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Plant-based Bioeconomy in Central Germany - Mapping of Actors, Industries and Places

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Plant-based Bioeconomy in Central Germany - Mapping of Actors, Industries and Places*

Abstract

The challenges facing the 21st century, presented by a growing global population, range from food security to sustainable energy supplies to the diminishing availability of fossil raw materials. An attempt to solve these problems is made by using the concept of bioeconomy. Plants, in particular, possess an important function in this context - they can be used either as a source of food or, in the form of biomass, for industrial or energy purposes. Linking industrial and agricultural research and production, bioeconomy provides growth potential, in particular in rural areas.

The aim of this article is therefore to outline the status of plant-based bioeconomy in three states of Central Germany - Saxony, Saxony-Anhalt and Thuringia - and to compare this to German plant-based bioeconomy. We take an in-depth look at the different sectors and outline the industries involved, the location and age of the enterprises as well as the distribution of important NACE codes. In conclusion, we highlight the significant number of new or small enterprises and the high research and innovation rate of Central Germany. We also stress the future potential of Central German plant-based bioeconomy as well as the importance of a more plant-focused view of the technology sector.

Keywords: plant-based bioeconomy, Central Germany, renewable resources, research and development, bioenergy

JEL Classification: O13, Q01, Q16, Q55

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Die pflanzenbasierte Bioökonomie in Mitteldeutschland - Akteure, Industrien und räumliche Verteilung

Zusammenfassung

Durch die steigende Weltbevölkerung stellen sich für das 21. Jahrhundert weitreichende Herausforderungen in Form von Ernährungssicherheit und nachhaltiger Energieversorgung bei gleichzeitig sinkender Verfügbarkeit fossiler Rohstoffe. Eine Bestrebung, diese Probleme zu lösen, stellt das Konzept der Bioökonomie dar. Besonders Pflanzen erfüllen in diesem Zusammenhang eine bedeutende Aufgabe. Sie können sowohl als Nahrungsgrundlage als auch, in Form von Biomasse, für industrielle Zwecke und zur Energiegewinnung genutzt werden. Durch die Verbindung von landwirtschaftlicher und industrieller Forschung und Produktion bietet die Bioökonomie Wachstumspotenziale speziell in ländlichen Räumen.

Das Ziel dieses Beitrags ist somit, den Entwicklungsstand der pflanzenbasierten Bioökonomie der drei mitteldeutschen Bundesländer - Sachsen, Sachsen-Anhalt und Thüringen - zu erfassen und diesen mit dem gesamtdeutschen zu vergleichen. Es soll hierbei ein detaillierter Blick auf die verschiedenen Sektoren geworfen und die beteiligten Industrien dargestellt werden. Dies bezieht sich auf deren Ansiedlung, das Alter der Unternehmen sowie deren Verteilung über die Klassen der NACE Systematik. Abschließend wollen wir die große Anzahl junger und kleiner Unternehmen sowie die hohe Forschungsrate Mitteldeutschlands betonen. Ebenso werden die zukünftigen Potenziale der pflanzenbasierten Bioökonomie Mitteldeutschlands hervorgehoben, und gleichfalls die Notwendigkeit, den Technologiesektor im Kontext der Pflanzenforschung zu betrachten.

Schlagwörter: pflanzenbasierte Bioökonomie, Mitteldeutschland, erneuerbare Ressourcen, Forschung und Entwicklung, Bioenergie

JEL-Klassifikation: O13, Q01, Q16, Q55

1 Introduction

Against the backdrop of a growing global population, challenges facing the 21st century range from climate change and food security to sustainable energy supplies. These challenges are intertwined and sometimes counteract each other (European Commission 2012a, p.3; BMBF 2011, p. 4; BMELV 2013b, p. 4). By 2050, the world's population will have risen to over 9 billion, 34 percent higher than it is today (Food and Agriculture Organization of the United Nations n.d., p. 2). As diminishing fossil resources face a constantly increasing demand for energy sources and raw materials, a shift towards a bio-based economy is crucial if future demands are to be met (BMBF 2011, p. 4). To add to these challenges, the capacity of productive land is limited while demand for crops increases. Consequently, the quest for innovative and sustainable solutions is fundamental to meeting such economic, ecological, and societal challenges.

The concept of bioeconomy has the potential to reduce these problems. In many countries, policies have been implemented that foster agricultural innovation and place greater emphasis on a bioeconomic focus for the future (Brunori 2013, p. 48). The Organisation for Economic Co-operation and Development (OECD) defines the term bioeconomy as an economy "where biotechnology contributes to a significant share of economic output" (OECD 2009, p. 15). Through research, innovation and networks interlinking several actors from the fields of science, politics and economics, a foundation has been created from which to react to the diverging phenomena. Innovation and research aimed at promoting increased efficiency of biomass usage and optimizing plant-breeding and plant-based processing have helped to reduce threatening problems and to broaden application options.

Today, biomass is the only renewable source of carbon; the transition to a bio-based economy will thus be both a huge challenge and an enormous opportunity for rural areas which have the greatest production potential (Benitez Salas 2010). In addition, bioeconomy holds the potential to develop a competitive edge and a solid platform for economic growth and employment (European Commission 2012a, p. 3; BMBF 2011, p. 5). Currently, sectors of the European bioeconomy "account for more than 22 million jobs and approximately 9% of the workforce" (European Commission, 2012a, p. 5). More than 300 million people are employed in bio-based industries, such as the bio-chemicals and plastics sector or in the production of enzymes and biofuels, with a total turnover of more than 56 billion Euros (European Commission

2012b). However, in order to ensure its international competitiveness, innovation and knowledge exchange in bioeconomy must be further supported and coordinated (European Commission, 2012a, p. 3; BMBF 2011, p. 5).

Over the coming years and decades a safe, healthy and prosperous environment must be ensured in Europe to allow bioeconomy to change the potential for sustainable production and conversion of biological material (European Technology Platforms, n.d., p. 4). Establishing a European bioeconomy holds great potential: "it can maintain and create economic growth and jobs in rural, coastal and industrial areas, reduce fossil fuel dependence and improve the economic and environmental sustainability of primary production and processing industries" (Schmid, Padeland, Levidow, 2012, p. 49). Natural and renewable resources such as livestock, micro-organisms, plants and their components build the basic raw materials for a bioeconomy. Plants, in particular, perform a dual function. Plants provide both a direct and an indirect base for food, while at the same time providing important raw materials for non-food applications. As a result of emerging challenges, this last function is attracting increased attention. Although the priority is global food security, the potential for using plants in non-food applications is immense.

In pharmaceuticals and chemistry, plants and their components serve as important base materials in the production of medical products (e. g. in the molecular farming sector, plants are used as raw materials in the production of pharmaceutical substances such as vaccines and antibodies) or as a non-finite source of carbon (BMELV 2013a, p. 4). Biopolymers, which are generated from plant fiber among others, can be processed into bioplastics. Furthermore, plants, such as timber and energy crops, provide a valuable renewable source of energy. Plant-based biomass has taken on an increasing role as an energy source or base material for substance-based products. Liquid and gaseous biomass such as biodiesel, bioethanol and biogas are used as electricity and heating sources and as biofuels. Furthermore, biomass is used in substance-based applications in the construction and chemical industries. The efficiency of biomass can be increased by its multiple uses as residual materials are used as animal feed or are processed further into other products (BMELV 2009, p. 13).

In response to both the complex challenges posed by these applications and their potential, the OECD and the European Union, among others, have promoted the concept of bioeconomy. Various strategies and policies, including the EU's

"Bioeconomy Strategy" (European Commission, 2012), have been introduced to foster the transition to a bio-based economy. Moreover, the current state of bioeconomy is evaluated as its strengths and weaknesses are outlined to determine important courses of action. In Germany, the Federal Ministry for Education and Research (BMBF) has formulated the "National Research Strategy BioEconomy 2030" (BMBF, 2011).

As Germany has limited access to fossil resources, efforts are being made to find innovative ways of decreasing its dependency on fossil resource imports. Moreover, while Germany has a strong agricultural sector and is actively using and processing renewable resources, limited capacity and deterioration in the quality of productive land is hampering such efforts. Therefore, bioeconomy strategies are currently being fostered and clear goals and policies are being developed. The BMBF promotes innovative companies that have a strong focus on research and technology and a solid infrastructure of networks to support the transition to a bio-based economy. However, the BMBF sees weaknesses in Germany which limit the success of bioeconomical approaches. The various actors in the process need to be more closely interlinked and knowledge exchange across different fields must to be promoted and further coordinated. The ability to innovate constitutes an important source of competitiveness in high-tech industries.

