



# Innovation and Networks in the Bioeconomy: A Case Study from the German Coffee Value Chain

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## Abstract

The transition to a circular bioeconomy requires innovation across many sectors, but social dynamics within a sector's network may affect innovation potential. We investigate how network dynamics relate to the perceptions and adoption of bioeconomy innovation using a case study from the food processing sector. Our case study of the German coffee value chain represents a technologically advanced sector with a strong sustainability focus and potential for residue valorization, which is an important dimension of a sustainable circular bioeconomy. We identify three distinct views (pioneers, traditional and limited users) related to residue valorization, map linkages between actors using social network analysis, and highlight barriers to innovation. We collected data through an online survey and semi-structured interviews with key actors in the coffee roasting sector. Within the social network analysis, we find that public waste managers are closely linked to the most influential actors, state actors such as the customs and tax offices can quickly interact with others in the network and promote the spread of information (highest closeness centrality) and specific roasters play an important role as intermediaries for efficient communication (highest betweenness centrality). Finally, we identify four main barriers including the structure of the coffee network, inconsistencies in federal waste regulations, economies of scale, and visions of sustainability. To support a sustainable bioeconomy, we recommend that policy makers revise the primary regulatory frameworks for waste (e.g., German Recycling Act) to clarify how to classify food residues, their disposal structures and broaden their use streams.

**Keywords** Bioeconomy · Coffee · Value chain · Germany · Social network analysis · Residue valorization

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## Introduction

The emergence of a sustainable bioeconomy depends on sufficient availability of biological resources, which do not compete with food or feed production [1]. To limit competition with food and feed production, an important aspect of the sustainable bioeconomy is a cross-sectoral use of residues, especially those stemming from the food industry [2, 3]. This follows the biomass cascading principle, which refers to the integrated optimization of biomass usage for raw materials and energy [4] and is a key component of the transition to a sustainable, circular bioeconomy [3]. This means that biomass should be used multiple times (i.e., for material uses) before it is ultimately converted to energy [4, 5].

Given the growing demand for biomass, residual biomass presents many opportunities for valorization but the profitable exploitation of residues (waste) is a complex problem [6]. Residue valorization involves a variety of actors including the regulators, waste managers and the private firms producing waste. This extends to the broader category of circular business models, in which the traditional customer–supplier relationships are replaced by multi-actor relationships [7].

In the context of the bioeconomy, it has been found that underlying power dynamics in social network structures can affect innovation potential. Previous studies have focused on the role of different actors in supporting the transition to the bioeconomy. The studies focused on different aspects of the transition with focus on networks around the wood-based bioeconomy [8, 9], bioenergy [10–12] and bioplastic [13]. Alternatively, a few studies have focused on the role of a specific actor in the transition, such as primary producers [14] or large companies through their mergers & acquisitions activities [15]. One case study investigated the network supporting the feedstock of cassava [16]. A case study from the Thessaly region in Greece, where agriculture is the predominant economic activity, explored the main challenges to the circular waste bioeconomy. To exploit the potential of agricultural and agro-industrial residues, they argue that organizational, societal and knowledge actions are key and that stakeholders within the network must synergize and collaborate [17].

Although the majority of studies from social sciences and economics literature focused on holistic and broader aspects of the bioeconomy (e.g. wood-based bioeconomy, biofuels, etc.), the technical bioeconomy literature often focused on valorization of specific feedstocks [18]. Although there is a strong technical focus on the use of agricultural and food industry residues, we found few papers which investigate barriers to their usage and the potential of key actors in promoting the adoption of these innovations.

To better align with the technical expertise developed for the use of different biomass residues, we focus on a case study from the German food processing industry. The German coffee value chain offers the ideal case study due to the cascading potential of coffee residues and the industry's status as a leader in agricultural commodity eco-certification [19, 20]. Thus, we focus on bioeconomy initiatives in the downstream coffee value chain and the role of coffee roasters as key actors, who dominate the downstream activities (e.g., roasting; packaging) of a highly vertically integrated industry. Specifically, we investigate perceptions of using coffee residues, analyze how actors such as roasters can support bioeconomy initiatives by mapping their position within the network and identify policy barriers to the development of the bioeconomy in the German coffee roasting industry.

## Case Study: the German Coffee Value Chain

The global coffee value chain can be organized into upstream, downstream and consumption segments (Fig. 1). In our case study, we focus on the German coffee value chain. This includes the downstream actors: importers, traders, roasters, various government agencies (customs, taxes) and roasters. The global coffee industry's downstream activities usually attract the highest profits and margins along the value chain, including coffee trading, roasting, branding and packaging. Globally, Germany has become an economic powerhouse in the coffee industry. Many German companies roast beans, sell them domestically or re-export them.

Coffee processing produces ten million tons of agricultural residues, which often end up in a waste incineration plant or are left unused [20]. Coffee residues may be used in applications ranging from energy production to nutritional supplements to fertilizers. The high content of phenolic compounds in coffee residues makes them particularly promising for cascading. Although the potential application of high-nutrient coffee residues has been studied [20], and the concept of the bioeconomy has garnered attention on the international stage, it is unclear which barriers stand in the way of residue usage as part of circular bioeconomy initiatives.

Every step of green coffee production generates residues including the husk through the dry-method; pulp through the wet-method; defective and premature coffee beans through harvesting and roasting; coffee silverskins through roasting; and spent coffee grounds coffee through brewing [20]. The residues' physical and chemical properties, consistency and perishability largely depend on how the green coffee was produced (i.e., dry- or wet-method). Roasting involves three major steps: the bean drying stage, the browning stage (the Maillard reaction) and the roasting stage (exothermic reaction/beans crack). At large-scale coffee companies, an additional step using water follows these stages to cool the beans.

The coffee silverskin is a thin layer which encloses the two coffee beans and detaches during the roasting process [21]. They are estimated to amount to about 76 million kg/year and is one of the main coffee residues available in Germany [22]. Although research on its applicability is still in its infancy, coffee silverskins are considered a comparatively stable product due to their lower moisture content [23]. Additionally, silverskins are rich in protein, dietary fiber and soluble fiber [23] and their antioxidant properties could be used for antioxidant beverages, flakes, bread, biscuits, and other snacks for weight control [24].



