Food Landscape Matrix: A Structured Approach to Mapping Food Chains for Crisis Preparedness

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ABSTRACT

Recent crises have revealed vulnerabilities in Germany's food supply system, emphasizing the need for effective crisis management which in turn depends on system overview. Emergency crisis managers face challenges in understanding and assessing the complex, interconnected food supply system. Existing value chain mapping methods analyze individual commodities but cannot provide a comprehensive overview of multiple commodities. The Food Landscape Matrix was developed as an innovative mapping framework that identifies key actors, services, inputs, outputs, and products from primary production to final consumption. Twelve Landscapes have been created using secondary data with validation by key stakeholders. The matrix's flexible structure allows varying levels of detail while maintaining a sectoral overview, enhancing transparency and navigation. This aggregated approach enables emergency managers and stakeholders to better assess interdependencies, vulnerabilities, and cascading effects, ultimately supporting crisis preparedness in the food sector.

Keywords

Food Supply Chain, Value Chain Mapping, Food System, Crisis Management, Food Security

INTRODUCTION

Natural disasters, economic crises, pandemics, and military conflicts are extreme events that can affect food systems at national and international levels. Recent crises like COVID-19 or the Ukraine-Russia war demonstrate how quickly disruptions in production, logistics, and trade can cascade across supply chains (Aday & Aday, 2020; Engemann & Jafari, 2022; Laborde et al., 2020). These developments have intensified the need for robust approaches to food system resilience and crisis preparedness.

Food is considered a critical infrastructure in Germany (BBK, 2020). To ensure food security for the population, the maintenance of operational food supply and trade flows is of high relevance (European Commission, 2025). This is particularly important in highly interconnected food systems where dependencies between actors, resources, and infrastructure increase systematic vulnerability and the risk of local disruptions escalating into broader crises. COVID-19 and the Ukraine-Russia war highlighted vulnerabilities and raised questions about Germany's emergency food preparedness, though in both cases supplies remained stable (Jagtap et al., 2022; Liu, 2020; Nakamura et al., 2024). Several ongoing and finished research projects are investigating solutions for German food security, including emergency food preparedness (Menski, 2016), decision-support-tools for modeling food flows (Balster et al., 2016), emergency food stocks (Eberhardt et al., 2024), emergency logistics and collaboration (NOLAN, n.d.), and development of cooperation and decision-making systems (ML NI, 2024).

The Food Security and Emergency Preparedness Act in Germany formally outlines responsibilities and authorizations of public institutions related to food production and supply during severe crises (ESVG, 2017). A central challenge for public authorities responsible for emergency food preparedness is responding effectively to potential disruptions in the food supply. Food supply chains span from primary production to final consumption, linking numerous actors, services and resource flows across sectors. Assessing their interdependencies, vulnerabilities, and cascading effects requires a structured and system-oriented knowledge of food supply chains.

Existing value chain mapping methods, like value chain analysis, are well suited for analyzing individual commodities in detail and identifying specific stakeholders and flows (Kaplinsky & Morris, 2001). However, due to their granularity, they are limited in their ability to support a practical overview of multiple commodities or food groups. As a result, they offer limited support for strategic decision-making in crisis situations where a cross-commodity overview is required.

This paper introduces a qualitative framework for mapping food chain actors and activities from production to consumption at an aggregate level. The developed Food Landscape Matrix applies supply chain logic and examines physical flows, resembling physical input-output analysis (Yakovleva & Flynn, 2004). The framework is applied to twelve food groups, resulting in Food Landscapes which are based on secondary literature sources and validated by stakeholders of the given commodity. This approach integrates value chain mapping with participatory methods, engaging relevant stakeholders to develop the matrix structure and validate the Food Landscapes.

A limitation of conventional food chain models is their neglect of external factors (Sobal et al., 1998). Incorporating supplementary information such as policies, previous experiences and challenges encountered by the actors allows the Food Landscape Matrix to extend beyond the analysis of sequential material flows. Using the matrix across a wide range of commodities enables mapping of interactions between multiple food chains.

This study contributes to value chain research by establishing a matrix for qualitative, aggregate-level description of supply chains. The Food Landscapes of different commodities offer a foundation for practitioners and public authorities in emergency food preparedness to better understand the German food system, highlighting actors, services, products, inputs and outputs. By mapping actor connections and dependencies between actors and resources across the entire value chain, crisis managers are equipped with the systematic understanding necessary to rapidly and effectively assess the food system under time-critical conditions, thereby supporting the identification of vulnerabilities, the improvement of system resilience, and the development of informed crisis response strategies.

The following section first introduces the relevant definitions and reviews existing literature before presenting the framework and results. The paper concludes with a critical discussion and outlook.

SYSTEMS DEFINITION AND LITERATURE

Food Systems

Food systems are described as "all the elements and activities related to the production, aggregation, processing, distribution, consumption, and disposal of food waste, and the outcomes of these activities" (HLPE, 2017, p. 23). Engaged in these activities are a range of people (actors) who, in turn, are influenced by elements such as environment, technology and innovation, policy, economics and socio-cultural drivers (HLPE, 2017; Zurek et al., 2022). Outcomes of the food system can be categorized into different components: Economic and social well-being, food and nutrition security, and environmental sustainability (Zurek et al., 2022).

Food availability, a key aspect of food security, depends on functioning production, distribution and exchange mechanisms (FAO, 1996). Food security can therefore only be fulfilled by a working producer subsystem (or food supply system) which receives inputs from the environment and utilizes these materials for production, processing and distribution of foods as outputs for the consumer subsystem (Ericksen, 2008; Ingram, 2011; Sobal et al., 1998). Consequently, understanding the producer subsystem, including critical actors and activities, is essential in food system research.

Value Chains

A commonly used framework for providing an overview of stakeholders is the food chain model: It focuses on the movement of materials or objects through a series of steps, often ordered and linear (Sobal et al., 1998). (Food) Value chains are high-level models that show the journey of a product, with all stakeholders involved in production and value-adding activities (Kaplinsky & Morris, 2001).

According to Kaplinsky and Morris (2001), mapping is a key element of value chain analysis and involves a methodical investigation of the people engaged and the movement of goods through the value chain. This process takes into account the supply of inputs, production, processing, distribution, and marketing activities associated with a specific product or service (Kaplinsky & Morris, 2001). It provides a visual depiction of the essential structure and a framework for systematic chain analysis, which is used to evaluate aspects such as sustainability (Anastasiadis et al., 2020, 2024; Wesana et al., 2019) or food security (Mossie et al., 2021).

Due to its complexity, most value chain mapping studies are highly specific, focusing on one country, commodity, and/or sector. Examples include tomato, cucumber, and date in Iraq (GIZ, 2023); eggs, beef, sheep, and goat in Kenya (Alarcon et al., 2017; Onono et al., 2018); or vegetables and wine in Greece (Anastasiadis et al., 2020, 2024; Anastasiadis & Alebaki, 2021). The mapping method has also been employed in more complex contexts, such as the analysis of food supply networks, actors and institutions within the United Kingdom, focusing on fruit and vegetables, meat, dairy and staples (Kumar et al., 2013). The method often involves a two-stage approach: literature review and preliminary mapping followed by stakeholder interviews for validation (Liddy et al., 2023). Used sources include industry reports, case studies, governmental sources, and gray literature (Anastasiadis et al., 2020, 2024; Anastasiadis & Alebaki, 2021; Kumar et al., 2013).

To identify different perspectives and problems, participatory mapping can be used. In this method relevant stakeholders participate in the mapping process through focus groups, workshops, or interviews to pinpoint a system's key characteristics, such as actors, their activities, and relationships (Alarcon et al., 2017; Burgoa et al., 2019). However, the complexity of the food system poses challenges for the participatory approach, notably in identifying and filtering the most relevant information (Ghadiri et al., 2024).

METHOD

The Food Landscape Matrix showcases the structure, dynamics, and interdependencies of food chains on a sectoral level, connecting to the functional analysis of a (food) value chain. It shows both vertical and horizontal connections between food chains. It provides a qualitative description of supply chains at an aggregate level, using the logic of input-output flows, enriched with details relevant to potential vulnerabilities. The Food Landscape Matrix highlights actors, services, inputs, outputs, and (by)products across six value chain stages illustrating how they connect, even across different food items and commodity groups, allowing the development of an interconnected network.

The matrix structure is based on six central value chain stages along a food chain (i.e., production/cultivation, collection, processing, further processing, distribution and sales, and final consumption; see **Figure 1**, left column). This structure can be applied to any food item, meaning single food products (e.g. sugar beets) or commodity group (e.g. grains including wheat, rye, and others).

The resulting Landscape for a food item or commodity is filled with content boxes about products, byproducts, services, and groups of actors/products/purposes, arranged in four columns: the value chain with products and services, other inputs, other outputs, and additional important information. This structure provides a clear overview of actor relationships, material flows, and systematic dependencies. A separate booklet offers more detailed information about a given commodity. The following subsections explain the matrix structure in more detail.

Six Value Chain Stages Along the Food Chain

The Food Landscape Matrix is organized into six value chain stages (see **Figure 1**, left column) and can be applied to any food commodity (e.g., grains, milk and dairy products, beef, and fruits and vegetables) for a specific region or country. The first step is always the production (or cultivation) of the analyzed food item; for example, a farmer may grow wheat or keep livestock. The second step involves collecting and consolidating raw materials from multiple producers. Third, processing transforms these materials, such as grinding wheat into flour. The fourth step is further processing, where materials like flour are transformed into new products, such as bread, while byproducts like feed meals are generated for agricultural use. Fifth, distribution and sales move products through wholesale and retail channels. The final step is consumption, where end customers purchase and use the products.

A key methodological choice is where to begin the value chain analysis. In this approach, mapping starts at the production or cultivation stage to prevent duplication across different Food Landscapes. Some value chain stages provide outputs that serve as inputs to other Landscapes, so their upstream processes are not repeated within each Landscape. To capture real-world complexity, multiple Landscapes should be developed and considered as interlinked rather than as isolated representations. Thus, the present Food Landscape Matrix serves as a structural proposal for visualizing commodity-specific food value chains, which can be expanded to include further upstream value chain stages and processes when necessary.