In order to draw a more precise picture of the current state of plant-based bioeconomy and its development potential for rural and relatively less industrialized areas, we take a closer look at the Central German states of Saxony, Saxony-Anhalt and Thuringia. Located in the south of the former GDR, Central Germany still lags behind West Germany in terms of GDP per capita, which remains at about two thirds of the West German average, even though it was one of Germany's core economic regions before World War II. Although precise historical figures are scarce, Boltho et al. (1997) indicate that in 1936 the East German GDP per capita (splitting Berlin into East and West) just exceeded the West German average. It should be kept in mind that while the remaining two East German states of Brandenburg and Mecklenburg-West Pomerania are still and have largely always been agricultural, the area of Central Germany has traditionally featured strongly in the chemical sector as well as in plant and seed breeding, both of which are important fields in bioeconomy. Although only about 10 percent of the German population currently lives in Central Germany, its area covers 15 percent of the German national territory. Seventeen percent of German farmland is located in this area, but only 5 percent of German

agricultural holdings, indicating a high degree of industrialization in the Central German agricultural sector (DESTATIS, 2014).

In linking industrial and agricultural research with production, the concepts of bioeconomy point to growth potential, particularly in areas with a mixed industrial and agricultural economy. We believe that bioeconomy holds immense potential for Central Germany, characterized as a catching up region. The bioeconomy sector requires high levels of innovation and technology which are significant to the particular region (Günther, Titze et al. 2013, pp. 138ff.). The purpose of this article is therefore to outline the status quo of bioeconomy in Saxony, Saxony-Anhalt and Thuringia. We identify different actors in bioeconomy in Central Germany and outline their particular characteristics. In addition, we examine the distribution of companies and organizations engaging in bioeconomy in Central Germany. The remainder of the article is structured as follows: in section 2 we develop a definition for a plant-based bioeconomy. In section 3 we outline the data and methods used. Empirical findings are provided and discussed in section 4 and 5. Section 6 concludes the paper.

2 Plant-based bioeconomy - a tentative definition

Given the importance of plant-based resources and production technologies for the economic prosperity of a country, it is all the more astonishing that we still have no clear idea of how a plant-based bioeconomic industry is made up or and what the factors are that affect the generation of innovative products. In order to express this more precisely, which firms and organizations are located at the very heart of the industry and how research and development partnerships and innovation network involvement affect the innovative performance of the actors involved are questions which are still largely unexplored. Consequently, differently nuanced distinctions of the term have been introduced by various actors. The OECD definition of bioeconomy focuses on biotechnology as a core indicator for bioeconomy. Therefore, bioeconomy emerges "where biotechnology contributes to a significant share of economic output" (OECD 2009, p. 15). The rationale behind the strong focus on biotechnology is the fact that without the major technical and scientific progress of past decades in this field, the current state of bioeconomy and linked research and innovation would be largely unknown. The German Federal Ministry for Education and Research (BMBF) provides a relatively broad definition of bioeconomy: "The concept of bioeconomy

covers the agricultural economy and all manufacturing sectors and associated service areas that develop, produce, process, handle, or utilise any form of biological resources, such as plants, animals, and microorganisms. This spans numerous sectors, such as agriculture, forestry, horticulture, fisheries and aquaculture, plant and animal breeding, the food and beverage industries, as well as the wood, paper, leather, textile, chemicals and pharmaceutical industries, and aspects of the energy sector" (BMBF 2011, p. 2).

However, if we are to emphasize the highly innovative features of bioeconomy, a finer distinction is needed. The bioeconomy sectors have strong innovation potential owing to their use of a wide range of sciences (life sciences, agronomy, ecology, food science and social sciences), their use of industrial technologies (biotechnology, nanotechnology, information and communication technologies (ICT) and engineering), as well as local and tacit knowledge (European Commission 2012b). Nonetheless, the highly multidisciplinary structure of bioeconomy, combining and interlinking elements of chemistry, pharmacy, plant-construction and engineering, animal and plant breeding, must be acknowledged and should not be neglected by focusing chiefly on biotechnology. In view of existing societal, economic and environmental challenges as well as the newly indentified potential of biomass and plant research, co-operation between several actors, for example, the chemical and plant-breeding industries, is crucial to developing new applications.

For this reason, the concept of a "bio-based economy" (Langeveld et al. 2010, p. 19) introduces a suitable base for further action. Bio-based economy is defined as a "technological development that leads to a significant replacement of fossil fuels by biomass in the production of pharmaceuticals, chemicals, materials, transportation fuels, electricity and heat" (Langeveld et al. 2010, p. 6). The core object of bioeconomy thus embraces those sectors of an economy that engage primarily in the use of renewable raw materials, either for material or energy purposes. Similarly, the European Commission specifies the term "bioeconomy" as "an economy using biological resources from the land and sea as well as waste, including food wastes, as inputs to industry and energy production. It also covers the use of bio-based processes to green industries" (European Commission: Research & Innovation, Bioeconomy n.d.).

Nevertheless, a clear distinction between this and the traditional use of renewable resources must be drawn. For the purposes of substance-based usage, the focus is

limited to the (bio-) chemical conversion of renewable raw material. The rationale for this limitation is expressed in the opinion that the particular value of bioeconomy lies in its ability to introduce innovative substitutes for on-going fossil-based processing. For this reason, we follow in our research Langeveld et al.'s (2010) definition of a bio-based economy as all fields of plant-based bioeconomy featur raw materials for material and energy use by renewable plant-based materials and research and innovation based on this topic. However, as the term bioeconomy embraces a large number of fields and actors, a further distinction is necessary.

Plant-based bioeconomy holds huge potential to foster the transition from a fuel-based to a bio-based economy. Plants and plant-based biomass act as a valuable non-finite source of energy and material for industries and science. Through research and innovation, the efficiency of plants and plant-based biomass can be increased. Sectors of interest are the manufacturing industries, such as chemistry and pharmaceuticals, the energy sector and plant-breeding as well as research and development in these sectors. The focus on a plant-based bioeconomy necessarily excludes applications which rely on animals or micro-organisms as base materials. In addition, research primarily based on human-beings and animals is not considered further.

3 Methodological approach and data sources for identifying actors in plant-based bioeconomy

In order to present the current state of plant-based bioeconomy in Central Germany an appropriate data set was required, which would provide essential information for the selection of the relevant actors, for instance trade descriptions and addresses. As a basis for the generation of the required data set, online and printed databases were composed. One printed information source was provided by the "Biocom Biotechnologie 2014 Jahr- und Adressbuch", containing profiles of companies in the biotechnology sector. These profiles are based on information from 2013. In addition, important associations in the field of biotechnology were listed. Online sources were represented by "www.transcript.de" and its company database. This database specializes in companies in the biotechnology sector. The online source "www.biotechnologie.de" provided profiles on biotech companies as well as public and private research organizations. The data were retrieved in 2013. "www.biokunststoffe.de" displayed company profiles of bioplastic producers based on information from 2013. The internet site

of the "Bundesverband Deutscher Pflanzenzüchter (BDP)" ("www.bdp-online.de") contained information on plant breeding and research firms from 2013. Finally, the company database "Amadeus" provided company profiles in general but did not focus on biotechnology or bioeconomy in particular. These profiles included information from 2008 to 2013. We also launched online research based on keywords at the beginning of 2014 in order to minimize the threat of missing information.

Initially, the data were restricted to companies and organizations located in Central Germany (Saxony, Saxony-Anhalt and Thuringia). Based on this data set the actors in plant-based bioeconomy were selected. In order to identify suitable actors, we created a keyword base containing keywords referring to relevant plant-based bioeconomic inputs, outputs and technologies. This keyword list was used in the online research as well as in the trade descriptions of the online data sources. As the Amadeus database does not specialize in biotechnology or bioeconomy, it contains an immense number of enterprises and profiles (almost 1.5 Mio. Data sets for Germany, and almost 102,000 data sets for Central Germany specifically). We thus developed an advanced keyword/classification-based search routine to identify relevant actors. In an effort to minimize possible sources of error, we reviewed all generated results. Furthermore, we carried out an additional online search to verify inadequate trade descriptions and to minimize the risk of an incomplete data set.

Beyond the trade description, we collected data containing information on the location, primary economic activity, age and number of employees of the companies and organizations. We categorized the results according to the type of actors: enterprises, research institutes, universities and associations. The selected and prepared data were then analyzed by type and number of actors, industries involved and employment. An extra keyword-based search routine was developed for actors related to biogas as we have found that biogas plays a significant role in the Central German bioeconomy.

4 Empirical findings for Central Germany

4.1 Number and type of actors

In this section we analyze the results regarding number and type of companies and organizations identified as actors in plant-based bioeconomy. The total number of

observations in Saxony, Saxony-Anhalt and Thuringia amounted to 183 (see figure 1). Of the total actors, 80 were located in Saxony-Anhalt (43.72 percent), 61 in Saxony (33.33 percent) and 42 in Thuringia (22.95 percent). Although our study includes private enterprises as well as universities and research institutes, the number of actors involved in plant-based bioeconomy is clearly smaller when compared to other studies (e. g. BMBF 2013). Consequently, results differ when regarding biotechnology in general than when focusing particularly on a plant-based bioeconomy.