**Fig. 1** Overview of the Coffee Value Chain

This means the silverskins could have the biggest economic potential and health benefits. However, as its antioxidant activity is correlated with high amounts of phenolic compounds and caffeine, it can cause health issues. Thus, detoxification is essential for a safe and sustainable use [25]. Moreover, depending on the processing method of the green beans, there are different technical distinctions between dry and wet silverskins. Wet silverskins are difficult to convert into an economically viable product because it can be time-consuming and costly to dry them as the most common means of drying them are through freeze-drying and spray drying [26].

Other residues from coffee production include defective and premature beans, spent coffee grounds and coffee oil. As they could decrease the final product's quality, defective and premature beans are removed before the roasting process. Although there are only few studies on their potential application fields, it was found that chlorogenic acid and caffeine can be extracted from defective/premature beans [27]. During the production process, ground coffee is treated in percolators through which hot water flows to extract the soluble components. In addition to large industrial operations, spent coffee grounds are produced in large quantities in catering establishments such as coffee houses, hotels or cafeterias. However, there is no study on the amount of spent coffee grounds generated in those facilities, and private households are probably the largest source of coffee grounds. Based on a study that assessed the oil content of spent coffee grounds generated during domestic coffee brewing, it is estimated to be up to 20% of content [28]. The coffee oil can be processed into biodiesel. Although spent coffee grounds are suitable for compost in crop production, it is not suitable as animal feed due to missing acid components [29].

From a legal standpoint, the framework for biogenic waste, residual materials and by-products is defined by European, federal and state directives, regulations and laws. According to the EU Waste Framework Directive (Directive 2008/98/EC on waste), all agricultural residual materials or by-products accumulated in the EU are to be regulated as residuals, co-products or by-products rather than waste. This is because these are generated alongside the cultivated biomass [1]. Implemented into German law under the *Kreislaufwirtschaftsgesetz* (German Recycling Act), it states that if residual materials, co-product or by-product is reused, marketed or used to produce other products, it must be classified as a by-product (§ 4 KrWG). However, the KrWG does not provide clear guidance on how to classify a by-product. Rather than the state, the federal states are ultimately responsible for making the final classification of agricultural by-products accumulated in their jurisdiction. This is because federal law is supplemented by the waste legislation of the respective federal states, which have waste laws with supplementary provisions and administrative regulations in place. In practical terms, this means that the federal states can legally classify by-products if the federal government has not done so. Moreover, federal state authorities and subordinate bodies carry out control tasks to ensure that the overall use does not lead to harmful effects on humans and/or the environment while the federal state's tax and customs authorities are responsible for the correct taxation of the by-products when they are resold.

In terms of taxes, German coffee is also subject to the German coffee tax. This tax is collected by the federal states' customs authorities, but the tax revenue is due to the federal government. For roasted coffee, it is €2.19 per kilogram and for soluble coffee, €4.78 per kilogram [30]. Companies can reclaim the coffee tax if the coffee or coffee-containing goods were originally taxed but justify a refund.

The development of the bioeconomy related to coffee production and processing falls within the larger issue of governance of sustainability in the coffee value chain. Sustainability (environmental, social and economic) has been of increasing concern for coffee

consumers worldwide with a strong focus on the upstream value chain. In a meta-analysis of eco-labelling of coffee including organic, Country of Origin and fair trade labels, it was found that organic labels generate the highest willingness to pay due to their perceived health and environmental benefits [19]. In particular, the German coffee landscape has experienced several recent changes. In a cross-country comparison of willingness to pay for Fair Trade coffee, Germans were found to pay for Fair Trade coffee, but only up to a critical level [31]. Further, in more recent comparisons of sustainability labels for coffee, it was found that consumers feel environmental sustainability and biodiversity is important, but tend to avoid choosing “Wild Grown” coffee labels compared to Fair Trade or Organic Coffee [32]. Moreover, Germany’s biggest coffee corporations, such as Tchibo, Melitta, and Darboven have become members of certification organizations (e.g., Rainforest Alliance/UTZ) allowing them to sell specific coffee blends labelled as “certified coffee”. Despite increasing awareness of sustainably sourced coffee amongst coffee corporations and consumers, coffee residues use has found little to no attention in state environmental strategies.

## Methods

To understand how underlying dynamics within a network may affect innovation potential, we use a mixed-method approach, which combines a survey and interviews. The survey was used to assess the intensity of each firm’s current bioeconomy practices and their perceptions of future initiatives. The interviews were divided into two sections: social network questions (i.e. relational questions, which were used to map flows of communication and knowledge) and open questions about the challenges faced by the firm in adopting bioeconomy initiatives.

## Conceptual Framework

Social networks play an important role in learning and the diffusion of technology, opinions and behaviors [33]. Particularly given the innovations needed for the transition to the bioeconomy and adoption of bioeconomy initiatives (e.g. new business models), individual actors may affect the behavior of their peers. For example, in various fields, such as agricultural economics, there is a long tradition of studying the effects of peers on technology adoption [34].

Beyond studying the effects of peers, it is important to understand the position of each actor within the network to understand power relationships [33]. In our case, the network itself is situated within a global value chain. From a governance perspective, there are three main approaches to understand chains, networks and their functions in global production: global commodity chains, global value chains and global production networks [35]. We use the concept of the value chain as it is best suited to evaluate power relationships [36] within the coffee value chain and their role in governing and facilitating sustainability innovations (i.e. transition to the bioeconomy). In the value chain concept, the conceptualization of power is strongly centered on the linkages between lead actors link and other members of the chain. To understand these linkages, we apply network theory, which goes beyond the depiction of actors linked through a set of ties and rather evaluates why actors occupy a specific position within a network and the effect this has on the network as a whole [37].

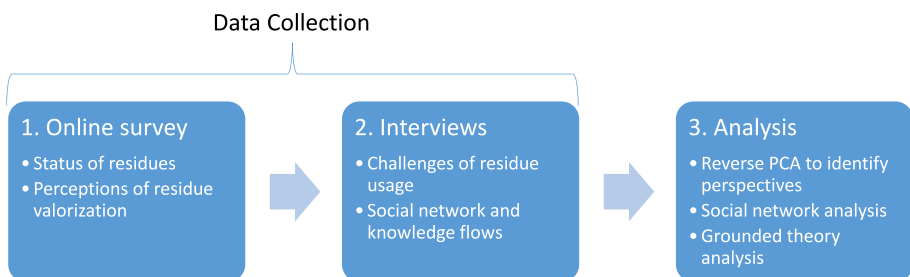
## Data Collection

The target population was employees from coffee roasting companies located in Germany. According to the German Coffee Association, they have over 360 members including various organizations and traders as well as large roasters and 150 specialty roasters [38]. Assuming that most roasters are members of the association, we were able to identify 83 professionals (e.g. sustainability managers, managing directors, scientists, engineers), which we invited for participation. Thus, we estimate that our sample represents around 4% of the industry. This included sustainability managers, managing directors, scientists, or engineers. Respondents were invited to participate by email, phone and at coffee and gastronomy trade fairs as well as recruited via the snowball process.