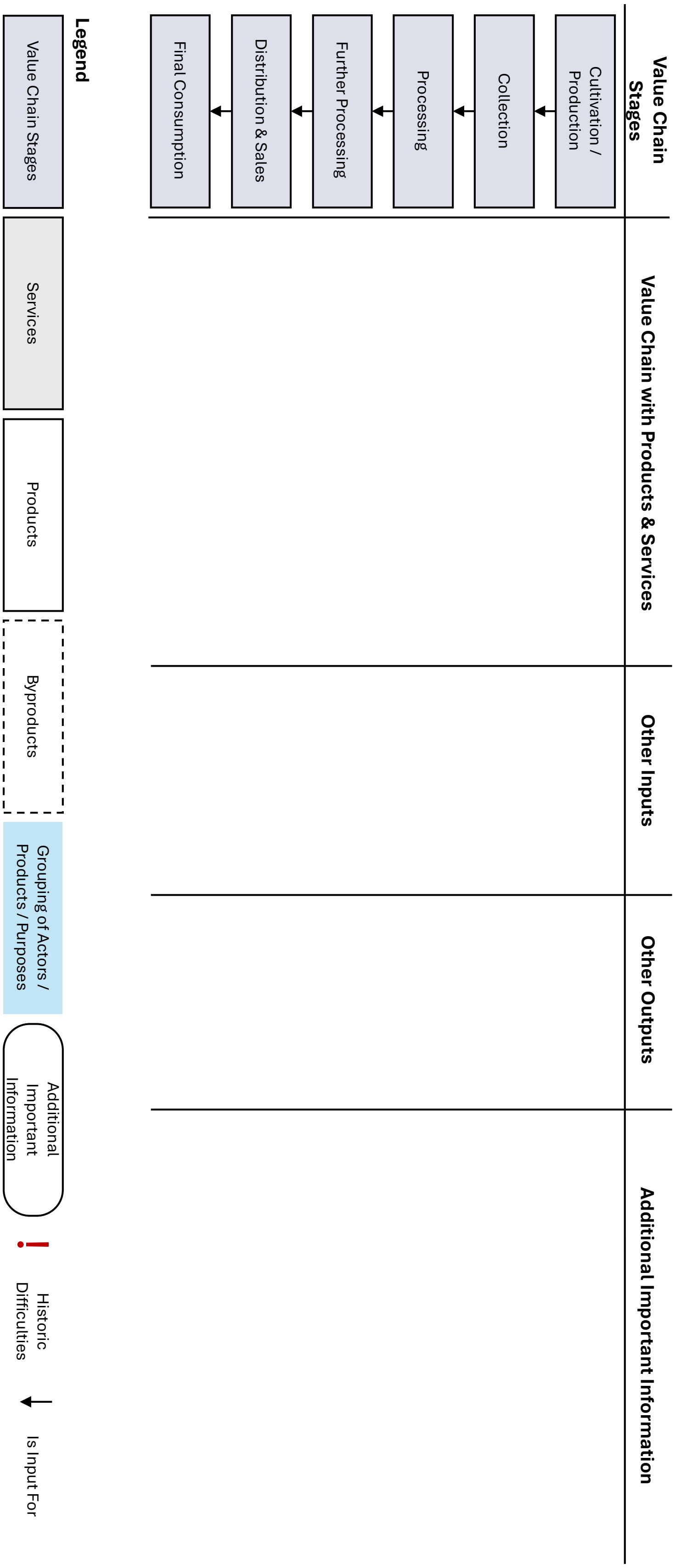

Figure 1. Food Landscape Matrix Structure

Column Categories

Within each value chain stage, information is organized into four columns: (1) products and services that are central to the commodity's value chain, (2) other inputs, referring to materials or services entering from upstream or parallel sectors, (3) other outputs, representing flows that move out to other chains or sectors, and (4) additional important information, providing relevant context or sector-specific qualitative insights. This structure helps map the connections and dependencies between various actors and resources, enabling an aggregated yet nuanced overview of the entire value chain.

Content Categories

The matrix's content boxes fall into five categories: services, products, byproducts, groups of actors/products/purposes, and additional important information. A red exclamation mark indicates past shortages, problems or vulnerabilities, such as unavailability of auxiliary materials, employee movement restrictions during COVID-19, or a limited number of suppliers. Examples of these categories are illustrated in the legend of **Figure 1**.

Services support the value chain, directly or indirectly without physically handling the product. Products and byproducts are outcomes of a value chain stage, where byproducts emerge alongside the "main" product; for example, buttermilk as a byproduct of butter production (BLE, 2024b). Byproducts can serve as inputs at later stages of a value chain. Groups of actors, products, or purposes cluster related boxes at the same step, either by commodity family or reference category. Boxes with additional important information provide context and sector-specific information and link to the accompanying booklet with more details.

Content for the five categories is sourced from sectoral literature, including official government websites (e.g., the Federal Office for Agriculture, Food and Regional Identity in Germany, BMLEH, formerly BMEL), food commodity associations, and commodity-specific expert companies in the German food sector.

Matrix Structure

The matrix structure presents six value chain stages, four column categories, and the possible content categories that fill the matrix with information (see **Figure 1**). Arrows between boxes indicate that the content box serves as input to the subsequent box. For example, molasses, a byproduct of sugar production, serves as an input for yeast and alcohol production.

The five content categories are utilized in varying quantities across different Landscapes. Content boxes within the same value chain stage may appear simultaneously, as in the case of storage and agricultural trade of producer associations for grain. However, not every content box is required for each product. For instance, some grains proceed directly to the processing stage without storage, allowing certain boxes to be omitted.

Logistics services are essential at every stage of the value chain and are therefore referenced in a general manner within the matrix: "Logistics services operate within and connect stages of the value chain." Similarly, imports and exports are not represented as separate content boxes but are instead detailed in the Food Landscape Booklet.

Food Landscape Booklet

A detailed booklet accompanies each Food Landscape Matrix, providing commodity-specific explanations that cannot be included in the visual overview. This separation serves two purposes: it preserves the clarity and navigability of the matrix by preventing information overload and ensures that relevant contextual details remain accessible. For example, crop rotation is documented in the booklet rather than the matrix itself.

The Food Landscape Booklet is organized according to the six value chain stages of the Food Landscape Matrix and elaborates on the information presented in the matrix's content boxes. While the matrix offers a rapid visual overview for situational awareness during crises, the booklet provides comprehensive and nuanced information to support informed decision-making.

Validation

The Food Landscape Matrix has been applied to twelve food items and commodity groups and is currently undergoing external validation by expert companies and associations through a two-stage process. In the first stage, the Landscapes and accompanying booklets were mailed to the research project KRITIS-ENV's associated partners (companies in the food sector from relevant food groups), followed by a workshop to collect general structural feedback. Integrating auxiliary and operating materials was considered important, as was including specific crisis experiences linked to solutions from the regulatory context.

In the second stage, seven 60-minute expert interviews were conducted via Microsoft Teams (see **Table 1**). Prior to each session, participants received the relevant Food Landscape(s) and key discussion questions covering:

1. Additive and auxiliary materials used in production
2. Critical supply chain vulnerabilities and past experiences
3. Interactions with public authorities during crisis situations

The validation process is particularly valuable for capturing industry-specific knowledge such as reliance on additive materials at specific supply chain stages that is rarely publicly available but critically relevant during crisis.

Table 1. List of Interviewees for Landscape Validation

Company	Food Landscape	Value Chain Stage	Company Description	Role of Interviewed Expert(s)
1	Wheat	Further Processing	Industrial Bakery	1. Head of Finance & Controlling 2. Head of Procurement
2	Sugar Beet	Processing	Sugar Factory	1. Head of Risk Management 2. Lead Insurance & BCM
3	Apple	Vegetable Collection	Producer Association	Managing Director
4	Milk and Dairy Products	Milk Collection, Processing, Further Processing	Dairy Company	Head of Occupational Safety and Environment
5	Beef & Pork	Processing, Further Processing	Meat Producer & Retailer	Authorized Signatory / Animal Welfare, Research & Public Relations
6	Beef & Pork	Processing, Further Processing	Meat Producer & Retailer	Authorized Signatory
7	Poultry	Livestock Farming, Processing, Further Processing	Poultry Meat Producer	Managing Director

RESULTS

The applied Food Landscapes illustrate food value chains for several commodities. This section explains commodity selection, matrix application, and results, using the Grain Food Landscape as the main example. Further Food Landscapes for potatoes, onions, carrots, oilseeds, sugar beets, apples, poultry, eggs, pork, beef, and milk and dairy products are detailed in the Appendix.

Food Commodity Selection

The food commodity groups were selected based on the highest consumption volumes and their status as staple foods in Germany. To determine the highest consumption volumes, the BMLEH's Supply Balances (BLE, n.d.-a) for food products were consulted. Since the Food Landscapes are designed for Germany, the national relevance of food commodities was also a decisive factor. For example, sugar beets were chosen over sugarcane due to their importance in Germany and the European Union (BLE, 2024d; Bundesinformationszentrum Landwirtschaft, 2024).

Application of the Food Landscape Matrix

After choosing a food item, the content is researched through secondary literature, including official government websites, food commodity associations, and commodity-specific expert companies. Some sources relevant across all Food Landscapes are the BMLEH, the Federal Office for Agriculture and Food (in German Bundesanstalt für Landwirtschaft und Ernährung, BLE), the German Farmers' Association (Deutscher Bauernverband, DBV), the food commodity profiles from the Thünen Institute, and the Chambers of Agriculture. Additionally, research on food waste and losses, such as Meyer et al. (2018), also provides relevant information for several Food Landscapes.

For commodity-specific sources, the food items' specific associations are of great importance, for example, the Umbrella Association of North German Sugar Beet Growers e.V. (Dachverband Norddeutscher Zuckerrübenanbauer e.V.) and the Association of German Mills e.V. (Verband Deutscher Mühlen e.V.) for sugar beets and grain, respectively. Such associations exist for nearly every commodity group.

Food Landscape: Grain

To illustrate the application of the matrix, this section explains the Food Landscape of Grain in Germany, which is shown in **Figure 2**.

Grain includes wheat, barley, rye, corn, millet, and oats, grouped together due to similar value chains (Verband Deutscher Mühlen e.V., n.d.). The matrix starts with grain cultivation, factoring in upstream inputs like seed, machinery, fertilizer, and pesticides.

In 2023, Germany's level of grain self-sufficiency was 107% (Bundesinformationszentrum Landwirtschaft, n.d.), with key importers including Poland, the Czech Republic, and France, as mentioned in the Food Landscape Booklet (Statista, 2024). After harvest, grain is collected, cleaned, sorted, and stored, often by producer associations, agricultural traders, and storage operations. Producer associations and agricultural traders can also serve as a marketing cooperative. Additionally, in Germany, there are national reserves of cereals for crisis situations operated by both private and public actors.

Processing follows, with grain converted by mills (flour, grist), hulling mills (muesli), starch and gluten manufacturers, alcohol producers, and malt manufacturers. Processing and further processing vary by use case and product. Further processing yields food and beverage products (bread, pasta, beer), while other outputs include pharmaceuticals, packaging, bioethanol, biogas, and animal feed. Grain's role in agriculture, especially animal feed, highlights its interdependence with other Food Landscapes (e.g., milk and dairy products, beef, pork, chicken, and eggs). A potential disruption in grain production can have adverse effects on these food commodities. Distribution and sales occur via wholesale, retail, bakeries, and hospitality businesses, ultimately reaching consumers.

Challenges in the grain value chain include climate-related crop failures, input supply disruptions (e.g., fertilizer from Russia/Ukraine), carbon dioxide shortages affecting shelf life and breweries, and logistical issues highlighted during COVID-19.

Overall, the Grain Landscape demonstrates how the Food Landscape Matrix can be applied in practice and how several Landscapes together form an interconnected network.