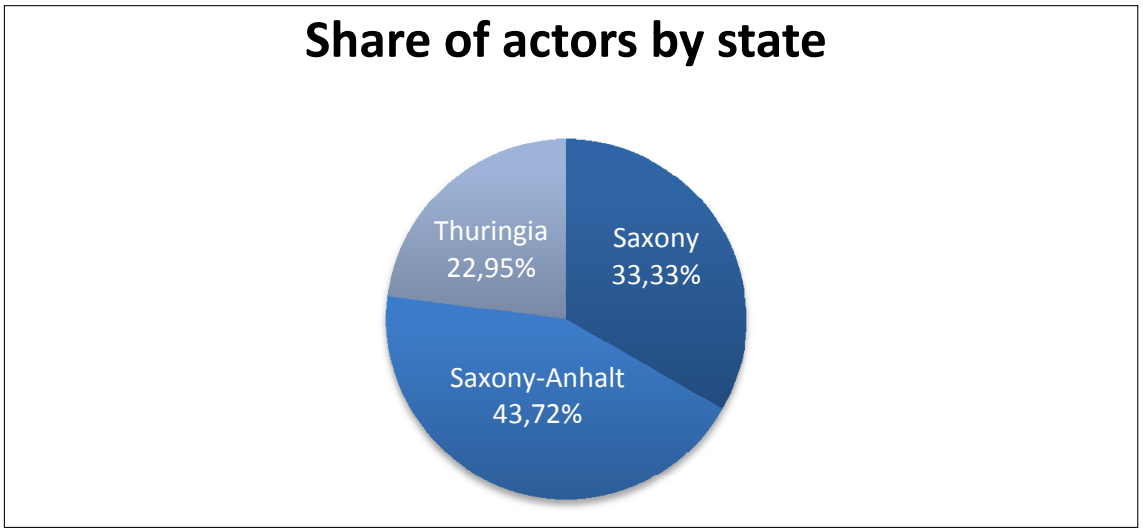

Figure 1: Total number of identified actors in the observed states.
Source: Own illustration.

In order to provide a detailed description of the current state of plant-based bioeconomy, we distinguished four types of actors. These types were labeled as follows: enterprises, research institutes, universities and universities of applied science, and associations. Universities and universities of applied science were classified as one type (see figure 2).

The majority of actors (149) were enterprises, representing a proportion of 81.42 percent. This type also represented the largest share relative to the others within each of the three states. In Thuringia, enterprises accounted for 90.48 percent and in Saxony, 81.97 percent. Compared to the other states, Saxony-Anhalt had a slightly smaller share of enterprises (76.15 percent). However, among the federal states, Saxony-Anhalt, with a count of 61, hosts the highest number of enterprises. In contrast, with 38 enterprises, Thuringia recorded the smallest number. In 2012, Saxony was one of the leading German states as far as the establishment of projects in the biotechnology sector were concerned, with four new enterprises, while Thuringia

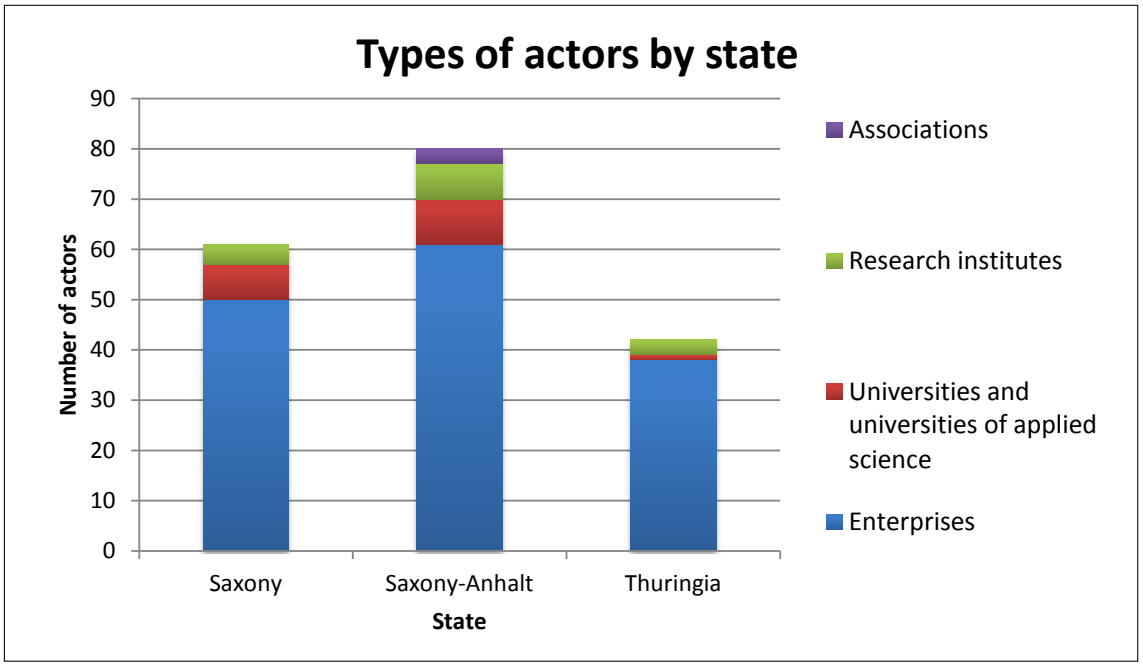

Figure 2: States and types of actors combined - total numbers.
Source: Own illustration.

saw significant growth in the total number of German companies - from seven to 10 (BMBF 2013, p. 4).

Total numbers of other actor types varied, but were single figures. In Saxony-Anhalt, nine of a total of 80 identified actors were universities and universities of applied science. In Saxony, we identified seven universities and universities of applied science, whereas in Thuringia, only one actor was attributed to the category of universities and universities of applied science involved in the field of plant-based bioeconomy. However, the numbers for Saxony-Anhalt may appear relatively high. This results in part from the fact that in general we selected single departments at universities rather than universities as a whole in order to guarantee a precise picture of the current state of plant-based bioeconomy.

Within these three federal states, research institutes focusing particularly on plant-based bioeconomy accounted for a maximum share of 8.75 percent in Saxony-Anhalt and a minimum share of 6.56 percent in Saxony. Saxony-Anhalt was home to 50 percent of identified research institutions, which amounted to seven in total. Associations accounted for a minimum share among the defined types, namely 1.64 percent. Actors related to associations, three in all, were identified only in Saxony-Anhalt. Overall among the federal states, Thuringia represented the minimum

number of actors of all four types. In contrast, this state accounted for the maximum number and share among all types (see figure 3).

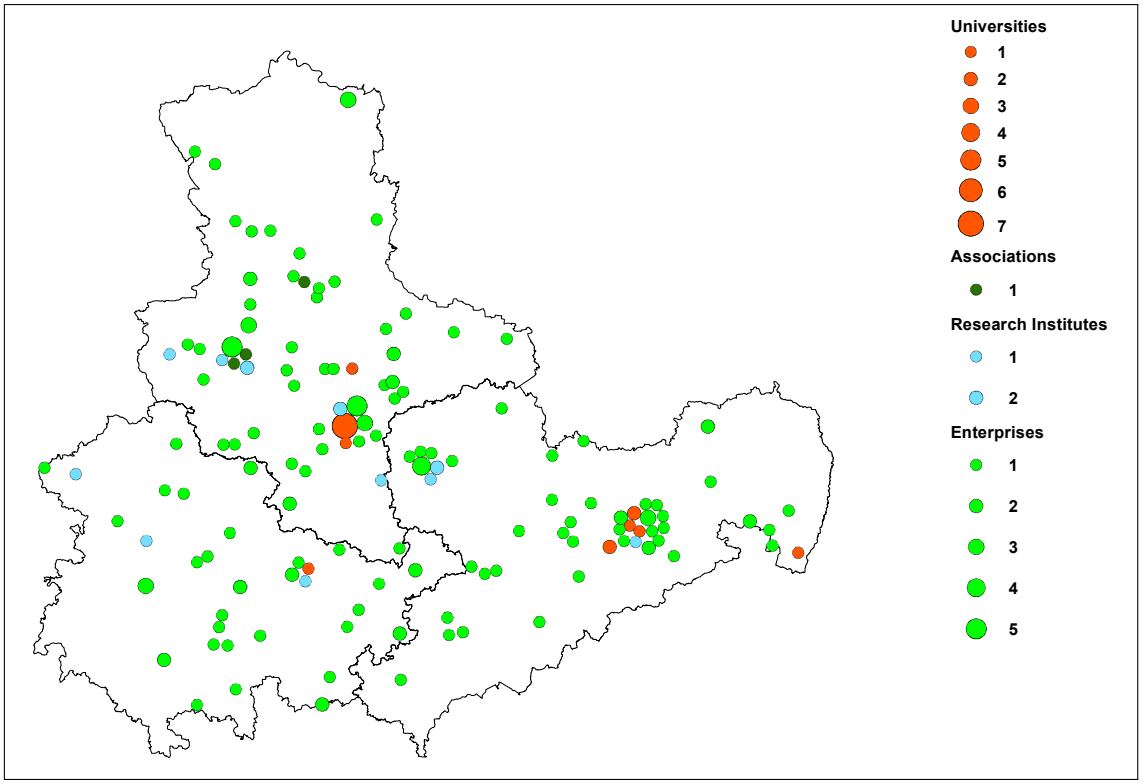

Figure 3: Actors in Central Germany by type.
Source: Own illustration.