In total, 18 respondents from 15 German coffee companies participated. Two companies had two respondents each, who responded as a team. Of the companies, three were micro-sized (up to 9 employees), seven were small/medium-sized (up to 249 employees) and five were large (more than 250 employees). In addition to interviews with coffee companies, two expert interviews with a recycling company and the German coffee association were conducted to corroborate the findings. One roaster (coffee11) did not participate in the survey.

Figure 2 shows the structure of our data collection and analysis. Our study comprised of (i) an online survey and (ii) semi-structured interviews with 15 German coffee roasting companies and two experts. Our online survey focused on the technical measures used in the context of coffee residue valorization and perceptions of the firm's potential. Thus, in "Case Study: the German Coffee Value Chain" section, we explain the terminology and processing of coffee and its residues, which helped us design the survey instruments. We sent the online survey in advance to the respondents and used their responses in the survey to guide our development of the interviews. Both the translated survey and interview guide can be found in the Supplementary Material.

After respondents filled out the online survey, we scheduled follow-up interviews online or in person. The interviews were organized in two parts. In the first part, we asked open questions about the firm's challenges in implementing bioeconomy initiatives (e.g. economic feasibility, use of waste and residues as a resource, resource efficiency, preservation of product value, waste management, integrated bio-biorefineries and general sustainability issues). In the second part, we asked relational questions about the network's structure. Specifically, we asked: "How often are you in contact with actor X during the past year (April 2021-April 2022)?" This included various mediums of communication: in-person, phone calls and emails. If they were in contact, respondents were asked to select one of four categories, which we coded with the following values (width: 1–4): "rarely



**Fig. 2** Overview of data collection and analysis

in contact”, “in contact”, “often in contact” and “very often in contact”. Interlinkages between actors who did not have any contact (0 – not in contact) were not included.

## Data Analysis

### Survey

The results from the quantitative survey were used to descriptively assess the residues used at each firm, identify perceptions towards residue usage and form the basis of the qualitative interviews. From the categories of residue types (silverskins, defective beans, coffee grounds and other), we created a count of the number of sources used. We summarized the share of each residue type used and its stream.

For perceptions, we included 25 Likert-scale questions about the perception of residue usage. These were organized into 7 categories: knowledge, potential business area, current business area, profitability, laws and regulatory environment, connections with other actors and administrative capacity. Similar to the analysis in the Q-methodology, we use principal component analysis (PCA) to identify interrelationships between respondents, rather than the variables as in regular PCA [39]. We use the *qmethod* package in R to analyze the data and specify an unforced distribution. This allows us to identify unique perspectives (i.e. group individuals with similar opinions) among the different coffee firms.

PCA is standard multivariate data reduction technique that can be used to reduce a complex dataset to a lower dimension [40]. In our analysis, we were aimed to understand commonalities in attitudes about residue valorization between different firms. We organized our data as followed: the perceptions about residue usage (each cell with a score based on the degree that each respondent agreed/disagreed with each statement) are treated as rows and respondents are treated as columns. In the first step, a correlation matrix is built and PCA reduces the correlation matrix into components, which are ordered based on the total variability explained [39]. For this reason, the first components explain the greatest share of variability. In the second step, several of the components are selected and rotated to obtain a clearer structure of the data. The rotation of the components is mathematically optimized (varimax). The researcher may select how many components to select based on several criteria. Based on a Scree plot, eigenvalues, total explained variance, number of respondents significantly associated with each component and qualitative interpretation [41, 42]; we extract three components.

We evaluate and describe each perspective by exploring a plot of the z-scores, which represent the typical opinion on each statement for a member of a given perspective. The z-scores represent the position of each statement in the sorting grid. The scoring was performed on a Likert scale, which is represented by z-scores ranging from -2 (strongly do not agree) to 2 (agree strongly). In the Appendix, Fig. 5 compares the three perspectives and the z-score shows a representative score for each opinion statement.

### Social Network Analysis

To complement this analysis, we performed a social network analysis to depict the governance structures of the German coffee value chain. We analyzed the social network using the *igraph* package in R [43]. This allowed us to evaluate actors’ specific positions within a network including the centrality; in-betweenness and eigenvector metrics as well as the connectivity of

the whole network (i.e., graph density.) The graph density represents the ratio of the number of edges and the number of possible edges [44].

By definition, a network is a graph on a set  $N$  of nodes with a finite number of members  $n$  [33]. Nodes may also be referred to as agents. The graph is a pair  $(N, g)$  where  $g$  is an  $n \times n$  adjacency matrix on the set of nodes. Within this,  $g_{ij}$  indicates the relationship between  $i$  and  $j$ . The relationship (or link, edges or ties) between nodes can be present, absent or weighted. The graph can be directed or undirected, which depends on assumptions about the relationship. If the relationship requires mutual consent (e.g. contract), the network is often represented as an undirected graph.

We focus on flows of knowledge and measure the frequency of contact for each actor (e.g., on average, a coffee roaster is in contact with a coffee importer four times a month). We focused on contact within the past year (April 2021-April 2022). For example, we were able to determine whether being in contact with a coffee importer twice a month is below or above the average. As not all respondents were able to give precise numerical answers (e.g., sometimes, often, etc.), the following responses were coded as 2.5 (rarely in contact) to 100 (very often in contact). Moreover, interlinkages between actors who were not in contact (0 – not in contact) – were not included.

We present descriptive measures for the full social network (including the individual IDs of each coffee roaster). This allows us to understand the betweenness, degree, closeness and eigenvector calculated for each node in the graph. The betweenness centrality is a measure of the shortest number of paths passing through each node, which allows us to measure the actor's role as a bridge. The shortest path betweenness of a given vertex  $v$  can be calculated following:

$$C_B(v) = \sum_{i,j: i \neq j, i \neq v, j \neq v} \frac{g_{ivj}}{g_{ij}}$$

where  $g_{ijk}$  is the number of geodesics from  $i$  to  $k$  through  $j$  [45–47].

