment to the Paris Climate Agreement, according to which Brazil is to reduce its carbon emissions by 37 per cent (compared to 2005 figures) by the year 2025. RENOVABIO thus represents a market-based mechanism for the trade in GHG emissions reduction certificates. Based on the annual decarbonisation targets stipulated by the National Council for Energy Policy (CNPE), biofuels are to be certified via a life cycle analysis. Those who reduce emissions in line with the framework of targets are rewarded with GHG emissions reduction certificates called "Cbio" (an acronym for "Crédito de Descarbonização" – Decarbonisation Credit), which can then be traded. Those who receive negative certificates are fined. The programme's central aim is "to create a market-based mechanism that incentives the search for better energy efficiency together with the reduction of the carbon footprint."[9] According to BNDES, if implemented correctly, RENOVABIO may indeed create a regulatory framework that attracts new investments in the production of ethanol (Milanez et al., 2017, p. 121).

These government initiatives correspond to the green reframing of the entire sugar(cane)-ethanol sector in Brazil, which began with the introduction of the flexible fuel vehicle. At times, the favourable carbon footprint of Brazilian ethanol was called into question when, for example, the indirect conversion of land use, such as the replacement of pasture with sugarcane plantations in forest regions, was included in the carbon footprint calculation (Lapola et al., 2010). Vehement interventions in the international debate by the Brazilian government and sugarcane sector, e.g. through lobbying efforts by the sugarcane federations UNICA in Brussels, however, helped establish a positive carbon footprint for Brazilian ethanol. As mentioned above, it is universally accepted today that E1G already exhibits a positive carbon footprint. Even though extreme right-wing president Bolsonaro has announced that Brazil will leave the Paris Climate Agreement, the sugarcane sector will nevertheless seek to retain both this image and the RENOVABIO programme.

[8] See http://biofutureplatform.org/, last accessed on 05/14/2020.

[9] See http://biofutureplatform.org/wp-content/uploads/2018/06/RenovaBio-Mechanism-Policy-and-Instruments.pdf, last accessed on 05/28/2019.

4 Reconfigurations and continuities of global asymmetries in knowledge production

This explorative study shows that the lofty promises of the bioeconomy must be considered with caution: neither the development nor the implementation of advanced biofuels can be regarded as given, be it regarding technology development or the required political framework conditions. Likewise, neither do the hopes of (semi-)peripheral countries like Brazil of becoming (bio-)technological centres of the emerging bioeconomy seem to be materialising. As this study suggests, the global asymmetries in knowledge production that exist in the "high technology fields" persist (see Delvenne and Kreimer 2017, p. 393). This is not to say, however, that the old colonial dichotomy of centre and periphery are simply being reproduced. After all, Brazil has indeed developed its own homegrown (bio-)technological processes and products in the area of agro-industrial sugarcane production as well as in the production of E1G and, in part, E2G. The country has also succeeded in successfully "reframing" Brazilian ethanol as a climate-friendly alternative to fossil fuels at a global level. Brazil's sugar(cane)-bioenergy sector has, in this sense, become a firm fixture at every international bioeconomy conference and is successfully intervening in the debates on the direction of the emerging global bioeconomy. That said, given the small scale of the global sugarcane market and the worldwide lack of markets for Brazilian ethanol as well as for the relevant technological expertise, currently there are no new areas of accumulation arising. E2G seems to have little impact on this situation. Contrary to neoliberal rhetoric, it is the state – and not the private sector – who remains the prime funder of development and innovation.

The Brazilian state plays a central role in all aspects of the sector by creating new markets for the crisis-ridden industry through blending quotas, tax incentives and infrastructure funding measures. This underscores the powerful role the sugar(cane)-energy sector has played in Brazil since colonial times. Only through its political influence has this sector been able to overcome numerous crises over the past centuries and assert itself at the heart of Brazil's geographical and political centre. The funding of research and development in E2G has strengthened this nucleus of production and research within the country. At the same time, a new knowledge centre appears to be emerging via the GranBio mill in the north-eastern state of Alagoas, i.e. in the Brazilian periphery. Only time will tell what effect this will have in terms of the (re)production of centres and peripheries within Brazil.

The answer to the question of what and whose knowledge is produced in this field is a simple one: knowledge-production belongs exclusively to the agro-industrial and biotechnological sugar(cane)-bioenergy sector. As the sector itself positively points out, it is so strongly embedded within the national psyche as the story of a peripheral country's success that the public would not even think to question or challenge it.

Critics[10] from social movements or NGOs, then, remain isolated and largely unheard, while the European discourse on Brazilian ethanol is, in turn, considered damaging to the sector's reputation.

The sugar(cane)-ethanol sector has created a business model and infrastructure that cannot simply be reconfigured at will. Even though it may be technically feasible to convert existing sugarcane mills to E2G production, this is not the same as restructuring the entire sector. This circumstance calls the narrative mentioned at the beginning of this paper – that the first-generation biofuels are merely a bridging technology, filling the gap until a more climate-friendly technology is developed – into question. Salles-Filho describes this path dependency as a problematic lock-in effect. It may be added that this dependency likewise applies to the monocultural agro-industrial mode of production, which, despite yield increases and technical innovations to aid the reduction of emissions and improve CO_2 balances, will not be able to abandon fossil fuels, for example for the production of pesticides and herbicides, in the foreseeable future. Furthermore, the ethanol sector is tied to the oil price and therefore remains part of the "carbon lock-in". Here, the dilemma of the entire field of biofuels and the emerging bioeconomy becomes apparent: their trajectory follows the capitalist growth imperative, albeit under a green banner. Instead of fundamentally calling into question the increasing energy consumption and individual transport model, the fossil resources are merely to be (partially) substituted. At the same time, the increased utilisation of renewable energies is undermined by the growth of the transport sector itself, which accounts for a third of global energy consumption. This sector grew by 39 per cent between 2000 and 2016 (REN 21, 2018, p. 38).

A number of questions for further research arise from this: building on the research field of the "carbon lock-in" (Buschmann & Oles, 2019), an investigation ought to be carried out into how these path dependencies that exist in the sector are being (re-)produced. In terms of a non-deterministic conception (see ibid.) of path dependency, or "lock-in", this is linked to the question of starting points for a social-ecological transformation of the sector. Proceeding from there, an inquiry from a broader political-economic perspective is needed that establishes the extent to which the – currently often-stated – re-primarisation of the Brazilian economy is actually occurring and which implications this has for the development of a sugar(cane)-ethanol sector (as set out in this paper), which is oriented not towards export but the domestic market.

Another important issue requiring examination is the question which knowledge and which views are being excluded from this Brazilian success story. Yet, such objections have thus far been brushed aside as scientifically untenable by the industry. One conceptional and empirical challenge for the research on global social inequalities in

[10] e.g. Landless Workers' Movement: *Movimento dos Trabalhadores Rurais sem Terra – MST*; the NGO *Repórter Brasil* or the catholic Pastoral Land Comission: *Comissão Pastoral da Terra – CPT.*

knowledge production is to integrate this aspect of knowledge production into its transnational analyses.

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