Comparing the current state of plant-based bioeconomy in Central Germany to its state in Germany as a whole revealed further interesting findings on the distribution of actors. However, building up a data set that embraced all the aforementioned data sources for Germany as a whole would have exceeded the scope of our study. Consequently, we restricted ourselves to enterprise data from the Amadeus database in order to make this single comparison. Since enterprises represent the most prominent share within the defined types, this choice seems adequate. For this purpose, we used the same keyword-based search routine as we had for the data set pertaining only to Central Germany. In this regard, false positive results might be a possible source of errors. However, since for this particular scenario neither observations from Central Germany nor observations relating to Germany as whole had been adjusted, we assume that this error is approximately equal among the states. In total, 1686 enterprises were identified as actors in plant-based bioeconomy (see figure 4).

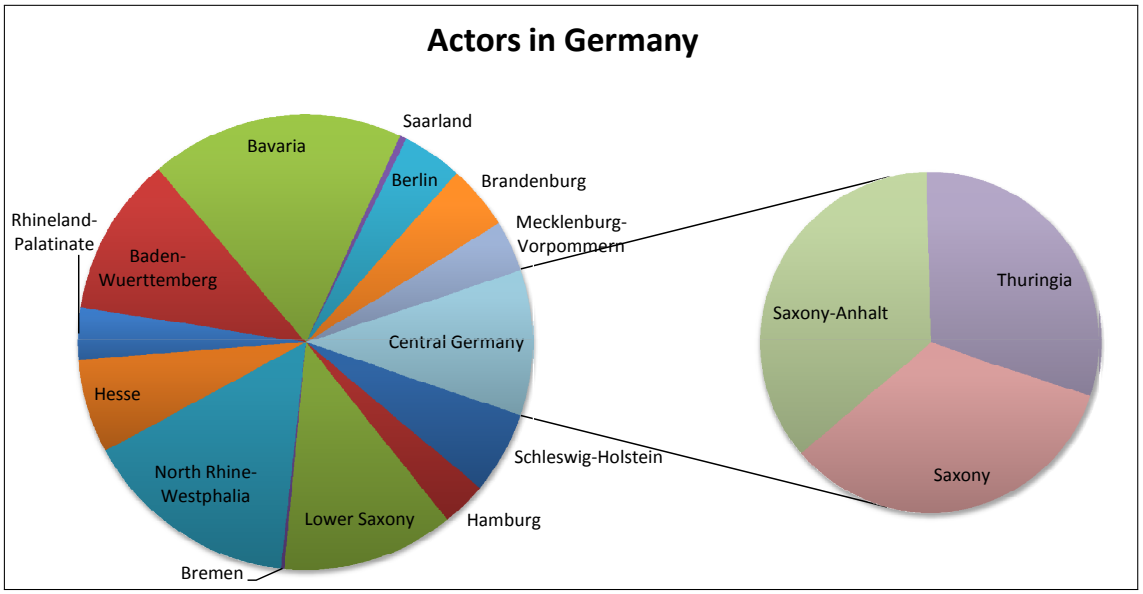

Figure 4: Actors in Germany as a whole identified in Amadeus.
Source: Own illustration.

In Central Germany, observed actors totalled 176. Regarding Germany as a whole, Saxony, Saxony-Anhalt and Thuringia represented a total cumulated share of 10.44 percent. Among the three states, Thuringia held a minimum share of 3.20 percent, whereas Saxony-Anhalt represented a maximum share of 3.74 percent. Beyond Central Germany, larger proportions were detected in Baden-Wuerttemberg, Lower Saxony, North Rhine-Westphalia and Bavaria, ranging from 11.33 percent (Baden-Wuerttemberg) to 17.97 percent (Bavaria). Although Henn and Demuth (2012, p. 208) outlined the outstanding position of Central Germany in biotechnology as a whole and emphasized the large number of actors in Saxony, Saxony-Anhalt and Thuringia, our findings concerning actors in plant-based bioeconomy did not support this statement. Although the accumulated share of Central Germany reached a relatively high value, the individual states represented a smaller share when considering Germany as a whole. Moreover, the total share of Central Germany is lower than that of other individual states.

4.2 Industries involved in study

Industries involved in this study were classified according to the NACE classification system Rev. 2 (European Commission and Eurostat 2008). A total number of 136 actors were classified in NACE codes. This number differs from the total number of

actors identified as involved in plant-based bioeconomy since only enterprises and not other types, such as universities and universities of applied science, are recorded by NACE codes. Given this fact, the terms "actors" and "enterprises" are used interchangeably in the following section. However, NACE codes for some enterprises were not available. NACE codes are hierarchically structured in sections, divisions, groups and classes. Actors involved in plant-based bioeconomy were identified in nine of the 21 sections, mainly "A Agriculture, forestry and fishing", "C Manufacturing" and "D Electricity, gas, steam and air conditioning supply". Furthermore, the actors were spread over 22 divisions containing numerous classes (see table 1).

Table 1: Total actors by NACE sections in Central Germany.
(For purposes of legibility, some terms have been abridged.)
Source: Own calculations.

NACE section code	Number of actors	Share
Agriculture, forestry and fishing (A)	12	8,82%
Manufacturing (C)	53	38,97%
Electricity, gas (D)	21	15,44%
Water supply (E)	5	3,68%
Wholesale and retail trade (G)	12	8,82%
Information and communication (J)	1	0,74%
Professional and scientific services (M)	25	18,38%
Administrative activities (N)	4	2,94%
Other services (S)	3	2,21%
Total	**136**	**100,00%**

Actors involved in sections A and C made up a total share of 47.79 percent. Of this share, section A accounted for 8.82 percent. In the remaining 52.21 percent concerning all observed enterprises, large shares were represented by section D, with 15.44 percent, and division M72 "Scientific research and development", which amounted to 16.91 percent. Remaining enterprises were spread over several other sections and divisions and consequently represented minor shares.

In section A, enterprises involved in plant-based bioeconomy were identified in divisions 01 and 02. Division 01 included, among others, the production of livestock and crops. We identified a total of eight enterprises, six of which were situated in Saxony-Anhalt. Half of these eight actors were categorized in group 01.30, "Plant propagation", particular enterprises explicitly involved in research on plants or plant breeding by keeping laboratories or by using new applications of breeding such as

in-vitro propagation. In addition, their focus was on crops, agricultural and energy crops or plant cultivation for energy purposes. These aspects were considered vital for classification as plant-based bioeconomy. Four actors were selected from division 02 "Forestry and logging" - group 02.10, "Silviculture and other forestry activities". These enterprises, located in Saxony-Anhalt and Thuringia, were identified as they cultivated or processed timber for energy purposes.

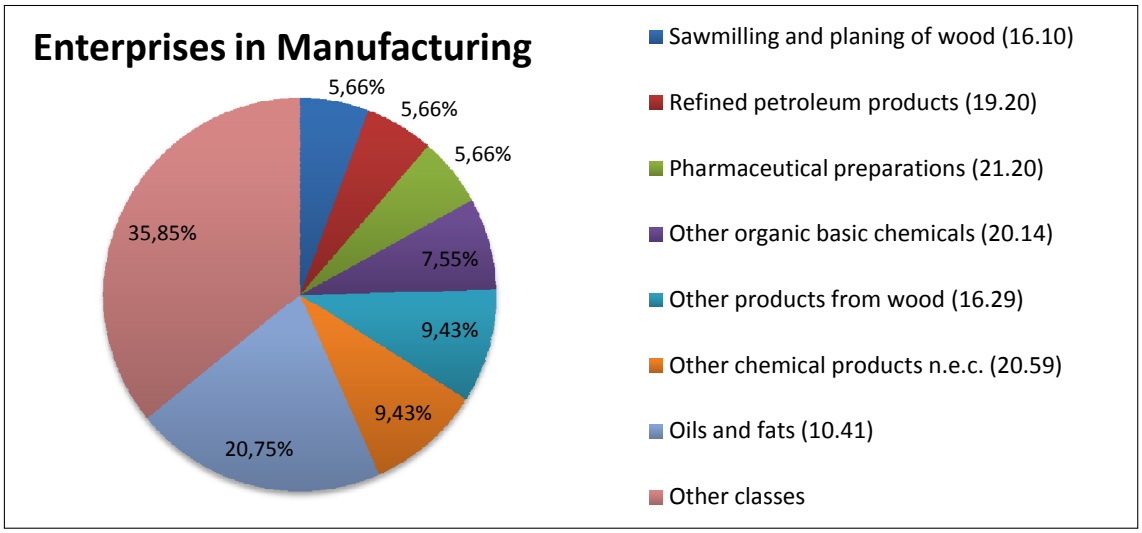

Figure 5: Actors in the classes of section "C Manufacturing".
(Names have been abridged for legibility purposes.)
Source: Own illustration.

