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A framework for sustainability assessment tailored to floricultural value chains

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"*Sustainability is not a state, but (at best) a direction*."

(Bouchery et al., 2017)

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III. Abbreviations

CFP	Carbon Footprint
FPPs	Flowering Potted Plants
FFP	Fair Flowers Fair Plants
FSI	Floriculture Sustainability Initiative
GHG	Greenhouse Gas
LCA	Life Cycle Assessment
NGOs	Non-Governmental Organizations
RISE	Response-Inducing Sustainability Evaluation
SAFA	Sustainability Assessment of Food and Agriculture Systems
S-LCA	Social Life Cycle Assessment

IV. Abstract

Floricultural products are criticized, emphasizing negative environmental and social impacts. This study developed an indicator-based sustainability assessment method, specifically for the value chain of flowering potted plants. The study employed a qualitative research approach, conducting interviews with chain actors. In the framework developed, social indicators are allocated based on regional differences and stakeholder groups. Environmental indicators are assigned to chain stages, and economic indicators are designed to assess the performance of chain actors.

German abstract

Zierpflanzen werden wegen ihrer negativen ökologischen und sozialen Auswirkungen kritisiert. Im Rahmen dieser Studie wurde eine Nachhaltigkeitsbewertungsmethode für die Wertschöpfungskette von blühenden Topfpflanzen mittels qualitativer Forschungsmethoden entwickelt. Die Bewertungsmethode ordnet die sozialen Indikatoren nach regionalen Unterschieden und Interessengruppen zu. Umweltindikatoren werden den verschiedenen Stufen der Wertschöpfungskette zugeordnet und die ökonomischen Indikatoren dienen zur Bewertung der Kettenakteure.

V. Summary

Flowering potted plants (FPPs) are an important segment in the German market for ornamental plants, at an estimated 33% of the total market volume. Despite their economic and cultural importance, floricultural products are frequently criticized for their impacts on environmental and social sustainability.

Sustainability assessment is an approach for improving the sustainability performance of agricultural systems. Assessing the current sustainability state of a system supports chain actors in improving sustainability performance. A range of methods have been developed for the assessment of agricultural systems, among them indicator-based assessment methods. However, since the value chain of FPPs is not comparable to other agricultural systems, it cannot be assessed using the existing tools. A context-specific method is needed to assess the concrete sustainability challenges associated with the value chain of FPPs. Thus, the goal of this dissertation was to develop an indicator-based assessment method, specifically for the value chain of FPPs, considering the social, environmental, and economic dimensions of sustainability.

The study employed a qualitative research approach. The value chain and sustainability challenges were investigated by conducting twenty in-depth interviews with chain actors from different stages in the value chain. The data collected was analyzed through qualitative content analysis. The process of the framework development is a mixed top-down participatory approach, where stakeholders were involved in characterizing the value chain and the investigation of sustainability challenges. However, themes, subthemes, and suitable indicators were determined by the researcher. The indicators were extracted from the universal agricultural assessment tools Sustainability Assessment of Food and Agriculture Systems (SAFA) and Response-Inducing Sustainability Evaluation (RISE). New environmental indicators were developed to assess subthemes with no available indicators in the existing tools. Future practical development stages of the framework, such as determining the feasibility of indicators, will require further participation by stakeholders.

The framework for the value chain of FPPs enables the sustainability performance assessment of single actors across the chain, but also the possibility for assessing the entire value chain. Environmental, social, and economic indicators were allocated differently across the value chain. Social indicators are allocated according to regional differences in provision of healthcare and social safety nets. Furthermore, a distinction is made between indicators for each stakeholder group: workers, consumers, and the local community, because each group is affected by different possible sustainability impacts. Environmental impacts are related to product-specific processes and therefore indicators are assigned differently to the chain stages: breeding, production, and distribution. Economic impacts may differ due to higher regional risk attributed to climate change or political stability.

Implementing the assessment method will help determine areas of weak sustainability performance, and thus support actors in targeting their efforts for sustainability performance improvement. Furthermore, the framework provides the foundation for the development of future or existing standards, specific to the assessment of potted plants. In addition to the use for conducting sustainability assessment, the framework can also influence policy makers to promote policy changes and regulation by providing background and by eliciting discussion.

According to the present study, the driver for sustainability performance improvement in the floricultural sector is normative, due to pressure by stakeholders such as NGOs and retail chains. Adoption of sustainability innovations is the dominant strategy by chain actors to deal with pressure from upstream actors, and improve sustainability performance. In contrast, regulatory pressure was less influential in driving innovations in the floriculture industry.

1 Introduction

Ornamentals and floricultural products are a specialized branch of agriculture and are generally grown for decorative purposes (Gabellini and Scaramuzzi, 2022). Ornamental products have a significant cultural value in many societies, and have been demonstrated to contribute to well-being and quality of life (Hall & Hodges, 2011). The ornamentals industry is global, with its main markets in Europe, China, the USA, and Japan (Darras, 2020). The world market for ornamental plants and flowers in 2019 was estimated to have an economic value of 42.4 billion dollars (Thörning et al., 2022). Europe is the largest consumer market, within which Germany is a leading market, with an estimated value of 9.4 billion euros in retail sales (2020) (Bonaguro et al., 2021; Zentralverband Gartenbau e. V., 2021). Floriculture and ornamental plants include a range of products, such as cut flowers and potted plants (Bonaguro et al., 2021). Potted plants can be divided into green and flowering plants. Flowering potted plants (FPPs), consisting of bedding plants and flowering indoor plants, represent an important market segment, estimated to comprise 33% of the total market volume in Germany (Zentralverband Gartenbau e. V., 2021).

The value chain of FPPs is considered a fresh chain and thus can be compared to those of other horticultural products, such as fruits and vegetables. The typical characteristics of fresh chains are seasonality of production, global sourcing, yield variability (in quality and quantity due to changing environmental conditions, such as weather and pests), perishability, and temperature-controlled shipment (Bloemhof et al., 2015). Differences from fresh-food sector can be found in the high diversity of flower and plant varieties. Furthermore, differences are apparent in the market share of sales channels. Whereas fruits and vegetables are generally sold in supermarkets, a significant proportion of floricultural products is sold by specialized retailers (de Keizer et al., 2015).

In recent years, there has been growing criticism of the environmental and social impacts associated with ornamental plant production and supply (Darras, 2020; Riisgaard & Gibbon, 2014; Sahle & Potting, 2013). Environmental impacts reported in association with the production and distribution of floricultural products (cut flowers and potted plants) are related to greenhouse gas (GHG) emissions due to the heating of greenhouses (Abeliotis et al., 2016; Bonaguro et al., 2021; Russo & Lucia Zeller, 2008; Soode et al., 2013; Wandl & Haberl, 2017), as well as GHG emissions associated with containers (Bonaguro et al., 2016; Ingram et al., 2019; Koeser et al., 2014; G. Lazzerini et al., 2015), substrate (Ingram et al., 2019; G. Lazzerini et al., 2015; Wandl & Haberl, 2017), electricity for artificial light (Koeser et al., 2014), electricity for storage (Abeliotis et al., 2016), and transportation (Abeliotis et al., 2016). In addition, irrigation in the floriculture sector is related to the depletion of water reservoirs and water shortages (Mekonnen et al., 2012; Russo & Lucia Zeller, 2008; Sahle & Potting, 2013; White et al., 2019). Fertilizer use has been connected to the pollution of water bodies (Bonaguro et al., 2021; Russo & Lucia Zeller, 2008; Sahle & Potting, 2013), and chemicals used for pest control have been found to result in environmental pollution and risk to human health (Bonaguro et al., 2021; Russo & Lucia Zeller, 2008; Sahle & Potting, 2013).

Social aspects of the floriculture industry that have been criticized are primarily related to the labor conditions of nursery workers in low-wage labor markets, such as in Africa and Latin America (Riisgaard, 2009). The employment of workers in cut-flower nurseries in Africa and Latin America is characterized by low wages (Anker & Anker, 2014; de Vries, 2010; Evers et al., 2014; Franze & Ciroth, 2011), high work load (Evers et al., 2014; Franze & Ciroth, 2011; Kirigia et al., 2016), temporary employment relations (Anker & Anker, 2014; Evers et al., 2014; Franze & Ciroth, 2011; Riisgaard & Gibbon, 2014), and high risk due to health and safety issues (Evers et al., 2014; Franze & Ciroth, 2011; Kirigia et al., 2016; Mengistie et al., 2017; Nigatu et al., 2015; Thilsing et al., 2015). Specific health and safety issues, such as exposure to endotoxin, were also investigated among workers in a potted plant nursery in Denmark (Thilsing et al., 2015). The impacts on the local community in low-wage markets have also been criticized: for example, in regard to employment of locals as opposed to hiring migrants from distant regions (Evers et al., 2014; Franze & Ciroth, 2011; Kirigia et al., 2016).

Growing consumer awareness of social and environmental sustainability issues in the floriculture industry (Berki-Kiss & Menrad, 2019; Dennis et al., 2010; Riisgaard, 2009) has increased pressure on chain actors to improve their sustainability performance. Furthermore, as sustainability extends to the entire life cycle of a product, firms taking part in global value chains are increasingly held responsible for the sustainability performance of their suppliers (Qorri et al., 2018; Seuring & Müller, 2008).

Industry actors have reacted by adopting private standards in order to mitigate the criticized negative social and environmental impacts (Riisgaard, 2009). Multiple private standards have been developed for the floriculture sector. However, the most relevant standards for plants in the European market are the Milieu Programma Sierteelt (MPS), GLOBALG.A.P., and Fairtrade. MPS was developed in 1995 by a group of Dutch growers and auction houses (Riisgaard, 2009). The “G.A.P.” in GLOBALG.A.P. stands for “good agricultural practices,” and was initiated by a coalition of European retailers. GLOBALG.A.P was extended to cut flowers and plants in 2003 (GLOBALG.A.P., 2022; Riisgaard, 2009). Both MPS and GLOBALG.A.P. are business-to-business certifications, generally initiated for the purpose of risk management. Another standard is Fairtrade, which is a consumer label aiming at product differentiation. The label was released for flowers by the Fairtrade labeling organization in 2006 (Riisgaard, 2009). In 2015, the Fairtrade label was extended to potted plants, propagated from cuttings, supplied to the German market (Fairtrade-Blumen & Pflanzen, 2022).

Due to the proliferation of standards in the sector, the Floriculture Sustainability Initiative (FSI) is seeking to harmonize standards. FSI is an international non-profit association of stakeholders in the floriculture sector. The association, established in 2013, includes producers, wholesalers and retailers, certifying bodies, and NGOs (FSI, 2022). The association currently brings together 16 existing standards that are benchmarked to the criteria of GLOBALG.A.P for environmental practices and the criteria of Global Social Compliance Program (GSCP) for social practices (FSI, 2019). Projects in the initiative focus on four key sustainability topics: working conditions, agrochemical use, climate, and smallholders (FSI, 2016). A similar approach was attempted earlier with a different label: Fair Flowers Fair Plants (FFP) (Riisgaard, 2009). However, FFP is no longer active, because of the difficulties of creating sufficient market size for the label (FFP, 2017).

Consumer brands are a different approach to marketing sustainable plants. PlusPlants and Natürlich Nachhaltig® are examples of consumer brands, initiated by local potted plant producers for the German market. PlusPlants offers a German consumer label and was founded in 2013 by an organization of growers. The growers are committed to certain practices, such as using renewable energy, sustainable water consumption, reduced use of chemicals for pest control, and reduced use of peat as substrate. The PlusPlants label signifies a fair, certified, and local product (PlusPlants, 2022). Another growers' initiative for the sustainable production of potted plants that offers a consumer label is Natürlich Nachhaltig®. The partners involved focus on strategies to reduce peat use, pesticide use, and waste from plastic containers, as well as energy-saving measures and the prevention of groundwater pollution due to fertilizers (Natürlich Nachhaltig®, 2022).

Despite the proliferation of sustainability initiatives in the floriculture sector, as listed above, their impact on the sustainability performance of the sector is debatable. Business-to-business certifications in the floriculture sector have been criticized for giving more power to European retail chains. Moreover, the motivation of actors to become certified is generally to gain market access (to be able to supply to retail chains), rather than to improve their sustainability performance (Kuiper & Gemählich, 2017). Consumer labels, in general, are often criticized for offering a misleading sense of problem solving to the consumer (Riisgaard, 2009).

Another approach to support chain actors in improving their sustainability performance is by conducting sustainability assessments of agricultural systems (van Cauwenbergh et al., 2007). Sustainability assessment can provide information about the sustainability state of specific characteristics of a system. Assessing the current sustainability state of a system is important because it enables planning and decision-making for improving its sustainability performance (Sala et al., 2015).

The majority of methods implemented for sustainability assessment of agricultural chains are generally a form of either indicator-based assessment (also referred to as integrated assessment) or Life Cycle Assessment (LCA) (Moreno-Miranda & Dries, 2022). The most prevalent environmental assessment method implemented in the ornamental sector is the standardized LCA, assessing various impact categories (Abeliotis et al., 2016; Bonaguro et al., 2021; Sahle & Potting, 2013), or GHG emissions alone (Ingram et al., 2019; Koeser et al., 2014; Lazzerini et al., 2015; Wandl & Haberl, 2017). Other life-cycle approaches were implemented to investigate the carbon footprint (Soode et al., 2013; Soode et al., 2015), water footprint (Knight et al., 2019; Mekonnen et al., 2012), or water use (Ingram et al., 2019) associated with horticultural products. Nevertheless, LCAs require high resolution of data and implementation of the method requires extensive expertise (O’Rourke, 2014; Schader et al., 2014). Moreover, the interpretation of the results of an LCA is complex and difficult to communicate (Hagen et al., 2020). A further shortcoming of the LCA method is its neglect of environmental impacts such as biodiversity, as well as socio-economic impacts (O’Rourke, 2014; Schader et al., 2014).

Social aspects of cut-flower production have been investigated implementing social life cycle assessment (S-LCA) (Franze & Ciroth, 2011). Economic aspects have been investigated through cost benefit analysis (Torrellas et al., 2012), cost of production (Brumfield et al., 2018), or variable costs (Ingram et al., 2019).

Sustainability assessment is performed to assess the current sustainability state of the chain and to facilitate a continuous improvement process. Indicator-based assessment methods are designed to evaluate the most important environmental, social, and economic aspects of a system (Binder et al., 2012). The assessment is then followed by a sustainability evaluation, which involves comparing the assessed chain to a benchmark system (Bloemhof-Ruwaard, 2015) or reference values (van Cauwenbergh et al., 2007). The diversity in perceptions of sustainability and the multiple approaches to pursuing sustainable development has led to the development of a variety of tools for the sustainability assessment of agricultural systems (Binder et al., 2010). Some of the methods are aimed at specific branches such as arable crops, and other methods are considered “universal,” designed to assess a large range of agricultural systems (Binder et al., 2010; Bonisoli et al., 2018; de Olde et al., 2016).

De Olde et al. (2016) observed 48 indicator-based sustainability assessment methods designed for agricultural systems. The majority of these methods are dedicated to assessing environmental aspects of sustainability at the farm level. Bonisoli et al (2018) identified at least 15 indicator-based assessment methods that are also designed to assess social and economic aspects in addition to environmental aspects. Each dimension contains a list of themes and indicators (Bockstaller et al., 2015). Among the methods that are structured across three dimensions, only SAFA, SSP, and Avibio have been developed to assess value chains (Binder et al., 2012; de Olde et al., 2016). Avibio is a method designed for sustainability assessment of the organic poultry industry (Pottiez et al., 2012), whereas SSP is designed to assess the Swiss milk value-added chain (Binder et al., 2012). The SAFA method was developed as a universal tool to assess food and agricultural value chains (FAO, 2014).

Agricultural systems are diverse in their production and logistics processes and therefore also in their sustainability impacts. Thus, standardization in assessment methods for agricultural systems is limited compared to, for example, industrial production processes, because the production of agricultural goods strongly depends on agro-technical conditions, natural settings, and socio-political conditions (Wirén-Lehr, 2001). Field production of arable crops, for example, has impacts on soil quality, among other things. Protected agricultural systems generally require energy to be invested in maintaining controlled conditions, including temperature and other factors. The value chain of FPPs differs from those of other agricultural systems due to FPPs' distinctive features. They are cultivated in protected environments, namely greenhouses, and plants are generally cultivated in containers as opposed to soil or field production. Potted plants in general are distributed and sold as whole plants, whereas in other agricultural segments, such as fruits and vegetables, only part of the plant is harvested and distributed. Marketing of entire plants, as opposed to parts of plants, creates differences in production processes and the logistics chain. Furthermore, production of FPPs is unlike that of other horticultural products because it is broken down into distinct stages that take place in different regions of the world (Havardi-Burger et al., 2020). Because the value chain of FPPs is not comparable to other agricultural systems, it cannot be assessed by the existing tools. A context-specific tool is needed to assess the concrete sustainability challenges associated with the value chain of FPPs. Furthermore, since chain stages are interconnected and a decision at any level can influence other stages (Albajes et al., 2013), the entire value chain can be defined as one system (Fearne et al., 2012). Thus, a value-chain perspective for the assessment of sustainability performance is desired. Therefore, the goal of this dissertation was to develop an indicator-based assessment method, specific to the value chain of FPPs, considering the social, environmental, and economic dimensions of sustainability.

Indicator-based sustainability assessment methods are typically structured into at least three hierarchy levels, described in the literature with different terminology (Table 1). The first level is the most abstract, where sustainability goals or principles are defined. The second level is dedicated to the areas of action or sustainability themes associated with the assessed system. The area of action or themes are then broken down into more specific sustainability objectives also known as subthemes. The third level is comprised of indicators designed to assess sustainability performance in a specific area of action or theme (Bitsch, 2016; Bockstaller et al., 2015; Gasso et al., 2015; de Olde et al., 2016; van Cauwenbergh et al., 2007).

Table 1: Hierarchy levels in sustainability assessment methods and the alternative terminology employed in the literature

Hierarchy level	Definition and alternative terminology
Goals	Principles of sustainability agreed upon in international treaties, standards, or agreements (Bitsch, 2016). The challenge is to take the general concept of sustainable development and focus on the specific problems of agriculture (Binder et al., 2010). Terminology: Principles (Bitsch, 2016), goals (de Olde et al., 2017)
Themes and subthemes	Specific objectives derived from the principles or sustainability concept, which should be selected based on detailed knowledge of the system (van Cauwenbergh et al., 2007). Terminology: Themes and subthemes (FAO, 2014; Bockstaller et al., 2015), areas of action (Bitsch, 2016), principle (van Cauwenbergh et al., 2007), criteria (Bitsch, 2016; van Cauwenbergh et al., 2007), key issues (Gasso et al., 2015), hotspots (Petit et al., 2018), impact categories (Haas et al., 2000), subcategories (Benoît et al., 2010), attributes (Schmitt et al., 2016; van Calker et al., 2006)
Indicators	Indicators are variables that can assess the system objectively and give an indication of the state of the system (van Cauwenbergh et al., 2007).

Source: adjusted from Havardi-Burger et al., 2021, p. 12

Different approaches have been suggested for the procedure and the development of an assessment method. Van Cauwenbergh et al. (2007) suggested a framework for Sustainability Assessment of Farming and the Environment (SAFE), developed by setting the system boundaries and defining principles, criteria, and indicators. A further step includes setting reference values for each of the indicators. A different evaluation approach to reference values is a benchmark system that makes it possible to compare different systems or monitor systems over a period of time (Binder et al., 2010). In a review of methods, Deytieux et al. (2016) determined that sustainability assessment of cropping systems generally comprised four steps: (1) objectives definition, (2) definition and description of the system, (3) criteria and indicator selection, and (4) assessment and evaluation using thresholds or reference values. De Olde et al. (2017) proposed a development process for a sustainability assessment tool divided into six phases: (1) determining system boundaries and the purpose of the assessment, (2) refining the concept of sustainability so as to be able to identify sustainability goals, and defining themes and subthemes accordingly, (3) defining indicators and evaluating their feasibility, validity, and relevance, (4) setting reference values and translating the results into comparable scores, (5) acquisition of data and assessment, (6) reflection on the development process.
Building on the above-listed literature, a general procedure was extracted that includes the following phases:

1. System description and scope definition (Deytieux et al., 2016; de Olde et al., 2017; van Cauwenbergh et al., 2007).
2. Setting sustainability goals (de Olde et al., 2017), also referred to as principles (van Cauwenbergh et al., 2007) and objectives (Deytieux et al., 2016).
3. Definition of themes and subthemes (de Olde et al., 2017), or criteria (Deytieux et al., 2016; van Cauwenbergh et al., 2007).
4. Setting suitable indicators (Cauwenbergh et al., 2007; Deytieux et al., 2016; de Olde et al., 2017).
5. Data acquisition and assessment (Deytieux et al., 2016; de Olde et al., 2017).
6. Evaluation of results by comparison to reference values (Deytieux et al., 2016; de Olde et al., 2017; van Cauwenbergh et al., 2007) or benchmarking (Binder et al., 2010).
7. Development of strategies to improve the sustainability performance of chains by meeting sustainability goals (Reed et al., 2006). Such strategies could, for example, involve the adoption of sustainability innovations.

This procedure for framework development correlates to the structure of the hierarchical framework that includes goals (phase 2), themes (phase 3) and indicators (phase 4) (Figure 1). Furthermore, since the framework developed in this study is system-specific, investigating the particular characteristics of the system and defining the scope of the assessment is also part of the procedure (phase 1).

The procedure is generally clustered into two main functions: (1) framework development and (2) sustainability performance monitoring. The current study focused on framework development, which includes four phases (1–4), in order to develop a system-specific sustainability assessment framework for the value chain of FPPs. Future research could concentrate on the subsequent phases that include the implementation of the framework: assessment, evaluation, and chain performance improvement (phases 5–7).

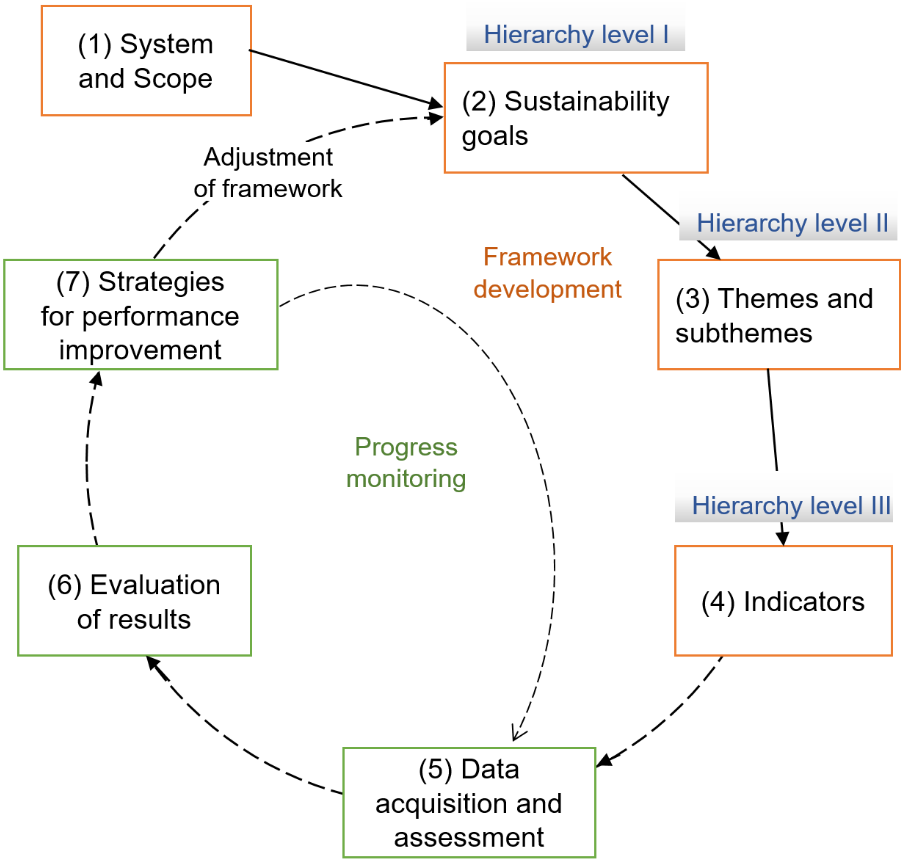

Figure 1: Procedure for the development of the sustainability framework and assessment.

Orange boxes are phases related to the development of the framework, followed by green boxes representing the progress monitoring phases: sustainability assessment, evaluation, and sustainability improvement (adjusted from Reed et al., 2006, p. 414, and Havardi-Burger et al., 2021, p. 3).

1.1 Research aims

The development of a system-specific indicator-based assessment method has to be based on profound knowledge of the system (van Cauwenbergh et al., 2007). Investigating the system in the case of a value chain is even more complex, as it involves considering different chain stages, each characterized by specific processes. Since the value chain of FPPs supplied to the German market is yet to be described in the literature, the first aim of the present work was to investigate processes and value-adding activities, as well as driving forces, in the value chain of FPPs.

Drivers in the chain were investigated in order to understand the specific economic challenges in the sector. Investigating driving forces in the chain can further help chain actors to anticipate future developments in the sector and adjust their strategic business decisions accordingly.

The first hierarchy level of a sustainability assessment framework deals with the definition of sustainability goals. Although the definition of what is considered sustainable is open to interpretation (Thompson, 2007), it has become widely accepted that sustainability should involve a balance between environmental, social, and economic factors (Binder et al., 2010; Bitsch, 2016). Sustainability goals and objectives are derived from the concept of sustainable development and correspond to the sustainability challenges of the specific sector (Binder et al., 2010).

The second hierarchy level of an indicator-based assessment method involves determining areas of action or sustainability themes in the specific sector. To determine sustainability themes, sustainability challenges across the value chain of FPPs have to be examined and defined. Therefore, a further aim of this study was to investigate social, environmental, and economic sustainability challenges across the value chain of FPPs.

Sustainability challenges have the potential to promote the development of sustainability innovations (Hansen et al., 2009). Such innovations can provide the means for improving sustainability performance along the value chain. Though such innovations are often promising at the trial level, few have been adopted by the horticultural industry at a significant level (Barrett et al., 2016). Therefore, an additional aim was to study the implementation of sustainability innovations by chain actors and the limitations to their adoption.

The third level of an assessment method generally includes a set of indicators suitable for the assessment of the identified areas of action, which corresponds to the main sustainability challenges of the system. Therefore, a further aim of the present research was to identify suitable indicators from established frameworks, or develop new indicators in case no suitable indicators were available in prior work.