The degree centrality is a measure of the number of edges connected with each node (actor), which can be understood as a measure of popularity or importance in the network. Based on the adjacency matrix,  $A = (a_{ij})$ , degree centrality can be formulated as [48]:

$$\sigma_D(x) = \sum_{i=1}^n a_{ix}$$

Closeness centrality is a measure of how close a given node is to other nodes. Thus, actors with higher closeness centrality have shorter average distances to other actors. Thus, the lower the score, the more central the actor. The closeness centrality refers to the inverse sum of distances to all other vertices in the graph. It can be formulated as [49]:

$$\frac{1}{\sum_{i \neq v} d_{vi}}$$

Eigenvalue centrality is a measure of the influence of an actor in the network, which also considering the influence of its neighbors. If an actor has a higher eigenvalue centrality, it is connected to other influential actors. It can be formulated as a non-zero vector  $c = (c_i)_{i \in N}$  such that, for some scalar  $\lambda > 0$ , we will have [50]:

$$\lambda c_i = \sum_{j \neq i} g_{ji} c_j \text{ for all } i \in N$$



However, because the coffee roasters did not disclose any links with other companies beyond general categories (e.g. Big 10 or speciality companies, which are usually small/medium) for privacy reasons, we cannot assess linkages between the individual companies. For that reason, we visualize the network in a present a simplified form (Fig. 4) by grouping the coffee roasters according to their size (e.g. micro: up to 8 employees; small/medium: up to 249 employees; and large: more than 250 employees). It is important to note that because of this clustering, the roasters themselves appear to be at the center of the network, which is not the case in the full network analysis. However, it allows us to better visually depict the relationships among different sizes of coffee roasting firms with other actors. We used a force-driven layout for the social network: Kamada Kawai [43]. Force-driven layouts use an algorithm to visually depict closer nodes. Intuitively, a force-driven layout shows a visually meaningful relationship between individual nodes. This means that nodes are more directly related tend to be closer to each other in the visual representation of the network [51].

### Qualitative Data Analysis

The qualitative interviews were transcribed according to guidelines [52] and analyzed following the Grounded Theory Methodology [53]. In the Grounded Theory Methodology, the researcher inductively and empirically explores the research object in its context [54]. To support coding and analysis, we used the program MAXQDA.

In total, 591 segments of the text were coded. During the first coding process, a variety of different categories emerged including “saving waste management costs by giving away silverskin” or “café customers use coffee grounds as a fertilizer”. In the second order analysis, we focused on concepts. Then, we evaluated the materials in terms of umbrella terms. Finally, the findings from the qualitative data analysis were contextualized with the findings from the preceding survey on the economic feasibility of coffee residues and by-product usage.

## Results

First, we present a descriptive overview of residue usage among German coffee roasters. Second, we identify and describe three unique perspectives related to residue usage. Third, we map the social network to understand key players. To analyze the role that coffee roasters can play in the transition to a sustainable bioeconomy, we include insights from the qualitative interviews within each step.

### Status of the Bioeconomy Network

In terms of the company size, 47% of companies surveyed were small/medium-sized enterprises; 33% were large enterprises and 20% were small enterprises (Table 1). In terms of residue collection, silverskin is the most collected residue (80%) followed by defective beans (53%) and spent coffee grounds (47%). There were some interesting differences based on company size: defective beans play a more important role for large companies (80%), while spent coffee grounds predominately play a role for medium/small (57%) and micro-sized companies (67%). Awareness of residue amounts does not appear to be a barrier for usage as the majority of participants are aware of the actual

**Table 1** Overview of current residue usage

	Share of firms from sample		
	Micro ( <i>n</i> = 3)	Large/Medium ( <i>n</i> = 7)	Large ( <i>n</i> = 5)
Collection of silverskin	67%	71%	100%
Collection of defective beans	33%	42%	80%
Collection of grounds	67%	57%	20%
Collection of other residues	-	14%	20%

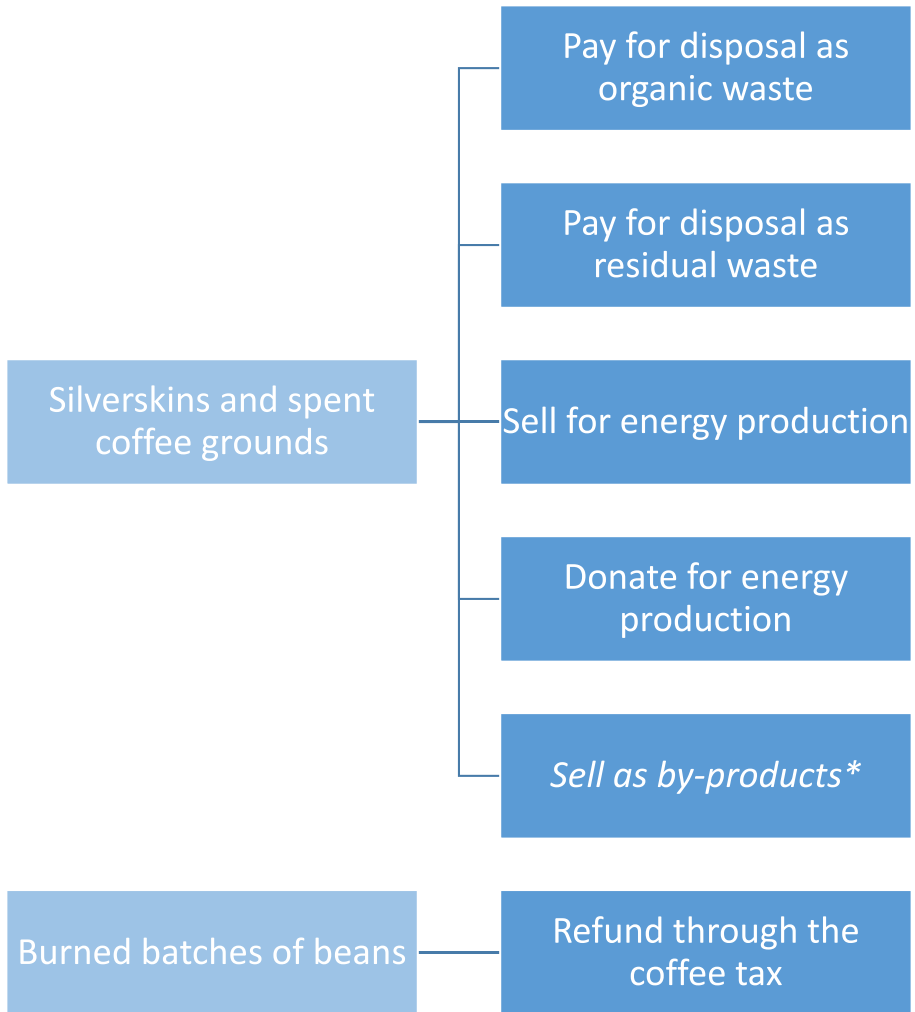
accumulated generated amount of silverskin (60%), followed by defective beans (54%), spent coffee grounds (50%) and other (33%).