In manufacturing (section C), actors were spread widely over groups and classes (see figure 5). A relatively large group of 12 actors was observed in group 10.40, specifically in class 10.41: including among others the manufacture of vegetable oil. In a few cases, the manufacturing of oil for further technical or energy purposes was mentioned explicitly. In particular, rapeseed often provided a base material for further processing in these cases. Actors categorized in section 16, relating to processing wood, excluding the manufacture of furniture, represented 5.88 percent of total actors categorized in NACE codes and were located only in Saxony (see figure 6).

The enterprises investigated in this case processed timber particularly for energy purposes. Within division 20, "Manufacture of chemicals and chemical products", actors were found in several groups. Groups displaying relatively large numbers in this section were 20.14, "Manufacture of other organic basic chemicals" and 20.59, "Manufacture of other chemical products n.e.c.", four and five actors respectively. Sur-

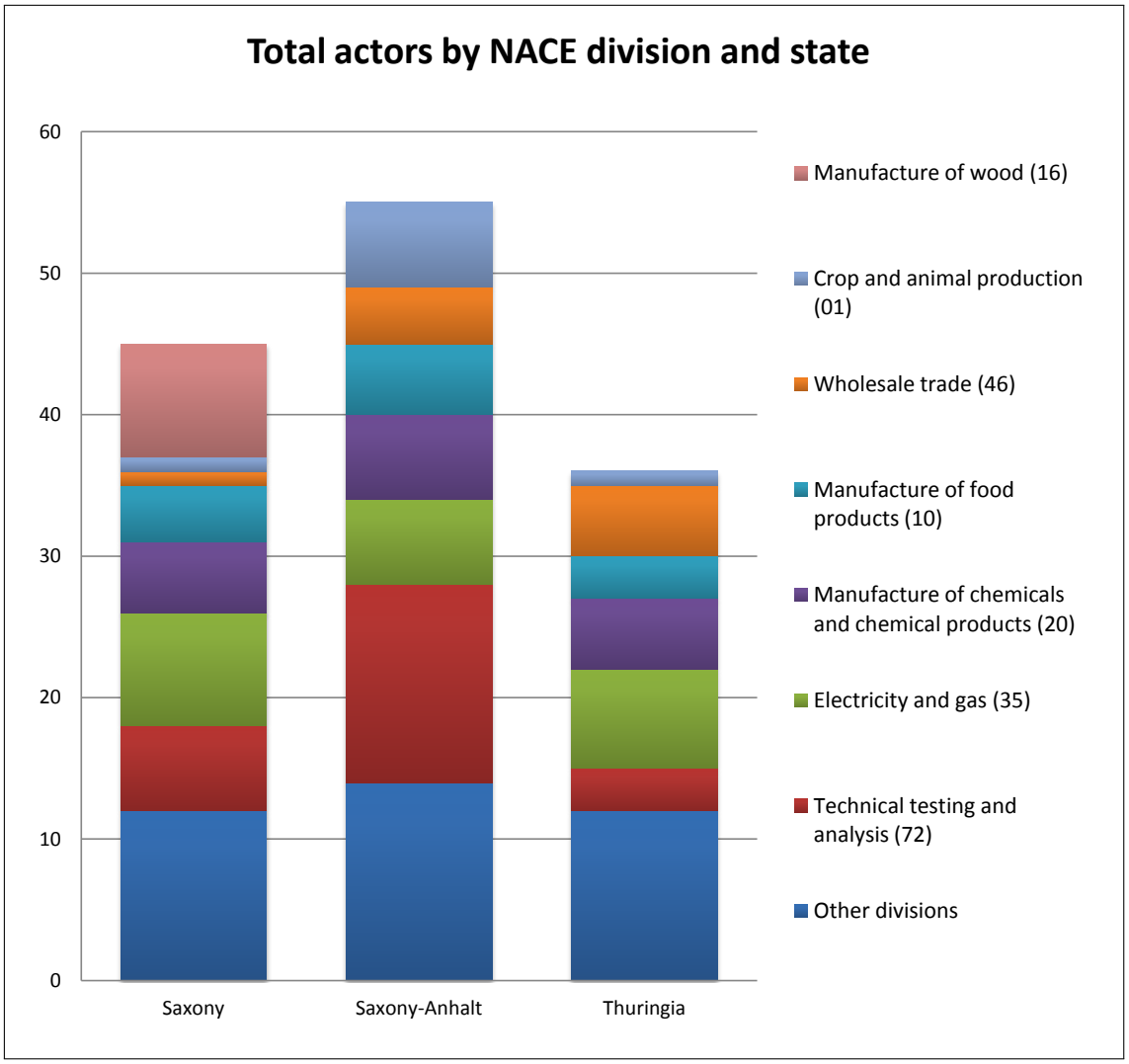

Figure 6: Total actors across NACE divisions and observed states - total number of actors. (Terms have been abridged for purposes of legibility.)
Source: Own illustration.

prisingly, in group 20.59 most of the observed actors were involved in the production of biodiesel. The same phenomenon occurred in group 19.20, which is characterized by manufacturing refined petroleum products. Division 21, concerned with the manufacture of pharmaceuticals and related products, and division 22, including rubber and plastic products, represented only minor shares of 2.94 percent. Interestingly, in group 26.51, "Manufacture of instruments and appliances for measuring, testing and navigation", one enterprise producing biosensors was detected and was categorized as an enterprise suitable to a plant-based bioeconomy.

Section D (Electricity, gas, and others) was represented by 15.44 percent of the actors, and had a relatively dominant position in the analysis. Remarkably, group 35.11 "Production of electricity" appears the most important, adding up to 11.03 percent. A frequent formulation was "production and distribution of bioenergy" or closely corresponding wording. This aspect served as a selection criterion as constructors or maintenance contractors of energy plants only were not included, owing to the prior distinction of plant-based bioeconomy in section 2. Regarding division D35, actors were located relatively equally across the three federal states. Although this section concerned energy production in particular, actors involved in producing energy, electricity and gas were detected in various different groups, for example, section C "Manufacturing". A possible explanation for this phenomenon may be that bioenergy plants are often run when large amounts of biomass are produced as by-products. This is the case, for instance, in large enterprises that process timber or horticultural products.

Another prominent share was represented by section "M Professional, scientific and technical activities", amounting to 18.38 percent. Of all observed enterprises, 6.62 percent fell into group 72.10, "Research and experimental development in natural sciences and engineering" and 4.41 percent into class 72.11, relating particularly to biotechnology. In addition, class 72.19, concerning other research and development in natural sciences, represented 5.88 percent. This group and its classes focus explicitly on biotechnology. Within division 72, "Scientific research and development", Saxony-Anhalt accounted for a total share of 60.87 percent while Saxony contained 26.09 percent of the detected actors and Thuringia a minimum share of 13.04 percent.

Enterprises classified in divisions 46 and 47, referring to wholesale and retail trade excluding trade of motor vehicles and motorcycles, totaled 8.82 percent. The actors were spread widely over different groups within these divisions, such as those focusing on timber, fuels and vegetables. Notably, in both divisions Saxony held the least shares or none at all. Some sections, for example, "N Administrative and support service activities" and "S Other service activities", represented minor shares in the total observation.

As we see it, actors cannot be assigned to one precise NACE code based on the given definition of plant-based bioeconomy because there is no section or division other than 72.10 explicitly focusing on biotechnology. As a result, the majority of actors are spread across various sections and divisions. Furthermore, in some cases

the classification of enterprises according to the predefined NACE codes appears difficult. As a considerable number of enterprises were not involved in only a single business activity, but in various stages in the value-added chain of materials and products, the classification was not unique. One solution would have been to split the enterprise and assign shares to the NACE codes, but the segmentation across the stages of the value chain would have been difficult to estimate.

For example, a frequent formulation in the trade descriptions was "production and distribution", or very similar wording. Consequently, such enterprises can be found in "C Manufacture" as well as in "G Wholesale and retail trade". Therefore, the retail sector could not be generally excluded although by definition focus is clearly on the processing of plant-based materials. A further challenge regarding the Amadeus database emerged as the selection of actors was limited to the trade descriptions provided. Whereas in other databases particular enterprises were clearly identified as suitable actors, the Amadeus trade description of exactly the same enterprises did not indicate any relation to plant-based bioeconomy. In many cases the trade descriptions were worded rather generally, as in "manufacturing of other chemical products" and did not contain any of the predefined keywords. We tried to minimize such possible errors by conducting extensive additional online research.

4.3 Locations

In this section, we take a closer look at the spatial allocation of the actors. In order to do this, we conducted the analysis at the district level and distinguished various types of regions. Identified actors were located in a total of 45 districts. Consequently, only small numbers of actors were located in most of the districts. However, some districts accounted for larger numbers. In such cases we also allocated a five-digit municipality key ("Amtlicher Gemeindeschlüssel"; AGS) in round brackets.