1.2 Dissertation structure

The dissertation articles build on each other in a cascade flow of development (Figure 2). Each article correlates to a step in the development of a system-specific sustainability assessment method generated in this work. The characterization of the value chain of FPPs was the first step in the development of the sustainability assessment framework. This made it possible to define the system under investigation, including chain stages and processes (Paper 1). This understanding of the value chain was required to be able to progress to the next step, performed in Paper 2, which investigated sustainability challenges and innovations across the chain.

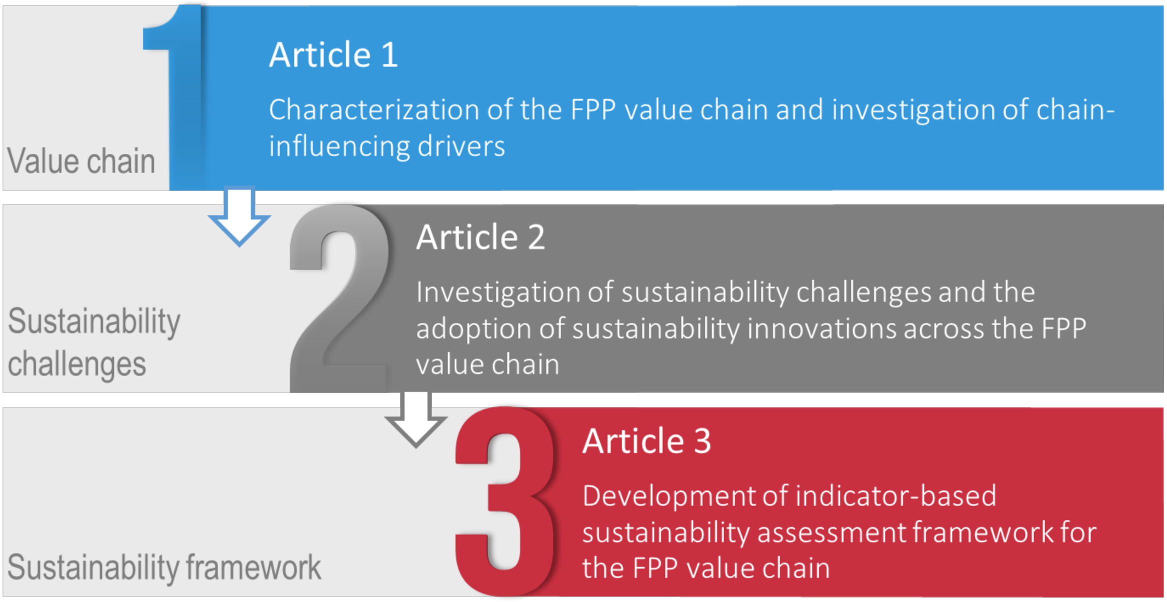

Figure 2: The structure and focus of the dissertation articles.

Having characterized the value chain and identified relevant sustainability challenges in the first two papers, it was then possible to set the scope or boundaries for the assessment tool in Paper 3 (Figure 3). This was necessary because, according to the FAO (2014), the assessment should include all processes that can generate significant sustainability impacts, which can only be determined by the investigation of sustainability challenges. Furthermore, the scope can be defined based on the product life cycle, the temporal and spatial components (van Cauwenbergh et al., 2007) of which were determined in Paper 1. The definition of sustainability themes and subthemes in Paper 3 was based on the investigation of sustainability challenges (Paper 2) and the setting of sustainability goals and objectives. The process of indicator selection and development was also conducted in Paper 3.

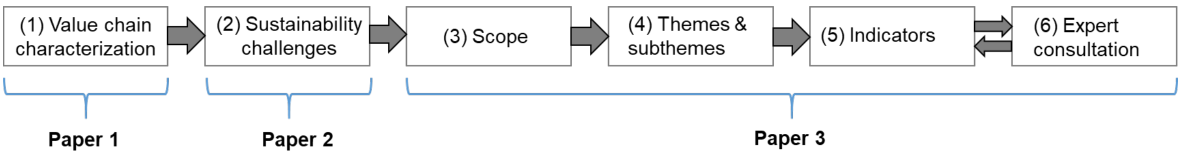

Figure 3: Steps in the development of the sustainability framework and the assignment of steps to dissertation articles.

Indicators in the new framework are designed to assess important environmental features, as well as social and economic issues, which have so far mostly been neglected in sustainability assessments of FPPs. Moreover, apart from the production stage—generally considered for sustainability assessments—the framework also includes the breeding, propagation, and distribution stages of the value chain. The stages included in the framework were estimated to contribute to considerable sustainability impacts.

2 Theoretical and conceptual background

The first part of this section is dedicated to the concept of sustainability and the definition of environmental, social, and economic sustainability and sustainability goals. The subsequent subsection provides a literature review on the theoretical and practical implications of sustainability assessment, followed by a literature review on the development of system-specific assessment frameworks, and the last subsection provides the reader with background on sustainability innovations.

2.1 Sustainability definitions and goals

The term “sustainable” is often used to express “being able to last or continue for a long time” (Bitsch, 2016). This interpretation is generally used in the context of financial sustainability, referring to the ability of businesses to maintain their economic viability over a long period of time. Von Carlowitz (1713), a German forest scientist, recognized that the survival of a business also depends on ecological factors, in this case the maintenance of the forest for future use (Bitsch, 2016). The inclusion of the social dimension of sustainability is attributed to the Brundtland report (1987), which defined the term sustainable development (Bitsch, 2016). The report was published by the World Commission on Environment and Development, and emphasized that future generations’ needs must not be compromised by present development actions. The social dimension was highlighted by the report’s concern about the capacity of poor countries to meet the basic needs of their people (Brundtland Report, 1987).

A business is considered economically sustainable if it can sustain itself for an extended period of time without depleting its resources and if it is able to cope with future changes (Christian Schader et al., 2014). **Economic sustainability** in the agricultural sector can be simply defined as economic viability (FAO, 2014) and the profitability of farming systems (Lebacq et al., 2013). Such systems are considered economically sustainable, providing that profitability is not at the expence of the environment (Smith & McDonald, 1998) or society.

Economic sustainability goals for nursery products were defined by Krug et al. as “maintain[ing] agricultural productivity and promot[ing] economic viability,” (2008, p. 43). The economic sustainability themes relate to increased productivity and economic viability, and take into account consumer concerns regarding product sources (Krug et al., 2008; Lopez et al., 2008).

Environmental sustainability is generally related to depletion of natural resources and the environment’s capacity to absorb inputs such as waste and pollution, as formulated by Meadows et al. in *The Limits to Growth* (1972). This early perspective from Meadows et al. (1972) is directly related to the two existing approaches for conceptualizing sustainability:

resource sufficiency and functional integrity. When sustainability is defined as a problem of "resource sufficiency," the question of whether a practice is sustainable is related to how long the practice can continue given the existing resource stock. If sustainability is conceptualized as functional integrity, a practice that threats the capacity of the system to reproduce itself is considered unsustainable (Thompson, 2007). The two approaches do not contradict each other, because depleting resources such as water directly threatens ecological processes and thus the capacity of the system for regeneration.

In the context of agricultural sustainability, both approaches (functional integrity and resource sufficiency) are considered, as agricultural systems rely on the maintenance of ecological processes (Smith & McDonald, 1998). The maintenance of such processes is itself dependent upon the conservation of the functions of natural resources that are provided by the ecosystem, such as water, air, soil, energy, and biodiversity (van Cauwenbergh et al., 2007). Specific environmental goals for the agricultural sector involve the conservation of land, water, and plant and animal genetic resources (FAO, 2014).

The general environmental goals for the sustainable production of greenhouse crops were defined as "reduce environmental degradation, conserve resources and energy" (Krug et al., 2008, p. 43). Environmental sustainability themes associated with container greenhouse production are pollution from fertilizers and other chemicals, plastic waste, carbon footprint (CFP) due to heating and shipping, conservation of water, and pesticide use (Krug et al., 2008; Lopez et al., 2008).

According to Phills et al. (2008), **social sustainability**, or social value, is "the creation of benefits or reduction of costs for society—through efforts to address social needs and problems—in ways that go beyond the private gains and general benefit of market activity" (Phills et al., 2008, p. 39). Social sustainability when it comes to agriculture has two main elements: (1) ensuring the well-being of the farming community and (2) fulfilling society's demands, from necessities such as food security and safety, to luxury or cultural goods with an aesthetic value (Lebacq et al., 2013; van Cauwenbergh et al., 2007).

Social sustainability goals for nursery plant production were defined as "maintain stable communities and quality of life" (Krug et al., 2008, p. 43). Social sustainability themes were also concerned with maintaining a safe working environment and supporting communities by hiring local residents and purchasing locally (Krug et al., 2008; Lopez et al., 2008).

A further distinction is made between goal-oriented and means-oriented approaches to sustainability evaluation. In goal-oriented approaches, sustainability is viewed as a property of a system and therefore the emphasis is on the capacity of the system to meet specific goals (Binder et al., 2010). In this approach, sustainability assessment is based on the formulation of distinct sustainability aims to reach a sustainable state. The state of the system is then assessed using selected indicators to measure specific parameters. For instance, soil health is indicated by parameters for microbial biomass and activity (Wirén-Lehr, 2001). In means-oriented approaches, achieving sustainability is dependent on adopting sustainable techniques or techniques that are considered more sustainable than others (Binder et al., 2010). Under this concept, management strategies that are considered sustainable have to be defined (e.g., organic farming). Agricultural systems that implement specific practices that were defined as sustainable—e.g., crop rotation—are measured directly (Wirén-Lehr, 2001). Still, according to Wirén-Lehr (2001), only goal-oriented concepts allow for adaptation for case- and system-specific sustainability assessment.

System-specific adaptation of assessment tools has been elaborated at the normative, temporal, and spatial dimensions (Wirén-Lehr, 2001). The normative dimension deals with normative environmental, economic, and social settings and with the question of what to assess and how to assess it within a studied system (Binder et al., 2010; Wirén-Lehr, 2001). The normative dimension generally corresponds to the specific sustainability challenges in the sector (Binder et al., 2010). The spatial dimension corresponds to assessment at the field, farm, regional, national, and global scales. The temporal scale ranges from assessment of short-term aspects of a system, taking days or weeks, to assessment of long-term aspects that can cover timeframes of years (Wirén-Lehr, 2001).

2.2 Theoretical and practical implications of sustainability assessment tools

The general aim of sustainability indicators is to support the shift toward sustainability. Specifically, the desired outcome is to identify critical points of impact, followed by the implementation of strategies to improve sustainability (Wirén-Lehr, 2001). This type of measurement can further support policy makers in decision-making and increase public awareness (Lyytimäki et al., 2013). According to Binder et al. (2012), an assessment tool can play a role in improving the performance of a system in two ways: (1) keeping system performance within the limits that were set in the reference values for each indicator, (2) changing system conditions through policy, regulations, and the market. In the latter case, the assessment provides stakeholders with knowledge for the discussion of different alternatives. According to Schader et al. (2017), sustainability assessment can potentially contribute to agricultural policy by monitoring sustainability performance and by supporting policy makers in allocating funds to farmers based on the extent to which they meet sustainability goals. Furthermore, sustainability assessment frameworks help to design and target agricultural policy by defining what is sustainable (Schader et al., 2017). Sustainability assessments can further serve policy makers by measuring how development actions contribute to sustainability goals, as well as monitoring how their interventions affect a chain's sustainability performance (Acosta-Alba et al., 2022). Binder et al. (2010) differentiate between the monitoring of changes in systems over time and comparison between different systems, also known as benchmarking. Monitoring over time can provide evaluation of the effect of policy strategies on systems' sustainability performance. Evaluation of differences in geographical, economic, or social conditions between systems can support policy strategies at the international level (Binder et al., 2010).

Sébastien and Bauler (2013) differentiate between the "use" and the "influence" of indicators. "Use" means the handling of indicators by actors to peruse their original purpose for assessing sustainability, whereas "influence" refers to the influence of indicators on policy makers, regardless of the assessment. The influence of sustainability indicators on policy and society can be direct or indirect (Figure 4). Direct influence can take place through their use, whereas indirect influence occurs through the process of designing and developing indicators or the existence of an indicator or set of indicators (Lehtonen et al., 2016). On the one hand, the use of indicators does not always result in influence and might even have negative or unintended results. On the other hand, even indicators that are not used (indirect) might generate influence (Lehtonen et al., 2016; Lyytimäki et al., 2013). It is argued, for example, that elaboration of the indicators and their formulation can have influence through the initiation of dialogue and discussion (Sébastien & Bauler, 2013). Furthermore, indicator development, in some cases, can help to formulate and simplify problems and solutions. Such simplification makes the problems more accessible to non-experts and helps to mediate between different type of actors, such as those in the fields of policy and science, and those in society more broadly (Lehtonen et al., 2016).

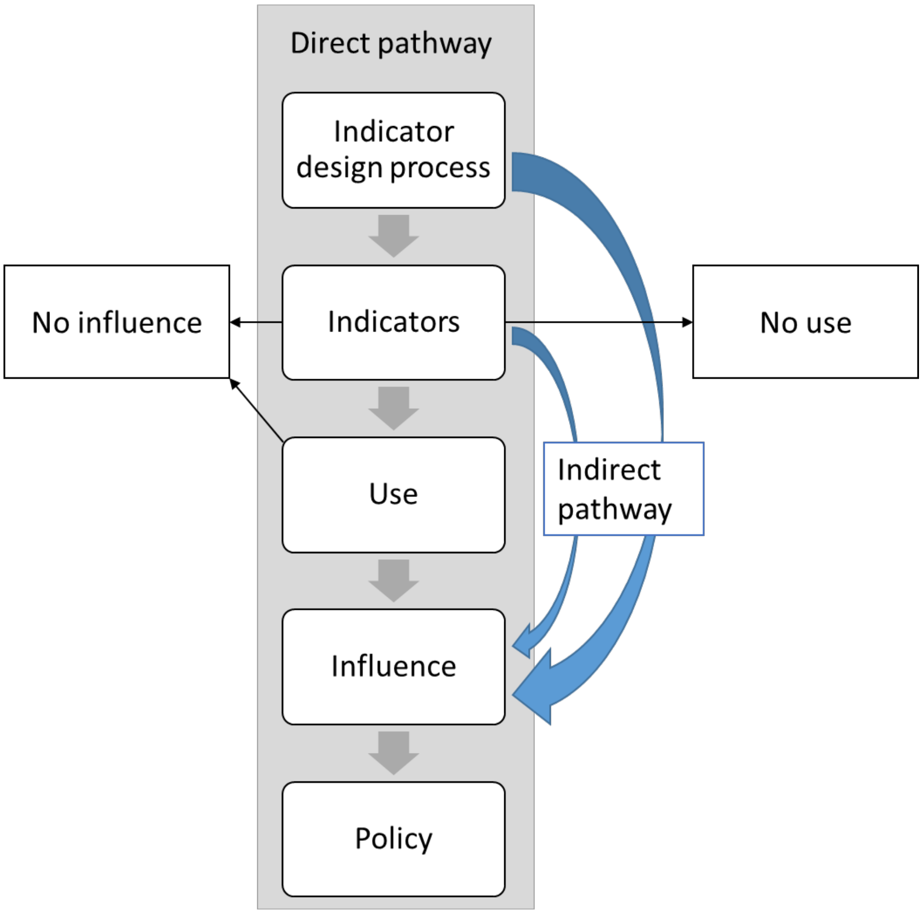

Figure 4: Direct and indirect theoretical pathways by which indicators can influence policy (and society).

Source: adjusted from Lehtonen et al. (2016).

2.3 Development of system-specific assessment methods for agricultural systems

Few examples of frameworks developed for specific agricultural systems are available (Table 2). Chain mapping or characterization is proposed as the first step for assessing sustainability in value chains (O'Rourke, 2014). In some cases, chain characterization is integrated as a stage in the development of the assessment method, such as in Binder et al. (2012) and Galli et al. (2015). Binder et al. (2012), for example, characterized the Swiss milk value chain as a first step in the assessment. Galli et al. (2015) analyzed each step in bread supply chains in Italy, to assess their sustainability performance. Acosta-Alba et al. (2022) mapped fisheries value chains in order to facilitate their sustainability assessment. In other studies, information about the system appears as background information or not at all (Gasso et al., 2015; Petit et al., 2018; Schmitt et al., 2016; Schwarz et al., 2016). Petit et al. (2018), for example, developed a framework for the indicator-based assessment of a French pork value chain. In the latter study, data was retrieved from two French cooperatives that, combined, represent the entire value chain (Petit et al., 2018). However, the value chain is not explicitly investigated and its characterization is possibly based on previous knowledge. The difference in approach can be explained by the level of knowledge on the system at the starting point.

The scope of the assessment framework generally includes the production or farming stage. Other upstream stages, such as fodder production in case of milk (Binder et al., 2012) or breeding (Petit et al., 2018), might also be included. Downstream stages, such as processing, distribution, retail, and consumption (Binder et al., 2012; Galli et al., 2015), might be also included in the scope of a sustainability assessment. Themes of consumer safety and consumer communication are generally included in the assessment scope (Schmitt et al., 2016). However, consumer behavior is generally assessed in cases of significant environmental impact. For example, the consumption stage is often considered for the assessment of agri-food products. In such cases, consumer behavior related to transporting food home, food preparation, and disposal can contribute to a significant water and carbon footprint (Soode et al., 2015). The impact of customer transport on product carbon footprint (PCF) was likewise assessed for the flowering plant poinsettia (Soode et al., 2013). Nevertheless, according to Soode et al. (2013), even the considerable impact of customer transport on total PCF has little influence on customer shopping habits. Retailers are mostly assessed for chain power and chain revenue distribution (Schwarz et al., 2016). Assessing market power (Binder et al., 2012) and revenue distribution in the value chain might be relevant due to the increased power of retailers compared to other chain actors.

Different terminology has been used in the literature to describe the sustainability challenges of a system—critical issues (Galli et al., 2015; Nadaraja et al., 2021; Schwarz et al., 2016), key sustainability issues (Gasso et al., 2015), hotspots (Galli et al., 2015; Petit et al., 2018)—and the most important environmental, social, and economic aspects of a system (Binder et al., 2012). Some studies conducted research, which generally included a literature review and stakeholder interviews, in order to identify sustainability challenges as a separate development phase of an assessment framework (Galli et al., 2015; Gasso et al., 2015; Petit et al., 2018). Siebert et al. (2018), screened sustainability standards in order to identify sustainability challenges associated with the wood-based product chain. This information was then complemented with a literature review of case studies and stakeholder interviews (Siebert et al., 2018).

After determining the sustainability challenges, suitable indicators to assess the relevant sustainability themes are generally adopted from existing assessment methods. The standardized LCA is implemented in some frameworks for the assessment of environmental impacts (Binder et al., 2012; Petit et al., 2018). Other frameworks adopted indicators from universal sustainability assessment methods such as RISE, SAFA (Schmitt et al., 2016;

Schwarz et al., 2016), corporate social responsibility (CSR), and Multi-attribute Assessment of the Sustainability of Cropping systems (MASC) (Petit et al., 2018).

An alternative approach is to leave out the development phase of determining sustainability challenges and search directly for indicators. For example, in a recent study, Nadaraja et al. (2021) searched for literature assessing the sustainability of agricultural plantations in order to identify the most commonly used indicators. Another study conducted direct literature research for indicators to assess agroforestry systems (Mullender et al., 2020).

Different authors emphasize the importance of involving stakeholders in the design process of an assessment method. Binder et al. (2010) claim that the participation of stakeholders in the research process is valuable to include a diversity of viewpoints. This allows a comprehensive understanding of the complexities of social, economic, and environmental issues. Stakeholder involvement during the design of the sustainability tool can further increase the acceptance of it and support its implementation (Coteur et al., 2018), as well as the acceptance of the results of the assessment (Gasparatos, 2010). Furthermore, the decision of when and how to involve stakeholders has to be taken in the preparatory stage (Binder et al., 2010). Mullender et al. (2020) claim that the subjectivity of the developer, determined by values and beliefs, can influence the decision-making process (Mullender et al., 2020). However, according to Gasparatos (2010), assessment tools are not neutral in terms of judgment value. In fact, each tool exhibits embedded value judgments, which determine what is important and relevant for the assessment and can further influence the outcome of the assessment. Thus, stakeholders' involvement in the development process does not neutralize the tool, because they bring their own value judgments. To overcome this subjectivity, Mullender et al. (2020) adopted a participatory or bottom-up approach to involving stakeholders in decision-making. Groups of stakeholders were involved in a Delphi approach to determine a final set of indicators for the assessment of agroforestry systems. Nevertheless, in their study, Mullender et al. (2020) emphasized difficulties in the Delphi process, claiming that different stakeholder groups have different interests and that they lack understanding of other stakeholder groups. Furthermore, stakeholders generally lack a comprehensive scientific knowledge of the subject and had difficulty understanding the indicators and the approach. Because of these limitations, stakeholder groups experienced difficulties reaching agreement on a final set of indicators.

The present study is not a typical bottom-up approach where stakeholders are directly involved in designing the sustainability framework. It is rather a mixed participatory approach, as stakeholders are involved in the research stage and contribute from their hands-on experience, knowledge, and opinions to characterize the system and the sustainability challenges. However, at later stages, the researcher determines themes, subthemes, and indicators, based on stakeholders' knowledge and perspectives and backed up with scientific data, to develop a comprehensive framework. Involvement of stakeholders and chain actors will be relevant in the future development phases, namely conducting the assessment and implementing indicators.

Table 2: System- or sector-specific sustainability assessment frameworks of agricultural systems

Reference	System/sector	Analysis/characterization of system	Dimensions	Source of themes or indicators or framework	Selection of themes/indicators
Binder et al., 2012	Swiss milk value chain	literature review, newspaper texts, and expert interviews	Environment, social, economy	Environment: LCA impact categories Socio-economic indicators (Binder et al., 2008; Schmid A., 2008)	Indicator selection: literature review and expert validation. Selection criteria only for ecological indicators.
Coteur et al., 2018	Different sectors (farm level): fruit production, beef production, greenhouse production, and arable farming	No description or characterization of system	Environment, social, economy	Stakeholder interviews for each subsector. Clustering of topics into themes.	Indicator selection from a pool of indictors of published peer-reviewed tools and verification with stakeholders.
Galli et al., 2015	Local and global wheat-to-bread chains supplying Italy	Case study analysis: in-depth interviews with stakeholders	Environment, social, health, ethical, economy	Indicator development by experts	Literature review to determined critical issues.
Gasso et al., 2014	Danish maize for German biogas	Case study: characterization is not elaborated	Environment, social, economy, governance	RSB, SAFA, and S-LCA	Key sustainability issues were selected; qualitative analysis of stakeholder interviews.
Lazzerini et al., 2018	Ornamental plants—container and open field production	Case studies: nursery farms were analyzed to characterize the system	Environment	Indicators from different sources (Lazzerini et al. 2018)	Issues for assessment based on previous projects.
Mullender et al., 2020	Integrated food/non-food system (agroforestry)	No description or characterization of system	Environment, social, economy, governance	Modification of Public Goods (PG) tool SAFA as reference for themes	Literature search to identify initial list of indicators. Delphi (experts) approach to identify sustainability indicators.
Nadaraja et al., 2021	Plantation agriculture	Entire plantation agriculture sector (no characterization of system)	Environment, social, economy, governance	UNCSD framework and literature assessing sustainability of agricultural plantation	Literature review to identify relevant indicators used to assess sustainability in agricultural plantation, categorizing indicators according to themes of UNCSD framework.
Petit et al., 2018	French pork value chain (case study)	Case study: data was retrieved from two French cooperatives	Environment, social, economy	CSR, MASC, LCA	Hotspots determined by stakeholder interviews.
Schmitt et al., 2016	Global and local cheese chains	Case study definition (process is not elaborated)	Environment, social, health, ethical, economy	SAFA, RISE, additional indicators were created and consulted on with stakeholders	Literature review and qualitative analysis to identify attributes followed by interviews with actors and finalized by Delphi survey.
Schwarz et al., 2016	Peruvian and Belgian asparagus value chain	Case studies: characterization is not elaborated	Environment, social, economy, governance	Most indicators from SAFA	Critical issues identified through stakeholder interviews.
Siebert et al., 2018	Wood-based bioeconomy products from Germany	The production system is presented and regional boundaries of the system are defined	Social	ISO 26000,SA 8000,Global Reporting Initiative (GRI), Sustainability Code, National Sustainable Development Strategy, Forest Stewardship Council (FSC) Germany, and Programme for the Endorsement of Forest Certification (PEFC) Germany	Screening of sustainability standards, case studies, and stakeholder interviews to identify sustainability themes and indicators. Indicators were selected based on their feasibility.
Yakovleva, 2007	Food supply chain (case studies of chicken and potatoes in the UK)	Case studies are described in previous publications (Yakovleva & Flynn, 2004b); supply chain was investigated by conducting interviews with stakeholders (Yakovleva & Flynn, 2004a)	Environment, social, economy	Indicators were developed based on the sustainable development objectives (agenda 21) (Yakovleva & Flynn, 2004b)	9 indicators were selected out of a list of 50 indicators, based on data availability.
Zaralis et al., 2017	Sheep and goat farming systems (EU)	Sheep and goat farming systems in Europe (no characterization of system)	Environment, social, economy, governance	SAFA and PG Tool	Literature review of tools and indicators, followed by online survey with stakeholders .and workshop discussions to select appropriate indicators (no list of indicators presented).

2.4 Sustainability innovations

Adoption of innovations by firms is important to sustain their competitive advantage in the face of increased competition and changing markets (Hermundsdottir & Aspelund, 2021). Innovations are defined by their novelty, context, or application and by offering improvement: the process or the outcome are more effective or more efficient (Phills et al., 2008). The OECD definition refers to innovations at the firm level and includes product, process, organizational, and marketing innovations (Bitsch, 2016). According to Porter (1998), innovations can also lead to structural changes within industries, referring to product, process, and marketing innovations.

Sustainability innovations improve sustainability performance compared to the alternatives and thus contribute to achievement of sustainable development goals (Boons et al., 2013; Klewitz & Hansen, 2014). Furthermore, since sustainability challenges can be viewed as a business opportunity (Boons et al., 2013), implementation of sustainability innovations has the potential to contribute to firm competitiveness (Hermundsdottir & Aspelund, 2021). However, the adoption of sustainability innovations is often associated with uncertainty because the relative sustainability improvement compared to the alternatives is often not determined. Moreover, some innovations might introduce trade-offs between different dimensions of sustainability (Hansen et al., 2009; Klewitz & Hansen, 2014).