In terms of current streams of residue usage, 40% of participants from all companies regardless of size dispose of their silverskins as waste. Based on the survey and the interview results, in Germany, there are several possibilities for waste (see Fig. 3). The residues (i.e. silverskin) are primarily treated as organic waste, which means it is either disposed of by waste facilities or given away for free (e.g. to farmers for biogas).

The residues may be collected for a fee by the public waste authority or the coffee company may pay a waste management company to dispose of the residue, amongst other waste. In both cases, the exact amount of generated by-products is not very relevant to the coffee roaster as it will be disposed of and not sold for a profit. The third option is to sell the waste to a waste management company. If the residue is sold, the coffee roasters are aware of the exact amount (as per the delivery note of the waste management company). If the residues are not disposed of as residual or organic waste, they can be sold and used for energy production. We found that two companies in our sample used silverskins for energy production. None of the respondents used or sold the residues for other purposes (e.g., pharmaceutical, cosmetic, ingredient in foods, fertilizer in private gardens).

While material uses of residues can be difficult, it is not banned. For example, the expert from a recycling company explained that coffee residues combined with other substances can be approved for material use (e.g. plastics) if they are approved on an EU Food Contact list, which specifies which substances may be combined with plastic and food (e.g. coffee). With the exception of flavored instant coffee and coffee extract, coffee is not included on this list (Article 18(1)(a) of Regulation (EC) No 1333/2008). However, if a material in combination with another substance is approved, it can be used across the European Union (Expert Interview, lines 130–134).

The respondents identified several important reasons for the failure to use residues. First, there are often unclear costs and benefits for using/reselling the residues. For example, one respondent described a failed initiative to promote the usage of silverskins for potting soil in collaboration with a public authority, which failed due to cost reasons (ID 15). Second, perishability poses a challenge and requires efficient storage systems to prevent mold. For example, one respondent described an idea to give the waste to feed companies, but they struggled with storage and potential contamination. Third, there can be issues with separating residues. One technological solution to separation is the pellet mill, which is attached to the roasting machines and directly presses silverskins after the beans have been roasted. The respondents had mixed experiences with this technology. While one found it to be useful in facilitating silverskin collection for a local farmer, another respondent argued that it entailed high maintenance costs. Specifically, silverskins are not easy to “pelletize” because they have a very low moisture level, which can make it very dangerous and lead to fires or explosions (ID 18). Fourth,



*Note:* \*No residues are currently sold as by-products

**Fig. 3** Streams for waste from coffee roasting

respondents explained that complicated tax rules have made it difficult to sell residues as by-products. Finally, although several respondents were members of sustainability certification organizations, they claimed that these organizations offered very little guidance on how to use residues.

### Perceptions of Residue Usage

We identify three perspectives related to the knowledge and usage of residues from coffee processing. A plot of the z-scores and the list of statements can be found in the Appendix (Table 4 and Fig. 5). Table 2 shows a summary of the perspectives. The three perspectives

**Table 2** Three perspectives about residue usage among coffee roasters

	Perspective 1	Perspective 2	Perspective 3
Name	Residue pioneers	Exclusive roast utilizers (limited users)	Conventional roasters (traditional)
Number of significantly loading responses	5	4	3
IDs	2, 8, 9, 13, 14	1, 6, 12, 15	3, 5, 18
Eigenvalues	3.67	3.01	2.29
Percentage of explained variance	24.49	20.04	15.28
Average residue usage score (max = 4)	1.8	1.75	1.67

explain 59.81% of the variance in opinions and 12 of the roasters are significantly loading on one of the three perspectives. Each perspective corresponds to the components extracted from the principal component analysis.

The first perspective can be conceptualized as “residue pioneers”. This group has already established business streams for silverskins and coffee grounds (e.g. energy) and support the idea of using coffee grounds, beans, and silverskin for various purposes. However, they do not seem interested in relying on recyclers for handling coffee by-products or seeking economic support from the state or the European Union in the form of subsidies. The firms significantly loading on this perspective are mainly small/medium, with one large and one micro firm.

The second perspective can be conceptualized as “exclusive roast utilizers”. This group is also interested in exploring potential business opportunities related to coffee grounds, beans, and silverskin and recognize the value of these residues and their potential for generating revenue. However, this group specifically highlights their lack of interest in exploring other by-products produced during the roasting process or using coffee by-products in other industries like pharmaceuticals, cosmetics, food, or agriculture. The firms loading on this perspective are only micro (2) and small/medium (2).

The third perspective can be conceptualized as “conventional roasters”. They have a traditional approach to using residues with limited current application of residue usage, but are interested in understanding the quantities of residues produced and are open to exploring potential uses. The firms loading on this perspective are mainly small/medium (1) and large (2).

## The Role of Coffee Actors in the Bioeconomy

To understand how underlying social dynamics within a network may affect innovation potential in the bioeconomy, we map the network of information flows and communication between actors. Table 3 shows that the full social network: 43 nodes, including 17 coffee roasters. In terms of degree centrality (central or influential role), public waste management has the highest score (19), followed by state actors such as the customs and tax offices. As the degree centrality captures the count of connections (edges of each node), it can be a simple measure of popularity and well-connected nodes that can connect with the wider network. In terms of betweenness centrality, we see that roasters have the highest scores (IDs 12, 11). This information is helpful to identify intermediaries or communication hubs, who may influence the flow within a system. In terms of non-roaster respondents, other businesses and public waste management have the highest betweenness centrality. In terms of closeness centrality, two specific coffee roasters (ID16, ID17) are the closest to other nodes (i.e. lowest