In Saxony, 15 actors (8.20 percent) were located in the city of Dresden (AGS 14612). These actors translate to 10 enterprises, four universities and universities of applied science and one research institute. The four actors identified as universities and universities of applied science all belong to departments of the TU Dresden. Two further departments of this institution focusing on plant-based bioeconomy were identified in the city Tharandt which is situated in the district of Sächsische Schweiz-Osterzgebirge (AGS 14628). Moreover, a relatively dominant share of actors, namely 5.46 percent, was identified within the city of Leipzig (AGS 14713). Of these actors,

three were research institutes while seven were classified as enterprises. Relatively small numbers of actors came from the remaining districts, ranging from one (0.55 percent) to seven actors (3.83 percent).

Nineteen actors (10.38 percent of the total number) were identified in Halle (Saale) (AGS 15002), Saxony-Anhalt. This district had the largest group of actors; eight of these 19 actors were characterized by the type universities and universities of applied science and belonged to the Martin-Luther-University and its bio-scientific departments. Another two actors were categorized as research institutes. The remaining 19 actors were classified as enterprises. A further 14 actors were identified in the district of Salzlandkreis (AGS 15089). This district includes the cities of Aschersleben and Bernburg. Interestingly, nine of these 14 actors were located in the city of Seeland and its urban district Gatersleben, consequently revealing relatively high activity in the context of a plant-based bioeconomy. The actors were distributed across the abovementioned types as follows: 11 actors were enterprises, two were research institutes and one was an association. These results are in line with the findings of Henn and Demuth (2012, p. 208) who detected similar agglomerations of actors in the biotechnology sector in Saxony-Anhalt, namely in Halle (Saale) and Gatersleben. However, in our study, Magdeburg did not reflect a prominent share of the plant-based bioeconomy. However, in a district known as Börde (AGS 15083), four out of the eight enterprises located there focused on manufacturing vegetable oils.

Despite having the smallest number of actors of the three observed states, Thuringia showed the largest spatial fragmentation with 19 districts. Consequently, by comparison, shares and total numbers were small. Within Thuringia, the city of Jena reported the maximum agglomeration of five actors, which was equal to a share of 2.73 percent. Whereas Henn and Demuth (2012, p. 208) emphasized Jena as being the largest group of actors in biotechnology, our results showed only a slightly larger share within Thuringia and only a minor share of the three states together. The three research institutes identified as actors in plant-based bioeconomy were located in Jena, Oberdorla (AGS 16064) and Kirchgandern (AGS 16061). On the other hand, the actors in Saxony-Anhalt were spread over relatively few districts, namely 14, although the largest number of actors was located there. However, this aspect is not surprising as 33 of the total 80 actors were situated in only two districts, Halle (Saale) and Salzlandkreis.

In general, our study confirms the findings of Henn and Demuth (2012) in that a significant concentration of actors was located in urban rather than in rural areas. In Saxony and Saxony-Anhalt in particular, these results are aligned. However, we are aware that in our study the number of actors in urban areas might have been increased because we listed individual departments of universities and universities of applied science rather than the universities in general.

4.4 Firm size by employment

As already mentioned, bioeconomy is considered to have great potential for employment. For this reason, we took a closer look at the current state of employment in plant-based bioeconomy in Saxony, Saxony-Anhalt and Thuringia. The 2013 report of the German Biotechnology sector showed the importance of plant biomass as a raw material. A total of 24 companies in Germany operate in the sector of green biotechnology that focuses on higher-yielding and robust crops (BMBF 2013, p. 12). Of the 149 enterprises identified, 139 provided data referring to their workforce. Staff numbers of the remaining types were not taken into account since relevant information was widely lacking or no clear distinction could be made, for example in universities and universities of applied science. Regarding numbers of employees, we distinguished four categories (see figure 7). Enterprises employing between one and nine persons were assigned to the first category. Category two included enterprises offering employment to between ten and 49 persons. The third category consisted of enterprises employing a workforce of between 50 and 249 employees. Category four was defined by enterprises employing over 250 people.

In our study only five actors, or 3.60 percent, were not classified as small and medium-sized enterprises. These enterprises were located in Saxony-Anhalt and Thuringia. Category three made up a share of 13.67 percent. Category one represented the largest share of identified enterprises, with 53.96 percent and a total number of 75. Moreover, category one and category two amounted to a total share of 82.73 percent. Microenterprises also constituted a considerable number of actors within each federal state when compared to the remaining categories. Total numbers of microenterprises ranged from 19 actors in Thuringia to 29 in Saxony-Anhalt. Those defined as small enterprises made up 18 in Saxony-Anhalt and accounted for 11 in Saxony and Thuringia.

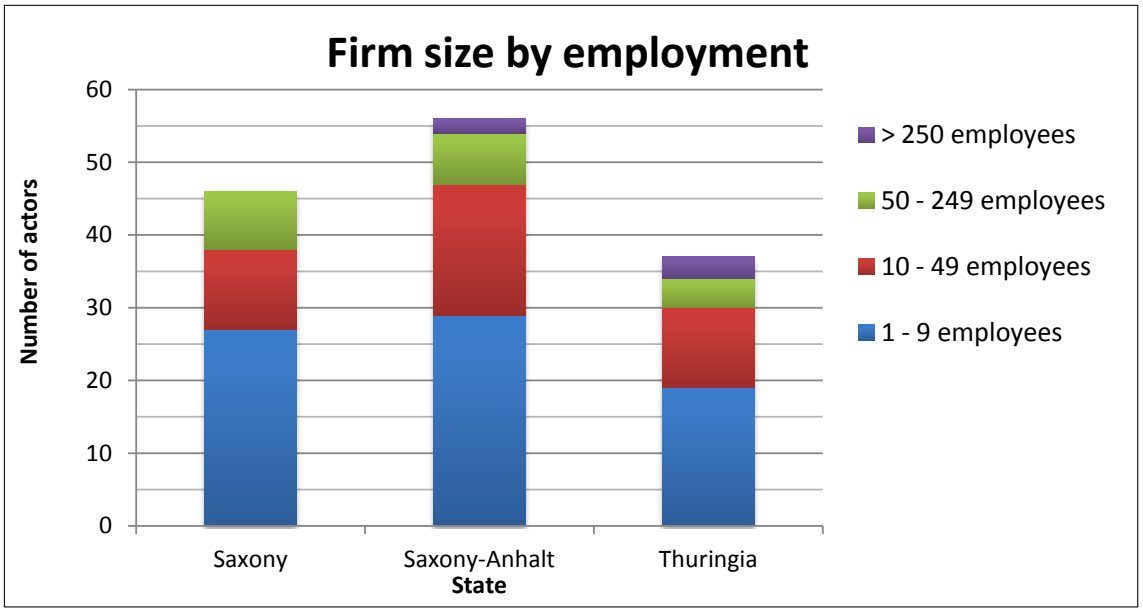

Figure 7: Firm size of actors across the observed states - total numbers.
Source: Own illustration.

Consequently, the majority of enterprises identified as actors in plant-based bioeconomy can be defined as microenterprises or small enterprises (cf. European Union 2003, p. 4). Significant for these microenterprises were high innovation rates and growth potential. Small and medium-sized enterprises are significant for the national economy: they are drivers of innovation in bioeconomy and introduce new technologies through cooperation and networks with large companies and academic partners (BMBF 2011, p. 9).

Evaluation by the German Federal Ministry for Education and Research of the Biotechnology sector in 2013 also found that German biotech companies are mostly small. About 44 percent have fewer than 10 employees on their books, and an equally large percentage (42.8 percent) has between 10 and 50 employees. Only 33 employ more than 100 people and only seven of these, more than 250 (BMBF 2013, p. 9).

Combining workforce and NACE division data for each of the federal states provided further insights into the structure of the individual actors. In Saxony, 26 enterprises were classified as category one and were spread over ten different NACE divisions. Within this fragmentation, eight actors were identified in NACE division 16 which included the manufacture of wood and products from wood and cork, among others. In addition, a considerable number of enterprises were attributed to section C. In

category three, four of the six identified enterprises were situated in the manufacturing sector.

In Saxony-Anhalt, 28 actors were assigned to category one and spread over 10 different NACE divisions. A relatively large number, eight of 28 actors, were categorized in NACE division 72, "Technical testing and analysis". In category two, a relatively large number also fell into NACE division 72. Interestingly, three actors characterized as SMEs were classified in NACE division 01 which includes, among others, crop production offering employment to more than 50 people. One of two enterprises not categorized as an SME was located in NACE division 21, "Manufacture of basic pharmaceutical products and pharmaceutical preparations".

In Thuringia, NACE division 35, which refers to electricity and gas combined with employment category one, applied to a large number of actors relative to other combinations. SMEs occurred solely in NACE division 17, manufacturing of paper and related products, and division 20, referring to chemical products. Two enterprises not classified as SMEs could also be classified under NACE divisions, namely 17, "Manufacture of paper and paper products" and 22, "Manufacture of rubber and plastic products".