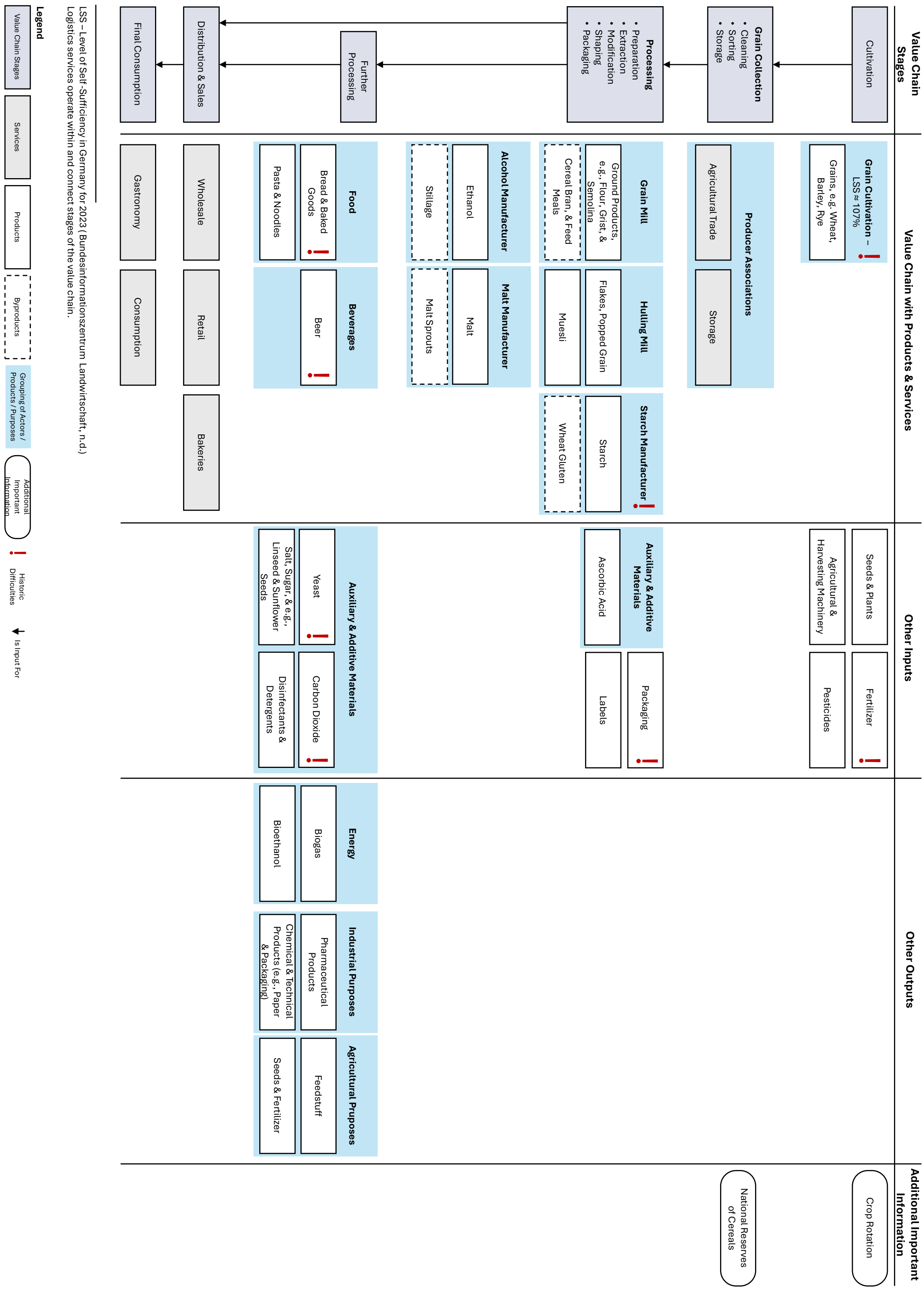

Figure 2. Grain Food Landscape

DISCUSSION

The Food Landscape Matrix presents a novel framework to visualize food commodity value chains from primary production to final consumption, mapping actors, services, (by)products, inputs, and outputs at a sectoral level to reveal interdependencies and vulnerabilities. This section explores its value, challenges, limitations, and future research directions.

Value and Applications of Food Landscape Matrix

The Food Landscape Matrix is a valuable tool particularly for public authorities and crisis managers who require rapid system-wide assessments of several food commodities. The matrix's strength lies in visualizing interdependencies and potential cascading effects across food commodities through their embedded chain structure, enabling users to quickly identify critical connection points and assess system vulnerabilities without becoming overwhelmed by operational details.

Another key advantage is the framework's versatility. The matrix can be applied across diverse food commodities, ranging from a single food product to entire food commodity groups. Furthermore, the Food Landscape Matrix adapts readily to different production systems, requiring only minor modifications, such as changing the production value chain stage to cultivation or livestock farming for vegetable or animal products, respectively, while maintaining its core value chain stage structure. This flexibility enables systematic comparison across commodities and identification of cross-sector interdependencies.

Involving industry actors in the development of the matrix and validation of the Food Landscapes has produced results that incorporate domain-specific insights about vulnerabilities, dependencies and operational realities which are otherwise not systematically captured by public authorities. The Landscapes enable the structured integration of decentralized sector knowledge into formal crisis management processes, linking community knowledge with information needs of public authorities.

Development Challenges and Solutions

The primary challenge involved maintaining an appropriate level of abstraction. Including too many operational details, such as specific machinery requirements or intricate byproduct utilization processes, would compromise the matrix's value as a structured overview, even though these details are useful and included in the supplementary Food Landscape Booklet. This problem is a recognized issue in food system mapping (Ghadiri et al., 2024).

Validation through industry experts presented similar challenges, as specialists naturally focus on operational detail and company-specific processes. Successful validation required careful communication of the Landscapes' intended scope, underscoring the importance of clearly defining the use case when developing system-wide frameworks.

Current Limitations

The abstraction level that makes the Food Landscapes valuable as overview tools simultaneously creates limitations. Sectoral aggregation omits detailed value chain variations and specific processes that may be critical for particular food items, as demonstrated by the Grain Food Landscape grouping grain together rather than considering wheat, rye, and corn separately (see **Figure 2**). While this trade-off is intentional, the Landscapes should be regarded as starting points for analysis rather than comprehensive system visualizations. This limitation is partially mitigated by the supplementary booklets, which provide more in-depth, commodity-specific information.

Depicting food items as sequential chains risks overemphasizing linear dependencies and omitting significant preceding or subsequent factors (Sobal et al., 1998). This limitation is partially addressed when multiple Food Landscapes are developed and analyzed collectively, as shown by the interdependencies between the Grain and Meat Landscapes.

The framework's focus on German value chains, legislation and market structures limits generalizability across countries and regions. While some systems may be transferable, others might require region-specific adaptation, especially regarding additive and auxiliary materials.

A further limitation is the static nature of the Food Landscape Matrix, which relies on secondary data and necessitates manual updates. Incorporating participatory data collection could address this issue (see Digital), enabling verified industry representatives to update the Landscapes and transform them into a dynamic, collaborative knowledge base.

Transport and logistics were excluded as discrete actors within the matrix because they are present at nearly every stage of the supply chain rather than at specific nodes. This is indicated by a general reference to logistical requirements within the matrix. However, in crisis scenarios where logistics infrastructure may fail, such as during fuel shortages or transport network disruptions, logistics services are underrepresented. Future versions of the matrix could more explicitly map logistical dependencies, for example, by quantitatively estimating logistical demand for each supply chain actor.

Future Research Directions

The Food Landscape Matrix offers several avenues for future research. Its combined sectoral overview and vulnerability indicators make it a valuable tool for identifying key actors and infrastructure, possibly enhancing food security assessments and crisis preparedness efforts.

Cross-validating the Food Landscapes against value chain structures from other countries would assess whether the identified supply chain stages and actor relationships are generalizable beyond Germany. Linking the Landscapes to spatial data like production sites and retail locations would further enable geographic analysis of regional supply chain risks. Additionally, mapping existing companies within the Landscapes would facilitate analysis of market concentration and identification of critical dependencies.

Currently qualitative in nature, the framework focuses on structural relationships rather than material flows. Future research could incorporate quantitative data on material or volume flows, enhancing measurability and enabling more detailed scenario analysis and capacity assessments.

Digital Implementation

While the Food Landscapes already offer a valuable knowledge base as is, digitization would enhance their usability for public authorities responsible for emergency food preparedness, supporting improved situational awareness, faster system vulnerabilities identification and more informed resource allocation during crisis.

An interactive dashboard represents the most immediately feasible implementation. Selecting an actor within the dashboard would retrieve contextual information from the booklet, thereby eliminating reliance on separate reference documents. Filter functionalities would enable users to query by food group, supply chain stage or crisis typology. Such a dashboard could further function as a collaborative platform, enabling verified industry experts to continuously update and annotate the Landscapes. This approach operationalizes citizen science principles through participatory co-production of crisis-relevant knowledge. This could prove mutually beneficial, as swift intervention by public authorities could mitigate cascading effects and help maintain supply chain functioning during crisis.

To enhance analytical capabilities during a crisis, the matrix could be embedded in a cascade effects simulation tool. Selecting a disruption at a specific supply chain point would highlight affected downstream actors and interdependencies, enabling early bottleneck identification and resource prioritization. To illustrate, a disruption in grain production would highlight cascading effects in pork, beef and poultry sectors through feed scarcity.

A more data-intensive approach would involve integrating the matrix with real-time data streams, such as import and export statistics, logistics alerts for disruptions, or regional production data. For instance, the recent shortage of fertilizer and sulfur resulting from the closure of the Strait of Hormuz has led to challenges in spring wheat fertilization and reduced crop yields (DLG e.V., 2026). By utilizing import data, potential ramifications for Germany’s wheat market and other interconnected food groups (e.g. poultry) can be evaluated. This integration would combine the static structural framework with dynamic crisis management workflows.

CONCLUSION

Food security and emergency food preparedness have become increasingly critical in the context of crises like pandemics and geopolitical conflicts. Maintaining food availability depends not only on overall production, but on the continuous functioning of entire food supply chains. This underscores the need for structured approaches that enhance situational awareness and informed decision-making by public authorities in crisis management.

This paper presents the Food Landscape Matrix as a framework for mapping food chains at a sectoral, aggregated level, focusing on key actors, services, inputs, outputs and products. This matrix has been applied to twelve food items and commodities: grain, oilseeds, potatoes, carrots, onions, sugar beets, apples, beef, milk and dairy products, pork, poultry, and eggs. The resulting Landscapes are structured to support system-level understanding while abstracting from individual firm-level processes. By helping authorities identify vulnerabilities, interdependencies and potential cascading effects, the framework supports emergency food preparedness and crisis decision-making.

Limitations of the Food Landscape Matrix include the generalized representation of food groups, a focus on a defined supply chain segment (potentially excluding relevant preceding or succeeding stages), and a German institutional and regulatory context that may constrain generalizability. Future works could extend the matrix to additional commodities, integrate spatial and material flow data, and pursue digital implementation.

In summary, this study demonstrates the value of abstracting complex food supply chains into structured, comparable Landscapes to facilitate cross-commodity analysis. By transitioning from detailed value chains to interconnected Landscapes, the approach establishes a foundation for emergency food preparedness. The Food Landscape Matrix represents an initial step toward a structured, decision-oriented representation of food supply systems, thereby supporting more effective crisis management.