**Table 3** Overview of network centrality measures from the social network analysis

Node	Name	Degree	Betweenness	Closeness	Eigenvector
1	coffee15	11	17.309	0.011	0.548
2	coffee16	1	0.000	0.006	0.003
3	coffee17	1	0.000	0.008	0.054
4	coffee18	15	34.963	0.012	0.721
5	coffee3	13	28.504	0.011	0.735
6	coffee8	10	11.961	0.011	0.536
7	coffee9	14	88.108	0.012	0.608
8	coffee13	8	14.580	0.010	0.412
9	coffee6	10	83.740	0.011	0.526
10	coffee1	15	27.528	0.012	0.763
11	coffee12	17	94.450	0.013	0.776
12	coffee5	13	55.961	0.012	0.629
13	coffee19	15	25.587	0.012	0.788
14	coffee2	15	39.328	0.012	0.748
15	coffee11	18	94.791	0.013	0.799
16	coffee14	15	48.565	0.012	0.653
17	coffee20	10	13.626	0.011	0.500
18	Speciality Roasters	14	37.525	0.014	0.713
19	Private Waste Management	6	3.928	0.010	0.319
20	Coffee Producers	12	24.748	0.012	0.650
21	Importers	15	42.841	0.014	0.764
22	Consumers	13	32.746	0.013	0.674
23	Customs	15	42.841	0.014	0.764
24	Certification	14	36.258	0.014	0.732
25	Public Waste Management	19	59.915	0.014	1.000
26	Tax Office	15	42.841	0.014	0.764
27	Research	8	8.659	0.011	0.428
28	Food retailers	4	1.319	0.009	0.175
29	Regional farmers	2	41.000	0.008	0.042
30	Other businesses	13	62.035	0.012	0.691
31	Coffee Association	10	14.250	0.011	0.556
32	Gastronomy	11	22.082	0.012	0.600
33	Logistics	2	0.212	0.008	0.105
34	Charities	4	1.391	0.009	0.228
35	Hotels	2	0.697	0.009	0.110
36	Student initiatives	1	0.000	0.008	0.048
37	Big Ten	9	11.798	0.011	0.474
38	Facebook Group	2	0.403	0.008	0.093
39	Nurseries	1	0.000	0.008	0.061
40	Pharma, cosmetic, agribusinesses	4	2.016	0.010	0.233
41	World Coffee Organization	1	0.000	0.008	0.049
42	Packaging	3	0.496	0.009	0.166
43	International organizations	1	0.000	0.008	0.063

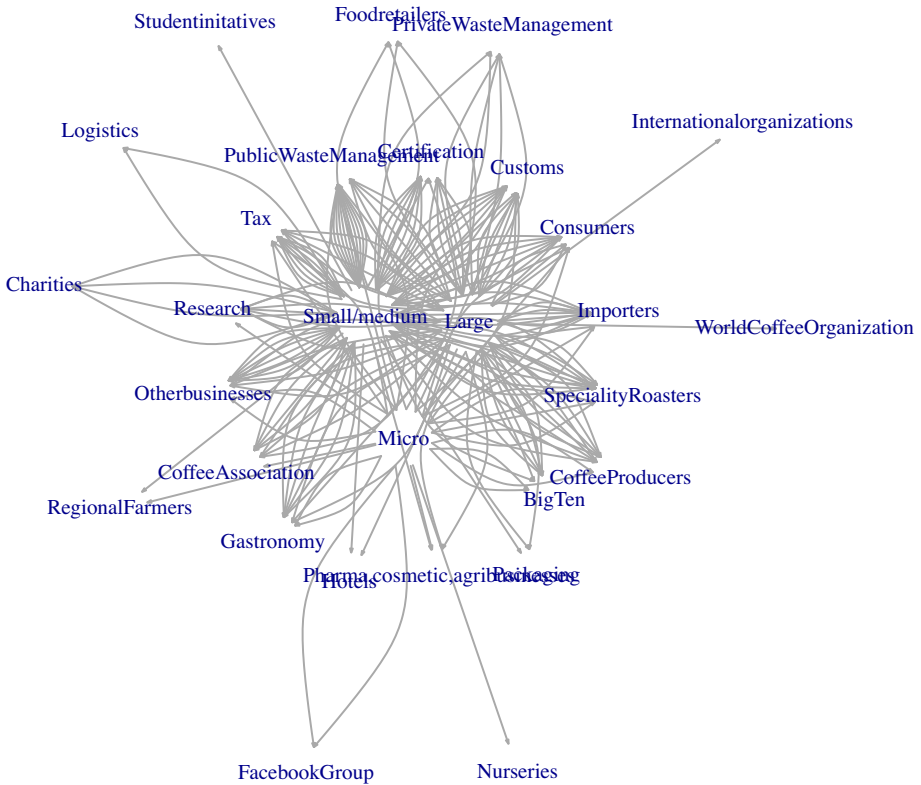
closeness centrality), which indicates potential for information diffusion and the ability to reach diverse areas of the network. In terms of eigenvector centrality, which is a measure of the node's centrality and its connections, public waste management and one roaster (ID 11) rank highest. This analysis can be useful for understanding how structural conditions may influence innovations and development processes [55]. In this case, we find that individual coffee roasters play an important role in connecting different actors. Thus, they may need to play a greater role in the diffusion of information about innovations.

In the social network analysis, we find that the general connections network has the highest value of graph density (0.172) followed by the bioeconomy network (0.087) and sustainability network (0.072). The graph density is an indication of how many ties between actors exist relative to how many ties between these individual actors may be possible (ranging from 0 to 1). Thus, we can compare that general communication between actors is higher than communication limited to specific topics (i.e. bioeconomy or sustainability). At networks with values closer to one are considered dense and cohesive, we can conclude that these networks are relatively incohesive. Table 3 shows a comparison of the betweenness, closeness and eigenvector centrality across the three networks.

Figure 4 shows the simplified social network. Each line between the roasters and other actors represents an individual coffee firm connection. For this network, we replaced all coffee roasters with their size category (micro, small/medium and large) to demonstrate how the roasters are linked with other actors. We also generate this simplified network because the coffee roasters did not disclose links with other roasting firms for privacy reasons. However, it is important to note that this depiction results in roasters as the central actors, although the full social network shows that government offices (e.g. public waste management, tax and customs) occupy the central roles. In this figure, the second ring of actors are most important to roasters; especially public waste managers, tax offices, and customs offices. The third ring of actors represent those least central in the network (e.g. student initiatives, charities, etc.).