Sustainability innovations can be clustered into environmental, social, and economic sustainability innovations. Environmental innovations are designed to reduce or prevent environmental impacts (Klewitz & Hansen, 2014). Three types of innovations have been defined in the context of environmental innovations (Klewitz & Hansen, 2014). Process innovations are related to manufacturing processes and technology (Porter, 1998), which may relate to efficiency in energy use or water-saving technologies, for example, as well as clean technologies that prevent pollution. Product innovations are related to change in the characteristics or qualities of the product, such as the choice of material (e.g., recycled or organic) (Klewitz & Hansen, 2014; Porter, 1998). Organizational innovations are new forms of management and reorganizations of structures (Klewitz & Hansen, 2014). According to Phills et al. (2008), social innovations create social value in situations of market failure when needs cannot be met otherwise. The value created is designed to benefit the public or society as a whole (e.g., labor standards) (Hermundsdottir & Aspelund, 2021; Phills et al., 2008). Economic sustainability innovations contribute to growth or capital stock retention without compromising environmental or social sustainability goals (Havardi-Burger et al., 2020). Sustainability labels are marketing innovations aimed at product differentiation and premium price. Such labels can be considered an example of economic sustainability innovations because they are designed to increase market share and the profitability of the product, without compromising environmental or social goals.

External pressure due to negative environmental and social impacts, as well as internal motivation for competitiveness, drives firms to adopt sustainability innovations. Governmental regulatory pressures and normative pressures (e.g., from NGOs and other actors) are considered an important external driver for firms to adopt sustainability innovations (Berrone et al., 2013), while cost reduction and firm reputation are considered typical internal motivations for the adoption of sustainability innovations (Hermundsdottir & Aspelund, 2021).

Evaluating sustainability impacts in the system can support decision-making around the adoption of sustainability innovations. In fact, according to Rogers (2003), the first stage in a decision process for innovation adoption is becoming aware of the problem (Rogers, 2003). Nevertheless, once the problem has been identified, a decision should be made as to which alternative is more sustainable and hence a more suitable solution. For example, there is a need to reduce the use of peat as a growing medium in order to reduce CFP. The choice of which alternative growing media to adopt has to be based on profound knowledge of the carbon footprint associated with the production and transport of the product. LCA of environmental sustainability innovations can provide evaluations that compare different alternatives, such as alternative growing media, or containers made from different materials. Stucki et al. (2019), for example, investigated the characteristics, availability, environmental sustainability, and social impacts of peat substitutes by performing LCA (Stucki et al., 2019). The costs and complexity of implementation are also important factors in the decision to adopt a preferable alternative. Ruett et al. (2020) suggested evaluating the economic competitiveness of innovative practices compared to current practices using the decision evaluation model. A partial farm budget is a decision evaluation method that was used to calculate the net benefits of an innovative technology or practice by comparing the benefits and costs to current practices in ornamental plants (Ruett et al., 2020).

3 Methods

The methods chapter is divided into two main parts. The first part is dedicated to the methods employed for the characterization of the value chain (Paper 1) and the investigation of environmental, social, and economic sustainability challenges (Paper 2). In the second part, an overview is given of the methods implemented in Paper 3 for the development of the sustainability framework. In the first subsection of the second part (3.2.1), the procedure for determining social, environmental, and economic themes and subthemes is elaborated. The second subsection (3.2.2) describes the methods employed for indicator selection and development.

3.1 Value chain characterization and investigation of sustainability challenges

Chain mapping is essential for determining chain sustainability (Moreno-Miranda & Dries, 2022) and is required as the first phase in the development of an assessment method (Acosta-Alba et al., 2022; van Cauwenbergh et al., 2007). Characterizing chain configuration requires mapping material flows, as well as classifying actors and activities and geographical distribution (Acosta-Alba et al., 2022; Moreno-Miranda & Dries, 2022). Binder et al. (2012) characterized the Swiss milk value chain based on literature review, newspaper texts, and expert interviews as the first step in the application of the assessment tool. Galli et al., (2015) conducted in-depth interviews with different stakeholders in order to analyze each stage in the supply chain.

The system that is under investigation in the present work is a floricultural value chain. In a preliminary study, the value chain of different commercially important floricultural products—among them cut flowers, perennials, and potted flowering plants—was investigated. It was shown that different FPP products, propagated from either seeds or cuttings, share similar value chain stages and processes and therefore can be characterized as a homogenized value chain shared by many potted-plant products (Havardi-Burger et al., 2017). On the contrary, cut flowers and perennials showed large diversity within each product group and therefore could not be characterized as single, uniform value chain.

There were several reasons for the decision to focus on the value chain of FPPs supplied to the German market in this dissertation. Other than identifying homogenized chain stages, processes, and value-adding activities in the value chain of FPPs, the chain has not been well studied, although it has an important commercial role, accounting for an estimated third of the market value of ornamental plants in Germany.

To characterize the FPP chain, value chain activities, material flows, and processes were investigated through interviews with different chain actors. Chain actors such as breeders and growers possess unique insights and hands-on experience of material flows and processes within the chain. Their knowledge about the diversity of plant varieties was not available in textbooks or scientific literature. Chain actors are also stakeholders and thus their involvement in the research reveals different perspectives and viewpoints, which is valuable (Binder et al., 2010).

This step of chain characterization is then followed by the identification of sustainability challenges (Figure 5) across the value chain (Bockstaller et al., 2015; Monastyrnaya et al., 2017; O'Rourke, 2014). Sustainability challenges have been investigated across the value chain of FPPs in order to determine areas of action or sustainability themes, which is the second hierarchy level in an indicator-based assessment framework (Figure 1). There is no single standardized procedure for determining sustainability challenges, but rather it is open to interpretation. Nevertheless, it is largely carried out by means of a literature review and stakeholder interviews. Galli et al. (2015), for example, conducted literature research on sustainability attribute lists published by Kirwan et al. (2014) in combination with wheat-to-bread chains. Gasso et al. (2014) identified key sustainability issues by analyzing stakeholder interviews. Sustainability hotspots in French pork value chains were identified by interviews with different chain actors (Petit et al., 2018). Sustainability challenges in the value chain of FPPs were also investigated by performing interviews with different chain actors and conducting an extensive literature review. Both chain characterization and the investigation of sustainability challenges followed a qualitative research approach.

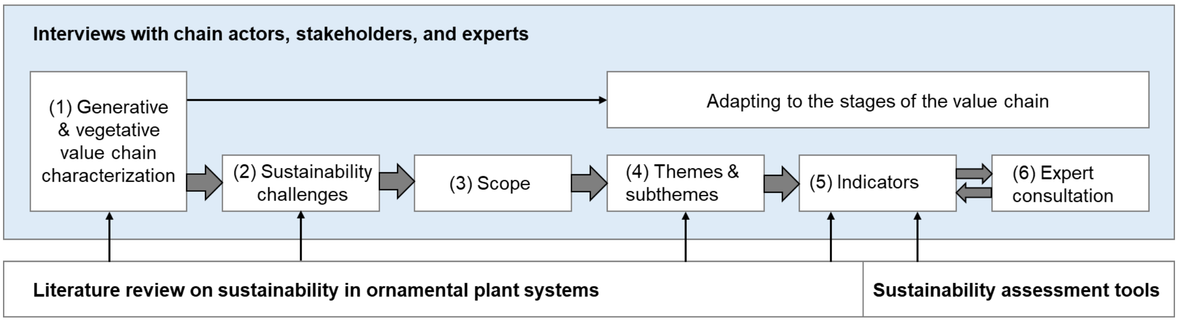

Figure 5: Steps to establish sustainability assessment method for the value chain of FPPs

Source: Havardi-Burger et al., 2021, p.4. Steps 3 to 6 are discussed in subsection 3.2.

Qualitative research is aimed at investigating topics in their natural settings and understanding phenomena based on the interpretation of the meaning that people ascribe to them (Denzin & Lincoln, 2011). As opposed to quantitative research, qualitative research deals with reading and analyzing texts (Krippendorff, 2013) and the researcher is interested in the subjective experiences and views of the research participants (Flick, 2009, p.24).

A qualitative approach is especially well suited to exploring, describing, and interpreting new topics or those that have not been well researched (Bitsch, 2005). As little is known about the value chain of FPPs and the associated sustainability challenges, a qualitative approach was chosen. Furthermore, a quantitative approach, such as a survey, is not appropriate for investigating a complex and diverse system like a value chain, as processes are not known and the possible sample is not large enough for statistical analysis. Moreover, qualitative methods are typically applied in problem-solving research (Bitsch, 2005). Because sustainability can be viewed as a wicked problem, the current study can be considered as problem-solving research, and a measurement system as a tool to manage the problem (Bitsch, 2016).

Interviewing is a common approach to data collection in qualitative research (Jamshed, 2014). In-depth interviews provide insight into the experience, views, and opinions of the participants, and allow the researcher to understand their perceptions (Arsel, 2017). In the present study, interviews were conducted in order to explore the value chain and investigate sustainability challenges across the chain. In-depth interviews were conducted using a semi-structured interview guide, which included open-ended questions. A semi-structured interview guide allows the researcher to ask multiple participants the same questions, which is important to reach data saturation (Fusch & Ness, 2015). However, as opposed to quantitative methods, such as a survey, open-ended questions leave room to collect unanticipated data (Bitsch, 2005).

Interviewees were identified through the IPM (Internationale Pflanzenmesse) exhibitor list, which is an international horticultural trade fair, taking place yearly, in Essen, Germany. Interview candidates were sent a written invitation and were encouraged to contact the researcher if they were willing to participate. Further recruitment was conducted following a snowball approach, as some participants suggested more potential interviewees. The snowball sampling method “involves seeking information from key informants about details of other ‘information-rich cases’ in the field” (Suri, 2011, p. 6). Interviews were conducted in two rounds, in the winters of 2016 and 2017. In the first round, interviewees were asked to describe activities and processes in the value chain. The interview guide covered the chain stages of breeding, propagation, young plants, potted plants, logistics, and distribution. The second-round interview guide was structured to fill in the remaining gaps about the value chain and to investigate social, environmental, and economic sustainability challenges across the chain. Therefore, the interview guide included also questions about procedures associated with environmental and social topics, as well as economic difficulties in the business, or the sector. In addition to questions about specific sustainability challenges, actors were also asked what they consider to be sustainability challenges associated with the value chain of FPPs.

Twenty in-depth interviews were conducted with different chain actors, including representatives of propagation nurseries, seed producers, growers, and wholesalers (Table

3). Three stakeholders who are not direct actors in the value chain were also interviewed, including a certifier, a business consultant, and a retail expert.

Topics were presented to the interviewee in a flexible manner according to the conversational flow, and adjusted to the type of interviewee, and to their profession, function, and business. Interviews were carried out in person, audio recorded, and transcribed verbatim, using the transcription software f4. Transcription was conducted in the original language, English or German, focusing on the content.

Table 3: Number of interviews conducted according to stakeholder groups and business actions

Interviewee groups	Business actions	Number of interviews (n=20)
Propagation nursery	Breeding, propagation material, and young plants	7
Seed producer	Breeding and seed production	4
Grower	Young plants and potted plants	3
Wholesaler	Growers' organization and distribution	3
Certifier	Certification	1
Business consultancy	Ecological Footprint	1
Retail expert	Academic research	1

Qualitative content analysis is a method that is focused on describing and interpreting the meaning of the data (Schreier, 2012). It is done by systematically classifying text fragments to a coding system. The classification of text fragments to different codes is based on their meaning in relation to the research question or aims. The process of developing codes is referred to as an open coding process (Bengtsson, 2016). Code generation can be concept-driven (deductive) or data-driven (inductive). According to Schreier (2012), code development is often a combination of a deductive approach determined by the research question and an inductive approach employed to describe the material in depth. In the current work, the analysis followed this hybrid approach. A deductive approach was used, as some knowledge already existed on the value chain stages (Paper 1) and social and environmental aspects of sustainability (Paper 2). The inductive approach was implemented to explore further processes and activities in the value chain, as well as chain drivers (Paper 1). Further sustainability challenges, especially regarding economic sustainability, as well as sustainability innovations, were also analyzed inductively (Paper 2).

The constant comparative method is an approach used to interpret qualitative content. The principle of this analysis process is comparison, contrasting and reflecting. In this systematic process, text fragments of newly collected data are coded and are repeatedly compared to already coded, previously gathered data (Bowen, 2008). The constant comparative method was employed to qualitatively analyze the content of the transcribed interviews using the

software ATLAS.ti. During the analysis, text fragments were labeled with codes that reflect their meaning. In a later stage, related codes were grouped into code families. Patterns were identified in an ongoing process of constantly contrasting and comparing (Boeije, 2002; Bowen, 2008; Corbin & Strauss, 2015). Text fragments of each code or code family were compared to identify patterns. Moreover, during the analysis process, ideas and thoughts were documented and considered later for the interpretation of the results.
The focus in the analysis was on the following topics:

1. Processes and value-adding activities within the chain of FPPs (Paper 1)
2. Driving forces in the value chain of FPPs (Paper 1)
3. Environmental, social, and economic sustainability challenges across the value chain of FPPs (Paper 2)
4. Implementation of sustainability innovations within the value chain of FPPs (Paper 2)

3.2 Development of a sustainability framework for the FPPs value chain

The interviews conducted in the present study continued to serve as a basis for the development of the sustainability framework, and also supported scope definition, the determination of themes and subthemes, and the selection and development of indicators (Figure 5).

3.2.1 Scope definition

The boundaries of the system or the scope of a framework is determined according to the product life cycle and its spatial and temporal elements (van Cauwenbergh et al., 2007). According to Bockstaller et al. (2015), the boundaries of the system should generally include all sustainability issues of concern and all the relevant locations (spatial) that may suffer due to negative impacts from the system (Bockstaller et al., 2015). Based on the SAFA guidelines, the scope for value chain assessment should include all processes that generate significant sustainability impacts and are part of production or distribution (FAO, 2014). In the present study, the scope was defined to include all value chain stages that are likely to contain significant sustainability impacts and the geographical sites associated with these impacts in the chain. Temporal elements were considered in the assessment when they were found to be relevant. For example, the indicator “net income,” adopted from the SAFA framework, is measured for a period of five years.

3.2.2 Determining social, environmental, and economic themes and subthemes

Themes and subthemes were determined by the characterization of the value chain and the investigation of sustainability challenges across the value chain. Subthemes were developed for each theme by defining specific sustainability objectives. The objectives corresponded to the sustainability goals for sustainable development in agriculture defined

by the FAO (2014), and the specific area of action for potted plant production in greenhouses set by Krug et al. (2008).
Furthermore, during the investigation of the value chain and the role of the different actors, it became apparent that themes from each sustainability dimension should be allocated differently across the value chain.

3.2.3 Indicator selection and development

Different approaches have been used for the selection of the indicator set in the development of agricultural frameworks. Binder et al. (2012) selected environmental indicators from the LCA impact categories, as well as socio-economic indicators, after setting a range for each of the indicators. Indicators that resulted in the highest impact were selected for the final framework. Indicators for the French pork value chain were chosen from three sustainability frameworks, CSR, LCA, and MASC, to match chain hotspots as expressed in interviews by chain actors (Petit et al., 2018). In a different study, Schmitt et al. (2016) selected indicators from RISE and SAFA to compare Swiss and UK cheese product chains. According to Schmitt et al. (2016), these two frameworks were chosen due to the thorough explanation of the measurement method provided for each indicator and the possible application of a benchmark system. Additional indicators were created if necessary and were consulted on with relevant stakeholders (Schmitt et al., 2016). Indicators for assessing the Peruvian and Belgian asparagus value chains were adapted from the SAFA framework (Schwarz et al., 2016). Other studies conducted a literature search to identify suitable indicators. Mullender et al. (2020) searched the literature for suitable indicators for agroforestry. Nadaraja et al. (2021) also conducted a literature review to identify relevant indicators used to assess sustainability in agricultural plantations, and categorized the indicators according to themes of the United Nations Commission on Sustainable Development (UNCSD) framework. Searching the literature for suitable indicators might be applicable for some agricultural sectors, where there is a diversity and abundance of peer-reviewed sustainability assessments. However, in the ornamental plants sector, sustainability assessments have mostly been conducted implementing LCA, S-LCA, CFP, or water footprint analysis. The above-listed methods were not found suitable as indicators for the framework developed for the FPPs chain.
The abundance of indicator-based tools developed to assess agricultural systems can serve as a pool for potential indicators. Indicators from existing tools are likely to have been tested and optimized. In the present study, the most suitable sustainability assessment tools were discovered using literature reviews that compared existing assessment tools (Arulnathan et al., 2020; Bonisoli et al., 2018; Coteur et al., 2020; de Olde et al., 2016; Christian Schader et al., 2014). Bonisoli et al. (2018) suggested a process for the selection of the most suitable assessment tool for a given agricultural system. The process includes: (1) defining criteria

for indicator selection, (2) analysis of frameworks' characteristics, (3) categorization according to framework features, and finally (4) selection of a framework with suitable indicators (Bonisoli et al., 2018). Since the purpose of the current study is not to implement an existing tool but rather to locate suitable indicators, the following criteria were defined in order to choose suitable tools: (1) universal framework for agriculture, or sector-specific for ornamental plants, (2) comprehensive collection of indicators, preferably including all three dimensions of sustainability, (3) international tool, not country-specific, and (4) availability of comprehensive explanations of the method in English (Havardi-Burger et al., 2021). Industrial ecology assessment approaches, such as environmental LCA, were excluded as a source of indicators because they are intended to assess product performance rather than chain stage performance. Moreover, LCA impact categories do not match the sustainability themes and subthemes defined for the FPPs chain. Furthermore, the assessment itself is quite complex and thus unsuitable for self-implementation by chain actors, which is the target group of the present framework.

Three assessment tools were found suitable as a potential source of indicators for the development of a framework for the assessment of the FPPs chain (Table 4): SAFA and (RISE) as non-specific (universal) tools, as well as Lazzerini et al. (2018), developed specifically for outdoor ornamental plants (Havardi-Burger et al., 2021).

Table 4: Sustainability assessment methods selected as a potential source for suitable indicators

Method	Sector	Dimension	Assessment level	Reference
Lazzerini et al. (2018)	Ornamental plants	Environmental	Nursery, container, and open field production	Lazzerini et al., (2018)
RISE	Universal for agriculture	Environmental, economic, social	Farm	RISE 3.0 - Manual (Grenz et al., 2016)
SAFA	Universal for agriculture	Environmental, economic, social, governance	Supply chain	SAFA Guidelines, SAFA Indicators and SAFA Tool (FAO, 2014)

Source: adjusted from Havardi-Burger et al., 2021, p.12.

Different criteria for the process of indicator selection are discussed in the literature. Binder et al. (2010) suggested three main criteria for choosing indicators: (1) goal orientation, (2) system representation, and (3) data availability. Bonisoli et al. (2018) conducted a literature review and identified nine criteria, which can be divided into criteria associated with intrinsic requirements and criteria related to the usefulness of the indicator. Under intrinsic requirements are data availability, relevance, analytic validity, and flexibility with regard to changes and measurability. The usefulness of the indicator can be determined by policy relevance, as well as by whether it is implementable by farmers, understandable, and acceptable to users.

For the purposes of the current study, four criteria for indicator selection were found relevant and were adopted from the literature discussed above:

(1) Relevance, or how well the indicator fits the sustainability objective;

(2) Data availability, or whether data is likely to be available for the assessment;

(3) Understandability, or whether the measurement method is clear;

(4) Applicability, or whether the indicator is not too complicated, referred to as measurability by Bonisoli et al. (2018).

The procedure for indicator selection in the current study started with defining the measurement parameters. If an existing indicator was located that could measure the defined parameters, it was considered to comply with the criterion “relevance.” Indicators identified in this way were subsequently examined for the criteria “understandability,” referring to the clarity of the method, and “applicability” by assessing the complexity of the method. Data availability was also assessed by examining the likelihood and complexity of accessing data or the availability of data. If no suitable indicator was located from the existing methods—SAFA, RISE, or Lazzerini et al. (2018)—a new indicator was developed to assess the subtheme. In order to examine the validity of the newly developed indicators, expert consultation was carried out. Consultation was conducted with five experts in order to examine the relevance of subthemes and assess the feasibility of implementing the indicators. Two interviews were conducted with experts on propagation nurseries and breeding, one interview with an expert on breeding methods and production technology of ornamental plants, another interview with an expert on production techniques of bedding plants and flowering indoor plants, and a further interview with an expert on horticultural production and innovations and ornamental breeding. In a few indicators, further adjustments were implemented following the expert consultations.

4 Publication record

This thesis comprises three research papers. Havardi-Burger is the first and corresponding author of all three articles. This chapter provides a summary of each publication, with an indication of the contribution of the candidate to each of the articles.

4.1 Article I: Driving forces and characteristics of the value chain of flowering potted plants for the German market

Reference:
Havardi-Burger, N., Mempel, H., & Bitsch, V. (2020). Driving forces and characteristics of the value chain of flowering potted plants for the German market. *European Journal of Horticultural Science 85* (4), 267-278. doi.org/10.17660/eJHS.2020/85.4.8

Summary (I):
The first article investigated the value chain of FPPs supplying the German market and the drivers influencing chain actors. A value chain activity-based view provides the basis for strategy development for competitive advantage. The research builds on strategic and horticultural value chain literature. Qualitative research was chosen because it is especially suited to generating knowledge when the subject of interest is relatively unexplored. Twenty in-depth interviews were conducted with chain actors from different stages in the value chain. The collected data was analyzed via qualitative content analysis. Results indicated that the value chain of FPPs is divided into two pathways, owing to distinct propagation techniques, either vegetative (cuttings) or generative (seeds) (Figure 6). Furthermore, while propagation material is generally cultivated in southern countries, mainly in Africa and Central America, young plants and potted plants are produced within Europe. The geographic fragmentation in several production steps contributes to production efficiency and quality. Nevertheless, coordination between actors is crucial because of product perishability and the requirement for on-time delivery. The article identified driving forces classified under (1) economic framework, (2) natural environment, (3) politics, regulation, and innovation, and (4) technological progress. Examples of these chain drivers are weather conditions, innovations, retailer requirements, and price pressure. The study further provides an overview of processes and chain activities to assist the sector in predicting developments, and to support stakeholders in future strategic decisions. In addition, chain analysis of value-adding activities and processes provides the foundation for the development of a system-specific sustainability assessment framework for the value chain of FPPs.

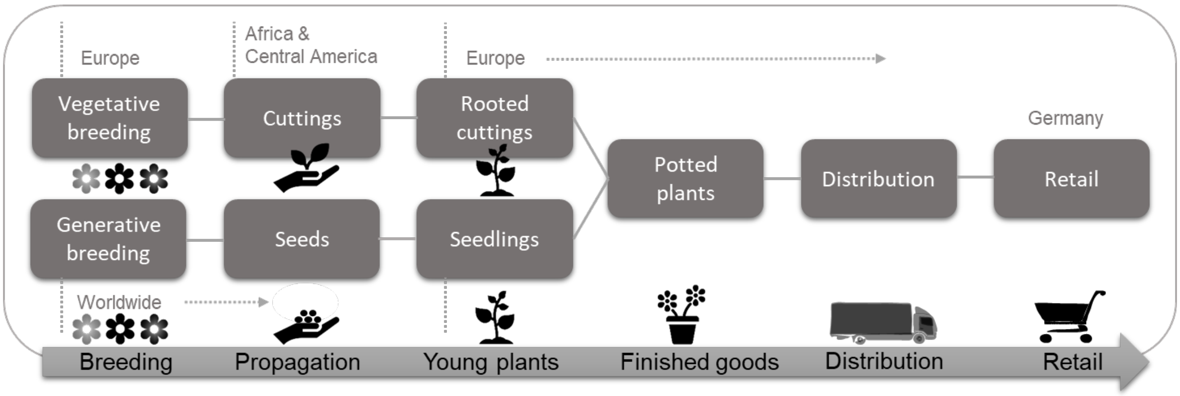

Figure 6: Vegetative and generative value chain pathways, as well as location of chain stages

Source: Havardi-Burger et al. 2021, p. 2

Author's contribution

The first author (Havardi-Burger) was responsible for data curation and analysis, which included conducting and recording the interviews and performing qualitative data analysis and interpretation. Furthermore, Havardi-Burger carried out a literature review on the value chain, developed the theoretical background on driving forces in the value chain, and wrote and prepared the original draft.

4.2 Article II: Sustainability challenges and innovations in the value chain of flowering potted plants for the German market

Reference:

Havardi-Burger, N., Mempel, H., & Bitsch, V. (2020). Sustainability challenges and innovations in the value chain of flowering potted plants for the German market. *Sustainability 12* (5), 1905. doi.org/10.3390/su12051905

Summary (II):

The second study investigated the sustainability challenges and the adoption of sustainability innovations across the value chain of FPPs supplying the German market. Eighteen in-depths interviews were conducted with different value-chain actors and data was analyzed through qualitative content analysis. Sustainability challenges were investigated from the breeding stage, followed by the propagation level. The propagation of cuttings takes place mostly in African countries, whereas rooted cuttings and potted plants are produced in Europe. Results indicated that the main environmental challenges in the production stages include carbon footprint, water scarcity, and pesticide use. Social sustainability challenges in Africa are characterized by difficult working conditions and low wages. Social challenges in Germany, involve product transparency, and recruitment and employee retention. Economic challenges consist of the need to comply with standards and profitability. Adoption of sustainability innovations by chain actors is a means to address at least some of the sustainability challenges. Nevertheless, the implementation of sustainability innovations is frequently associated with complexity of implementation, financial risk, and increased costs. Moreover, the possibility of transferring sustainability costs to the consumer by offering a sustainable product for a premium price is precluded due to the lack of product transparency. Business-to-business private standards have generally encouraged the implementation of sustainability innovations. However, retailers have become even more powerful chain actors by setting certification as an entry barrier for suppliers.

Author's contribution

The first author, Havardi-Burger, carried out a literature review on the aspects of sustainability in the value chain and described the theoretical background of sustainability innovations. The first author carried out data collection by conducting interviews with different stakeholders and value-chain actors. Qualitative data analysis and interpretation was performed by the first author, who also wrote and prepared the original draft.