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REFERENCES

Aday, S., & Aday, M. S. (2020). Impact of COVID-19 on the food supply chain. *Food Quality and Safety*, *4*(4), 167–180. https://doi.org/10.1093/fqsafe/fyaa024

Alarcon, P., Fèvre, E. M., Murungi, M. K., Muinde, P., Akoko, J., Dominguez-Salas, P., Kiambi, S., Ahmed, S., Häsler, B., & Rushton, J. (2017). Mapping of beef, sheep and goat food systems in Nairobi—A framework for policy making and the identification of structural vulnerabilities and deficiencies. *Agricultural Systems*, *152*, 1–17. https://doi.org/10.1016/j.agsy.2016.12.005

Anastasiadis, F., & Alebaki, M. (2021). Mapping the Greek Wine Supply Chain: A Proposed Research Framework. *Foods*, *10*(11), 2859. https://doi.org/10.3390/foods10112859

Anastasiadis, F., Apostolidou, I., & Michailidis, A. (2020). Mapping Sustainable Tomato Supply Chain in Greece: A Framework for Research. *Foods*, *9*(5), 539. https://doi.org/10.3390/foods9050539

Anastasiadis, F., Liontakis, A., & Tsoulfas, G. T. (2024). End-to-End Mapping Towards Sustainability: The Case of the Cretan Vegetable Supply Chain. In K. Mattas, G. Baourakis, C. Zopounidis, & C. Staboulis (Eds), *Value Chain Dynamics in a Biodiverse Environment* (pp. 1–14). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-49845-9_1

Balster, A., Friedrich, H., Ottemöller, O., & Rolko, K. (with Technische Informationsbibliothek (TIB), Boltze, M., & Technische Universität Darmstadt, Institut für Verkehr). (2016). *Schlussbericht zum Teilprojekt Quantitative Modellierung der Lebensmittelversorgung in Deutschland des Verbundprojektes SEAK*. Technische Universität Darmstadt. https://doi.org/10.2314/GBV:869870238

BLE. (n.d.-a). *Versorgungsbilanzen*. BMEL-Statistik. Retrieved 20 February 2026, from https://www.bmel-statistik.de/ernaehrung/versorgungsbilanzen

BLE. (n.d.-b). *Versorgungsbilanzen: Kartoffeln*. BMEL-Statistik. Retrieved 24 February 2025, from https://www.bmel-statistik.de/ernaehrung/versorgungsbilanzen/kartoffeln

BLE. (n.d.-c). *Versorgungsbilanzen: Obst, Gemüse, Zitrusfrüchte, Schalen- und Trockenobst*. BMEL-Statistik. Retrieved 21 February 2025, from https://www.bmel-statistik.de/ernaehrung/versorgungsbilanzen/obst-gemuese-zitrusfruechte-schalen-und-trockenobst

BLE. (n.d.-d). *Versorgungsbilanzen: Zucker, Glukose*. BMEL-Statistik. Retrieved 24 February 2025, from https://www.bmel-statistik.de/ernaehrung/versorgungsbilanzen/zucker-glukose

BLE. (2024a). *Bericht zur Markt- und Versorgungslage Fleisch 2024*. https://www.bmel-statistik.de/fileadmin/daten/0611090-2024.pdf

BLE. (2024b). *Bericht zur Markt- und Versorgungslage mit Milch und Milcherzeugnissen*. https://www.bmel-statistik.de/fileadmin/daten/0611100-2024.pdf

BLE. (2024c). *Bericht zur Markt- und Versorgungslage Ölsaaten, Öle und Fette—2024*. https://www.bmel-statistik.de/fileadmin/daten/0611030-2024.pdf

BLE. (2024d). *Bericht zur Markt- und Versorgungslage Zucker*. Bundesanstalt für Landwirtschaft und Ernährung. https://www.bmel-statistik.de/fileadmin/daten/0611050-2024.pdf

BLE. (2025). *Bericht zur Markt- und Versorgungslage mit Fleisch 2025*. https://www.bmel-statistik.de/fileadmin/daten/0611090-2025.pdf

BMEL. (n.d.). *Geflügelhaltung*. BMEL-Statistik. Retrieved 13 January 2025, from https://www.bmel-statistik.de/landwirtschaft/tierhaltung/gefluegelhaltung

Bundesinformationszentrum Landwirtschaft. (n.d.). *Wie wird Getreide in Deutschland genutzt?* Praxis-Agrar. Retrieved 4 December 2024, from https://www.praxis-agrar.de/service/infografiken/wie-steht-es-um-die-hofnachfolge-bei-landwirtschaftlichen-betrieben

Bundesinformationszentrum Landwirtschaft. (2024, November 10). *Zucker*. Landwirtschaft.De. https://www.landwirtschaft.de/einkauf/lebensmittel/pflanzliche-lebensmittel/zucker

Burgoa, J. M. F. D., Rist, S., Jacobi, J., Wambugu, G., Ngutu, M., Augstburger, H., Mwangi, V., Zonta, A. L., Otieno, S., Kiteme, B. P., Burgoa, J. M. F. D., & Rist, S. (2019). Mapping food systems: A participatory research tool tested in Kenya and Bolivia. *Mountain Research and Development*, *39*(1). https://doi.org/10.1659/MRD-JOURNAL-D-18-00024.1

DLG e.V. (2026, March 30). *Düngermarkt Hormus Naher Osten*. DLG e.V. https://www.dlg.org/magazin/duengemittel-hormus-naher-osten

Engemann, H., & Jafari, Y. (2022). COVID-19 and changes in global agri-food trade. *Q Open*, *2*(1), qoac013. https://doi.org/10.1093/qopen/qoac013

Ericksen, P. J. (2008). Conceptualizing food systems for global environmental change research. *Global Environmental Change*, *18*(1), 234–245. https://doi.org/10.1016/j.gloenvcha.2007.09.002

ESVG. (2017). *Ernährungssicherstellungs- und -vorsorgegesetz*. Bundesministerium der Justiz und für Verbraucherschutz. https://www.gesetze-im-internet.de/esvg/BJNR077210017.html

European Commission. (2025). *European Food Security Crisis preparedness and response mechanism (EFSCM)*. European Commission. https://agriculture.ec.europa.eu/common-agricultural-policy/agri-food-supply-chain/ensuring-global-food-supply-and-food-security_en#a-contingency-plan-for-food-supply-and-food-security

FAO. (1996). *Rome declaration and world food summit plan of action*. FAO.

Ghadiri, M., Newell, R., & Krawchenko, T. (2024). Participatory System Mapping for Food Systems: Lessons Learned from a Case Study of Comox Valley, Canada. *Challenges*, *15*(2), 22. https://doi.org/10.3390/challe15020022

GIZ. (2023). *Value Chain Analysis for Potato, Tomato, Cucumber and Date In Selected Areas of Al-Anbar Governorate, Iraq*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

HLPE. (2017). *Nutrition and food systems*. https://openknowledge.fao.org/handle/20.500.14283/i7846e

Ingram, J. (2011). A food systems approach to researching food security and its interactions with global environmental change. *Food Security*, *3*(4), 417–431. https://doi.org/10.1007/s12571-011-0149-9

Jagtap, S., Trollman, H., Trollman, F., Garcia-Garcia, G., Parra-López, C., Duong, L., Martindale, W., Munekata, P. E. S., Lorenzo, J. M., Hdaifeh, A., Hassoun, A., Salonitis, K., & Afy-Shararah, M. (2022). The Russia-Ukraine Conflict: Its Implications for the Global Food Supply Chains. *Foods*, *11*(14), 2098. https://doi.org/10.3390/foods11142098

Kaplinsky, R., & Morris, M. (2001). *A Handbook for Value Chain Research*. Institute of Development Studies, University of Sussex.

Kumar, M., Srai, J., Pattinson, L., & Gregory, M. (2013). Mapping of the UK food supply chains: Capturing trends and structural changes. *Journal of Advances in Management Research*, *10*(2), 299–326. https://doi.org/10.1108/JAMR-05-2013-0034

Laborde, D., Martin, W., Swinnen, J., & Vos, R. (2020). COVID-19 risks to global food security. *Science*, *369*(6503), 500–502. https://doi.org/10.1126/science.abc4765

Liddy, H., Mowlds, S., McKeown, P. C., Lundy, M., & Spillane, C. (2023). Food mapping approaches for understanding food system transformations in rapid-growth city regions in the Global South. *Frontiers in Sustainable Food Systems*, *7*, 1238124. https://doi.org/10.3389/fsufs.2023.1238124

Liu, S. (2020). Food Supply Pressure in France and Germany During COVID-19: Causes from Manufacturing. *Journal of Agriculture, Food Systems, and Community Development*, 1–4. https://doi.org/10.5304/jafscd.2020.094.007

Menski, U. (Ed.). (2016). *Neue Strategien der Ernährungsnotfallvorsorge: Ergebnisse aus dem Forschungsverbund NeuENV*. Freie Universität.

Meyer, C. H., Hamer, M., Frieling, D., & Oertzen, G. (2018). *Lebensmittelverluste von Obst, Gemüse, Kartoffeln zwischen Feld und Ladentheke* (LANUV-Fachbericht No. 85). Landesamt für Natur, Umwelt und Verbraucherschutz. https://www.lanuv.nrw.de/fileadmin/lanuvpubl/3_fachberichte/fabe85_Lebensmittelverluste_gesichert.pdf

ML NI. (2024). *Kritische Infrastruktur Ernährung (KRITIS-ENV)*. Niedersächsisches Ministerium für Ernährung, Landwirtschaft und Verbraucherschutz. https://www.ml.niedersachsen.de/startseite/themen/ernahrung/ernahrungsnotfallvorsorge/kritische-infrastruktur-ernahrung-231751.html

Mossie, M., Gerezgiher, A., Ayalew, Z., & Elias, A. (2021). Food security effects of smallholders' participation in apple and mango value chains in north-western Ethiopia. *Agriculture & Food Security*, *10*(1), 47. https://doi.org/10.1186/s40066-021-00310-z

Nakamura, T., Lloyd, S., Maruyama, A., & Masuda, S. (2024). Impact of the Global Food Crisis on Germany's Food Aid Measures: In the Context of COVID-19, Russia's Invasion of Ukraine, and Extreme Weather. *Journal of Disaster Research*, *19*(4), 666–677. https://doi.org/10.20965/jdr.2024.p0666

NOLAN. (n.d.). *NOLAN: Skalierbare Notfall-Logistik für urbane Räume als öffentlich-private Partnerschaft im Katastrophenfall*. https://www.nolan-sifo.de/

Onono, J. O., Alarcon, P., Karani, M., Muinde, P., Akoko, J. M., Maud, C., Fevre, E. M., Häsler, B., & Rushton, J. (2018). Identification of production challenges and benefits using value chain mapping of egg food systems in Nairobi, Kenya. *Agricultural Systems*, *159*, 1–8. https://doi.org/10.1016/j.agsy.2017.10.001

Sobal, J., Kettel Khan, L., & Bisogni, C. (1998). A conceptual model of the food and nutrition system. *Social Science & Medicine*, *47*(7), 853–863. https://doi.org/10.1016/S0277-9536(98)00104-X