To complement the network analysis, in the interviews, we find that coffee roasters do not consider themselves as the appropriate pioneering actors to encourage the adoption of bioeconomy practices in the German coffee sector. Rather, they emphasized the role that adjacent actors can play (e.g. pharmaceutical or cosmetic companies) that may buy the collected coffee residues. However, only a few respondents knew which industries would be interested in buying their residues. Thus, the majority of respondents believed that the German state and the European Union should take an important role as a regulator who fosters innovation. For example, respondents argued that the state could regulate by-products and incentivize adjacent industries (e.g. pharmaceuticals) to engage with the coffee roasters and buy their residues.

The topic of sustainability for coffee was of utmost importance. The majority of respondents reported a corporate sustainability strategy, which incorporated both social and ecological components. However, these sustainability strategies primarily focus on the upstream value chain including cultivation and farmer employment practices. Respondents referred to three outside certifications including B-Corp, Rainforest Alliance/UTZ and the German organic label (Bio Siegel) and noted that none specifically refer to by-products. In terms of the upstream value chain, several respondents mentioned that by-product usage was part of their sustainability strategy. For example, one respondent referred a project with a roasting plant in Brazil, which uses its residues and is committed to circular economy practices (ID 5). Another company has emphasized the use of residues (e.g. pulp, honey-water, processed water) in producer countries and cited their efforts to increase farmer income possibilities and promote agro-ecological farming practices (ID 11).



**Fig. 4** German coffee roasting network (simplified to show size of roasting firms)

At the same time, respondents believed that the state did not appropriately foster bioeconomy initiatives. For example, several participants mentioned the unsustainable practices incentivized by the coffee tax refund for burnt coffee batches. In the case of burned batches, companies can reclaim the coffee tax if the coffee or coffee-containing goods were originally taxed. Respondents described the situation in which, in order to receive a refund for the previously paid coffee taxes, the state (in the role of the customs authority) may contaminate burnt batches to render them unsellable (ID8, ID11, ID9). This was viewed critically as using these residues for biogas generation would not qualify for a tax refund.

## Discussion

In our exploratory study about bioeconomy initiatives in the German coffee sector, we focus on three key topics: perceptions of using coffee residues, the role of different actors in supporting the transition and barriers to the development of the bioeconomy in the German coffee roasting industry.

The four barriers relate to state regulations, contact with adjacent industries and sustainability attitudes. One barrier to the adoption of bioeconomy initiatives in the coffee value chain is related to the structure of the coffee social network. According to the roasters, the state

actors occupy a central role within the bioeconomy network and there are limited means for other actors to exert their influence or initiate bioeconomy projects. Additionally, non-coffee firm actors (e.g. pharmaceutical, cosmetic industries) are viewed as influential for the adoption of bioeconomy initiatives, but are weakly linked to coffee roasters, who would be the main suppliers of residual biomass. Thus, it is critical that non-firm actors (specifically state actors) lead efforts as they determine the economic and political conditions for bioeconomy initiatives.

This is closely related to the second barrier, which is related to regulations for residues at state, federal and European levels. Although the German government has made efforts to foster bioeconomy by classifying most agricultural waste as residues or by-products (rather than as waste) in the Recycling Management Act (de: Kreislaufwirtschaftsgesetz- KrWG), our findings show that the legal specification of coffee by-products is unclear. In our study, most participants viewed the residues from coffee processing as waste and more importantly, disposed of them as organic waste or residual waste. Only a minority of respondents sold residues to waste disposal companies as waste products to generate biogas. Another example of challenges related to residue usage for energy generation is related to the bureaucratic implications of resale. Specifically, we find that there are different taxation regulations of each federal state. This must be simplified as only large firms had the administrative requirements to manage residue resale.

This aligns with previous findings that found that a lack of EU authorization for by-products use for cascading represents the biggest obstacle for pharmaceutical and agricultural use [56]. Thus, bioeconomy initiatives in the coffee value chain require political initiatives to include coffee residues on the food contact list and the development of a comprehensive, federal regulatory framework that supports streams of material use (in addition to existing energy generation). As this could potentially be the case for other value chains in Germany, additional research is required. Further, if there is evidence that legislation is also unclear for the use of residues from other value chains, policymakers would be more willing to adjust the regulatory framework. The third barrier is related to the economies of scale and the logistics of gathering, transporting and using residues. The resale of residues requires significant administrative capacities, which means that only large coffee companies would be capable of coordinating residue resale. Further, residues (e.g. silverskins) are perishable and can only be stored for a limited time. Thus, they require an efficient infrastructure and storage system to prevent mold and contamination. However, it is likely that only larger companies would have sufficient quantities of residues to render these systems profitable.

Finally, the fourth barrier is related to differing viewpoints and visions about the circular economy and sustainability in the coffee sector. There are two aspects here: (i) critical views of circular nature of residues for energy generation and (ii) the focus on the upstream value chain in certification. In the public discourse, there have been critical views as to whether residue usage for energy generation should be considered as part of the circular economy. For example, the environmental NGO Greenpeace has declared that only material use of residues is part of the circular economy. This strongly contrasts with the only existing bioeconomy initiative currently used in the coffee sector: energy generation.

In a broader sense, the issue of the bioeconomy is closely related but not synonymous to discussions of sustainability in the coffee value chain. For example, while many respondents focused on social and ecological sustainability in producer countries within the upstream value chain (e.g. fair trade, organic labels), discussions of sustainability in the downstream chain are focused primarily on packaging, but do not represent a core concern. Thus, the downstream activities in the value chain must also be incorporated into sustainability discussion within the coffee chain.



## Conclusions

As the underlying power dynamics in social network structures can affect innovation potential, we focus on a case study from the German coffee value chain to understand the cascading potential of coffee residues based on the perceptions of key actors and the structure of the social network. Specifically, we investigate perceptions of the economic feasibility of using coffee residues, analyze how actors such as roasters can support bioeconomy initiatives in coffee value chain and identify policy barriers to the development of the bioeconomy in the German coffee roasting industry.

We find that in terms of residue collection, silverskin is the most collected residue, followed by defective beans and spent coffee grounds. Awareness of residue amounts does not appear to be a barrier for usage as the majority of participants are aware of the actual accumulated generated amount of different residues. In terms of current streams of residue usage, 40% of participants from all companies regardless of size dispose of their silverskins as waste. The residues (i.e. silverskin) are primarily treated as organic waste, which means it is either disposed of by waste facilities or given away for free (e.g. to farmers for biogas).