4.3 Article III: Framework for sustainability assessment of the value chain of flowering potted plants for the German market

Havardi-Burger, N., Mempel, H., & Bitsch, V. (2021). Framework for sustainability assessment of the value chain of flowering potted plants for the German market. *Journal of Cleaner Production 329*. https://doi.org/10.1016/j.jclepro.2021.129684

Summary (III):

The production and distribution of FPPs is associated with environmental and social sustainability impacts. The sustainability performance of agricultural value chains can be assessed by the implementation of indicator-based assessment methods, which supports decision-making for improving sustainability performance. The FPP value chain differs from other agricultural systems due to its distinctive features, such as production in greenhouses and cultivation in containers as opposed to field production. Thus, existing indicator-based methods designed for agricultural systems are not suitable to assess the value chain of FPPs. In this article, a sustainability assessment framework was developed specifically for the FPP value chain, from breeding to distribution. The process of framework development involved defining sustainability themes and subthemes based on the investigation of environmental, social, and economic sustainability challenges. The universal sustainability assessment methods SAFA and RISE served as sources for indicator selection and development. The present study highlighted the necessity for a system-specific inspection of unique agricultural systems such as the FPP value chain, since the universal assessment methods, SAFA and RISE, do not include all relevant sustainability subthemes. Indicators missing from the universal assessment methods were generally environmental indicators. The environmental sustainability assessment is related to product-specific processes; therefore, indicators were assigned to the value chain stages of breeding, production, and distribution. National and regional socio-economic conditions, such as the existence of social safety nets and government provision of healthcare, influenced social sustainability themes. Therefore, geographical regions and stakeholder groups determined the allocation of indicators. Industry structure and sector-specific conditions, such as high uncertainty and low margins, influenced the economic themes. The framework presented here provides an initial evaluation of suitable indicators. Further inspections are required to determine the feasibility of the suggested indicators in order to determine a final list. Implementation of the assessment method presented here will provide valuable insights into the sustainability performance of the FPP value chain. Such an assessment will support actors in making decisions for performance improvement and guide policy makers in establishing sustainability targets.

Author’s contribution

Havardi-Burger was wrote and prepared the original draft, conducted a literature review on sustainability assessment methods, and described the theoretical background for the development of the indicator framework. The results of this article build on data previously collected and analyzed by the first author, which served as the foundation for indicator selection and development.

4.4 Future development of the framework

This subsection (not published) is dedicated to suggestions for the future development of the framework and concludes by presenting a general approach for the development of a system-specific sustainability assessment method.

The next development phase of the framework presented here is to test the individual indicators with users, in order to determine their feasibility by verifying data availability, validity, and relevance as suggested by de Olde et al. (2017). Following indicator evaluation, a final set of indicators can be determined. For the evaluation of value chain performance, assessment result values have to be compared to either reference values, also referred to as absolute evaluation (Deytieux et al., 2016; de Olde et al., 2017; van Cauwenbergh et al., 2007; Wirén-Lehr, 2001), or benchmarking systems (Binder et al., 2010; Wirén-Lehr, 2001). Another possibility is to monitor a system's performance over time. In both benchmarking and performance over time, values will be compared to previous assessments and therefore considered relative evaluation (Binder et al., 2010; Wirén-Lehr, 2001). Reference values can be defined by different sources, such as: scientific publications, expert opinion, policy targets, community averages, and historic records (Deytieux et al., 2016). Benchmark systems can be developed if the assessment of different actors is reproducible and comparable (Binder et al., 2010). To simplify the comparison of results, assessment values are commonly normalized into scores (e.g., 1 to 5) (de Olde et al., 2017). Moreover, aggregation of results to the subtheme level is commonly in praxis in many assessment tools (de Olde et al., 2017). Indicator aggregation refers to the evaluation of multi-indicators as one total grade or sustainability index (Binder et al., 2010; Wirén-Lehr, 2001). In the SAFA framework, for example, aggregation of results takes place at the subtheme and theme level (FAO, 2014). Aggregation of indicators can simplify the comparison of different systems but also result in information loss about weak and strong performance points in the system (Binder et al., 2010; Coteur et al., 2018; Wirén-Lehr, 2001). Furthermore, both non-aggregated and aggregated indicators can be implemented in different stages of the assessment (Coteur et al., 2018).

A diversity of approaches for the development of sustainability assessment methods is available in the literature (e.g., van Cauwenbergh et al., 2007, and de Olde et al., 2017). The present study proposes a harmonized, general approach for the development of sustainability assessment methods (Table 5). The approach builds on literature on sustainability assessment in the agricultural sector (Binder et al., 2010; Deytieux et al., 2016; de Olde et al., 2017; Reed et al., 2006; van Cauwenbergh et al., 2007) and the practical experience acquired in the present study (Havardi-Burger et al., 2021; Havardi-Burger et al., 2020a; Havardi-Burger et al., 2020b). It is defined as a mixed top-down participatory approach because it involves stakeholders in the phases of characterizing the value chain, the investigation of sustainability challenges, and the final determination of indicators' feasibility. The stage of specifying sustainability themes and subthemes, as well as indicator selection and development, is to be conducted by the developer of the framework. Differences in the need to adopt development phases, such as chain characterization or investigation of sustainability challenges, depends upon the existing level of knowledge about the system and the previous sector-specific sustainability assessments and availability of suitable indicators.

Involving stakeholders at the research level provides valuable hands-on experience and different perspectives and approaches to sustainability. A further advantage compared to a bottom-up participatory approach, such as Delphi methodology, is that it is less complex and time-consuming, since reaching consensus among different stakeholders with contradicting interests is not necessary. Theme and subtheme definition is based on systematic investigation of the particular sustainability challenges across the chain, and not on lists of available indicators. In addition, selecting themes based on available indicators might disregard the need to assess overlooked sustainability impacts. Moreover, indicator selection is based on comprehensive knowledge of the different sustainability issues and must be consistent with the defined sustainability goals.

One potential drawback remains the willingness of actors to accept the framework and participate in future sustainability assessments. Such acceptance of the assessment tool is generally considered higher in bottom-up approaches.

The procedure for the development of a sustainability assessment framework has been developed based on literature on the agricultural sector and the experience obtained in the present study specifically for the value chain of FPPs. Nevertheless, the procedure is likely applicable to diverse industries and sectors, and is not limited to horticultural or agricultural sectors. Furthermore, although the procedure presented here is designed for assessing a value chain, the approach can be applied to develop an assessment framework of one-stage systems such as the production stage or a farm-based framework. In addition, systems such as value chains are dynamic and subject to processes of change and development. Changes in the system, such as spatial conditions, will require the developer to reconsider whether the developed assessment method is still suitable or in need of adjustments.

Table 5: General approach for the development of specific assessment method

Phase	Approach
Value chain characterization/ mapping	(1) Literature review and expert interviews with stakeholders (2) Determining chain stages and classifying actors, material flows, value-adding activities, and processes within the chain (3) Determining geographical distribution (4) Determining the economic settings in the industry
System-specific sustainability challenges	(1) Setting sustainability goals (2) Literature review and expert interviews with actors and stakeholders (3) Determining social, economic, and environmental sustainability challenges (4) Specifying sustainability themes and subthemes across the value chain, consistent with sustainability goals
Determining sustainability indicators	(1) Setting sustainability objectives for each subtheme and determining possible parameters for measurement (2) Indicator selection from existing frameworks supported by indicator selection criteria; alternatively, development of suitable indicators and expert validation (3) Determining indicators' feasibility by verifying data availability, validity, and relevance by users (conducting focus groups with users) (4) Final list of indicators
Sustainability assessment	(1) Setting specific reference values or benchmarking (2) Development of scoring system (3) Data acquisition and assessment by users (4) Reflection on the assessment method and process and determining improvement need
Evaluation	(1) Comparison of assessment results to reference values or benchmarking (2) Determining sustainability performance improvement need and prioritizing
Performance improvement	(1) Comparison of possible sustainability practices/innovations as alternatives for sustainability performance, economic evaluation, and feasibility of implementation (2) Implementation of sustainability practices (3) Monitoring sustainability performance to measure improvement

The approach is based on the following sources: Binder et al., 2010, Deytieux et al., 2016, Havardi-Burger et al., 2021; Havardi-Burger et al., 2020a, Havardi-Burger et al., 2020b, de Olde et al., 2017, Reed et al., 2006, van Cauwenbergh et al., 2007.

5 Discussion across dissertation topics

The first part of this section is dedicated to the discussion of the procedure for the development of an assessment method and the methods employed in the process. The focus in the development process is on the characterization of the value chain, scope determination, and investigation of sustainability challenges. The following subsection discusses the allocation of indicators in the framework across the value chain and the subsequent subsection discuss the assessment framework from the value chain perspective. A further subsection compares the new framework, developed in the present study, to existing sustainability initiatives in the floriculture sector, and the last subsection is dedicated to sustainability innovations.

5.1 Chain characterization and its relevance for framework development

As little was known about the value chain of FPPs, thorough and systematic investigation of the value chain was carried out to produce a detailed characterization of the system. As opposed to previous studies, the investigation of the value chain did not focus on a specific product or specific chain of actors, but identified a value chain that is shared by different products and different actors. This is rather the exception, as other studies have generally focused on a case study to analyze the system (Galli et al., 2015; Gasso et al., 2015; Giulio Lazzerini et al., 2018; Petit et al., 2018; Schmitt et al., 2016; Schwarz et al., 2016). An assessment framework designed for a specific case study might be only suitable for that particular concrete case study. However, it might be possible to extrapolate the framework to apply to different product chains or systems. In the present study, designing a framework suitable for a diversity of products was essential because, unlike agriculture, the floriculture sector is characterized by a high diversity of products and plant varieties (Gabellini & Scaramuzzi, 2022).

Such generalization is not always possible. Cut flowers, for example, supplied to the European market are produced in parallel within both Europe on the one hand and Africa and Latin America on the other, with very different production systems. Therefore, identifying common value chains shared by many products is challenging. For example, Franze and Ciroth (2011) described the value chain of cut roses for the purpose of social and environmental LCA. In their system, cut roses are produced in the Netherlands or in Ecuador. In both cases, development and cuttage of roses are conducted in Germany whereas the consumption is in the Netherlands. Chain stages include R&D and cuttage of roses in Germany, greenhouse production in the Netherlands or field production in Ecuador, and manual cutting and packaging in Ecuador versus automated cutting and packaging in the Netherlands. Although it is just an example of a value chain of cut roses, it emphasizes the diversity that can occur in value chain stages of the same product. Such differences in

value chains are significant for sustainability assessment and demonstrate the need for system-specific tools. Furthermore, differences in production systems for cut roses, such as greenhouse versus field production, change environmental impacts and assessment objectives, and different production locations change the social settings and therefore the assessment objectives. Such differences in the value chains of other product groups, such as cut flowers, further demonstrate the advantage of identifying a common value chain that is shared by different flowering potted plants, because it enables the development of a sustainability framework that can be implemented for the assessment of many products.
In contrast to the present study, where a common value chain was characterized by chain stages and processes shared by a diversity of products, Acosta-Alba et al. (2022), did not try to characterize a single value chain shared by different products, but rather included a diversity of different products, production systems, and processing. According to their approach, chain mapping is part of the assessment method. In their study, Acosta-Alba et al. (2022) implemented the Value Chain Analysis for Development (VCA4D) analytical process that contains four components: The functional component refers to the analysis of the value chain and the description of the relevant stakeholders, products and product flows, production systems activities, and operations in the value chains. The other three components contain pre-determined indicators for environmental, social, and economic analysis (Acosta-Alba et al., 2022). Since the aim of the chain mapping is not the development of a specific assessment tool, but rather the assessment method is already determined, the focus is different: to compare the sustainability of different products and production alternatives, as well as processing possibilities.
The value chain of FPPs was further investigated for sustainability challenges, in order to determine the relevant sustainability themes and subthemes. Galli et al. (2015), Gasso et al. (2015), and Petit et al. (2018) conducted similar approaches. The stage of determining the sustainability challenges of the system under investigation might be redundant if such challenges are already defined. Nevertheless, the alternative approach of doing the indicator search directly and only later clustering them into themes, as adopted by Nadaraja et al. (2021), can be biased since it only considers what has already been assessed in other studies. Furthermore, in such a case, the normative dimension of defining sustainability goals and objectives is ignored.

5.1.1 Determining the scope for the assessment

The scope for the framework was set to include the value chain stages from breeding to distribution. Including the breeding stage in the assessment scope is uncommon, and there are only a few examples that do so. Petit et al. (2018), for example, included the breeding stage in the assessment of French pork chains. Nevertheless, themes included by Petit et al. (2018) in the breeding stage are very different from the FPP framework. In the present study, the focus is on breeding goals for sustainable traits in cultivars, whereas Petit et al. (2018) focused on pig performance and biodiversity of feeding species. Albajes et al. (2013) emphasized the impact of cultivar selection for the sustainability performance of an entire value chain, which supports including the breeding stage in the assessment. According to Albajes et al (2013), besides being a well-adapted cultivar with high yields and better quality, a sustainable cultivar has to demonstrate environmental qualities that allow, for instance, reduced use of chemicals such as pesticides, chemical fertilizers, and growth regulators.

Sustainability impacts at the retail and consumer stages were not included in the scope of the present assessment framework. The consumption stage is not part of the scope because the focus of the present framework is to improve the performance of chain actors rather than ameliorate the impacts of consumer behavior. Furthermore, according to Soode et al. (2013), it is unlikely that consumer behavior can be influenced, such that sustainability impacts associated with transport of the product can be reduced. Nevertheless, issues that are associated with the end of a product's life cycle, such as environmental impacts from waste, were considered in the material use of finished products, such as substrate and containers. Moreover, responsibility toward the consumer is considered in the social dimension, where consumer safety and transparency were included in the assessment. Petit et al. (2018) also included consumer-related themes, such as consumer information and consumer health, even though consumers are not part of the scope of the framework. Similar to the current study, Schmitt et al. (2016) included communication to the consumer, as well as nutritional health impacts to the consumer, in their assessment of cheese value chains. However, contrary to the present study, consumer behavior aspects, such as the indicators "cooking practices" and "taste preference," were also considered in the assessment. Aspects like cooking practices and taste preference are generally not relevant for ornamental plant products.

Schwarz et al. (2016) included retail in the assessment scope by assessing revenue distribution in an asparagus value chain (farm gate price/supermarket price). Binder et al. (2012) included retailers in their assessment by assessing employment as a social aspect of sustainability, as well as economic indicators such as productivity and return on investment. Market power was also assessed at the retail stage of the Swiss milk value chain (Binder et al., 2012). In the current study, retailers were not included in the scope of the assessment, because the main social and environmental impacts take place upstream from the retail stage in the value chain. Due to the short time that the products spend at the retail stage, plants generally do not receive further treatments, special illumination, or temperature conditions, excluding an occasional irrigation. Social impacts associated with retail employees are not particular to the ornamental plant sector and are generally shared by retail employees in supermarkets and retail chains. Furthermore, assessing market power or revenue distribution is complex and requires assessment and comparison across different chain actors.

5.1.2 Chain drivers

Chain drivers identified in the present study are classified under (1) economic framework, (2) natural environment, (3) politics and regulation, innovation, and (4) technological progress (Havardi-Burger et al., 2020a). For comparison, Gabellini and Scaramuzzi (2022) studied the characterized drivers of change in consumption trends of flowers and plants in Europe. Similar to the present study, Gabellini and Scaramuzzi (2022) found climate change influenced consumption trends due to unpredicted seasonal dynamics, which influence the volatility of volumes and price. In the present study, actors were concerned about the demographic development of the German market. In contrast, based on a gray literature review, Gabellini and Scaramuzzi (2022) found that the evolution of the socio-demographic context in Europe is generally expected to positively influence consumption. The positive expected development is due to two population segments: a growing population of retired individuals willing to invest in their gardens and houses, and young workers who perceive flowers and plants as lifestyle products (Gabellini & Scaramuzzi, 2022). However, the study includes six European countries, and expecting the same population development to occur in all of these countries is unrealistic. Nevertheless, in a different study, Ludwig-Ohm and Dirksmeyer (2013) also state that they expect the consumer groups that spend most on ornamental plants to grow, and thus anticipate a consumption increase in the German market (Ludwig-Ohm & Dirksmeyer, 2013). These findings do not necessarily contradict, because the concern to consumption growth in the present study is due to differences between generations. The claim of the interviewees is that the younger generation is less interested in gardening, which can eventually result in decline in consumption. However, the older generation, which was characterized as having more interest in gardening, is retiring and has more free time and money to spend on plants.

According to Gabellini and Scaramuzzi (2022), European consumers are increasingly aware of sustainability issues in flower and plant products and, therefore, are willing to pay a premium price for products with qualities that are associated with sustainability performance. Consumer preference study in the German market demonstrated that two thirds of the respondents favor sustainability-labeled cut roses (Berki-Kiss & Menrad, 2019). However, a different study showed that intrinsic flower attributes in cut flowers, such as appearance, are more important to the German consumer than extrinsic attributes such as certification, country of origin and price (Rombach et al., 2018). Though the preferences of the German consumer for sustainable flowering plants have not yet been determined, it has been demonstrated that sustainability-oriented consumers are more likely to choose products with better social and environmental performance when they are actively promoted as such by, for example, sustainability labels (Berki-Kiss & Menrad, 2022). Thus the growing investment of chain actors in sustainability innovations presented in the current study (Havardi-Burger et al., 2020a) emphasizes the need to label certified products to demonstrate the sustainable qualities of the product to the end consumer.

Investigation of chain drivers (Havardi-Burger et al., 2020a), contributed to the understanding of the economic environment in which chain actors are active and strive for competitive advantage. Understanding of the economic framework further contributed to the development of sustainability themes, subthemes, and indicators. For example, factors within the economic framework, such as price pressure and low margins, emphasized the importance of assessing profitability. In addition, the difficulty of hiring employees within the industry emphasized the need to assess job satisfaction as an indication of employee retention.

5.2 Allocation of indicators across the value chain

The present study identified differences between the assessment need of the different sustainability dimensions—social, economic, and environmental—across the value chain. In contrast, in previous frameworks developed for a specific value chain, a combination of themes from different dimensions were allocated, based on the relevant sustainability impacts (Binder et al., 2012; O'Rourke, 2014; Petit et al., 2018). For example, Petit et al. (2018) allocated sustainability themes from different dimensions across six value-chain stages of a French pork chain. Environmental indicators in the present study generally follow this perception, as impacts are related to product-specific processes (Figure 7). Consequently, indicators are allocated according to the different value chain stages: breeding, production, and distribution. In spite of the differences between the geographical regions of Africa and Europe, themes and subthemes associated with plant production are similar. Nonetheless, separate geographical regions can suffer from different sustainability impacts. For example, the risk of nutrient leaching is higher in plant production in Africa, due to the frequent use of open irrigation systems. In Europe higher GHG emissions are expected in plant production because of the need to heat greenhouses and the use of artificial light.

Unlike environmental impacts, social themes in the value chain of FPPs are associated with stakeholder groups and are determined by regional socio-economic conditions. However, the geographical regions do not refer to a specific region but rather a general differentiation between regions according to state provision of healthcare and social safety nets, and according to regional average salaries. Differentiation in social theme allocation based on socio-economic conditions is unique to the present study. Franze and Ciroth (2011), who assessed social sustainability in cut-rose production in Ecuador compared to the Netherlands, have demonstrated the influence of regional conditions on social sustainability performance. Similar to the present study, Siebert et al. (2018) also referred to the need for regional assessment of social impacts within Germany. However, as opposed to the present study, the regions are within the same country with very similar socio-economic conditions. Such differentiation in the value chain of FPPs is irrelevant because possible differences between regions in the same country are negligible compared to differences in socio-economic conditions between European countries and low-cost labor markets. Furthermore, there is no difference in the allocation of assessment themes between the regions. The differences are rather in the sustainability performance or hotspots. Differences may prevail, for example, in average regional wages or regional employment rates. The indicators for assessing the subthemes will be the same indicators in each region. Apart from geographical regions, social themes and subthemes in the present framework are specifically related to the following stakeholder groups: workers, consumers, and the local community. These stakeholder groups were found to be associated with social sustainability challenges in the value chain of FPPs. As in the present study, other sustainability frameworks have allocated social themes to specific stakeholder groups; however, differences can be found in the stakeholder groups that are considered for the assessment. Siebert et al. (2018) identified workers, the local community, and the national society as stakeholders that are exposed to social sustainability impacts of the wood-based product chain in Germany. The national society is not a stakeholder group in the present study. Nevertheless, it is a relevant group in the wood-based chain, because wood harvest can negatively influence the function of forests in nature conservation and recreation. The differences between the FPP chain and the wood-based chain emphasize differences in assessment needs of each system and the advantage of specific assessment frameworks, compared to universal assessment frameworks.

Van Cauwenbergh et al. (2017) and the S-LCA method (Benoît et al., 2010) include society as a stakeholder group in their assessment method. “Society” in van Cauwenbergh et al. (2017) could refer to two stakeholder groups that are included in the present study, consumers and the local community. However, there is no differentiation in the assessment needs of these two groups. Since the S-LCA method specifies consumers and the local community as separate stakeholder groups, it is not clear who is meant by the society as stakeholders, nor what the assessment needs of this group are.

The economic dimension of sustainability in the present study is viewed from the business perspective and therefore the assessment relates to each group of actors separately. Additional economic indicators are designated to assess only producers. Binder et al. (2012) also linked the economic indicators to each business actor in the chain: producers, processors, and retailers. In contrast to the present study, other economic indicators in Binder et al. (2012) were allocated across the chain to assess market power, as well as subsidies to farmers. In the present study, geographical regions do not play an important role in the economic dimension, as it is viewed from the company perspective and businesses taking part in the FPP chain are European-based. Nevertheless, spatial location might raise differences in risk level, especially at the production stages of the value chain. For instance, risk due to vulnerability to climate change exposes growers and propagation nurseries to unstable yields, due to extreme temperatures, droughts, or weather-related catastrophes such as floods or storms. Further risk is associated with political conditions, such as unstable regimes, or protests against European companies, which were reported in production countries such as Kenya and Ethiopia. Furthermore, personal risk to workers was generally reported in African countries, due to criminality. Economic indicators are also allocated differently for the actor group producers, with additional specific indicators, such as “cost of production” and “production risk.”

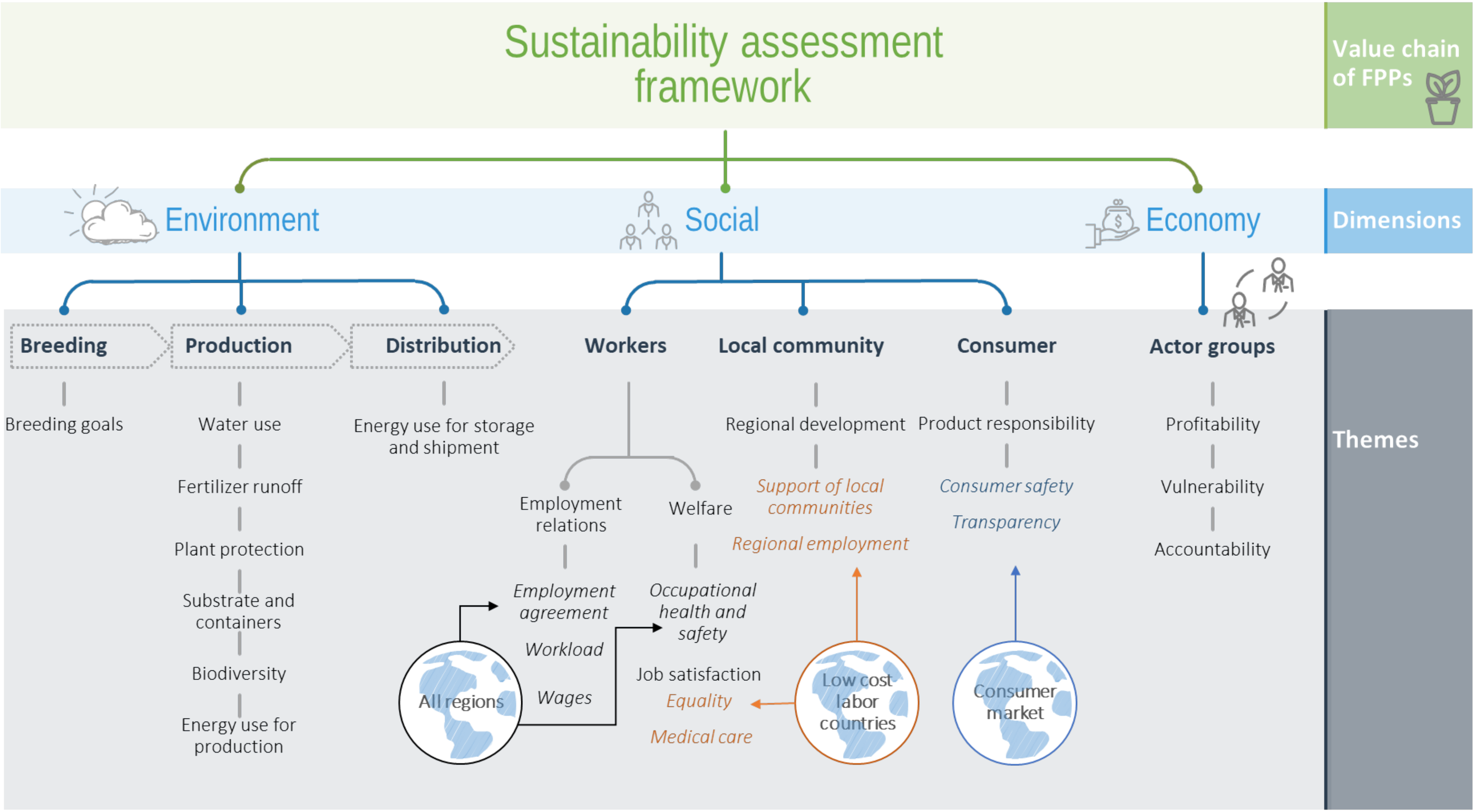

Figure 7: Theme allocation according to sustainability dimensions in the framework for sustainability assessment of the value chain of FPPs.

Themes in the social dimension are represented in color according to the different geographical regions to which they are allocated: orange for low-cost labor markets, blue for consumer markets, and black for themes that are assessed in all regions.

5.3 Sustainability assessment of value chains

Improving the sustainability performance of entire value chains will enhance the competitive advantage of chains. Furthermore, chain coordination was found to be crucial in the value chain of FPPs, especially because of the short shelf life of the products. Moreno-Miranda and Dries (2022) further claim that chain coordination also promotes sustainability performance across chains. The contribution of coordination mechanisms can be explained by the reduction of uncertainty and transaction complexity, as well as the promotion of social welfare and ecological resilience (Moreno-Miranda & Dries, 2022).

Comparable to the present study, the universal SAFA tool also is designed in a similar manner for assessing the sustainability of firms taking part in agricultural value chains. The SAFA framework allows separate actors involved in the production, processing, distribution, and marketing of food and agricultural products to assess their performance, but also enables the assessment of the entire value chain (FAO, 2014). In contrast to the present study, the assessment method designed by Binder et al. (2012) to assess the Swiss milk value-added chain results in a cumulative indicator value that includes all chain stages. Other system-specific assessment methods of agricultural value chains, such as Schmitt et al. (2016) or Schwarz et al. (2016), also resulted in a single value for each indicator for the entire chain (Schmitt et al., 2016; Schwarz et al., 2016). Such results are conclusive and enable simple comparison between different chains, such as asparagus produced in Belgium compared to in Peru, as conducted by Schwarz et al. (2016). However, as opposed to the present study, no distinction is made between sustainability impacts in different chain stages. Therefore, there is no direct comparison between different stages, such as the carbon footprint associated with production as compared to transport.