4.5 Age of enterprises

As far as the age of the actors is concerned, information on a total of 148 enterprises, universities and universities of applied science, and research institutes was available (see figure 8). Remarkably, 50 percent of the actors were no older than ten years. A large proportion was made up of actors that had been in existence for between six and eight years, making up 5.41 percent to 8.78 percent respectively. However, an interesting exception was provided by actors of the age of 22. These particular actors accounted for a maximum share of 9.46 percent and made up a total of 14. In the decades after German unification the newly formed German states were economically supported by state subsidy programs. At the beginning of the 1990s, the biotechnology sector reported new innovations such as the epigenetic of plants genome and rapidly increasing growth rates, which influenced the birth rate of bioeconomy enterprises (c. f. von Braun 2013, p. 9). Actors of 25 years or older made up a cumulative share of 5.43 percent. The oldest enterprise identified was 104 years old. This enterprise, engaged in plant propagation, was classified as NACE group 164. Interestingly, no actors in existence for between 58 to 91 years were identified. This

might be due at least in part to the fact that many former East German companies moved to Western Germany after World War II.

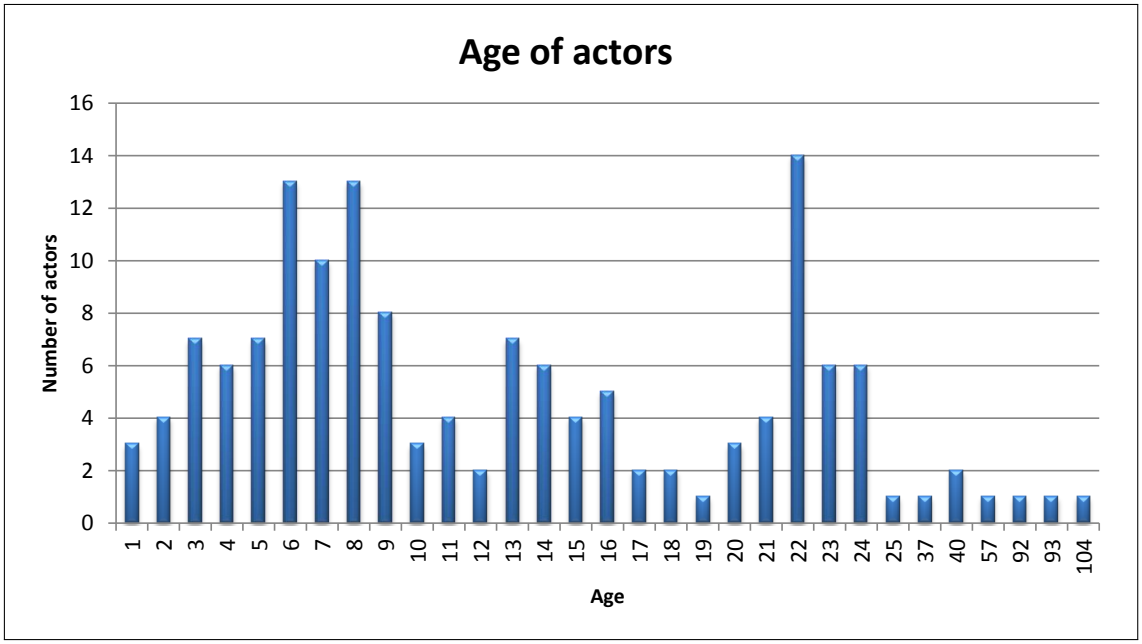

Figure 8: Age of actors - total numbers.
Source: Own illustration.

5 Digression: Biogas

In this section the role of biogas and its related production is reviewed in detail because of its importance to the Central German plant-based bioeconomy owing to the large number of actors involved in its production (322) relative to the 183 observations discussed above. In 2010, 5900 German biogas plants produced about 2300 MW total plant power (German Biomass Research Centre 2011, p. 36); in this respect, Germany is the leader in Europe (EBA - European Biogas Association 2011). We split the investigation concerning biogas from the remaining analysis as we considered that such a distinction was crucial if we were to stick to our prior definition of plant-based bioeconomy. Basically, the production of biogas and its further processing perfectly serves the requirements of our aforementioned definition outlined in section 2. At the same time, producing biogas on its own is not a source of innovation.

During production, biomass is processed for the purposes of providing energy. Biogas can be produced from most types of organic raw material, the most common being

agricultural products such as energy crops and by-products such as manure, various kinds of biowaste, including sewage sludge, municipal waste and organic fractions of household and industrial waste (EBA - European Biogas Association 2011). As illustrated, biogas production is not based exclusively on plant-based raw materials. Furthermore, as we analyzed the data, we became concerned that running a bioenergy plant often developed into an additional business in agriculture or a corresponding field. Therefore, we came to the decision not to include biogas in the general analysis as this aspect would have distorted our data set on the current state of plant-based bioeconomy in Central Germany considerably.

Overall, a total of 322 actors were involved in the production of biogas. The number was spread fairly evenly across the three states (see figure 9). Saxony accounted for a minimum share of 30.75 percent whereas Saxony-Anhalt reached a total share of 38.20 percent.

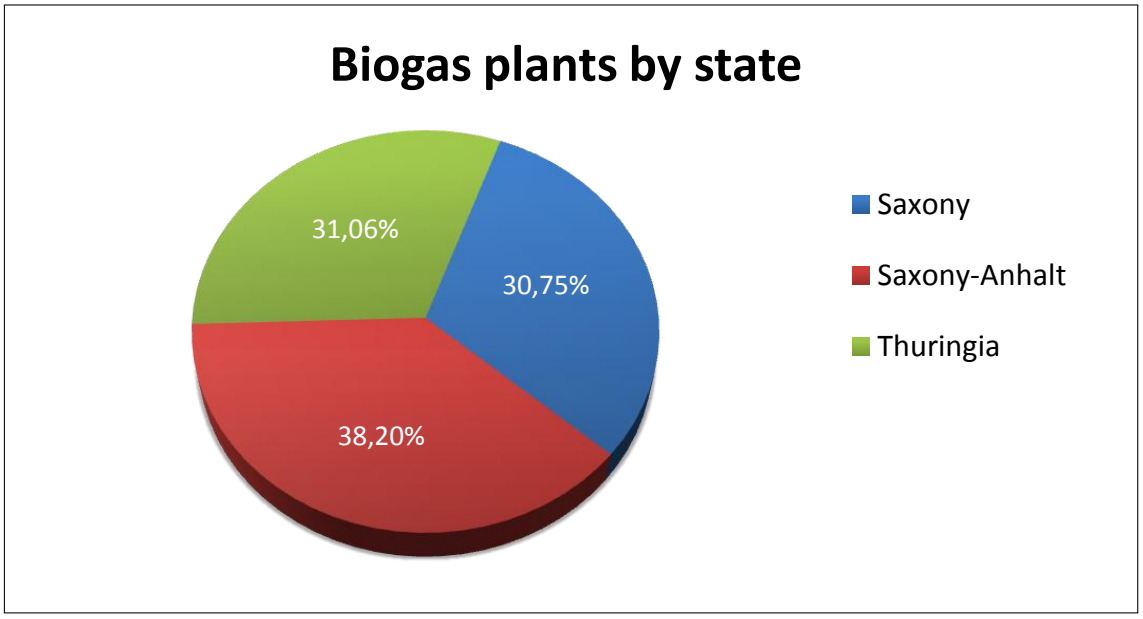

Figure 9: Biogas plants across the three observed states, based on Amadeus database.
Source: Own illustration.

Greater insight was provided by the classification under NACE codes. In division 01, "Crop and animal production, hunting and related service activities" made up a share of 31.37 percent of total actors in the biogas analysis. In particular, in group 01.50, "Mixed farming", a total number of 45 actors was observed. A frequent formulation in the trade description was "production of animal- or plant-based commodities" linked to the phrase "operating a biogas plant", or closely

corresponding wording. Interestingly, no observations were made in division 02, "Forestry and logging", although considerable quantities of biomass are produced there as well as by-products.

A further prominent share was categorized in section "D Electricity, gas, steam and air conditioning supply", amounting to 62.42 percent. Remarkably, classes 35.11, "Production of electricity" and 35.21, "Manufacture of gas" came to a total of 67 and 122, respectively. However, a frequent formulation was "operating a biogas plant" or similar wording. In a few cases the further processing for energy or heating purposes was explicitly mentioned. Further groups and classes accounted for minor shares and mostly comprised one or two actors, such as in 20.14, "Manufacture of other organic basic chemicals" and 46.21, "Wholesale of grain, unmanufactured tobacco, seeds and animal feeds". Interestingly, few actors in biogas were detected in classes that particularly addressed services. For example, group 81.30, "Landscape service activities" and 96.09, "Other personal service activities n.e.c." had only one actor each.

6 Concluding remarks

As considerable emphasis is placed on the concept of bioeconomy in meeting future challenges, this article has outlined the current state of plant-based bioeconomy in Central Germany. In so doing, we have derived a tentative definition of plant-based bioeconomy since a distinct definition of even the most basic term bioeconomy is as yet not available. Furthermore, our study once more stresses the relevance of bioeconomy and supports the focus it has received at a political level. However, as far as some of our findings are concerned, the influence of plant-based bioeconomy must be put in perspective both state-wise and for Central Germany as a whole.