Statista. (2024, February). *Getreide: Führende Lieferländer bis 2023*. Statista. https://de.statista.com/statistik/daten/studie/1240620/umfrage/importmenge-von-getreide-in-deutschland-nach-herkunftsland/

Verband Deutscher Mühlen e.V. (n.d.). *Getreidewissen: Getreidearten*. Mein Mehl. Retrieved 14 November 2024, from https://www.mein-mehl.de/getreide/getreidearten#

Wesana, J., Gellynck, X., Dora, M. K., Pearce, D., & De Steur, H. (2019). Measuring food losses in the supply chain through value stream mapping: A case study in the dairy sector. In *Saving Food* (pp. 249–277). Elsevier. https://doi.org/10.1016/B978-0-12-815357-4.00009-2

Yakovleva, N., & Flynn, A. (2004). Innovation and sustainability in the food system: A case of chicken production and consumption in the UK. *Journal of Environmental Policy & Planning*, *6*(3–4), 227–250. https://doi.org/10.1080/1523908042000344096

Zurek, M., Ingram, J., Sanderson Bellamy, A., Goold, C., Lyon, C., Alexander, P., Barnes, A., Bebber, D. P., Breeze, T. D., Bruce, A., Collins, L. M., Davies, J., Doherty, B., Ensor, J., Franco, S. C., Gatto, A., Hess, T., Lamprinopoulou, C., Liu, L., … Withers, P. J. A. (2022). Food System Resilience: Concepts, Issues, and Challenges. *Annual Review of Environment and Resources*, *47*(1), 511–534. https://doi.org/10.1146/annurev-environ-112320-050744