Similar to the approach taken in the present study, the LCA assessment results for each chain stage are presented separately by Sahle and Potting (2013) for each impact category. The tool designed by Petit et al. (2018) for the French pork chain has a mixed approach. In contrast to the present study, the result of the environmental assessment, based on LCA impact categories, is cumulative, meaning that each indicator has a result of one value throughout the value chain, whereas socio-economic indicators are specific to each value chain stage, which is similar to the present study (Petit et al., 2018). Presenting the results for each chain stage independently makes it possible to recognize the weak and strong performance points across the chain. However, having one result for each indicator for the entire value chain makes it possible to easily identify the high impacts compared to other products or chains. For instance, the indicator “GHG emissions value,” if calculated for the entire chain, can be compared to other chains or products to identify relatively high or low GHG emissions. However, in such a case, the information on which chain stages contribute the most to GHG emissions is then lost.

5.4 Comparison to existing sustainability solutions

The sustainability framework presented here was developed specifically for the sustainability challenges in the value chain of FPPs. In contrast, the international Floriculture Sustainability Initiative (FSI) standards are benchmarked against standards that were not specifically designed for the floriculture sector. Therefore, the FSI, which is designed to foster harmonization among a diversity of standards in floriculture, does not necessarily focus on the most important sustainability challenges in the sector. Harmonization between diverse standards can help to simplify the acceptance of standards by business partners, and prevents the need for businesses to be certified to multiple standards. However, such harmonization processes can either raise or lower the bar, depending on the benchmarking standard compared to the other participating standards (Riisgaard, 2009).

Compared to the FPP framework, the international environmental benchmark themes of FSI do not include measures for energy saving or reduction in GHG emissions or themes associated with biodiversity. The social benchmarking of FSI is missing the themes of job satisfaction, local community (including regional employment), and support of local communities, as well as consumer safety aspects (FSI, 2019). Moreover, the economic dimension is not part of the FSI initiative, as opposed to the FPP framework, possibly because business-to-business standards are designed for risk management, and therefore the economic performance of the supplier is not measured.

The growers that produce products for the German consumer label PlusPlants are certified with GLOBALG.A.P. and growers labeled with Natürlich Nachhaltig® are certified with a diversity of standards, among them MPS and GLOBALG.A.P., partly combined with standards for organic production (Bio) (Natürlich Nachhaltig®, 2022; PlusPlants, 2022). In addition to offering certified products, these sustainability initiatives have set a number of environmental sustainability goals, slightly differently formulated in each initiative. The sustainability goals, like the FPP framework, were developed to deal with specific environmental challenges in the production of potted plants. In contrast to the FPP framework, the social dimension is missing from the sustainability concept of Natürlich Nachhaltig®. The social criteria of PlusPlants are only partly represented by including the theme “fair,” referring to fair trade with business partners.

To fulfill the goals in the case of PlusPlants and Natürlich Nachhaltig®, growers are expected to follow certain guidelines, and adopt more sustainable practices. For example, PlusPlants growers are required to obtain two thirds of their energy from renewable sources (PlusPlants, 2022). Growers taking part in Natürlich Nachhaltig® are expected to use at least 25% peat alternatives in their growing media (Natürlich Nachhaltig®, 2022).

In addition to their efforts to become more sustainable, such growers could assess their performance against a neutral tool, such as the FPP framework, specifically designed to assess the sustainability of potted plants. Such a tool can further assist growers in decision-making around which practices or innovations to adopt that would lead to better sustainability performance.

5.5 Sustainability innovations

Implementation of sustainability innovations across the chain is a strategy for sustainability performance improvement. A variety of sustainability innovations are available for the floricultural sector. The identified sustainability innovations address environmental and socio-economic sustainability challenges in the sector (Havardi-Burger et al., 2020b). However, the present study indicated that the implementation of sustainability innovations in the value chain of FPPs, is frequently associated with cost increase, risk, and complexity of implementation (Havardi-Burger et al., 2020b). The existence of barriers to the adoption of innovations, as was observed in the present study, is supported by Hansen and Grosse-Dunker (2012). According to Hansen and Grosse-Dunker (2012), product innovation in general (not necessarily sustainability innovations) is often associated with high uncertainty of market success, because it is difficult to predict consumer preferences and market development. Furthermore, sustainability innovations, in different sectors, entail an even higher risk because they are expected to improve environmental and social sustainability performance. Such improvements, in some cases, cannot be easily determined (Hansen & Grosse-Dunker, 2012).

Similar to the present study, other articles identified barriers to the adoption of sustainability innovations being reported for the floriculture sector. According to Freda et al. (2015), relatively high investment costs for renewable energy sources, such as photovoltaic panels, were found to be a limiting factor for the adoption of such technologies in floricultural nurseries. The relatively higher costs associated with implementing sustainability innovations were also identified as a barrier in the present study. Dennis et al. (2010) concluded that the biggest obstacles to the adoption of sustainable production practices by nursery plant growers would be reduced compatibility compared to existing production systems. For example, growers are concerned about the risk of converting to new technologies such as biodegradable pots. Ease of implementation and perceived level of production risk influenced the positive attitude toward the adoption of new technologies (Dennis et al., 2010). Obstacles such as those described by Dennis et al. (2010) were also observed in the present study, for example, concerning the risk of reduced quality of plants grown in biodegradable pots. Derksen and Mithöfer (2021) studied producers' attitudes toward the implementation of sustainability innovations in the floriculture sector in Germany.

Their findings are compatible with the findings of the present study concerning the risk and complexity of implementing sustainability innovations (Derksen & Mithöfer, 2021).

Adoption of sustainability innovations generally shows a positive relationship to firm competitiveness (Hermundsdottir & Aspelund, 2021). However, this relationship is complex (Hansen & Grosse-Dunker, 2012). In the present study, cost increase and certain business risks were identified as being associated with the adoption of some of the innovations. The negative impacts on firm competitiveness due to cost increases and business risk associated with innovations was confirmed by García-Sánchez et al. (2019) for different industries. Risk to product quality, in the present study, was especially related to changes in growth condition of crops. Nevertheless, the adoption of other innovations, such as closed-loop irrigation systems, or the adoption of sustainability standards brings increased costs but reduces the risk, and generally increases competitiveness. Due to the relatively high financial investment, such innovations can be seen as a long-term investment. Indeed, in accordance with the present study, García-Sánchez et al. (2020) found that sustainability innovations positively influence the long-term competitive advantage, as well as the market value, of firms from different industries.

In a literature review, Hermundsdottir and Aspelund (2021) concluded that sustainability innovations contribute to competitive advantage by increased value creation, reduced costs, and nonfinancial assets such as image, reputation quality, and customer satisfaction. In comparison to the present study, the contribution of sustainability innovations is dependent on the character of the sustainability innovation. For example, reduced costs can be expected in the long term as a result of implementing energy-saving technologies and transitioning to renewable energies. However, other innovations are generally associated with higher costs, such as the implementation of private standards (e.g., MPS, GLOBALG.A.P.), but contribute to the reduction of risk, such as the risk to the reputation of the company.

Drivers that influence actors in the adoption of sustainability innovations were identified for the present study (Table 6) (Havardi-Burger et al., 2020b, p.21). In a literature review, Bossle et al. (2016) investigated the drivers and motivations behind the adoption of eco-innovations in firms from different sectors. The drivers that were identified by Bossle et al. (2016) were compared to drivers that were found in the value chain of FPPs (Table 6). For example, “efficiency” is one of the internal drivers defined by Bossle et al. (2016), which refers to cost reduction, equipment upgrade, and R&D. Efficiency is partly comparable to the driver “cost reduction,” identified in the present study. For example, the adoption of LED lighting technology can be considered an equipment upgrade, but it also leads to cost reduction by reducing electricity consumption. However, the cost reduction may be offset in the long run due to the high initial investment compared to other technologies. Defining efficiency as a driver is more inclusive, but the decision to upgrade is possibly related to a management vision to reduce the carbon footprint rather than cost reduction.

"Performance" relates to sales growth, market share, and return on investment (Bossle et al., 2016) and, therefore, can be compared to product differentiation, identified for the present study. Differentiation is intended to distinguish the product and thus increase market share and return on investment. The driver "differentiation," as defined in the present study, refers to sustainability labels as a means of achieving a premium price. Sales growth, though, can also be reached through other means of marketing.

The driver "management vision," identified in the present study, is comparable to "managerial concerns," in which top management integrates sustainability into a firm's strategy. A comparable driver "company image," identified in the present study, could not be located in Bossle et al. (2016). Differences from Bossle et al. (2016) might relate to the variety of sectors that were examined and the associated sustainability innovations for each industry. Furthermore, diversity in terms that were used to cluster the drivers make the comparison challenging.

The external drivers "barrier to market entry" and "risk mitigation," identified for the FPP value chain, are both related to normative pressure defined by Bossle et al. (2016). The normative pressure, in the value chain of FPPs, comes directly from both NGOs and retail chains. Retail chains require all their suppliers to be certified, therefore setting a barrier to market entry. Growers may adopt sustainability innovations to protect themselves from NGOs, since according to interviews, some chain actors had been accused in the past by NGOs, for example, for irresponsible conduct regarding application of pesticides.

A different study examined whether different eco-innovations are driven by different factors relating to regulation, cost saving, and customer benefits in the German market (Horbach et al., 2012). Similar to the present study, cost savings were found to be a motivation for reducing energy consumption. However, in the current study, increased recyclability of the product is not driven by regulations, as suggested in Horbach et al. (2012), but rather expected customer benefits or requirements.

Table 6: Drivers that motivate firms to adopt sustainability-oriented innovations

Havardi-Burger et al. (2020b)		Bossle et al. (2016)	
Driver	Example	Factor	Definition
Internal drivers			
Cost reduction	Reducing energy costs	Efficiency	e.g., Cost savings due to environmental improvement
Product differentiation	Adoption of sustainability labels such as Fairtrade	Performance	Sales growth and market share
Management vision	“To become the most sustainable young plant company in the world” or “taking care of our employees”	Managerial concerns	Integration of sustainability and innovations in companies’ strategy, directed by top executives
Company image	Providing benefits to workers and communities in Africa	-	-
External drivers			
Barrier to market entry	Requirements from retail to adopt private standards	Normative Pressures (market demand)	“Consumer and societal demands, as well as other relevant stakeholders”
Risk mitigation	Adopting standards to prevent media attention	Normative Pressures (market demand)	“Consumer and societal demands, as well as other relevant stakeholders”

Sources: Havardi-Burger et al., 2020b, compared to drivers identified in the literature by Bossle et al. (2016).

Complexity of implementation, risk, and uncertainty in the present study were often related to the lack of practical experience and knowhow—for example in the adoption of alternative growing media and containers. Research on alternatives can reduce the risk and uncertainty of adopting sustainability-related innovations. For example, the investigation of the influence of alternative potting mix qualities on the growth performance of plants (Bassan et al., 2020; Gong et al., 2018; Zulfiqar et al., 2021) can support producers and reduce uncertainty.

Furthermore, it was shown that networking between actors, such as firms, researchers, and government, can support exchange in experience and knowhow (Boons et al., 2013). Pellegrini et al. (2019) even identified stakeholder networks as an interactive driver for the adoption of sustainability innovations. This exchange between actors in the value chain of FPPs, can reduce the risk and uncertainty among businesses, and remove barriers to the adoption of sustainability innovations leading to sector or industry change. Furthermore, industry context and regulations can influence whether the implementation of sustainability innovations is successful and whether the risk to businesses is reduced (Hermundsdottir & Aspelund, 2021). For example, public financing of training and subsidies is significant for the introduction of sustainability innovations (Bossle et al., 2016). Change in policy, such as financing the training of actors, could support the successful implementation of sustainability innovations in the floriculture sector.

6 Conclusions

In the present study, a system-specific sustainability assessment framework was developed for the value chain of FPPs. The development of the framework was based on the characterization of the value chain of FPPs, in addition to the investigation of system-specific sustainability challenges. Suitable indicators were extracted from the universal agricultural assessment tools SAFA and RISE. New environmental indicators were developed to assess subthemes with no available indicators in the existing tools.

The characteristics of the FPP chain presented here are unique, distinct from other agricultural chains, but also different from horticultural product chains such as fruit, vegetables, cut flowers, and perennials. Furthermore, although differences exist between the generative and vegetative chains, the same framework can be implemented for both value chains, due to comparable sustainability challenges. Similarities and differences compared to other greenhouse-cultivated potted plant chains—such as green potted plants, herbs, and potted vegetable plants—can be further investigated in order to assess the suitability of the sustainability framework developed in the present work to assess other potted plant products. Since the framework was constructed based on the specific sustainability challenges across the value chain of FPPs, similar processes that are identified in other value chains can indicate this suitability.

The practical operation of the framework is beyond the scope of this study. Future development phases of the framework include a feasibility test of each of the indicators by users, in order to determine a final set of indicators, setting reference values or alternatively a benchmark system.

The framework developed here can be defined as a mixed top-down participatory approach, where stakeholders are involved in the development phases of characterizing the value chain, and the investigation of sustainability challenges, along with determining the feasibility of indicators. This development procedure avoids the difficulties involved in the active participation of stakeholders in the development and selection of indicators, as described by Mullender et al. (2020), but benefits from the different perspectives of actors and stakeholders concerning the value chain and the sustainability challenges facing the sector. Moreover, actors using the framework will further support the development of the framework by testing the feasibility of the indicators and possibly providing suggestions for improved indicators. Nevertheless, as stakeholder participation is considered higher in bottom-up approaches, the willingness of actors to participate in future assessments by implementing the framework developed in the present work is still to be determined.

The sustainability framework for the value chain of FPPs offers the possibility to assess the performance of individual actors, but also to assess entire chains, given that the assessment is coordinated among the different actors. Entire chain assessment followed by performance improvement will support better sustainability performance of the entire chain compared to competing chains and potentially lead to competitive advantage over other chains. However, in order to detect the point at which performance improvement is needed, aggregating the results of the assessment into one score for the entire value chain may result in information loss about the specific points of impact.

6.1 Future research

The development of an assessment framework for a global value chain, with production locations in both Europe and low-cost labor markets, gave a different perspective on impacts across chains. For example, differences between geographical regions in government provision of healthcare and social safety nets helped to identify distinct sustainability challenges in each region. Social impacts were also found to be associated with different stakeholder groups. Environmental impacts are related to product-specific processes and economic impacts may differ due to higher regional risk attributed to climate change or political instability. Based on the distribution of sustainability impacts across the chain, assessment requirements are defined differently for each sustainability dimension.

Future research should address the question of whether such a distinction between impact assessment in the different sustainability dimensions (environmental, social, and economic) can be observed in other global value chains. Moreover, different allocation of indicators based on the sustainability dimension across the value chain can be tested in other sectors and industries. This principle of allocating indicators according to sustainability dimensions across the chain can guide the development of future sustainability assessment methods for other specific value chains, as well as universal assessment frameworks addressing agricultural value chains, such as the SAFA tool.

The sustainability framework presented here was developed specifically for the identified or existing spatial and temporal conditions within the system. Changes in temporal or spatial conditions, such as a change in production location (e.g., propagation material produced in Europe instead of in Africa), in the value chain will require the framework to adapt to the new conditions in the system, and can lead to changes in assessment needs, especially of social aspects. In addition, changes in the normative dimension would likewise require the adjustment of the framework. Minor normative changes might require, for example, adjustment of the reference values. Major changes in the normative dimension might require adjustment of the sustainability goals, followed by changes in assessment needs and indicators.

The floriculture Industry is under high external pressure from stakeholders (e.g., retail chains and NGOs) to improve environmental performance in areas such as carbon footprint and use of pesticides (neonicotinoids), in addition to social performance aspects such as better employment conditions in low-cost labor markets. According to Berrone et al. (2013)

firms under high normative pressure (e.g., from NGOs and other actors), are more likely to adopt sustainability innovations. Furthermore, firms comply better with the requirements of external actors and seek differentiation through innovations under strong institutional pressure (regulatory and normative) (Berrone et al., 2013). The present study demonstrated that the adoption of certain sustainability innovations, such as private standards, is widespread among actors in the FPP value chain. In fact, it has become a market entry requirement for supply to retail chains. As a result, potted plants supplied to large retail chains are generally certified with private standards.

The notion that some industries are characterized by higher incentives and drivers for the adoption of sustainability innovations was suggested by Cainelli et al. (2011). The high direct pressure on chain actors from retail chains and NGOs and the indirect pressure from increasing consumer awareness raise some suggestions for future research questions. For example, (1) is the pressure on the FPP sector higher than on the agri-food sectors? If this is the case, (2) can such pressure be explained by the luxury character of floricultural products, as opposed to the necessity of food products? Furthermore, (3) does pressure lead the industry to a higher level of adoption of sustainability innovations? If so, (4) does higher adoption of sustainability innovations result in better sustainability solutions and performance across the value chain?

Cost and benefit distribution among actors is essential for sustainability innovations (Boons et al., 2013). In the value chain of FPPs, the requirement for performance improvement generally comes from retail chains, whereas the costs for the implementation of social and environmental innovations are mostly borne at the producer level. In this case, costs are not evenly distributed across the chain. Not only do retailers act as gatekeepers to suppliers' sustainability performance, they also set prices, preventing a more balanced distribution of costs and benefits among different actors, including consumers. More even distribution of costs across the value chain will reduce the financial burden on upstream actors, which can potentially encourage more investments in sustainable practices and innovations, leading to overall improved sustainability performance. Since retail chains in the current study were identified as powerful chain actors, assessing revenue distribution or market power across chain actors, including retailers, should be considered in the future development of the framework. Moreover, assessing revenue distribution among chain actors can also indicate the capacity of actors to invest in sustainability improvements in the chain.

Marketing innovations for sustainable products, such as Fairtrade plants, are an opportunity for firms to charge premium prices and ensure higher margins for actors across the chain. However, such labels, in the potted plant sector, are still considered a market niche (Havardi-Burger et al., 2020b). Future research should focus on the preferences of German consumers for sustainability-labeled potted plants and determine their willingness to pay a premium price. Nevertheless, based on the present study, the leading strategy in the sector is not necessarily to aim at the responsible consumer who has a preference for sustainable products, but rather for actors to reduce the risk for scandals associated with sustainability impacts through certification and traceability. This tendency was developed because NGOs were threatening producers with exposing unsustainable practices, such as risk to employees. Retailers were threatened with bad publicity for selling unsustainable products, such as plants treated with neonicotinoids. In this case, the consumer is not necessarily encouraged to adopt responsible and sustainable consumption, but chain actors are pushed to take action to improve their performance and reduce risk.

6.2 Practical implications

Sustainability assessment can help actors to determine the current sustainability performance of a chain and enables them to plan better. By determining areas of poor sustainability performance, actors can direct their efforts for sustainability performance improvement through an educated decision-making process, directing investment and efforts so as to make the maximal contribution to the entire performance of the system. Furthermore, self-performance checks enable actors to develop their own business sustainability strategy (Schader et al., 2017).

Successful implementation of sustainability innovations requires examination of the alternatives. Such examination involves several aspects: Firstly, the need for sustainability performance improvement has to be considered through sustainability assessment of the system and prioritizing of improvement need. When the need for improvement is determined, different alternatives have to be compared in terms of sustainability performance, profitability (associated costs and potential financial benefits) and the complexity and feasibility of implementation. The decision about which alternative is preferable can be supported in research by conducting sustainability performance assessment of the different alternatives, combined with an economic evaluation of the competitiveness of different innovative practices. Furthermore, networking and exchange of knowhow in the industry can support actors in the implementation of sustainability innovations to overcome uncertainty and risk.

Different types of sustainability innovations can influence the competitiveness of firms in different ways. Generally, the adoption of sustainability innovations is associated with increased costs due to the financial investment. However, some innovations can lead over time to reduced costs, such as the adoption of closed-loop irrigation systems, which also contribute to cost savings on fertilizer and irrigation water. Cost reduction in the long term contributes to the competitiveness of the business. Some innovations are related to an increased initial risk, such as the adoption of peat alternatives in growing media. However, adapting to plant production with peat alternatives can increase the market value of the products, as well as firm competitiveness. A change in regulation settings to support the transition toward the use of peat alternatives will contribute to even better competitiveness for firms that grow plants on substrate containing peat alternatives.

The framework developed here can be used as a reference or a backbone for the development or adjustment of existing standards, to make them more specific to assessing potted plants. Sustainability themes and objectives defined for the present framework can provide orientation for other developers. Indicators chosen for the present framework could potentially replace other indicators used in existing standards and other assessment methods. Furthermore, existing standards could be benchmarked against the present framework, which was developed specifically for the sustainability assessment of potted plants, as opposed to the use of universal agricultural standards, which are less suitable for assessing the distinct sustainability challenges in the sector.

Existing sustainability labels such as PlusPlants and Natürlich Nachhaltig® can monitor their performance by conducting sustainability assessments implementing the framework developed in the present study. Reporting the results to the consumer will allow better transparency about the actual sustainability performance of the product. Furthermore, implementing the framework will allow growers to compare their performance to that of other producers. Through conducting such comparisons, growers can learn which sustainability practices lead to better overall sustainability performance.

Other more specifically targeted labels, such as “bee-friendly,” could potentially adopt only the relevant indicators (1) “insect-supporting varieties” and (2) “hazardous pesticides” to assess their performance and provide consumers with transparency. New consumer labels can be developed to provide the consumer with information about the safety of a product by assessing the indicator “hazardous pesticides.”

6.3 Policy implications

The implementation or “use” of indicators in the presented framework can support policy makers by helping with determining of target or reference values, monitoring over time, the development of incentives for the adoption of sustainable practices, the allocation of funds according to sustainability performance, and discussions of different alternatives.

Indicators can still influence policy and society without being used because their formulation and elaboration can initiate dialogue and discussion. A set of indicators provides policy actors with background information, problem definition, ideas, and insights that can support decision-making (Sébastien & Bauler, 2013). Moreover, according to Sébastien and Bauler (2013), indicators generally provide concepts and alternative perspectives, apart from their potential to produce sustainability assessments. This further emphasizes the contribution of the developed sustainability framework (Havardi-Burger et al., 2020b, 2021), in which sustainability challenges are discussed and the choice of selected or developed indicators is explained and compared to alternative available indicators. Thus, in addition to the future use of the framework for sustainability assessment, the present work can influence policy by providing background about the system and information about specific sustainability challenges, as well as by provoking discussions among different stakeholders such as scientists, NGOs, and industry actors. Stakeholders can then influence policy makers and thus promote changes in policy and regulation.

The driver for better sustainability performance in the sector is normative, not necessarily because of consumer preferences but via pressure from stakeholders such as NGOs and retail chains. NGOs and retailers frequently pressure upstream actors to improve their sustainability performance by adopting innovations. In contrast, regulatory pressure is less dominant in the floriculture industry in driving innovations. Nevertheless, it would be interesting to test the influence of newly introduced legislation or legislation in progress on the sustainability performance of chain actors in the FPP value chain. Examples of upcoming regulations are the proposal for EU regulations for the sustainable use of plant protection products (Sustainable Use Regulation) (European Commission, 2022), or the draft for the supply-chain law approved by the German Federal Council (June, 2021) that focuses mainly on compliance with basic human rights standards across global value chains (BMZ, 2022). Such regulation will have an impact on the sustainability performance of the FPP value chain if the regulation bar is higher than the private social and environmental standards that have already been implemented in the sector, and the requirements from retailers on the use of plant protection agents.

Normative pressure can be considered as a market force, which in the floriculture industry has a relatively high impact on industry change. However, although the pressure is aimed at real sustainability problems, it does not always result in an overall performance improvement. In the present study, some pressure was shown to lead to undesirable results, as can be seen with the example of neonicotinoids. In this case, some growers have reported increasing their use of harmful pesticides because of the requirement by different retail chains to stop the use of neonicotinoids, which are considered to be linked to the decline of pollinators and bees.

Impulses given to the industry from NGOs are not necessarily based on an overall assessment of sustainability challenges in the industry. Sustainability assessment of the FPP value chain can expose the high-impact challenges in the industry and thus guide policy makers in the development of a more holistic strategy for sustainability performance improvement, taking into account possible trade-offs. At the policy level, this can be achieved by changes in regulation aiming at higher sustainability performance. For example, more funding could be directed toward relevant research topics. Trainings on topics such as integrated pest management and the implementation of biological pest control could become mandatory. Incentives could be directed at chain actors for performing sustainability assessments, as well as for reaching certain performance targets, such as energy efficiency. Further incentives could be offered for the implementation of sustainable technologies, such as closed-loop irrigation systems, which support reduced water and fertilizer consumption and prevents pollution.

7 References

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8 Appendix

Appendix 1: Havardi-Burger, N., Mempel, H., & Bitsch, V. (2020). Driving forces and characteristics of the value chain of flowering potted plants for the German market. *European Journal of Horticultural Science*, *85*(4), 267–278.

Appendix 2: Havardi-Burger, N., Mempel, H., & Bitsch, V. (2020). Sustainability Challenges and Innovations in the Value Chain of Flowering Potted Plants for the German Market. *Sustainability*, *12*(5), 1905.

Appendix 3: Havardi-Burger, N., Mempel, H., & Bitsch, V. (2021). Framework for sustainability assessment of the value chain of flowering potted plants for the German market. *Journal of Cleaner Production*, *329*, 129684.

Original article

Driving forces and characteristics of the value chain of flowering potted plants for the German market

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Summary

The study investigated the value chain of flowering potted plants supplying the German market and the drivers influencing chain actors. The study builds on strategic and horticultural value chain literature. Data was collected by conducting 20 in-depth interviews with chain actors from different stages in the value chain and analyzed through qualitative content analysis. Results showed that the value chain of flowering potted plants is divided in two pathways due to distinct propagation methods, either generative (seeds) or vegetative (cuttings). Whereas propagation material is generally produced in southern countries, such as Africa and Central America, young plants and potted plants are cultivated within Europe. The paper identified driving forces such as retailer requirements, weather conditions, price pressure and innovations. Furthermore, the study provides an overview of chain activities and processes to help the sector anticipate developments, and support stakeholders in future decisions.

Keywords
certification, chain coordination, floriculture, generative propagation, ornamental plants, qualitative study, retail chains, vegetative propagation

Significance of this study

What is already known on this subject?
- European studies focused on supply chain management and logistics of floriculture. Value-adding activities and processes of flowering plants supplying the German market have not been investigated.

What are the new findings?
- The value chain is fragmented, but coordination is crucial because of product perishability, and the requirement for on-time delivery. Retail-chains are powerful chain actors through certification requirements and restrictions on pesticide use. NGOs also drive chain actors to take measures to avoid negative media attention. Furthermore, profitability concerns drive actors to strive for cost reduction and increase the consumer base.