The results show that the largest group of actors was represented by companies and was thus found in free enterprise. This aspect holds valuable economic potential. However, in terms of employment our study shows that the majority of observed actors were identified as microenterprises or small enterprises. This implies that the relevance of plant-based bioeconomy in Central Germany is reduced as far as the goal of providing large scale employment is concerned and once more underlines the significance of small enterprises.

Notably, actors were spread over a range of different industrial sectors. A substantial number of actors were identified in highly innovative sectors such as technical testing and analysis, as well as in more traditional sectors relating to plants, including agriculture and plant-breeding. Furthermore, in the traditional sectors various enterprises were identified as suitable actors in plant-based bioeconomy as they were involved in innovative processing and new techniques, for example, processing biomass or plant-breeding. Therefore, the innovative aspect of plant-based bioeconomy is evident and serves as a valuable base for facing future challenges. The distinct focus on research and development was displayed not only by universities, universities of applied science and research institutes but also by a large number of enterprises that operate in highly innovative sectors and/or state research and development as fundamental components of economic activity in the related trade description.

Moreover, the agglomeration of actors in urban areas, owing largely to the presence of institutes and universities there, was evident in Saxony and Saxony-Anhalt. In contrast, in Thuringia a fairly extensive pattern was identified and no clear center of plant-based bioeconomy emerged. In addition, it became evident that the three states were at different stages of development in terms of the current state of plant-based bioeconomy. Consequently, Thuringia constantly fell short of the other two states, especially regarding research institutes and universities, whereas Saxony-Anhalt was overall more advanced. Where previous research has emphasized the strong position of Central Germany in the biotechnology sector, our study concludes that individual states account for relatively minor shares in plant-based bioeconomy. Moreover, Central Germany as a whole still ranks behind other individual states.

As far as the high intensity of research and innovation in plant-based bioeconomy as well as extensive regional patterns are concerned, high levels of networking are crucial to ensuring future success. An additional challenge for plant-based bioeconomy may arise as it focuses particularly on using plants in non-food applications. This aspect may increase the need for justification in the face of the goal of global food security. This food vs. fuel dilemma might be (partly) solved by radical improvements in the cascade usage of biomass, such as by employing crop residues and nekromatter in chemical and pharmaceutical applications, as is already the case in the field of bioenergy. Moreover, a large sector of society may be opposed to new ways of processing plants and biomass, especially to plant breeding connected to GM technology (Devos et al., 2008).

Germany, with its central location within Europe and a well developed infrastructure, represents a good starting point for the growing German bioeconomic industry. Plants are set to play an ever-greater role in the years to come in the light of diminishing fossil resources. The German bioeconomy and biotechnology sector has shown a measurable growth over the past few years, and companies are well placed in the economy (OECD, 2009).

References

Benitez Salas, A. (2010) Director-General of DG Agriculture, talk at Conference on the "Knowledge-Based Bio-Economy Towards 2020", Brussels, 14 September. Available online at: http://sectie.ewi-vlaanderen.be/sites/default/files/documents/BENITEZ_SALAS_KBBE_2010-09-14.pdf. (Last accessed: March 18, 2014.)

BMBF (2011): National Research Strategy BioEconomy 2030. Available online at: http://www.bmbf.de/pub/bioeconomy_2030.pdf. (Last accessed: March 19, 2014.)

BMBF (2013): The German Biotechnology Sector 2013. Available online at: https://www.biotechnologie.de/BIO/Redaktion/PDF/de/umfrage/2013-umfrage,property=pdf,bereich=bio,sprache=de,rwb=true.pdf. (Last accessed March 19, 2014.)

BMELV (2009): Aktionsplan der Bundesregierung zur stofflichen Nutzung nachwachsender Rohstoffe. Available online at: http://www.bmelv.de/cae/servlet/contentblob/649756/publicationFile/39655/AktionsplanNaWaRo.pdf. (Last accessed: March 19, 2014.)

BMELV (2013a): Nachhaltige Nutzung von Biomassepotenzialen. Available online at: http://mediathek.fnr.de/media/downloadable/files/samples/w/e/webversion_02.pdf. (Last accessed: March 19, 2014.)

BMELV (2013b): Politikstrategie Bioökonomie. Available online at: http://www.bmbf.de/pubRD/BioOekonomiestrategie.pdf. (Last accessed: March 19, 2014.)

Boltho, A., Carlin, W. and Scaramozzino, P. (1997): Will East Germany Become a New Mezzogiorno? in: Journal of Comparative Economics, 29 (3), pp. 241-264.

Brunori, G. (2013): Biomass, Biovalue and Sustainability: Some Thoughts on the Definition of the Bioeconomy, in: EuroChoices (2013), pp. 48-52. Available online at: http://onlinelibrary.wiley.com/doi/10.1111/1746-692X.12020/pdf. (Last accessed: March 19, 2014.)

DESTATIS (2014): Statistische Ämter des Bundes und der Länder. Available online at: https://www.regionalstatistik.de/genesis/online/data;jsessionid=624444E4FD71692E45A1F28A621AA456?operation=statistikenVerzeichnis. (Last accessed: April 15, 2014.)

Devos, Y., Demont, M., Dillen, K., Reheul, D., Kaiser, M. and Sanvido, O. (2008): Coexistence of genetically modified (GM) and non-GM crops in the European Union. A review, in: Agronomy for Sustainable Development, 29 (1), pp. 11-30.

EBA - European Biogas Association (2011): Biogas - simply the best. Available online at: http://european-biogas.eu/wp-content/uploads/files/2013/10/EBA-brochure-2011.pdf. (Last accessed: March 18, 2014.)

European Commission (2012a): Innovating for Sustainable Growth: A Bioeconomy for Europe. Available online at: http://ec.europa.eu/research/bioeconomy/pdf/201202_innovating_sustainable_growth.pdf. (Last accessed: March 19, 2014.)

European Commission - MEMO/12/97 (2012b): Commission adopts its Strategy for a sustainable bioeconomy to ensure smart green growth in Europe. Available online at: http://europa.eu/rapid/press-release_MEMO-12-97_en.htm. (Last accessed: March 18, 2014.)

European Commission: Research & Innovation, Bioeconomy (n.d.): Commission adopts a Strategy for a sustainable Bioeconomy in Europe. Available online at: http://ec.europa.eu/research/bioeconomy/press/newsletter/2012/02/sustainable_economy/index_en.htm#en. (Last accessed: March 18, 2014.)

European Commission and Eurostat (2008): Metadata. Statistical Classification of Economic Activities in the European Community, Rev. 2 (2008). Available online at: http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE_REV2&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=HIERARCHIC&IntCurrentPage=1. (Last accessed: March 19, 2014.)

European Technology Platforms (n.d.): The European bioeconomy in 2030 - Delivering Sustainable Growth by addressing the Grand Societal Challenges.

Available online at: http://www.epsoweb.org/file/560. (Last accessed: March 18, 2014.)

European Union (2003): COMMISSION RECOMMENDATION of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises. Available online at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:124:0036:0041:en:PDF. (Last accessed: March 19, 2014.)

Food and Agriculture Organization of the United Nation (n.d): FAO How to Feed the World in 2050. Available online at: http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf. (Last accessed: March 19, 2014.)

German Biomass Research Centre (2011): Monitoring zur Wirkung des Erneuerbare-Energien-Gesetz (EEG) auf die Entwicklung der Stromerzeugung aus Biomasse. Available online at: https://www.dbfz.de/web/fileadmin/user_upload/Userupload_Neu/Stromerzeugung_aus_Biomasse_Zwischenbericht_Maerz_2011.pdf. (Last accessed: March 18, 2014.)

Henn, S. & Demuth, M. (2012): Biotechnologie-Cluster in Mitteldeutschland. Genese und Pfadentwicklung.

Langeveld, H., Sanders, J. and Meeusen, M. (2010): The Bio-based Economy-Biofuels, materials and Chemicals in the Post-oil Era.

OECD (2009): The Bioeconomy to 2030. Available online at: http://www.oecd.org/futures/long-termtechnologicalsocietalchallenges/42837897.pdf. (Last accessed: March 19, 2014.)

Schmid, O., Padeland, S. and Levidow, L. (2012): The Bio-Economy Concept and Knowledge Base in a Public Goods and Farmer Perspective. In: Bio-based and Applied Economics 1(1) (2012), pp.47- 63. Available online at: http://www.fupress.net/index.php/bae/article/viewFile/10770/10517. (Last accessed: March 19, 2014.)

Günther, J., Titze, M., Brachert, M., Ehrenfeld, W., Stahlecker, T., Kroll, H., Schricke, E., Konzack, T. and Soder, H. (2013): Sächsischer Technologiebericht 2012. Available online at: http://www.technologie.sachsen.de/download/Technologieberich_2012_Endversion.pdf. (Last accessed: March 19, 2014.)

Von Braun, J. (2013): Bioeconomy – science and technology policy for agricultural development and food security. Available online at: http://ppafest.nutrition.cornell.edu/authors/vonBraundraft.pdf. (Last accessed: March 19, 2014.)