APPENDIX

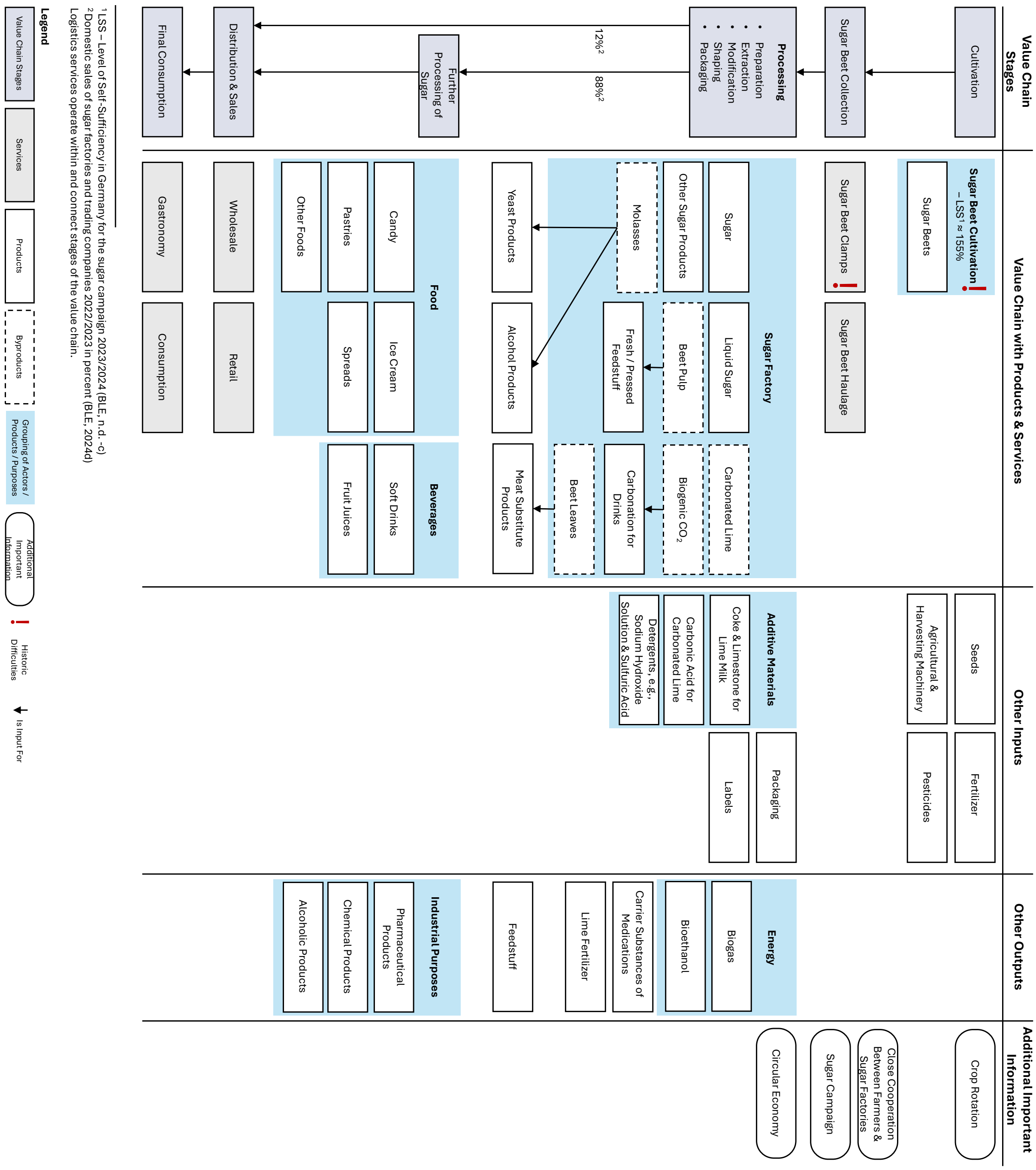

Figure 3. Sugar Beet Food Landscape

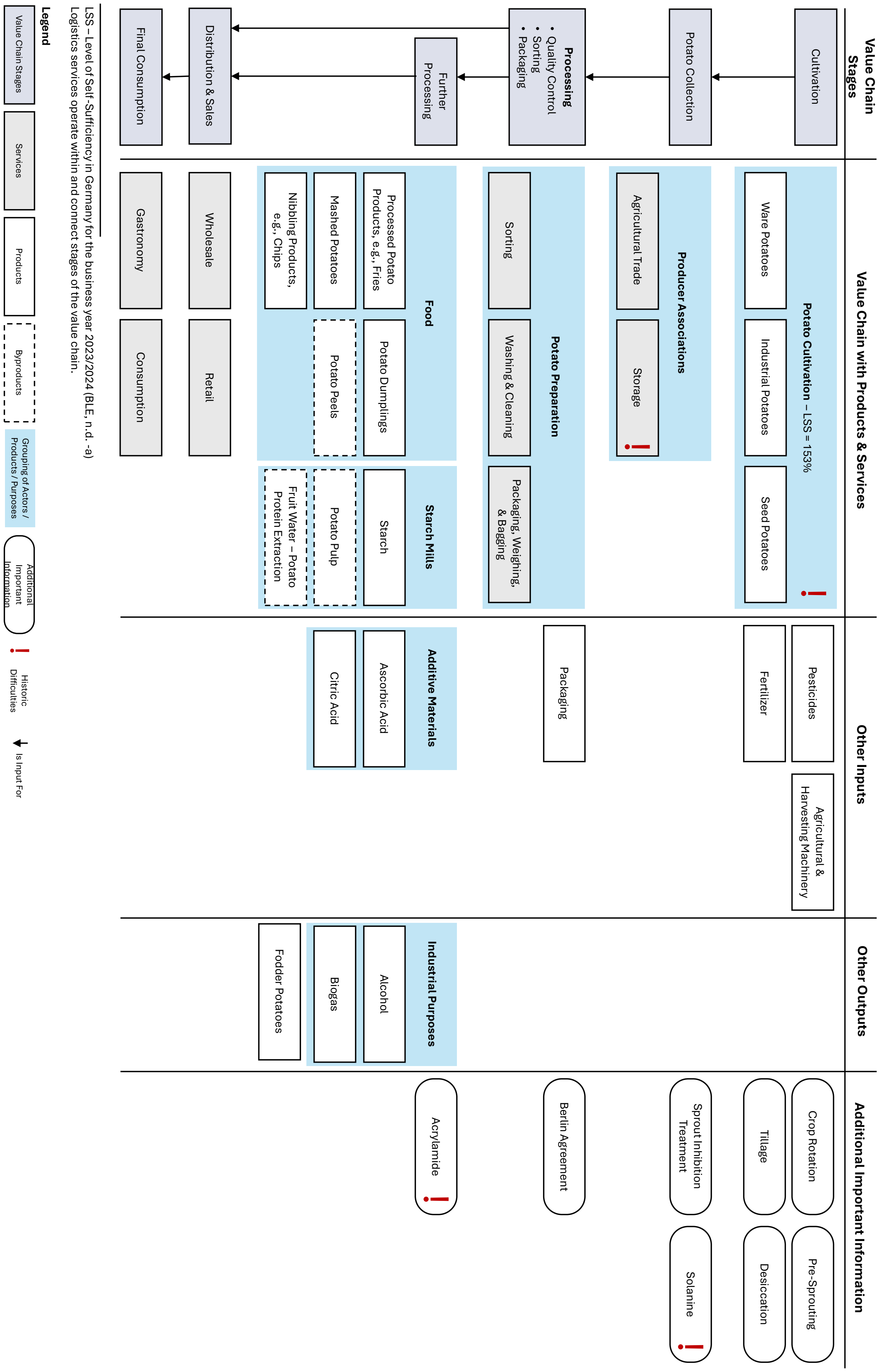

Figure 4. Potato Food Landscape

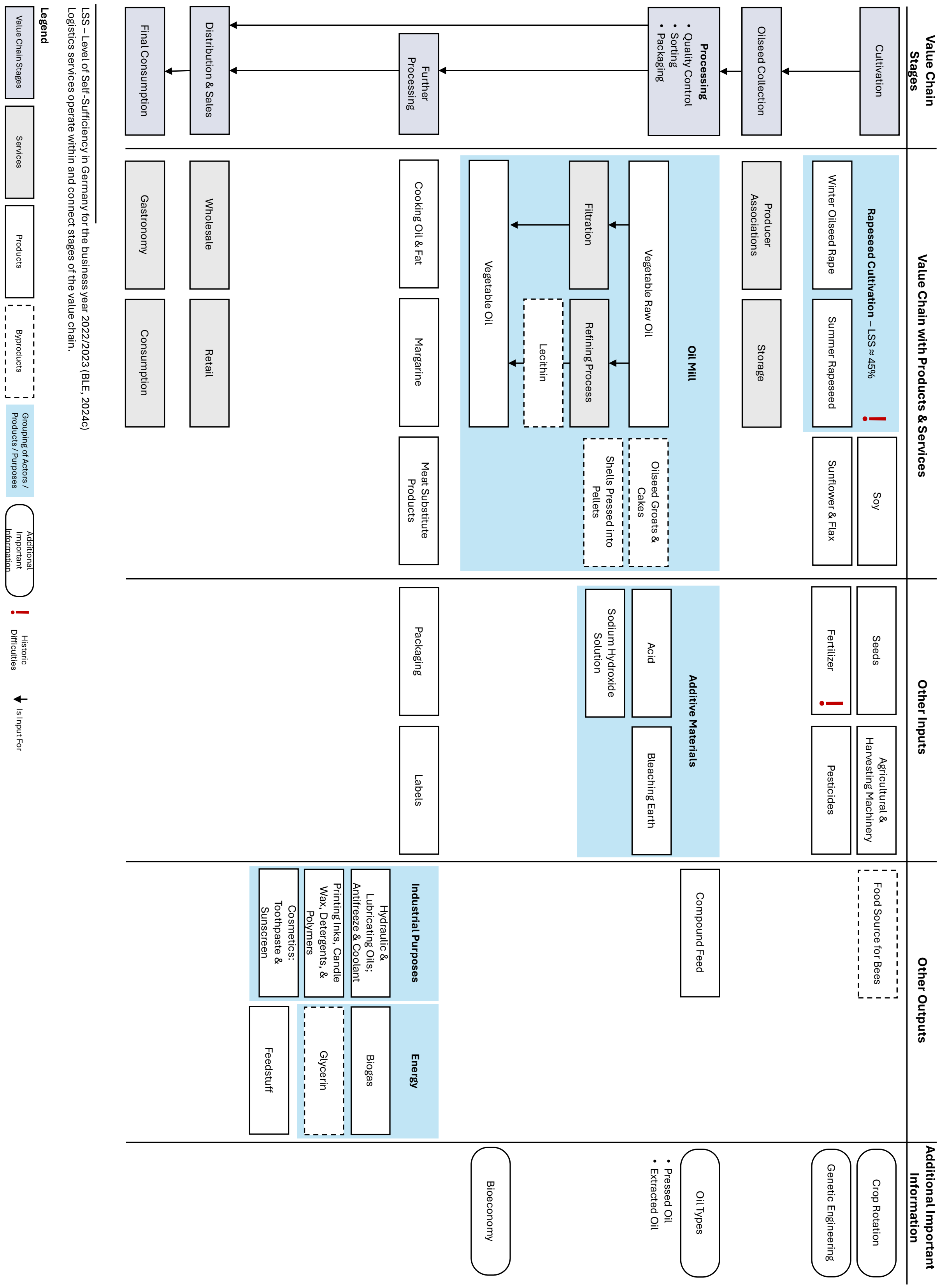

Figure 5. Oilseed Food Landscape

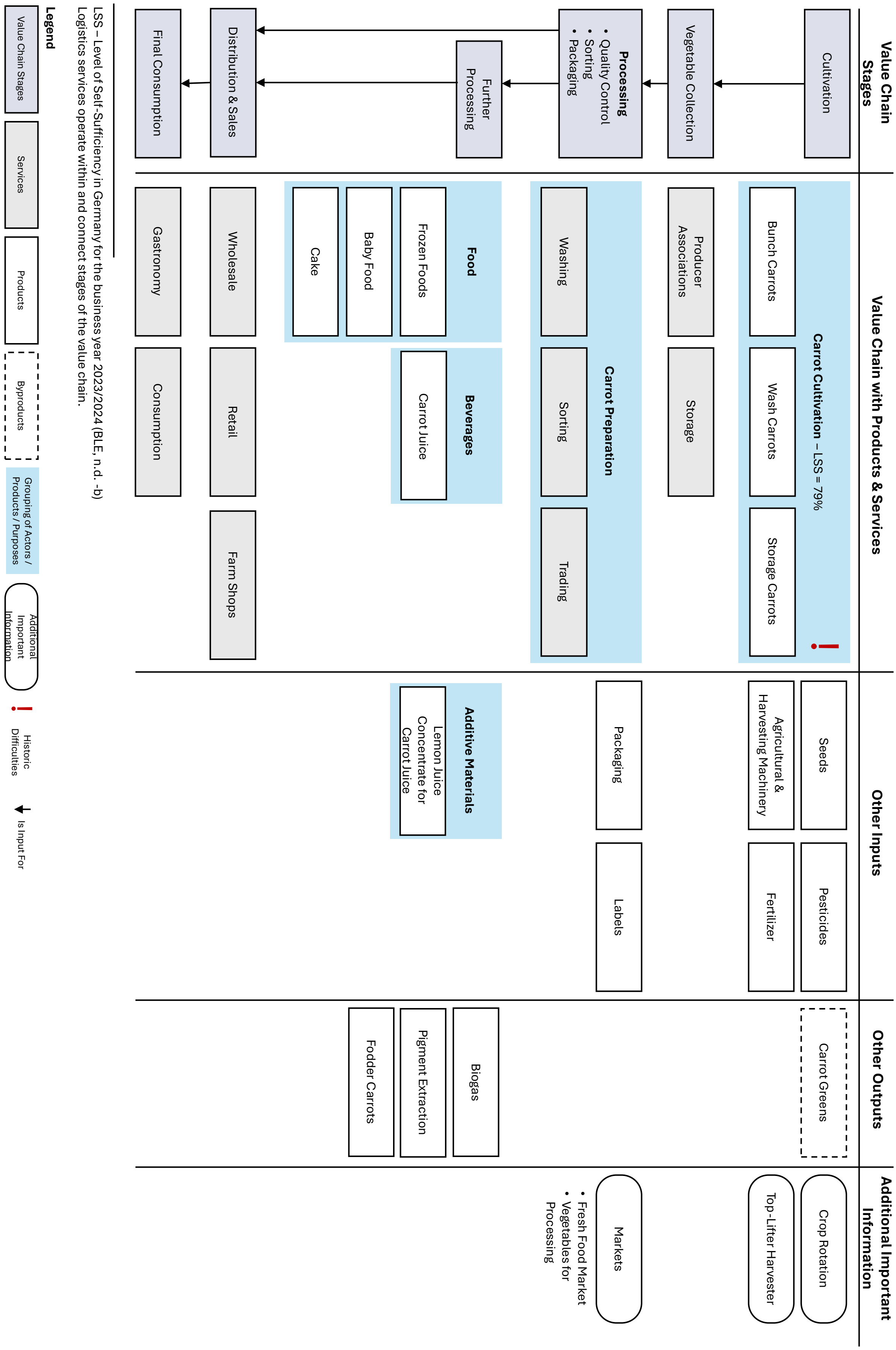