What is the expected impact on horticulture?
- An overview of the value chain of flowering plants and its drivers provides a foundation for strategy development and decision making across businesses within the sector.

Introduction

Firms' profitability is determined to a large extent by industry structure and attractiveness. Industry structure also shapes value chains within an industry (Porter, 1985). The value chain describes the range of activities required to bring a product from concept through the different phases of production to delivery to the end consumer (Kaplinsky and Morris, 2000). The value chain, as a concept, was first introduced by Porter (1985) as a framework for thinking strategically about the activities of a business to achieve competitive advantage. Competitive advantage is achieved when a firm earns a higher rate of profit than its rivals. Nevertheless, maintaining competitive advantage depends not only on the firm but on how the firm fits in the value-adding activities of the entire chain. Moreover, the activity-based view provides the foundation for strategy across multiple businesses (Porter, 1985). Within a value chain, such as the horticultural value chain, businesses are dependent on other actors and organized cooperation is required (Bokelmann and Adamseged, 2016). Organized cooperation across businesses is reflected, for example, in the requirement for on-time delivery of plants in the investigated value chain.

Ornamental plants have an important cultural value and contribute to quality of life and well-being (Hall and Hodges, 2011). The German market for ornamental plants is the biggest in Europe from the demand perspective (Menrad and Gabriel, 2009) and was estimated to be worth around 8.9 billion euros (retail prices) in 2019 (AMI, 2020). Potted plants have a market share of 47%, and are distributed via two main channels: (i) specialized retailers (florists, nurseries, garden centers and weekly markets) with 1.8 billion euros in retail prices, and (ii) unspecialized retailers (home improvement stores, supermarket chains and discounters) with 1.9 billion euros in retail prices (AMI, 2019). Flowering potted plants in Germany comprise 33% of the total market of ornamental plants, and can be divided into bedding plants (21%) and flowering indoor plants (12%) (AMI, 2020).

Ornamental plants are not a necessity product like horticultural food crops, and can be considered a luxury. The luxury character of floricultural products makes the sector more susceptible to economic losses during recessions (Brumfield, 2010). Furthermore, the German market shows signs of saturation demonstrated by the stable yearly market value of

8.6 billion euros on average in the past 15 years (AMI, 2020).

So far, research addressing the floricultural chain has focused on management and logistics in the Netherlands (De Keizer et al., 2015; Van der Vorst et al., 2016), and global value chain analysis in developing countries (Zylberberg, 2013). Value-adding activities and processes in Germany and the Netherlands have not been investigated. However, to understand the economic challenges in the floriculture sector, profound knowledge regarding the value-adding activities in each stage is vital. Furthermore, existing literature focuses mostly on cut flowers, whereas potted plant chains are generally unexplored.

The aim of this study is to identify processes and activities within the value chain of flowering potted plants, supplying the German market. Furthermore, this paper aims to investigate recent developments in the floriculture sector as well as drivers that influence chain actors. Investigating changes and driving forces in the value chain will help the sector to anticipate future developments, and thereby support stakeholders in their future decisions.

Literature review

A literature review was conducted on horticultural value chains and the driving forces influencing such chains. The first section describes the state of the art regarding horticultural value chains and compares the value chains of food products to cut flowers and potted plant value chains. The second section defines driving forces and emphasizes the importance of adaptation of chains to such forces. The second section also provides an overview of the different driving

Table 1. Chain drivers, based on the literature.

Driver	Description	Examples
Economic framework	Changes in life style, tastes, and social condition of the consumer population can influence consumer demand and preferences (Porter, 1998; Hobbs and Young, 2000; Bokelmann and Adamseged, 2016). Demographic development, for example, can change the size of the consumer population leading to alternation in demand for a product (Porter, 1998). Furthermore, changes in industry structure or changes in adjacent industries can have consequences for chain evolution (Porter, 1998).	Retail structure influenced by internationalization – Increased price competition – Higher quality requirements (Bokelmann and Adamseged, 2016) General economic conditions can also influence specific industries – Financial crises in 2008 influenced the ornamental plant industry and forced out a number of firms (Hall, 2011)
Natural environment	The horticultural sector is dependent on the natural environment as supply quantity and quality is influenced by biological variations connected to weather conditions and pest infestations (Bloemhof et al., 2015; Bokelmann and Adamseged, 2016). Furthermore, increasing climatic variability attributed to climate change is another factor that adds to supply risk (Bokelmann, 2009; Bokelmann and Adamseged, 2016).	– Weather dependent yields of horticultural crops, cultivated in the field are directly exposed to changing weather conditions
Politics and regulation	The socio-political environment also affects the value chain (Bourlakis and Weightman, 2004). Government can directly affect chain actors through national and international regulations that influence market entry, competitive practices, or profitability (Porter, 1998). Consumer concerns about safety, liability and traceability of the product (Hobbs and Young, 2000; Bourlakis and Weightman, 2004) can initiate further forms of regulation such as voluntary standards on quality, safety or environmental quality of a product (Porter, 1998).	Changes in legal requirements – Product liability: requirements for the traceability of the products and the need for certification (Bokelman and Adamseged, 2016)
Innovation and technological progress	Innovation can contribute to industry evolution (Porter, 1998). Porter (1998) describes three types of innovation: product, process and marketing innovations. Process innovations are developments in the manufacturing process or methods (Porter, 1998). In the agri-business sector, such developments leads to improved efficiency and increase productivity (Bourlakis and Weightman, 2004) or alternatively, reduce costs through large scale production or quality control (Hobbs and Young, 2000). Product innovations affect product characteristics such as perishability or differentiation (Porter, 1998; Hobbs and Young, 2000). Change in product characteristic can either widen the market or alter buyer experience and influence purchasing behavior (Porter, 1998). Marketing innovations can influence the demand through new marketing themes or channels. Such innovations are designed to reach new consumers or reduce price sensitivity through product differentiation (Porter, 1998).	Process innovation: micro-propagation – Fast and space saving propagation of healthy and uniform plants – Method became a commercially accepted practice for stock plant production (Menrad and Gabriel, 2009) Product innovations: genetic modification (GM) – Development of new cultivars, such as color-modified varieties – Opportunity for variety improvement for sterile varieties – Shorten the development process (Chandler & Tanaka, 2018) Marketing innovation – Fairtrade cut-flowers as a differentiation strategy (Riisgaard, 2009)

forces described in the literature, and explains the choice of the drivers relevant for the current study.

Chain characteristics and the floriculture sector

Agri-food chains are generally characterized by seasonality in production and global sourcing, variability in quantities and yields due to unpredictable weather conditions and pests, quality decay with time, temperature conditioned transportation and storage and the need for traceability due to quality and product responsibility (Bloemhof et al., 2015). The floriculture sector is also characterized by high uncertainty in supply quality and quantity. Differences to fresh food supply chains can be found in the large diversity of products (plant varieties), market share of sale channels, such as specialized retail for floriculture and supermarket chains for fruits and vegetables, as well as the large number of small and medium-size enterprises (De Keizer et al., 2015). Such differences indicate more diverse marketing channels and higher product differentiation compared to agri-food chains. Furthermore, the value chain of floricultural products is going through transformations in the past 25 years, as more production shifted to countries with more favorable weather conditions and lower production costs (Ferrante et al., 2015).

Although common characteristics exist within the floriculture sector, differences can be found between the supply channels of cut flowers and potted plants. The main trade mechanism for potted plants is direct trade, rather than auctions in the case of cut flowers. In addition, potted plants are supplied through a network of European sourcing as opposed to global sourcing of cut flowers. Furthermore, according to De Keizer et al. (2015), the supply of potted plants is demand driven because production is planned based on customer orders, as opposed to supply driven in the case of cut flowers where production is based on forecasts. Suppliers in demand driven value chains are highly dependent on the customers. Whereas cut flowers are harvested products, comparable to fruits and vegetables, flowering potted plants are viable plants and therefore require different handling techniques. To maintain the quality, post-production conditions have to consider a more complex relationship between flowers and leaves than in cut flowers. Post-production problems include bud and flower abscission (Ferrante et al., 2015).

Driving forces within the value chain

The transformation processes in the ornamental flower sector can be attributed to different driving forces. According to Porter's model for industry analysis, five forces determine the competition for profit: customers, suppliers, potential entrants, substitute products and rivalry (Porter, 1980, 2008). To adapt to changes in the environment of an industry, firms have to continuously improve, innovate and upgrade over time to maintain their competitive advantage (Porter, 1991). As firms are part of a system, successful upgrading has to involve other actors in the value chain (Porter, 1991).

Bourlakis and Weightman (2004) addressed the driving forces for change in agri-food chains. Though the term "drivers" is not used consistently, recent studies address challenges affecting the chain and strategy adaptation as chain drivers. Bloemhof et al. (2015, p. 103) defined a driver as "a factor that initiates and motivates firms to adopt a strategy".

Hobbs and Young (2000) emphasized that regulatory, technological and socio-economic drivers can affect product characteristics, which in turn change the transaction environment. Such a change in transaction environment can influence the coordination efforts between actors in agri-food supply chains. Bourlakis and Weightman (2004) state that the six key factors that influence agri-food supply chain management are quality, technology, logistics, information technology, the regulatory framework and consumers. Building on these two studies (Hobbs and Young, 2000; Bourlakis and Weightman, 2004), Bokelmann (2009) presented six driving forces that influence actors in German horticultural value chains. The driving forces according to Bokelmann (2009) are the economic framework, political and legal framework, natural environment, social and cultural development, demographic development and technological progress. Hobbs and Young (2000), Bourlakis and Weightman (2004) and Bokelmann (2009) all included technological, socio-economic and regulatory forces as drivers of agri-food chains. Bokelmann (2009) also included the natural environment that can directly influence agricultural produce. Porter (1991) further emphasized the need of firms to innovate. Therefore, the current study focuses on four groups of forces: (i) the economic framework, referring to socio-economic forces, such as market forces, demographic developments and consumer preferences; (ii) the natural environment, such as weather conditions; (iii) politics and regulation, including voluntary regulations such as private standards; and (iv) innovation and technological progress (Table 1).

Materials and methods

Qualitative research approaches are especially suitable to generate knowledge when the subject of interest is relatively unexplored (Bitsch, 2005; Corbin and Strauss, 2008). As little is known about the value chain of flowering potted plants, a qualitative research approach was chosen. Previous studies have used a qualitative case study approach to explore fresh vegetable value chains (Riedel et al., 2009) and investigate the supply of young plants in the floriculture sector (Verdouw et al., 2010).

Qualitative interviews are a method to explore and record practices. Investigating key actors and material flow requires multiple perspectives of the involved actors (Fusch and Ness, 2015), therefore in-depth interviews were chosen as a data collection method.

Twenty in-depth interviews were conducted in two rounds in the winters of 2016 and 2017. After the first round of seven interviews, the interview guide was adjusted according to the input from the first round. Interviewees included six propagation nurseries, four seed producers, among them one nursery owner that also cultivated potted plants, another two potted plant growers, three distributers, an agricultural certifier, a business consultant and a horticultural marketing and retail expert (Table 2). Propagation nurseries 1 and 5 and distributer 3 were interviewed twice (in 2016 and 2017). Interviews 2, 14, 15 and 16 were conducted with two interview-partners. Moreover, interview 14 took place with actors from different stages in the chain, the CEO of a grower organization and one of the growers in the organization. Interviewees from different businesses in the value chain were identified through an exhibitor list for an international horticultural trade fair in Essen, Germany (IPM). Subsequent snowball sampling followed, as some interviewees suggested several potential interviewees with different but relevant businesses.

All but two interviews were carried out in person, at the IPM. Two interviews took place in different locations, at a nursery and at a university building. On average, interviews lasted about 45 minutes. The semi-structured interview guide covered different stages from breeding, propagation,

Table 2. List of interviews: type of chain actor, business actions and interviewee role in the business.

Type of actor	Business actions	Interview No.	Interviewee role
Propagation nursery 1	Breeding, vegetative and rooted cuttings	1	Marketing director
		2	Marketing director
		2	Supply chain manager
Propagation nursery 2	Breeding, vegetative and young plants[1]	3	Marketing manager
Propagation nursery 3	Breeding, vegetative and rooted cuttings	4	Marketing manager and owner
Propagation nursery 4	Breeding, vegetative and young plants[1]	5	Marketing and product manager
Propagation nursery 5	Breeding, mostly vegetative young plants[1]	6, 7	Sales manager Germany (authorized representative)
Propagation nursery 6	Breeding, vegetative, generative, young plants[1]	8	Marketing and product management (EU)
Seed producer 1	Breeding generative and seed production	9	Sales manager EU
Seed producer 2	Organic seeds	10	Owner, CEO
Seed producer 3	Breeding, seeds and cuttings	11	Growing adviser
Seed producer 4 and grower 1	Breeding generative, seeds, seedlings and potted plants	12	Owner
Grower 2	Rooted cuttings and potted plants	13	Owner, CEO
Grower 3	Breeding generative, seedlings and potted plants	14	CEO
Wholesaler 1	Growers' cooperative, distribution	14	CEO
Wholesaler 2	Growers' organization, distribution and export	15	Sales manager
		15	CEO
Wholesaler 3	Growers' cooperative, distribution and export	16	CEO
		16	Public relations and marketing
		17	Quality management and sustainability (head of department)
Certifier	Certification	18	Commercial manager
Business consultancy	Ecological footprint	19	Sales Germany
Retail expert	Academic research	20	Scientist horticulture and market research

[1] Young plants refers to both seedlings and rooted cuttings.

young plants, and logistics to end product, and interviewees were asked to describe the different activities and processes within the value chain. In the second round of interviews, questions about economic challenges were included. Topics were presented according to the conversational flow of the interview and adjusted to each value chain (vegetative or generative) and the value chain stage of the interviewees. All interviews were audio-recorded and transcribed verbatim using the f4 transcription software. The transcription was a simple transcript, focusing on the content and was conducted in the original language of the interview, either German or English.

All resulting documents were systematically analyzed using the qualitative data analysis software Atlas.ti. The analysis followed a hybrid approach, partly concept-driven (deductive) and partly data-driven (inductive). According to Schreier (2012) qualitative data analysis is often combined, data-driven to be able to describe the material in depth and concept-driven because the research question already determines a framework for the analysis. In the current study, production phases served as the initial coding framework. Repeated reading of interview transcripts allowed capturing details on value chain activities and processes. The inductive approach was further applied to explore value chain drivers.

During the coding process, text fragments were marked and a code system was developed to identify activities and processes in the value chain. In later stages, related codes were associated in code families. The analysis and interpretation were an ongoing process, to identify patterns in a constant contrast and comparison process (Boeije, 2002). Patterns were identified by comparing text fragments of each code (or code family). Insights were documented during the analysis process. This documentation was also considered for the interpretation of the results.

Results and discussion

Results and discussion are divided into two sections. The first section is dedicated to the different stages of the value chain. In each stage, processes and activities identified in the current study are discussed in comparison to published literature. Furthermore, differences between the vegetative and generative pathways of the value chain, such as differences in breeding, production locations, post-harvest processing and perishability of the propagation material are discussed. The second section builds on understanding the characteristics of the value chain and explores the driving forces within the value chain.

Value chain stages

The supply chain of potted plants has changed in the past 25 years, as growers became more specialized. According to interviewees, propagation nurseries started to deliver young plants, taking over a work stage that was done previously by potted plant growers. Specialization in different production stages had been reported for the floriculture sector (De Keizer et al., 2015), but not specifically for the potted plant value chain.

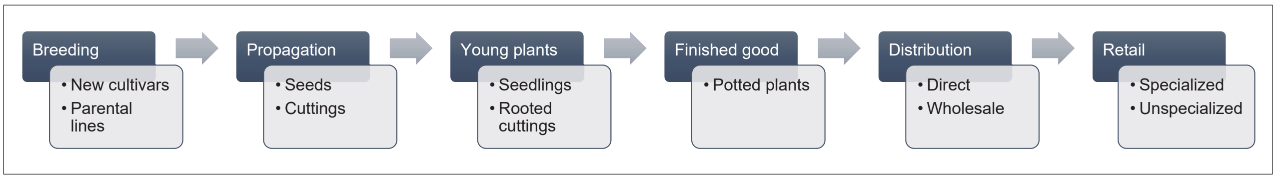

FIGURE 1. Value chain stages of flowering potted plants.

The value chain can be divided into two pathways that are distinct due to the propagation method, either generative (seeds) or vegetative (cuttings). Although in-vitro propagation is used for the propagation of plants such as orchids and Anthurium, the majority of flowering potted plants are still propagated from cuttings or seeds. Chain material flow starts at the breeding and propagation level. The propagation material is supplied to young plant nurseries; young plants are then distributed to potted plant nurseries and the finished product is supplied through wholesalers or directly to retail (Figure 1).

1. Breeding and propagation. Breeders are responsible for all new varieties and distribute propagation material worldwide. Based on the interviews with propagation nurseries, breeding of cultivars with new and attractive traits of shape and color is an important part of the business, as such novelties are the capital of the breeders. Therefore, propagation nurseries invest significant funds in the development of novelties, also including other breeding goals, such as disease resistance, temperature tolerance, longer shelf-life, and early bloom. As the development of new cultivars can take up to ten years, breeders have to anticipate long-term market trends and adjust breeding efforts accordingly. Shibata (2008) claimed that the need to continuously develop and release new cultivars to the market is due to consumers' preferences for new varieties. Some plants such as red and white poinsettias stay popular, but also among such plants, plenty of different varieties of color shades are available with new developed cultivars coming out yearly.

Traditional breeding techniques are used for the development of new varieties, such as cross-hybridization, selection and mutagenesis. Breeding of vegetative and generative cultivars is a similar process. Nevertheless, vegetative cultivars are not limited by the need for seed production, and therefore allow more possibilities for size, colors and patterns of flowers, evident in current varieties of Petunia and Pelargonium. According to Faust et al. (2016), breeding programs for seed production are more time consuming and costly because of the need to provide sufficient numbers of seeds with high germination rates.

After attaining the desired qualities, the new variety is tested before it can be commercially distributed. The major-

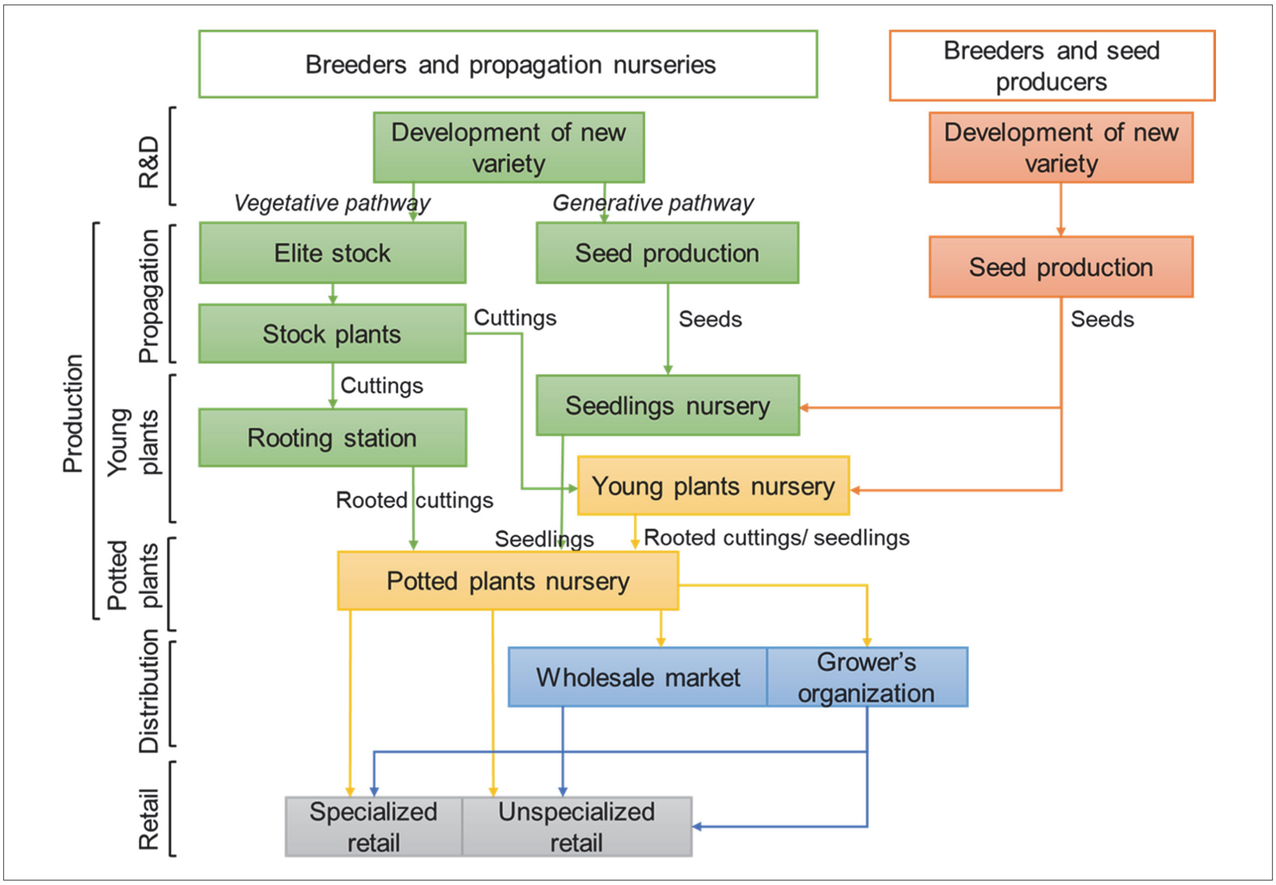

FIGURE 2. General overview of the value chain of flowering potted plants. Green: breeders and propagation nurseries; orange: breeders and seed producers; yellow: young plants and potted plants nurseries (independent from breeders); blue: distribution; gray: retail.

ity of breeders specialize in either vegetative or generative cultivars. Breeders that develop generatively propagated varieties produce seeds. Breeders that specialize in vegetatively propagated cultivars produce cuttings and young plants (Figure 2).

There are few companies worldwide, which specialize in breeding and seed production of a large assortment of flowering plants. McDonald and Kwong (2005) also found that seed supply is dominated by a few international flower seed companies from the USA, Japan and Europe. There are, however, also small producers specializing in few or single plant species. Production of seeds takes place in various locations around the world, including China, Central and South America, the USA, Africa and Europe. According to interviews with seed producers, the most important criteria for the choice of production location is optimal climate condition. Favorable locations have a mild climate, suitable for the cultivation of many plant species, and enable year-round production. Some crops, however, such as Primula, grow best under colder temperatures and are cultivated primarily in Europe.

Seed production is labor intensive, which is why labor costs are another important criterion for the choice of location. Based on interviews, seed production takes place in greenhouses or in the field by either cross-breeding to create F_1-hybrids or by open-pollinated varieties. Controlled conditions are preferred to achieve better quality and prevent pollen contamination. Seed producers explained that harvested seeds are cleaned by shape and size specific machines. Seed enhancement treatments are performed to ease handling by automatic seeders, accelerate the germination and induce uniform growth. In some cases, seeds are also treated against pathogens. Quality of seeds is tested to determine the germination rate.

According to interviewees, seeds are relatively stable and can be stored for long periods, depending on the crop. Due to their stability and low weight, seeds are distributed worldwide mainly by postal services or global logistics companies, and generally do not require temperature-controlled transport (Figure 3A). Seed producing companies distribute seeds either directly to seedling producers or through seed distributers (wholesale).

For vegetatively propagated cultivars, propagation nurseries produce cuttings and rooted cuttings. These companies play a central role in the value chain as they develop new varieties, supply propagation material and produce young plants. Company headquarters are mainly in Germany and the Netherlands, and are internationally active with worldwide distribution.

Elite stock plants are cultivated in Europe under strict hygienic conditions to prevent contamination (Figure 3B). Stock plants are propagated from elite stock plants and are the source for cuttings supplied to the European market. Stock plants are generally cultivated in African countries such as Kenya, Ethiopia, Uganda, and Tanzania. Some breeders also cultivate stock plants in Central America. Cuttings are harvested from stock plants cultivated in greenhouses under hygienic conditions. Harvested cuttings go through quality control, are packaged in cardboard boxes and air-shipped on the same day. From the airport, cuttings are transported in climate-controlled vehicles. To maintain quality, cuttings should reach the grower within three to five days from harvest.

The European supply of cuttings and young plants is orchestrated by propagation nurseries concentrated mostly in the Netherlands and Germany. These findings are supported by Menrad and Gabriel (2009) stating that the Netherlands and Germany are the largest producing countries in Europe for young plant material for potted plants and cut flowers. Menrad and Gabriel (2009) also refer to the well-established infrastructure for knowledge generation and innovation in horticulture in the Netherlands and Germany. Evers et al. (2014) further claimed that the global trade in cuttings was largely controlled by a few propagation nurseries located in the Netherlands, Germany and Switzerland. Interviewees from German, Dutch and Swiss firms confirmed that they supply cuttings to producers worldwide. The local competition and the transfer of knowhow due to the geographic proximity of propagation nurseries enabled those firms to become successful.

2. Young plants. Young plants are produced by propagation nurseries, collaborating contractors and independent growers (Figure 2). According to interviewees from propagation nurseries, young plants for the European market are generally produced within Europe, and distributed in climate-controlled vehicles. Interviewees also claimed that young plant production has become very effective, to achieve the required quality on time. The production of young plants takes place in state-of-the-art greenhouses under controlled temperature and humidity. Whereas seeds are sown by automated seeders, cuttings are generally hand planted. Seedling producers explained that cultivation duration of seedlings is diverse depending on the plant and the size of the product. For example, Viola need about five weeks and Cyclamen twelve weeks. Cultivation of cuttings is generally shorter, requiring between three to six weeks to develop roots.

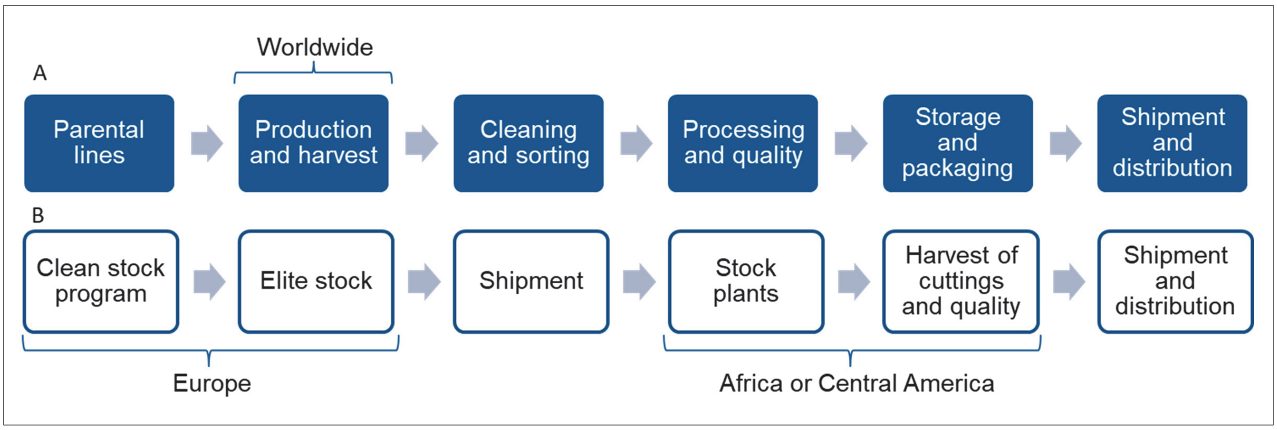

Figure 3. Stages in the production of propagation material: seeds (A); cuttings (B).