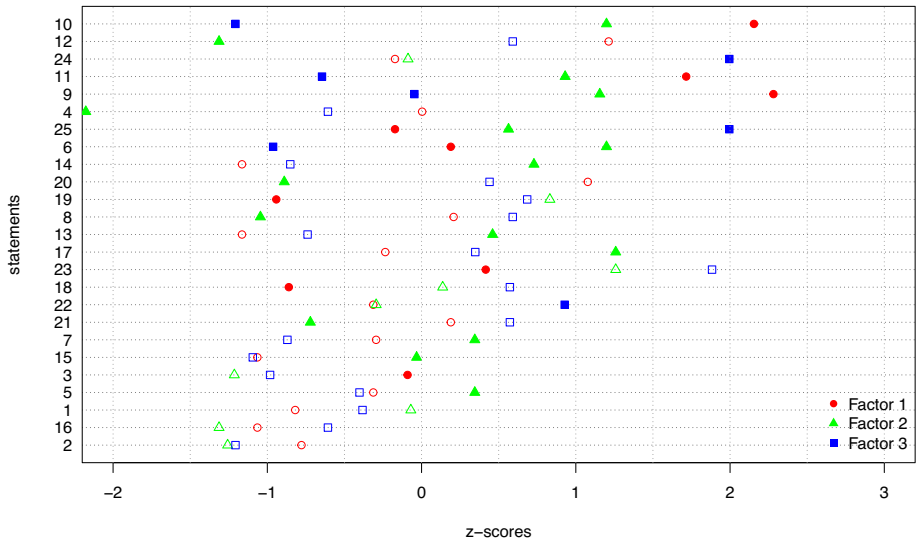
Additionally, we identify three perspectives related to residue valorization: (i) residue pioneers, (ii) exclusive roast utilizers and (iii) conventional roasters. These represent different attitudes toward residue usage among coffee roasters. While residue pioneers demonstrate willingness to explore other channels of residue usage, exclusive roaster utilizers only focus on exploring potential business opportunities related to coffee grounds, beans, and silverskin in the energy sector. Finally, conventional roasters are not yet pursuing opportunities associated with residues from coffee roasting due to lack of knowledge or administration/logistical capacities.

In our social network analysis, we find that public waste managers have the highest degree and eigenvector centrality, specific coffee roasters have the lowest closeness centrality (closest to other actors) and specific roasters have the highest betweenness centrality (i.e. intermediaries).

To support bioeconomy initiatives in the coffee value chain, policymakers must address the four main barriers related to the structure of the coffee network, inconsistencies in federal waste regulations, economies of scale, and visions of sustainability. Specifically, there are inconsistencies between German federal states in terms of waste regulations, which has made it difficult to use residues (e.g., coffee silverskins) for material usage. Instead, coffee residues are used primarily for energy use. Further, the resale of residues requires significant administrative capacities, which means that only large coffee companies are capable of coordinating residue resale.

As we focused on residues from downstream activities in the coffee value chain, our study could be complemented by studies on the upstream side of the value chain (e.g., green coffee beans; role of producers and traders) as well as the demand-side of residues (e.g. buyers of biomass, adjacent industries). From a practical perspective, future research should investigate the specific requirements within German and European waste regulations to understand other legal frameworks for handling coffee and other food industry residues in the context of the EU Waste Directive. From the technical perspective, further research is needed to develop specific technologies to prevent mold and contamination for residues from the food industry at different scales. From the theoretical perspective, research is needed on additional policy and regulatory tools for fostering the adoption of innovations in the transition to a sustainable bioeconomy.

## Appendix



**Fig. 5** Overview of z-scores of the three perspectives. Note: the z-scores represent score for each of the three factors (perspectives). For example, the figure shows that for statement 10, perspective 3 highly disagrees whereas perspectives 1 and 2 highly agree. The shape is filled in if it is significantly different from the other groups

**Table 4** List of statements about residue usage perceptions. Note: These statements were pre-defined by the researcher and the respondents rated them on a Likert scale according to how much they agreed/disagree with each statement (scale of 1–5). The number of the statement corresponds to the statements represented in Fig. 5

No	Category	Statement
1	Knowledge	Silverskin: Our company knows how many (i.e., in kg) by-products are produced during the roasting process
2	Knowledge	Beans: Our company knows how many (i.e., in kg) by-products are produced during the roasting process
3	Knowledge	Grounds: Our company knows how many (i.e., in kg) by-products are produced during the roasting process
4	Knowledge	Other: Our company knows how many (i.e., in kg) by-products are produced during the roasting process
5	Potential Business	Silverskin: Coffee by-products represent a potential business area for our company/coffee roaster
6	Potential Business	Beans: Coffee by-products represent a potential business area for our company/coffee roaster
7	Potential Business	Grounds: Coffee by-products represent a potential business area for our company/coffee roaster
8	Potential Business	Other: Coffee by-products represent a potential business area for our company/coffee roaster
9	Current Business	Silverskin: Coffee by-products are already a business for our company/coffee roaster
10	Current Business	Grounds: Coffee by-products are already a business for our company/coffee roaster
11	Current Business	Beans: Coffee by-products are already a business for our company/coffee roaster
12	Current Business	Other: Coffee by-products are already a business for our company/coffee roaster
13	Need information	Silverskin: Our company would like to know whether it would be profitable to sell our by-products
14	Need information	Beans: Our company would like to know whether it would be profitable to sell our by-products
15	Need information	Grounds: Our company would like to know whether it would be profitable to sell our by-products
16	Need information	Other: Our company would like to know whether it would be profitable to sell our by-products
17	Laws	It would make sense for the state to standardize the resale of coffee by-products by law, as it would make it easier
18	Laws	For our company, economic support from the state/EU (e.g. subsidies) would be an important impetus for the resale of coffee by-products
19	Other actors usage	Our company is aware of recyclers that recycle coffee by-products
20	Other actors usage	It is lucrative for our company that coffee by-products are to be used to generate energy (e.g. biogas)
21	Other actors usage	It is lucrative for our company that coffee by-products are or should be used in the pharmaceutical, cosmetics, food and agricultural industries, among others
22	Administration	Our company has the administrative capacity (e.g. staff) to handle the resale of by-products
23	Administration	Our company has sufficient facilities and capacity to store coffee by-products
24	Administration	Our company has the logistical means to transport the coffee by-products to a recycling facility
25	Administration	Our company has the financial means to store and ship the coffee by-products to a recycling facility

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## Declarations

**Conflict of Interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

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