Figure 6. Carrot (Root Vegetables) Food Landscape

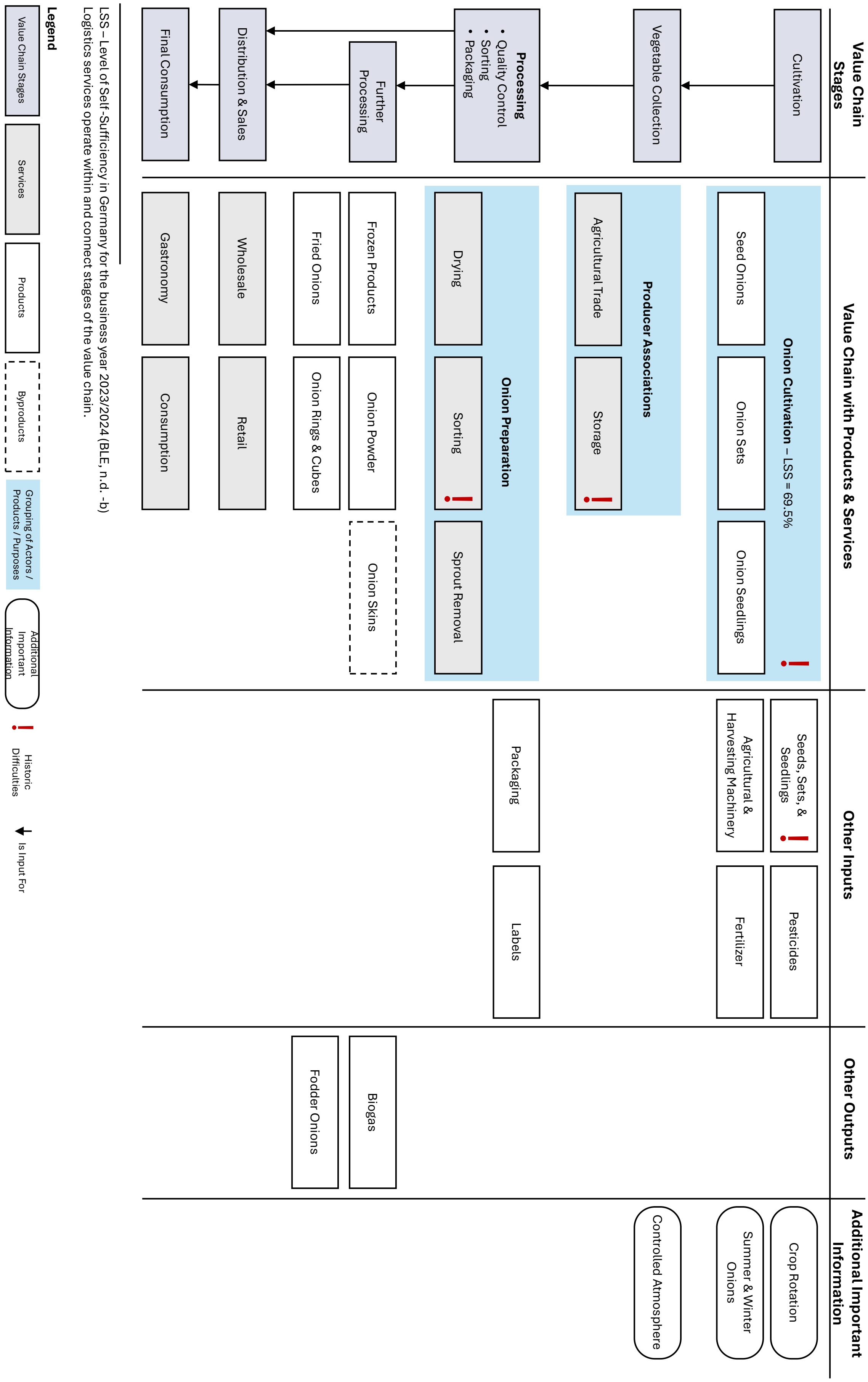

Figure 7. Onion Food Landscape

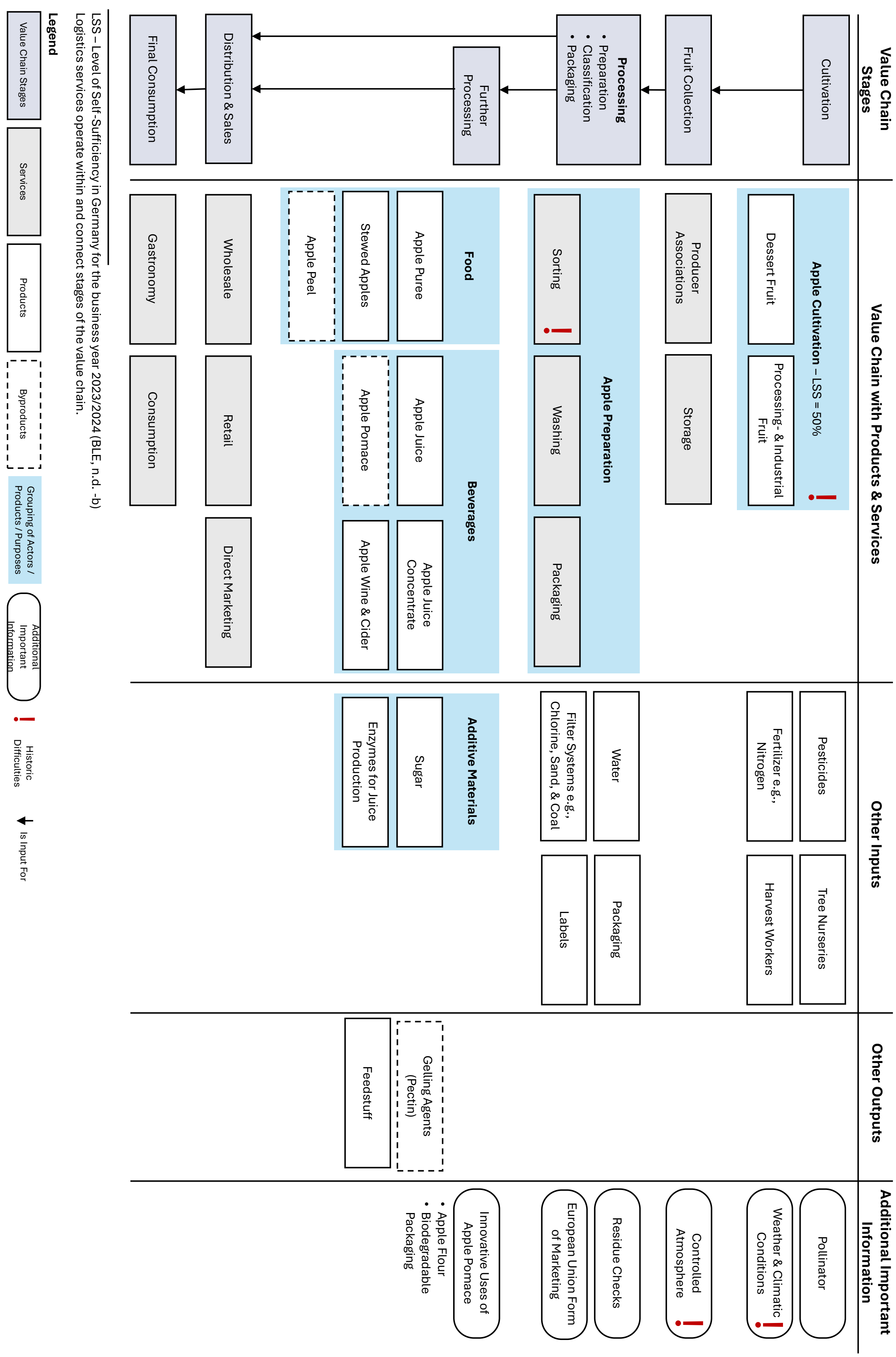

Figure 8. Apple Food Landscape

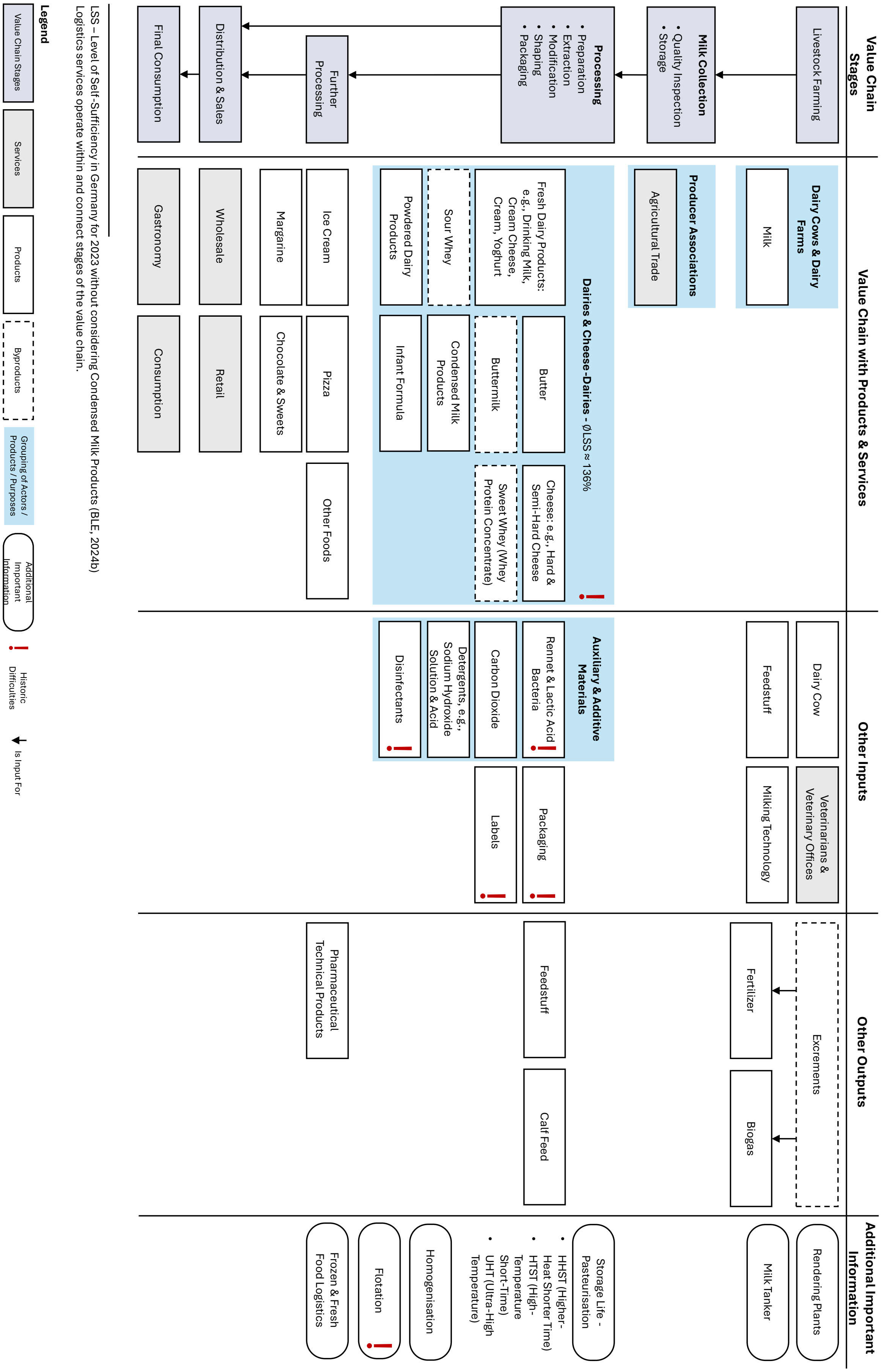

Figure 9. Milk and Dairy Products Food Landscape