3. Flowering potted plants. The cultivation of potted plants is a separate production phase with different growing conditions and treatments. Whereas young plant production is standardized to be able to deliver the required quality on-time, potted plant production depends on the scale of production and the assortment. Young plants are potted and cultivated under suitable conditions of light, temperature, irrigation, fertilizer, and humidity. Additional activities might be required, such as pinching for branching, as well as staking and tying for support.

Distribution channels influence the production requirements. Therefore, potted plant growers can be classified according to their distribution strategy and choice of assortment. The first group typically produce commodity plants and distribute directly to large retail chains or large cooperatives. Such growers have strict production times, because the supply date is predetermined, and the space is needed for the next culture. The second type of growers focuses on a specialty assortment. Such growers supply generally to specialized retailers of flowers and potted plants. The third group grow and directly sell specialties. In accordance with this classification of growers, evidence for distinct marketing channels of orchids was reported for large retail chains and specialized retail (Krause et al., 2015). De Keizer et al. (2015) also referred to a clear distinction between the assortments of commodity and specialty plants.

4. Distribution of the finished product. Potted plants are generally distributed either through grower organizations or directly to retail. According to one interviewee, a large grower organization and retail chains tend to work with growers that have the capacity for large-scale production. Small growers may sell their products directly. Another form of distribution are wholesale markets, where growers and specialized retailers trade flowers and plants (Figure 2). Grower organizations are an important distribution channel for flowering potted plants. The strategies of grower organizations to achieve a higher price include marketing innovations and differentiation. The largest horticultural grower organization in Germany has several distribution channels: (i) customers' orders and delivery through local logistic centers, (ii) cash-and-carry (C&C) markets for specialized retailers, and (iii) a flower auction hall located in a large horticulture region.

5. Retail. The growing market share of supermarket chains and discounters has led to their increasing power in the value chain. According to interviewees, the number of florists continues to decline due to high rental costs in city centers and the competition with retail chains. Consumer shift from specialized flower shops to retail chains was shown for the German and European markets and explained by the preference for one-stop-shopping (Gabriel and Menrad, 2013; De Keizer et al., 2015).

According to Porter (2008), buyers become powerful when few large buyers purchase relatively large volumes. Such buyers can request reduced prices, demand better quality (increasing costs) and generally increase competition among industry participants. Supermarket chains and discounters can be considered powerful buyers because they buy large quantities and therefore are able to demand reduced prices. For orchids, this strategy was confirmed by Krause et al. (2015). As a result, potted plants sold by retail chains differ in price and quality from those sold by specialized retailers. Moreover, according to interviewees, retail chains also set standards for potted plant suppliers regarding pesticide use and certification. Evidence of the power of retail chains was shown already for other horticulture sectors. Riedel et al. (2009) concluded that fresh vegetable value chains are governed by large retail chains, which set the rules and participation conditions for producers. Value chains of cut flowers, not distributed through auctions, are also governed by large retailers setting criteria regarding quality, price, logistics and production processes (Riisgaard, 2009).

While dividing tasks among specialized agents may increase efficiency of operations, multiple chain actors also require more challenging coordination efforts. Moreover, tight coordination is vital in the value chain of flowering potted plants due to perishability. The need for on-time delivery to retail influences the entire chain and requires coordination between all actors from propagation material to distribution of the finished product. This means that orders have to be made early, and plants (propagation material, young plants) have to be delivered in a timely manner to the next stage of production. Growers have to prepare for the new delivery in terms of space and workforce. The duration of production is planned by the day, and distribution has to be tightly coordinated. For example, because cuttings are very sensitive, a delay of even one day may threaten the success of the entire crop. Furthermore, as this is a living plant, the successful production and distribution is dependent also on external factors such as weather conditions, or pathogen infestation. According to interviewees, delivering good quality on time is extremely important for their reputation as a reliable supplier. In fact, delivering the right quality at the right time was already mentioned, as an added value, more important than speed by De Keizer et al. (2015). The need for closer vertical coordination was anticipated for agri-food (Hobbs and Young, 2000) and horticultural chains (Bokelmann, 2009). According to Hobbs and Young (2000) perishability is indeed increasing coordination efforts among chain actors, because coordination reduces the uncertainty of the buyer regarding the quality and reliability of supply and sellers' uncertainty in locating a buyer in a timely manner to avoid product deterioration.

Driving forces within the value chain

1. Economic framework. The German market is considered stable with minimal changes in market volume. Nevertheless, there is a growing concern among actors for the future of the floriculture sector. Generational changes are feared to result in a reduction in the consumer base, because young consumers have different preferences. On the contrary, Ludwig-Ohm and Dirksmeyer (2013) expected an increase in consumption, because the consumer groups spending most on ornamental plants (older than 55 and couples without children) are expected to grow.

In the current study, interviewees claimed that young consumers cannot appreciate plant quality, lack the knowledge on different plant species, and spend little time in gardening. Therefore, young consumers prefer to purchase mature products and finished arrangements. Furthermore, interviewees referred to the need to "tell a story" about the plant as a marketing strategy. Product differentiation strategies are developed by breeders or grower organizations and require growers to collaborate. Indeed, according to De Keizer et al. (2013), future competitiveness in potted plant chains will require more collaboration between actors to achieve differentiated marketing channels.

Based on interviewees, the German market is limited, therefore, grower organizations put efforts into expanding to new markets such as Eastern Europe. De Keizer et al. (2015)

also referred to Eastern Europe becoming a significant market for luxury products, such as cut flowers, due to improving economic conditions.

One of the most dominant factors affecting actors in the value chain is the low market price. Actors (breeders, growers and grower organizations) claimed that the downward "price pressure" coming from retail chains caused great difficulties for their businesses, and was one of the driving factors for relocating the production sites of propagation material to countries with low labor costs. Faust et al. (2016) also described a trend of stock plant production facilities to move to countries with low wages. Seed producers also reported to have relocated the production to locations with lower labor costs. Some actors claimed that the low prices can be explained by consumers' perception of plants as a cheap product. Ludwig-Ohm and Dirksmeyer (2013) also recognized that the end consumer does not appreciate the sophisticated plant production technology and knowhow that is required in horticulture.

Lack of prestige is often associated with difficulties in hiring employees. Ludwig-Ohm and Dirksmeyer (2013) linked the traditional image of the horticulture sector with the lack of interest of young people in pursuing horticultural careers. According to some actors, businesses struggle due to the shortage in personnel and difficulties in keeping employees motivated and loyal. A representative of an international seed company also reported that there are fewer students specializing in traditional plant breeding. Bokelmann (2009) anticipated a shortage of trained employees for the horticulture sector due to a low number of apprentices, which was confirmed by Ludwig-Ohm and Dirksmeyer (2013).

2. Natural environment. Unpredictable weather conditions are another challenge for potted plant growers. Although potted plants are mostly cultivated in protected environments, weather conditions still influence greenhouse production. In warm winters, bedding plants will mature too early. The demand for bedding plants is also weather-dependent. Consumers are more likely to purchase outdoor plants when the weather is warm and sunny. Moreover, they require early varieties which are temperature-resistant and bloom early. Verdouw et al. (2010) also reported that weather-dependent sales contributed to demand uncertainties in the floriculture sector. Brumfield (2010) even considered weather as more challenging than economic recessions.

Healthy vegetative propagation material is important to prevent pathogen transmission between the different production stages. To maintain healthy stock plants, vegetative propagators must follow a hygiene protocol (clean stock programs). Following this protocol, elite stock plants are cultivated in-vitro, and tested and treated against viruses and other pathogens. Elite stocks, which are the source for propagation material for stock plans, are also cultivated in more than one location for backup. Stock plants in Africa and Central America are also cultivated under strict hygienic conditions and in multiple locations. To maintain hygienic conditions, special ventilation filters are installed and irrigation water goes through advanced purification systems. Faust et al. (2016) confirmed the need for sanitation protocols to prevent pathogen infections that can jeopardize the entire harvest of cuttings.

3. Politics and regulations. European legislation prohibits import of plants of the Solanaceae family from non-European countries other than Mediterranean countries to prevent pathogen transmission to food crops such as tomatoes and potatoes (European Commission Directive 2000/29/EC). As a result, stock plants of the Solanaceae family (e.g., Petunia, Calibrachoa) are cultivated mostly in Southern Europe and Mediterranean countries. Some propagation nurseries have their own production sites in Europe (generally in Portugal or Tenerife). Others collaborate with growers in Israel to produce Solanaceae cuttings. In this case, "private stock" varieties, developed by the partner company, are reserved to the collaborating propagation nursery.

Minimum wage was introduced in Germany in January 2015. One grower reported that the minimum wage created difficulties, because costs cannot be transferred to the price of the product. As a result, the company had to reduce the workforce. Minimum wage does not seem to be an obstacle for wholesalers, exporting plants. An interviewee working at wholesale claimed to pay more to be able to hire workers at all. The difference in the attitude towards minimum wage could be explained by the different firms' locations that might influence wages paid. Furthermore, production workers tend to earn lower wages, although, according to experts, most horticultural wages were already meeting the minimum wage before the implementation of the law (Bitsch et al., 2017).

Propagation nurseries benefit from lower production costs and optimal weather conditions for cutting production in Africa. Some interviewees claimed that they were "pushed" to work in such locations, due to the price pressure. Moreover, according to interviewees, working in Africa is also associated with personal risk as European gardeners have been exposed to violent attacks. Faust et al. (2016) claimed that one of the most important conditions for stock plant production location is the political stability of the host country. Yet, important production countries, such as Kenya and Ethiopia, suffer from political instabilities and personal safety issues. According to newspaper reports, some attacks on foreign-owned horticultural farms took place in Ethiopia during September and October of 2016. Protestors accused the Ethiopian government of seizing land for little compensation (Secorun, 2016).

Non-governmental organizations (NGOs) also play an important role in influencing chain actors to adopt private standards. Chain actors including propagation nurseries, growers and retailers are taking measures to prevent media scandals. They claimed that NGOs cause negative media attention. Propagation nurseries adopted certification programs to increase transparency and also made efforts to improve the social conditions at the production sites in developing countries. Such programs generally include medical care, day care for working mothers, and training and education programs for employees. Furthermore, these production sites are also socially certified (e.g., MPS Socially Qualified or GLOBALG.A.P. GRASP).

Certifications have become a requirement for the entire value chain. Retail chains buy only certified products in an effort to reduce risk. Indeed, all actors interviewed, including breeders, growers and grower organizations were certified by either MPS or GLOBALG.A.P. Small potted plant nurseries are often not certified, due to the associated costs and the administrative burden. As a result, non-certified growers are excluded from distribution to retail chains.

Some retail chains introduced a new requirement for neonicotinoid-free plants. The neonicotinoids might be linked to the reduction in pollinators and are, therefore, controversial (Kerr, 2017). According to interviewees, to avoid neonicotinoids some growers reported to have used generally more pesticides (some reported twice as much), and substances more harmful for both insects and humans than neonicotinoids. Growers also claimed that each retail chain was listing different substances that are prohibited, which would make it even more difficult to comply. Furthermore, a new certification was introduced, MPS-ProductProof, to certify neonicotinoid-free plants.

Reactions of horticultural chain actors to NGO pressure was also shown by Riedel et al. (2009), for fresh vegetables when retailers required new standards for pesticide use. Getter et al. (2016) referred to retail specific requirements on the use of neonicotinoids in ornamental plant production in the USA. Evers et al. (2014) also claimed that international NGOs were putting pressure on European flower buyers (largely supermarkets) regarding working conditions in the supply chains. Whereas the former studies discussed retailers' reactions to pressure, in the current study, also other actors, such as propagation nurseries, reported taking measures to avoid media attention.

The requirement for certification by large retail chains in Germany was shown already for orchids (Krause et al., 2015), while claiming that certification was not an important criterion for the end consumer. Accordingly, the requirement for certification would be a measure to minimize risk rather than a strategy for product differentiation. Furthermore, Riisgaard (2009) claimed that certification was a way to redistribute the costs to suppliers.

4. Innovation and technological progress.

Product innovations. So far, genetically modifying (GM) technologies were considered too expensive for the development of new cultivars for the floriculture industry (Chandler and Tanaka, 2018). Moreover, the usage of GM technologies is controversial and the cultivation of GM crops is substantially banned in Europe (Tagliabue, 2017). While breeders claimed to use only traditional breeding techniques, one of the breeders interviewed did not rule out using GM techniques, if costs are reduced. Another company stated to investigate genes that are responsible for coloring in flowers. In the past years, new and less expensive gene editing technologies, such as CRISPR/Cas have emerged. This technology was already implemented for mutagenesis in *Chrysanthemum morifolium* and Petunia (Zhang et al., 2016; Kishi-Kaboshi et al., 2017). Gene editing technology was considered by many plant breeders and scientists equivalent to mutagenesis technologies, which are exempt from the European regulations on genetically modified organisms (GMO) (Callaway, 2018). However, a recent decision by the European court (July 2018) subjects gene editing technology to the obligations laid down by the GMO Directive (Court of Justice EU, 2018). Though genetically engineered varieties are currently not accepted in European countries, the lack of an internationally coordinated approach to regulation (Chandler and Tanaka, 2018) and future change in regulation leave some potential for GM varieties especially in other markets, such as the USA and Japan.

Peat is the main component of growing media in horticulture due to a unique combination of properties that provide highly favorable conditions for plant growth. Yet, harvesting of peat is associated with habitat destruction and contribution to climate change, as peatlands are crucial sinks for carbon in the terrestrial ecosystem (Méndez et al., 2015). According to interviewees, different peat substitutes are available in the market. Growers reported different levels of success with substitutes. Nevertheless, the majority of growers are still using peat-based substrates as the main growing media. Barrett et al. (2016) confirmed that although many of the renewable substitutes show promise at an experimental level, few have been adopted commercially at a significant scale. According to Barrett et al. (2016), for growing media to be commercially acceptable they have to achieve acceptable results for a variety of plant species and under different irrigation, fertilizer and pest control regimes. Furthermore, the comparative environmental costs and benefits of different growing media need to be determined to avoid the adoption of substrates that are even more environmentally harmful than peat (Barrett et al., 2016).

Process innovations. Light emitting diode (LED) technology has the potential to replace high pressure sodium lamps (HPS), commonly used for horticultural purposes. LEDs are considered more energy-efficient and the light spectrum can be adjusted according to need (Bergstrand and Schussler, 2013). LED technology was reported to be implemented in logistic centers, marketplaces and C&C markets as a way to reduce energy consumption. Large growers cultivating crops with assimilation light requirements might already use LEDs. The limitations for the adoption of LEDs is the high price and the complexity of realizing the full potential of the technology. For example, LEDs can be used for the production of compact plants, a desired quality in the morphology of ornamental plants (Schwend et al., 2015). However, results were shown on a model plant in a controlled experiment and not in a commercial environment. Therefore, successful implementation requires knowhow and return on investment remains uncertain.

Automation plays an important role especially in the production of young plants by reducing labor costs. Automatic seeders are used for seedling production. According to Faust et al. (2016) seed propagation is often the preferred means of propagation because of the ease of automation. Though robots for planting cuttings are available, the majority of cuttings are still manually planted. According to Adegbola et al. (2019), robotic transplanting of cuttings is cost-effective in case of high local wages and low manual labor efficiency.

Insect pollination, where bees and bumblebees replace the process of hand pollination, is a method implemented by seed companies to save on labor costs. One seed producer has implemented insect pollination successfully at a European production site. Nevertheless, another producer claimed that insect pollination is not feasible because insect pollination requires a separate hall for each variety. This technology might be applicable for seed production in industrialized countries, where labor costs are high; however, it requires restructuring the production.

5. Marketing innovations. Sustainability is viewed as a market opportunity and there is a growing effort for product differentiation. The market for Fairtrade cut flowers is already established in Germany with 28% market share (Fairtrade, 2017). Fairtrade plants such as poinsettia and Pelargonium are new in the market. The number of Fairtrade poinsettia sold was 890,000 plants in 2017, with an increase of 6% compared to 2016 (Fairtrade, 2017). Fairtrade plants are controversial as some actors claimed that most consumers are not aware that the propagation material is cultivated in developing countries, and therefore do not understand the relevance. In addition, some specialized retailers were reluctant to buy Fairtrade plants, due to the premium price. Consumer acceptance of Fairtrade potted plants is still to be determined.

Another trend observed is the reduction in use of pesticides and successful application of biological pest control. Two examples of products associated are bee-friendly plants and organic plants. Bee-friendly labeled products are plants that were treated with reduced amounts of pesticides harmful to insects and have attractive flowers for pollinators. Bee-friendly plants are an innovation, related to consumer awareness of the population decline of pollinator insects linked with pesticide use. Using the term "bee-friendly" received greater willingness-to-buy compared to plants labeled as "neonicotinoid-free" (Getter et al., 2016).

Organic products are still rare in the floriculture industry. However, organic production was reported by several seed producers who are also partly certified organic. Research on consumer preferences for organic ornamental plants was conducted mostly for the USA market. Yue et al. (2011) found that consumers were not enthusiastic about organically grown ornamental plants. On the contrary, Rihn et al. (2016) showed increasing probability of purchases for certified organic and organic production attributes for indoor foliage plants.

Conclusions

The value chain is geographically fragmented in several production steps contributing to production efficiency and better quality. Geographic fragmentation is typical also for other horticultural chains, but for potted plants only the propagation material is cultivated in southern countries, such as Africa and Central America. Yet, chain fragmentation complicates coordination efforts, which are essential due to perishability and the requirement for on-time delivery. Moreover, perishability of the product, especially of cuttings requires high coordination between chain actors in order to reduce buyer and suppler uncertainty. Marketing and differentiation further require close coordination between actors because such efforts are initiated already at the breeding level and continue all the way to retail.

Vegetative propagation has become popular due to attractive cultivars and shorter cultivation periods of young plants. Nevertheless, cuttings have a short shelf-life, and generally require manual planting and costly sanitation protocols. Different from cuttings, seeds have a long shelf-life, do not require climate-controlled transportation and are automatically sown. Still, seeds require after-harvest processing and quality tests. Moreover, the vegetative pathway relies on cutting production in Africa, which is risky, because of political instability. To secure the supply of cuttings, breeders must cultivate in multiple production sites. Profitable production of seeds also requires low-wage labor. But since seeds are a stable product, they can be easily stored and transported around the world.

Breeders control the supply of propagation material and offer a large variety of patented cultivars. However, substitutes are easily available by competitors, which reduces breeders' bargaining power. Local competition due to geographic concentration results in decreasing margins reported by propagation nurseries, but it also triggers innovation and upgrading, which contribute to successful global trade. Sophisticated demand from retail chains also stimulates competitive success by anticipating buyers' needs elsewhere. To avoid losses due to unpredictable weather conditions, growers will have to find solutions to slow the maturation of plants in warm winters. While a supply-side solution might be available, it is more challenging to control weather-dependent demand uncertainties. Consumers appreciate diversity and new varieties, and breeders try to differentiate themselves by offering unique cultivars. While some niche markets do exist and will re-develop for heritage varieties, they also need to be developed through breeding and marketing. Development of new cultivars is a long and costly process. Gene editing technologies can potentially reduce the costs of development, but are not currently allowed for the European market.

Potted plant growers are the group of actors with the least bargaining power and they face difficulties to stay competitive. They can be divided according to their competitive strategy. Large scale production enables growers to lower the costs per plant. Such growers generally produce commodity plants, and distribute directly to retail chains or alternatively to a large cooperative. Another strategy is producing specialty plants and distribution through a grower organization or other distribution channels such as wholesale markets. The focus here is on product differentiation through marketing innovations and diversity of assortment. The third strategy is also characterized by a specialty assortment, selling directly at the nursery. Such growers generally sell products regionally, avoid membership costs in grower organizations and certification fees.

Similar to other agricultural value chains, retail chains for flowering potted plants are powerful buyers. The requirement for certification is an entry barrier for growers wishing to supply this marketing channel, because it imposes more costs and administrative burdens, and uncertified growers are excluded from distribution through retail chains. Certification requirements might also contribute to standardization in the sector, as most actors follow similar certification standards. Another indication of retailers' powerful position is the risk distribution in the chain. Unpredictable weather conditions as well as pathogen infestation pose a high risk for growers because of financial loss, and they also risk their reputation as reliable suppliers. Weather-dependent demand also poses a risk to retailers. Other forces such as changes in consumer preferences require the reaction of all chain actors, from breeder to retailers, in order for the companies to stay competitive.

Contrary to other sectors, in floriculture, NGOs influence other chain actors, in addition to retailers, directly. Retailers also put substantial pressure on other chain actors. For example, when retailers prohibited the use of neonicotinoids, growers used more harmful pesticides. Sudden requirements without an adaptation period can have unfavorable results. Therefore, retail chains should consider gradual transition periods to allow growers to develop suitable solutions.

Public awareness and NGO pressures motivate growers to reduce pesticide use and search for alternative strategies for pest control such as beneficial insects. These efforts are visible in marketing innovations such as bee-friendly plants. Product innovations, like peat-free potted plants, have the potential for product differentiation to attract environmentally conscious consumers. However, successful implementation requires experimenting to find suitable substrates. Process innovations such as LED technology, which offers several potential benefits, require high investments and expertise. Other innovations such as robots for planting cuttings can reduce labor costs, but are also associated with large investments.

Concerns regarding the future of the sector drive actors to strive for costs reduction, and to increase the consumer base by attracting young consumers and expanding into other markets. This strategy works under prosperity market conditions. However, the ornamental industry is more susceptible to lower demand during recessions than other horticultural industries, as was observed during the financial crisis in 2008. The popularity of organic, bee-friendly or peat-free products is expected to grow due to the increasing public awareness of sustainability issues in the value chain. Nevertheless, consumer research is needed to support actors in their differentiation efforts. Future research could also address the sustainability challenges of such complex and fragmented value chains. Better understanding of the sustainability challenges could help actors to reduce their environmental and social impacts and improve their competitive advantage.

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Sustainability Challenges and Innovations in the Value Chain of Flowering Potted Plants for the German Market

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Abstract: This study investigated the sustainability challenges and the adoption of sustainability innovations along the value chain of flowering potted plants supplying the German market. Data was collected through eighteen in-depths interviews with chain actors from different stages of the value chain and analyzed through qualitative content analysis. The material flow of the value chain begins at the breeding level followed by the propagation level. Cuttings are produced mostly in African countries, rooted cuttings and potted plants are cultivated in Europe. The main environmental challenges include water scarcity, pesticide use and carbon footprint. Social challenges in Africa include low wages and difficult working conditions. In Germany, social challenges include recruitment and retention of employees and product transparency. Economic challenges include profitability and the need to comply with standards. Sustainability driven innovations can address some sustainability challenges. However, their implementation often leads to increased costs, financial risk and complexity of implementation. Furthermore, the lack of product transparency prevents the transfer of sustainability costs to the consumer by offering a sustainable product for a premium price. Business-to-business standards have generally had a positive influence on the adoption of sustainability innovations. But by setting certification as an entry barrier for suppliers, retailers have become more powerful chain actors.

Keywords: agriculture; certification; cuttings; floriculture; horticulture; NGOs; ornamental plants; private standards; qualitative research

1. Introduction

Floriculture is a global industry, with main markets in Europe, the USA and Japan. Germany is the largest market in Europe for flowers and ornamental plants with a market volume of 8.9 billion euros in retail prices (2019) [1]. Flowering potted plants in Germany hold a market share of 33% of the total value, comprising of outdoor and indoor plants.

The majority of the commercially available flowering plants are propagated either from seeds or cuttings. Some plants such as orchids and Anthurium are propagated in-vitro. Vegetative asexual propagation through cuttings is essential for many commercially significant, herbaceous, ornamental species [2]. Apart from being the only mean of propagation for some plants, vegetative propagation has several advantages. For instance, the breeding process is generally faster than by generative breeding, because the time from spotting new mutations until the cultivar is market-ready is shorter [2]. Because there is no need for seeds development, vegetative breeding offers more possibilities for attractive traits of flowers, which makes them popular among consumers [3]. Furthermore, the unique traits of the cultivar stay stable from generation to generation [2]. For growers, vegetative cultivars are attractive because of the generally shorter cultivation period and the higher market price [3].

In recent years, there has been a growing criticism on the environmental and social burdens associated with ornamental plant production [4,5]. However, so far sustainability challenges in the value chain of flowering potted plants have not been defined. Investigation on social and environmental sustainability impacts in floricultural value chains focused on the production of cut roses in Africa and Latin America [6–8]. Sustainability assessment of potted plant focused mainly on environmental aspects such as carbon footprint [9]. Furthermore, only production stages taking place in Europe or in the USA, such as young plants and potted plants were assessed in prior studies (Figure 1). Other value chain stages such as breeding and propagation were not considered for the assessment.

Figure 1. Value chain stages of flowering potted plants.

Sustainability challenges can promote innovations and offers new business opportunities [10]. Environmental concerns had led scientist to develop and innovate more environmentally sound materials such as renewable alternatives. Many of these innovations are promising at the trial level, however, few have been adopted by the horticulture industry at a significant scale [11]. Social concerns had led to the emergence of different innovative tools such as standards that seek to regulate the social conditions in the production of floriculture products aimed at the European Union (EU) market [12]. The influence of adopting such standards was investigated for cut-flowers in Africa [13,14]. However, the extent of the adoption of such standards and their influence on the value chain is not known.

Therefore, the aim of this study is to investigate sustainability challenges along the whole value chain of vegetatively propagated flowering potted plants (Figure 1) including social, environmental and economic challenges. In addition, the current study aims to investigate sustainability innovations implemented and the limitations for their adoption.