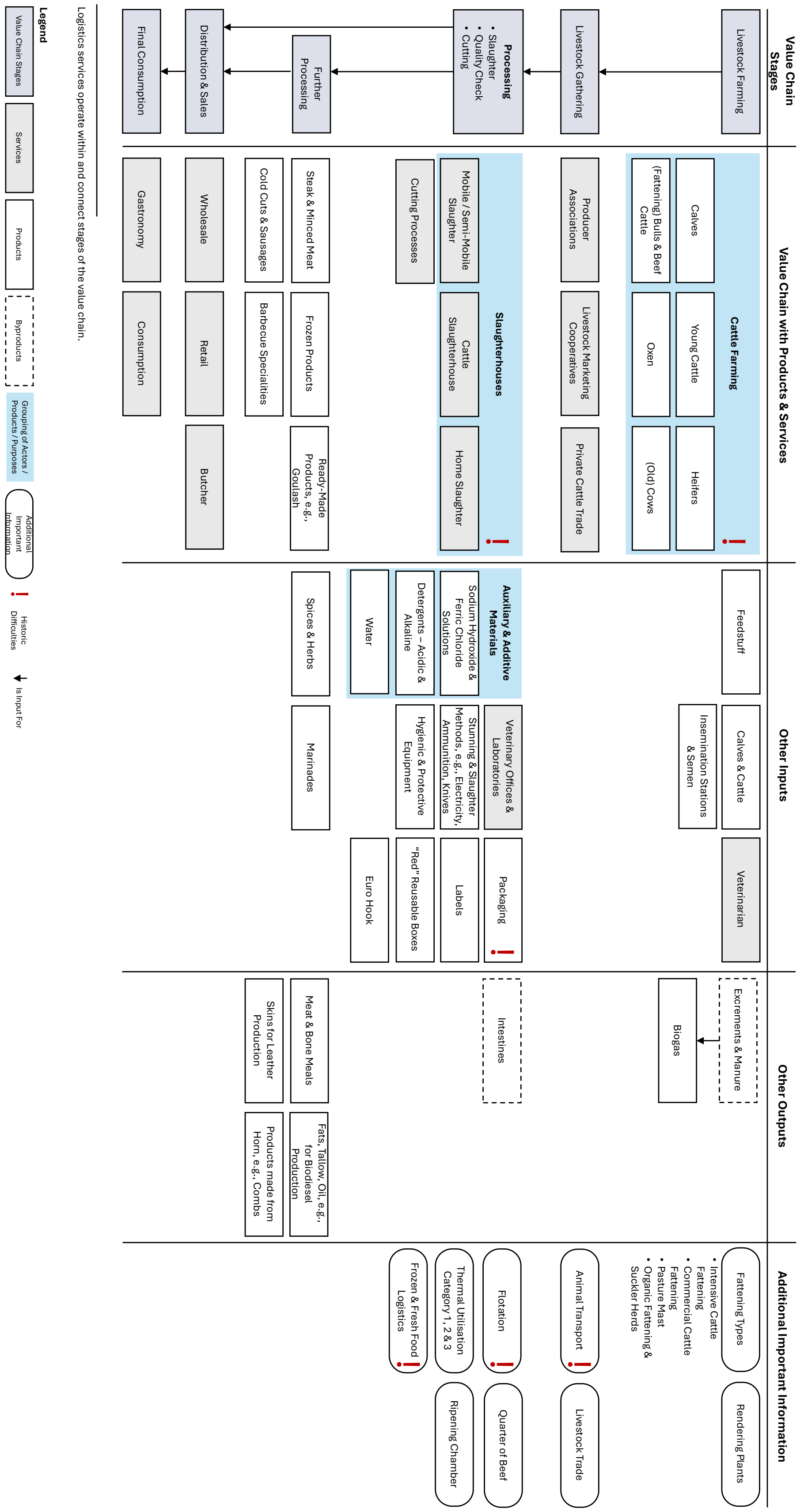

Figure 10. Beef Food Landscape

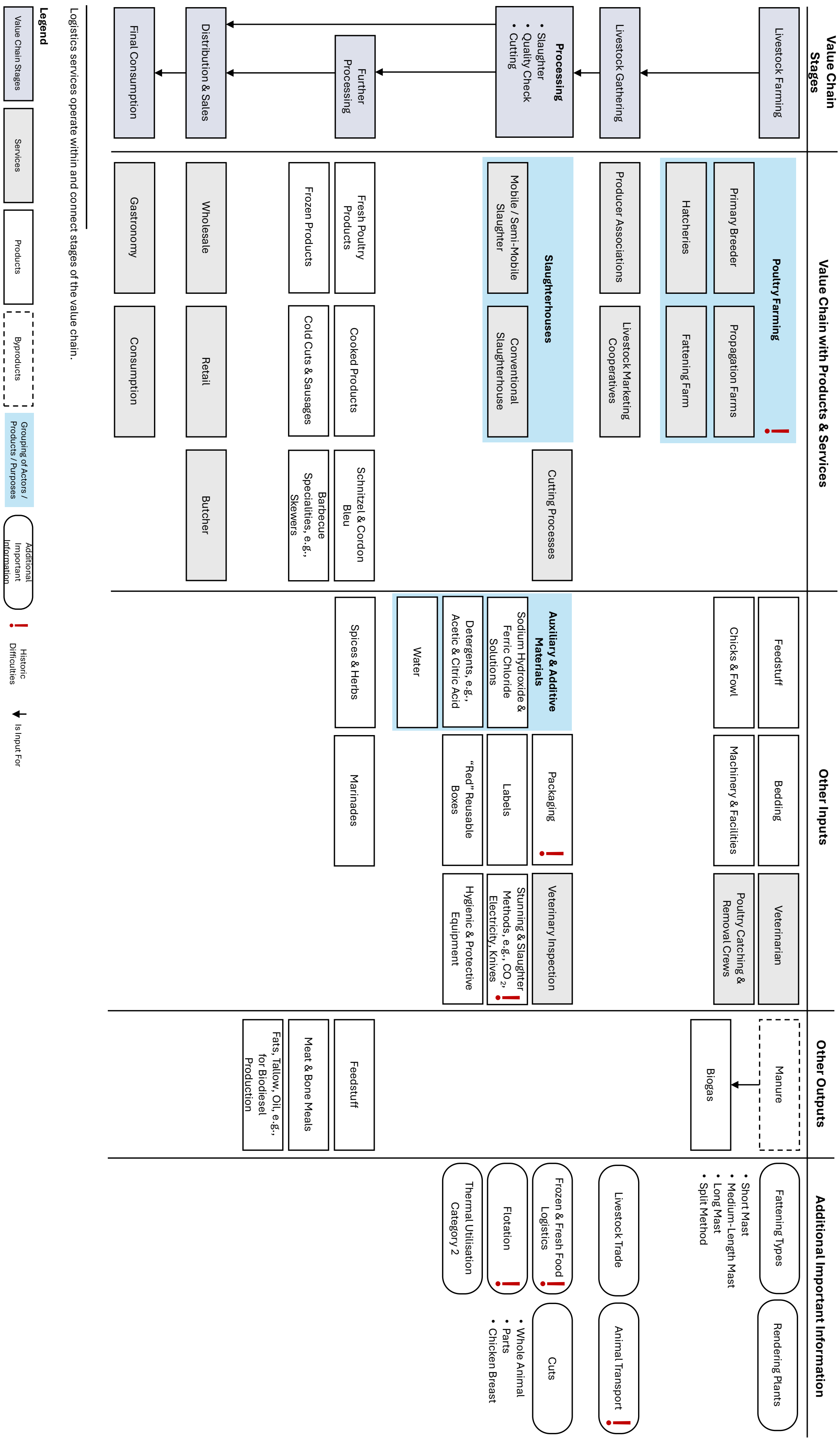

Figure 11. Poultry Food Landscape

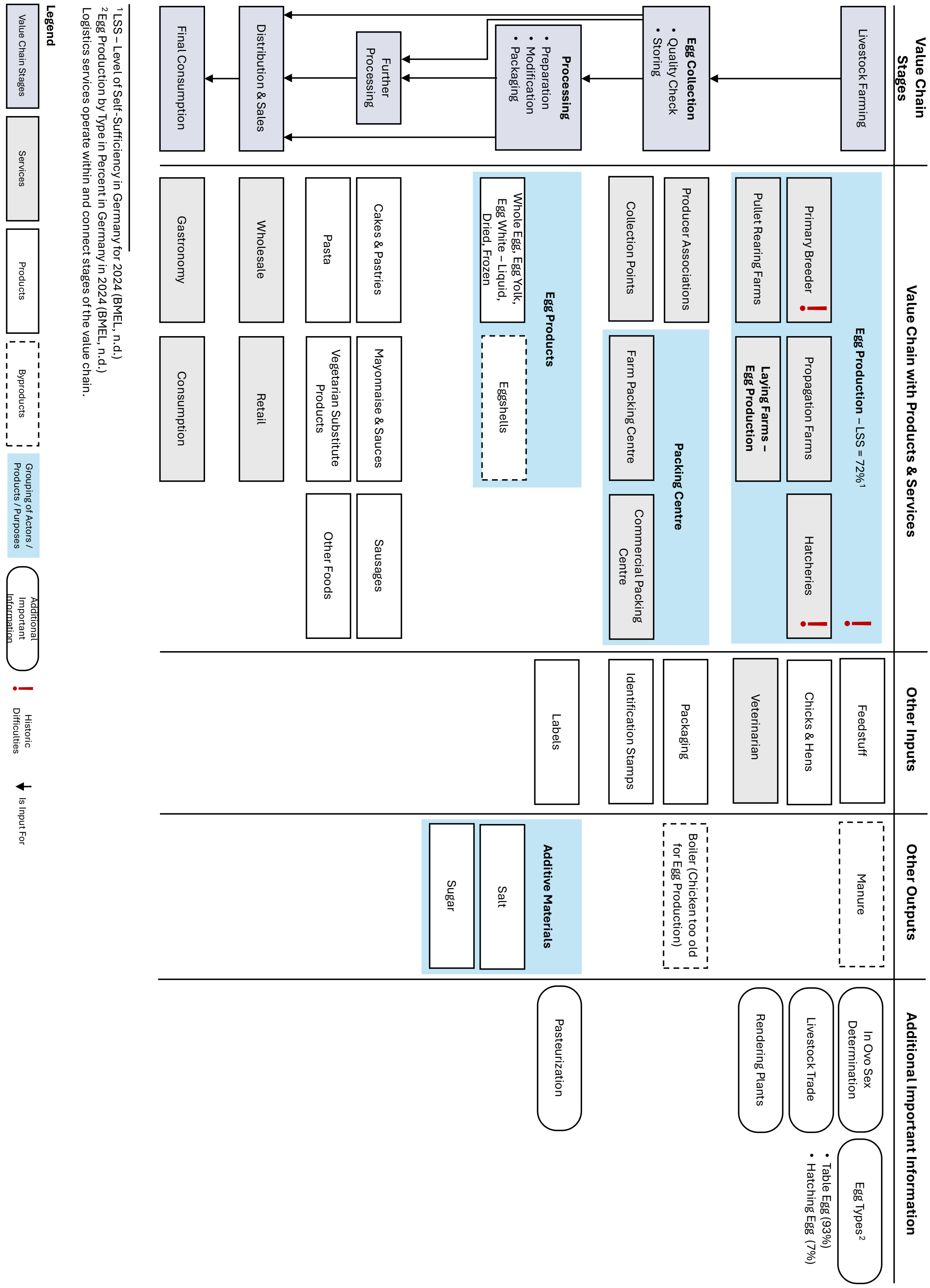

Figure 12. Egg Food Landscape

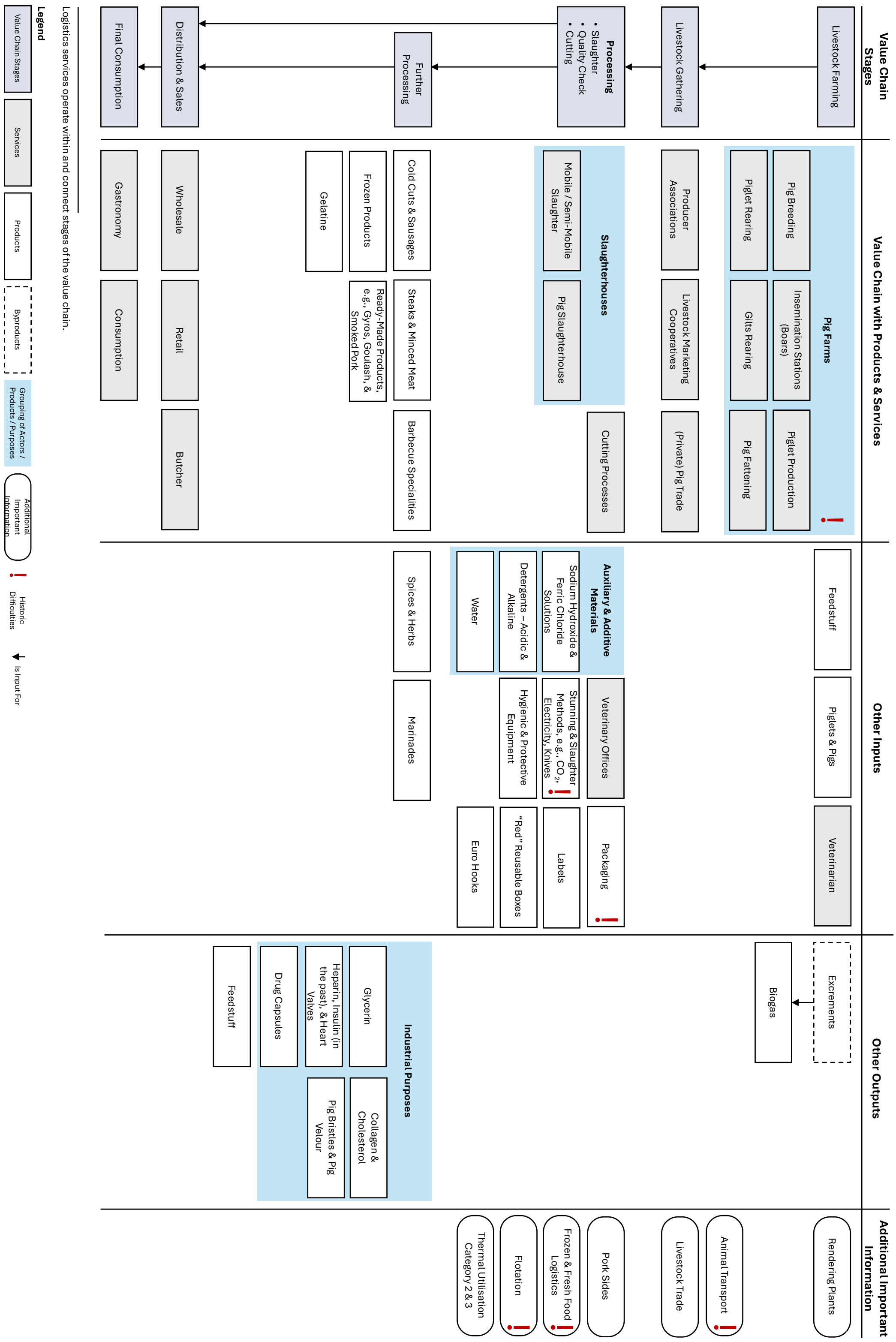

Figure 13. Pork Food Landscape