2. Literature Review

2.1. Sustainability in the Floricultural Sector

The concept of sustainability was first described by the forest scientist von Carlowitz (1713), referring to economically harvesting timber while sustaining the forest for future use [15]. This concept deals with both economic and environmental goals because in this case financial gain is directly dependent on maintaining the natural resources. According to Bitsch (2016), social goals were initially introduced by the Brundtland Report's definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [16] (p. 41). Nowadays, sustainability is typically framed as the three pillar concept, which distinguishes between environmental, social and economic dimensions [15]. The general goals are defined as reducing environmental degradation, economic instability and social insecurity [17]. In accordance, Krug et al. (2008) defined sustainability goals for sustainable greenhouse production of potted plants as follows, "reduce environmental degradation, maintain agricultural productivity, promote economic viability, conserve resources and energy and maintain stable communities and quality of life" [18] (p. 43).

According to Krug et al. (2008) and Lopez et al. (2008), the main environmental issues associated with greenhouse production of potted plants are (i) pollution from fertilizers and other chemicals, (ii) plastic waste, (iii) carbon footprint due to heating and shipping, (iv) conservation of water and (v) pesticide use. General economic issues are to increase productivity and economic viability as well as account for consumer concerns regarding the source of the product, such as local and sustainable. Social issues are maintaining a safe working environment and supporting communities by hiring local citizens and purchasing locally [18,19].

A literature review was carried out to identify studies that assessed the sustainability or deal with different sustainability aspects of ornamental plant products to identify the state of the art regarding sustainability challenges. Although the present study focuses on flowering potted plants, assessments of other ornamental plant groups, such as cut flowers, were also included because they can contribute information about relevant sustainability aspects. In addition, studies of the social situation of the horticulture sector were included.

The research identified 36 studies, most of them assessing environmental aspects (26), using Life Cycle Assessment (LCA) or assessing only carbon or water footprint (Table 1). Among them, one study performed both social and environmental LCA [8]; six studies included cost calculation with the environmental assessment. Eight studies evaluated only social aspects, such as work satisfaction, employment relations and workers' safety. Potted plants were investigated mostly for greenhouse gas (GHG) emissions and water consumption. Social aspects were generally investigated in cut-flower farms in Africa. In Europe and the USA, studies of social aspects focused on job satisfaction. Economic aspects investigated in the USA and Europe focused on cost calculations of flowering potted plants. The 36 studies focused on a variety of different sustainability issues, which cannot be discussed in detail here due to space limitations (Table A1 in Appendix A).

Table 1. Publications dealing with sustainability aspects in the value chain of ornamental plants divided according to sustainability dimension—environment, society and economy.

Publications		Culture/Location	Main Topic(s) Investigated	Env. [1]	So. [2]	Ec. [3]
[20]	Abeliotis et al. 2016	Cut-carnations/Greece	LCA [4]	X		
[21]	Anker and Anker 2014	Cut-flowers/Kenya, Lake Naivasha	Living wages		X	X
[22]	Bitsch 1996	Horticulture/Germany	Job satisfaction		X	
[23]	Bitsch 2007	Horticulture/USA	Job satisfaction		X	
[24]	Blonk et al. 2010	Cut-roses /Kenya, The Netherlands, potted Phaelenopsis and potted poinsettia/The Netherlands	CF [5] based on LCA [4]	X		
[25]	Bonaguro et al. 2016	Potted poinsettia, pelargonium and cyclamen/Italy	LCA [4] (GHG) [6]			
[26]	Brumfield et al. 2018	Potted petunia/USA	GHG [6] and cost of production	X		X
[27]	De Lucia et al. 2013	Potted bougainvillea/Italy	LCA [4] and substrate assessment	X		
[28]	de Vries 2010	Cut roses/Ethiopia, The Netherlands	Qualitative comparison [7]	X	X	X
[29]	Evers et al. 2014	Cut flowers and cuttings/Uganda	Value chain governance		X	X
[8]	Franze and Ciroth 2011	Cut roses in Ecuador/The Netherlands	LCA[4] and Social-LCA	X	X	
[30]	Ingram et al. 2018	Potted wax begonia/USA	LCA[4] (GHG) [6] water consumption and variable costs	X		X
[31]	Ingram et al. 2018	Potted chrysanthemum/USA	LCA[4] (GHG) [6] water consumption and variable costs	X		X

Table 1. *Cont.*

	Publications	Culture/Location	Main Topic(s) Investigated	Env. [1]	So. [2]	Ec. [3]
[32]	Ingram et al. 2019	Potted poinsettia/USA	LCA[4] (GHG) [6] water consumption and variable costs	X		X
[33]	Ingram et al. 2017	Young foliage plants/USA	LCA[4] (GHG) [6] water consumption and variable costs	X		X
[34]	Kirigia et al. 2016	Cut flowers and cuttings/Kenya, Tanzania, Uganda, Ethiopia	Local development and food security	X	X	
[35]	Knight et al. 2019	Potted plants/USA	Consumptive water use and water footprint	X		
[26]	Koeser et al. 2014	Potted petunia/USA	LCA [4] (GHG) [6]	X		
[36]	Lazzerini et al. 2015	Woody plants/Italy	LCA [4] (GHG) [6]	X		
[4]	Lazzerini et al. 2018	Potted plants/Italy	Sustainability assessment indicator based	X		
[7]	Mekonnen et al. 2012	Cut roses/Kenya	Water footprint	X		
[37]	Mengistie et al. 2017	Cut flowers/Ethiopia	Pesticide use and private standards	X	X	
[38]	Meyerding 2015	Horticulture/Germany	Job satisfaction		X	
[39]	Nigatu et al. 2015	Cut flowers/Ethiopia	Endotoxin exposure		X	
[5]	Riisgaard and Gibbon 2014	Cut-flower/Kenya	Labor management		X	
[40]	Russo and de Lucia Zeller 2008	Young plants of grafted rose and sowbread seedlings/Italy	LCA [4]	X		
[41]	Russo, Buttol and Tarantini 2008	Cut roses and potted Cyclamen/Italy	LCA [4]	X		
[42]	Russo, Scarascia Mugnozza and de Lucia Zeller 2008	Cut roses and potted Cyclamen/Italy	LCA [4]	X		
[6]	Sahle and Potting 2013	Cut roses/Ethiopia	LCA [4]	X		
[9]	Soode et al. 2013	Potted poinsettia/Germany	CF [5]	X		
[43]	Soode et al. 2015	Roses and orchids/Germany	CF [5]	X		
[44]	Staelens et al. 2018	Cut-flowers/Ethiopia	Job satisfaction		X	
[45]	Thilsing et al. 2015	Potted campanula, lavandula, rhipsalideae and helleborus/Denmark	Exposure to endotoxins, bacteria and fungi		X	
[46]	Torrellas et al. 2012	Cut-roses/Europe	LCA [4] and cost-benefit analysis	X		X
[47]	Wandl and Haberl 2017	Cut flowers and potted plants/Austria	LCA [4] (GHG) [6]	X		
[48]	White et al. 2019	Floriculture/USA	Water management	X		
	Total: 36			26	13	9

[1] Environment; [2] Society; [3] Economy; [4] All topics addressed by the standardized life cycle assessment (LCA) method (ISO 14040, ISO 14044); [5] Carbon footprint (CF); [6] Only greenhouse gas (GHG) emissions were measured based on LCA; [7] Different topics related to environmental, social and economic aspects.

2.2. Sustainability Innovations

Innovation is defined by the Organization for Economic Co-operation and Development (OECD) as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (OECD/Eurostat, 2005, p. 46, cited in Reference [15]). This definition refers to products, processes, organizational and marketing innovations at the firm level, while innovations at the industry level, economy-wide changes and industry reorganization are not part of the above definition [15]. However, according to Porter (1998) innovation is a major source of industries' structural changes [49].

Innovation is extremely important for achieving sustainability, at the corporate level [10]. New environmental or social regulations and laws increase the pressure for the development of innovations. Sustainability as a concept also inspires ideas that can lead to new business opportunities. However, adopting sustainability innovations poses uncertainty regarding market success and for some innovations, it is not yet clear whether they have a positive or a negative impact on sustainability. Moreover innovations may introduce trade-offs between sustainability dimensions [10]. Due to the uncertainty in the effect of sustainability innovations, Hansen et al. (2009) introduced the concept of sustainability-oriented innovation, referring to "innovations which are individually perceived as adding positive value to sustainable development" [10] (p. 686).

Environmental or eco-innovations are designed to reduce or avoid negative impacts on the environment [50]. Klewitz and Hansen (2013) defined three types of sustainability innovations with regard to the environmental dimension [50]. Process innovations are related to the production of goods and services. Organizational innovations involve new forms of management and reorganization of structures and routines. Product innovations are developments that improve product quality in terms of materials used (e.g., organic or recycled), high durability or low energy consumption.

According to Phills et al. (2008), while many innovations can create benefits for society by economic growth and increased employment, social innovations create social value in situations where the market fails and needs cannot be met otherwise. Furthermore, social innovations are designed to shift the balance towards creating benefits for the public or society as a whole, rather than private value or gain to companies or ordinary (not disadvantaged) consumers. The same authors also claimed that often the involvement of three sectors (private, non-profit and public sectors) is required to innovate and solve social or sustainability challenges. Furthermore, sector interaction serves as a fertile ground for social innovation [51].

Economic sustainability can be defined as activities that "lead to a retention or increase of a company's overall capital stock" [10] (p. 684). Therefore, sustainable economic innovations can be considered as innovations that contribute to growth or retention of capital stock without compromising social and environmental sustainability goals.

Bloemhof et al. (2015) differentiated between internal and external drivers that motivate firms to adopt sustainability strategies. Internal drivers are factors that help attain sustainable practices within the company. In their study, they included cost efficiency, product quality, process capability, brand reputation, sourcing and operations advantages, transport and logistics advantages, strategic objectives, top management vision and employee safety improvement as internal drivers. External drivers are factors beyond the boundaries of a company and include policy and regulations, stakeholder awareness, market forces, social issues and global warming reduction [17]. Although the above described drivers refer to strategies, such drivers can influence value chain actors to adopt sustainability innovations.

3. Materials and Methods

Qualitative research approaches are well suited to exploring new or not well-researched issues [52]. Sustainability challenges along the value chain of flowering potted plants are not well-researched, therefore, a qualitative approach was chosen. One of the most common qualitative methods for in-depth and extensive understanding of issues is the qualitative research interview [53]. Furthermore, in-depth interviews allow investigating multiple perspectives of key-actors [54]. Other studies of value chains have used qualitative interviews with different chain actors to explore sustainability hotspots, for example, in pork [55] or to identify critical issues in asparagus [56]. In the current study, interviews were conducted, using a semi-structured interview guide. Semi-structured interviews were chosen, because they allow exploring different issues systematically, without compromising the ability of interviewees to freely express themselves [53,57].

Eighteen in-depth interviews were conducted in two rounds, in the winters of 2016 and 2017. Interviews were conducted with seven propagation nurseries, three potted plant growers, one grower is also part of a growers' cooperative (wholesaler) and another two wholesalers, an agricultural certifier, a business consultant and a horticultural marketing and retail expert (Table 2).

Table 2. List of interviews (type of chain actor, business actions and interviewee's role in the business).

Type of Actor	Business Actions	Interview No.	Interviewee Role
Propagation nursery 1	Breeding, vegetative and rooted cuttings	1	Marketing director
		2	Marketing director
		2	Supply chain manager
Propagation nursery 2	Breeding, vegetative and young plants	3	Marketing manager
Propagation nursery 3	Breeding, vegetative and rooted cuttings	4	Marketing manager and owner
Propagation nursery 4	Breeding, vegetative and young plants	5	Marketing and product manager
Propagation nursery 5	Breeding, mostly vegetative young plants	6, 7	Sales manager Germany (authorized representative)
Propagation nursery 6	Breeding, vegetative, generative, young plants	8	Marketing and product management (EU)
Propagation nursery 7	Breeding, Seeds and cuttings	9	Growing adviser
Grower 1	Breeding generative, seeds, seedlings and potted plants	10	Owner
Grower 2	Rooted cuttings and potted plants	11	Owner, CEO
Grower 3	Breeding generative, seedlings and potted plants	12	CEO
Wholesaler 1	Grower-cooperative, distribution	12	CEO
Wholesaler 2	Growers' organization, distribution and export	13	Sales manager
		13	CEO
Wholesaler 3	Grower-cooperative, distribution and export	14	CEO
		14	Public relation and marketing
		15	Quality management and sustainability (head of department)
Certifier	Certification	16	Commercial manager
Business consultancy	Foot printing	17	Sales Germany
Retail expert	Academic research	18	Scientist horticulture and market research

The semi-structured interview guide covered different stages from breeding, propagation, young plants and logistics to finished product and interviewees were asked to describe the different activities and processes within the value chain. In the second round, questions covered also procedures associated with social and environmental sustainability aspects as well as the adoption of specific sustainability innovations, such as specific technologies or standards. Furthermore, interviewees were questioned regarding the main environmental and social sustainability challenges, as well as economic difficulties within their company and the sector. Findings about the value chain from the first round of interviews as well as the literature review on sustainability impacts of ornamental plant production and agricultural systems were used as a backbone to structure interview questions on sustainability aspects relevant to flowering potted plants.

Topics were presented according to the conversational flow of the interview and adjusted to the profession and function of each interviewee. All interviews were audio-recorded and transcribed verbatim using the f4 transcription software. Transcription was simple transcript, focusing on the content and was conducted in the original language of the interview, either German or English.

All resulting documents were systematically analyzed using the qualitative data analysis software Atlas.ti. The analysis followed a hybrid approach, partly concept-driven (deductive) and partly data-driven (inductive). In concept-driven approach, the coding frame is based on previous knowledge. In the data-driven approach, a coding frame is created inductively based on the data, to capture unanticipated details and describe the material in-depth [58]. In the current study, social and environmental sustainability aspects served as the initial coding framework (deductive). The inductive approach was implemented to explore further sustainability challenges, mostly regarding economic sustainability and identify additional sustainability innovations.

During the coding process, text fragments were marked, and a coding frame was developed to identify processes, sustainability challenges and sustainability innovations. In later stages, related codes were associated in code families. An example of a code family can be seen below for 'water', presenting interviews excerpts related to the value chain stage stock-plants (Table 3). Patterns regarding sustainability issues and innovations were identified by comparing text fragments in an ongoing process of constant contrast and comparison following Boeije (2002) [59]. The investigated procedures and processes as well as expert opinions allowed identifying sustainability challenges along the value chain. The analysis also focused on the difficulties and drivers for the adoption of sustainability innovations.

Table 3. Codes for the family 'water' for the chain stage stock plants, including interview excerpts.

Code	Findings	Interview Excerpt
Water source	Lake or ground water	"The water source-in Ethiopia from a well, in Kenya from the lake" (Propagation nursery 5). "The water level of the lake is always an issue and it is becoming even more important in recent years. However, this big discussion, that we are emptying the lake, that is not the case" (Propagation nursery 5). "In Uganda, water is not limited. Overall, as a country, Kenya has a water shortage and so does Ethiopia. But our production locations are not in the desert areas. We are next to Nairobi, because there is no water shortage there. I do not see any conflict with human needs for water" (Propagation nursery 1). "There are water problems in Kenya due to too much horticulture in one location, in Naivasha. Surely, there are also developments in Ethiopia. It happens so quickly, land use development is fast, there you need large amounts of water. For example, roses" (Propagation nursery 1).
Irrigation system	Advanced water filtration system, drip irrigation Open or closed irrigation systems	"People are investing more and more in how can we use less water" (Certifier). "It has to be pathogen-free. We really have to disinfect the circulating water" (Propagation nursery 5). "In Africa we are talking about bags [referring to plant containers], two-liter bags and we have a drip irrigation that means that there is a pipe with a little hole and water drips into the bag" (Propagation nursery 1).
Waste water	Biological treatment process in artificial wetland to capture fertilizer Pesticides contaminated water go through active coal based filter	"In the wetland there are plants which take out the fertilizer and clean the water" (Propagation nursery 1). "The plants are taking the active ingredients, which make the water again drinkable or they can reuse it" (Certifier). "For example, Kenya, the regulations are very strict. We cannot let unfiltered water back into the lake. We have there a biological wastewater treatment system. Only clarified water after the biological wastewater treatment can return to the lake" (Propagation nursery 5). "When we talk about water that is used for pesticide treatment, there we have a filter system, where we use active coal to filter the pesticides out of the water" (Propagation nursery 1). "There are enormous quantities of roses, there is a lot of water going directly into the ground and chemicals and so forth. I would say there are black spots, not everything is good there" (Propagation nursery 1).

4. Results and Discussion

This section is divided into five parts. The first part presents the specific characteristics of the vegetative value chain of flowering potted plants. The discussion of each sustainability dimension in the following three sections, environmental, social and economic sustainability, builds on understanding the value chain. The environmental section is divided according to the value chain stages, breeding, production and distribution. Although the production stages of propagation material, rooted cuttings and potted plants are separate stages (Table 4), they share similar environmental impacts. The social section differentiates between social sustainability in Africa or Central America and social challenges in Germany. The economic section discusses different challenges relevant to the economic sustainability of different business actors in the value chain. Sustainability innovations are discussed in the context of the different challenges. The last section is dedicated to structuring sustainability challenges and the innovations addressing them along the value chain.

4.1. The Vegetative Value Chain of Flowering Potted Plants Supplied to the German Market

The value chain consists of five stages—breeding for the development of new varieties, production of propagation material, young plant production, potted plant production and distribution to retail (Table 4). All stages take place in Europe, apart from the production of propagation material, which generally takes place in southern countries. Breeders or propagation nurseries generally develop new varieties, produce and sell cuttings and rooted cuttings. Cultivars have to go through an in-vitro cleaning process to achieve pathogen-free plants. The resulting tissue culture plant can then be cultivated in special facilities within Europe under strict hygienic conditions as elite stock plants. Elite stock plants are the source to generate the next generation of stock plants in Africa or Central America.

Table 4. The vegetative value chain of flowering potted plants.

Value Chain Stage		Function	Location
1.	Breeding	Development of new cultivars Cultivation of elite stock plants for propagation	Europe
2.	Propagation	Cultivation of stock plants Harvest of cuttings for production	Africa and Central America
3.	Young plants	Cultivation of rooted cuttings	Europe
4.	Potted plants	Cultivation of potted plants	Europe
5.	Distribution	Storage and shipment	Germany

Cuttings for the production of plants for the consumer in the German market are produced mostly in African countries namely Kenya, Ethiopia, Uganda and Tanzania. Few breeders also produce cuttings in Central America. The stock plants for producing the cuttings are cultivated in simple greenhouses made of plastic tunnels but under strict hygienic conditions. These include advanced water purification systems, ventilation filters and hygiene protocols to prevent possible transmission of pathogens through employees. Stock plants are cultivated in plastic containers and substrate based on volcanic rock. Harvested cuttings are air-shipped in cardboard boxes to Europe. From the airport, cuttings are transported to the rooting nurseries.

The production of rooted cuttings takes place in Europe, in state-of-the-art greenhouses under controlled temperature and humidity. Production of rooted cuttings takes between three to six weeks, which is the period required for the cuttings to develop roots, depending on the crop.

Cultivation of potted plants is a separate production stage, which takes about three to four months. Plants are potted and cultivated under adjusted conditions of temperature, light, fertilizer, irrigation and humidity. Temperature requirements for potted plants are slightly lower than for the cultivation of rooted cuttings. Potted plants can be distributed directly to retail or through growers' organizations. In some cases, small growers are selling their products directly to the end consumer.

4.2. Environmental Sustainability Challenges and Sustainability-Driven Innovations along the Value Chain

4.2.1. Breeding Stage

The main purpose of breeding is the development of novelties with attractive traits. In some cases, breeders also develop disease-resistant cultivars, plants with temperature tolerance and early bloom. For example, Lütken, Clarke and Müller (2008) reported on efforts to develop cultivars, which are resistant to pest and disease [60]. Cultivars that require less heating or varieties that are more pest-resistant can influence the entire chain by reduced energy consumption and less need for pest control. Therefore, breeding goals have an indirect influence on the environmental impacts in different stages of the value chain. According to interviewees, breeders generally use traditional breeding techniques such as cross-hybridization, selection and mutagenesis. Some companies did not exclude the use of genetically modifying (GM) technologies in the future. GM technologies can possibly expand the gene pool of ornamental crops, which in turn contributes to the development of novelties [61]. Furthermore, development of new varieties using GM techniques has the potential to reduce chemical use such growth retardants and pesticides [60]. Up to now, GM technologies were considered too costly for the floricultural industry [61]. However, the emergence of new and cheaper GM technologies, which was already implemented in different ornamental crops offers new prospects [62,63]. Adopting GM technologies might shorten the breeding process and eventually reduce the overall costs of the development of novelties. Nevertheless, the usage of GM technologies is controversial due to unknown and unpredictable impacts on the environment as well as health and safety concerns regarding agri-food products [60]. Although vegetatively propagated ornamentals are typically not eaten, the limited acceptance of GM technologies by the public and the restrictions on the European market prevent this transition.

4.2.2. Production Stages

Water consumption is an important sustainability aspect especially in arid regions of the world. According to interviewees, the source for irrigation water for the production of cuttings can be either groundwater or a nearby lake, depending on the region. A different study claimed that water is also obtained from rivers and rainwater harvesting [34]. According to interviewees, companies invest in advanced water purification and disinfection systems to prevent pathogen infections in plants. Water purification systems are required for the cultivation of stock plants because harvested cuttings must be free of pests [29]. Interviews with representatives of propagation nurseries producing in Africa confirmed that water shortage is a problem in several horticultural centers in Africa. However, they also argued that there is no water scarcity at their production sites. Although there is no evidence from the literature for water scarcity in cutting production areas, there have been reports on water shortages in cut-rose production regions in Africa. Water overuse for the production of cut-roses was shown in Kenya, which directly influenced the decline of Lake Naivasha's water levels [7]. Water scarcity was experienced also by cut-rose growers irrigating with ground water, during the dry season in the highland cultivation area in Holleta, Ethiopia [6]. De Vries (2010) also emphasized the general risk of water overuse for cut-rose production from lakes and rivers in Ethiopia [28].

According to interviewees, some companies implemented water saving irrigation technologies such as drip irrigation systems or closed irrigation systems. Another nursery reported to have implemented an irrigation system with about 20% drain water. Excess water is captured and treated as wastewater. The implementation of water-saving techniques had been reported previously for floriculture companies in Uganda and Ethiopia [34].

Interviewed plant growers in Germany expressed concern about the water supply due to longer dry periods that can be attributed to climate change. Some producers reported also to collect rainwater as a measure to guarantee a sufficient water supply. Nursery growers in the USA had also emphasized their concern about water availability [48]. In this recent study, growers referred to the possibility of water source depletion under conditions of long-term drought and uncertainty in accessing additional water resources. Growers also referred to a solution to water shortages by changing irrigation strategies, to be able to re-collect and recycle irrigation water and increases in nursery water storage capacity [48].

Fertilizer runoff is generally dependent on the irrigation system. According to interviewees, stock plants in Africa are grown on substrate in either open or closed irrigation systems. Wastewater is treated in special artificial wetlands. Fertilizer runoff from cut–rose farms was confirmed by Mekonnen et al. (2012) and Sahle and Potting (2013), resulting in pollution of water bodies in Kenya and Ethiopia [6,7]. Production of cut-roses is different from the production of cuttings because the majority of rose plants grow in soil and irrigation water with excess fertilizers drains into the ground [6].

In Germany, growers reported to irrigate using either closed loop recycling systems or open systems. Closed systems have the benefit of saving water and reducing fertilizer use. In these technologies, irrigation water is recycled through filtration and chlorination. Mist irrigation is another form of open irrigation system applied during the first weeks of the production of rooted cuttings, which serves to increase the humidity of the plant environment. According to interviewees, there is generally no fertilizer loss into the environment from neither open nor closed systems. Similarly, no fertilizer losses were reported in a Dutch recycling system for cut-rose production [28].

There is a growing effort to reduce the use of chemicals for plant protection. It is crucial for cuttings to be clean of any pests or diseases ("*zero pest tolerance*"). Therefore, pest control is very important in the cultivation of stock plants. According to interviewees, the producers of cuttings follow an integrated pest management approach. They have scouts regularly controlling the plants and with any sign of pests, plants are treated individually. The approach uses biological pest control first and chemicals only as a last resort. However, the use of beneficial insects is limited, as imported plants (cuttings), have to be free of insects. According to interviewees, a lot of pressure was put on growers to stop using neonicotinoid insecticides, which are suspected to harm the populations of pollinator insects. This requirement from retail was beyond the legal frame because at the time, only the use of some of the neonicotinoid insecticides was restricted by the European Commission [64]. However, some producers reported that in order to avoid neonicotinoids they had to use other more harmful pesticides. Furthermore, this pressure to stop using neonicotinoids has led to the development of a new standard, MPS-ProductProof, to certify neonicotinoid-free plants.

Pathogen-free propagation material (cuttings) is crucial at the rooted cutting stage, because pest control is restricted especially during the first two weeks. In the cultivation of rooted cuttings, fungicides can be applied after the first two weeks, to prevent proliferation of fungus at the conditions of high humidity and temperature. Application of beneficial insects or insecticide is not possible at this stage because of the high humidity and temperature. Other pest control solutions are available such as fungi against flies or bacteria that attack pests. Moreover, according to interviewees, growers avoid application of certain pesticides on rooted cuttings to allow the use of beneficial insects in the next stage of potted plant cultivation.

Potted plants require pest control management due to the longer production period. At this stage, growers reported to implement an integrated pest management approach and try to reduce the application of chemicals for pest control. Growers are also required to keep records of all treatments applied on the plants. Ornamental plants sold by different retailers in the UK, were found to contain a mixture of fungicides and insecticides including neonicotinoid insecticides [65]. As this last study investigated nectar- and pollen-rich ornamental plants, it was claimed that pesticide residues could influence pollinator populations. In Ethiopia, intensive use of pesticides was measured in cut-rose production. In a LCA, the use of pesticides was shown to contribute to fresh water and terrestrial eco-toxicity [6]. Although cut flower production is different from the cultivation of stock plants, plants are grown in similar greenhouses, therefore, leaching of pesticides into the environment cannot be excluded.

Several aspects have the potential of contributing to the carbon footprint (CF) in the production of potted plants. These can be divided into direct and indirect contributions to greenhouse gas (GHG) emissions. Direct contributions are emissions through energy consumption for heating of greenhouses and artificial light. Indirect contributions are GHG emissions due to non-renewable materials such as peat and plastics. Direct contributions to CF associated with the regulation of storage temperatures and transport will be discussed in the distribution stage.

In Africa, the cultivation of stock plants takes place under optimal climate conditions and there is no need for heating or the use of artificial light. Nevertheless, some plants are grown in high elevations, above 2000 m and heating is required during the night to prevent a temperature drop. Some stock plant growers reported to use geothermal energy for heating; others use coal and electricity. For the production of rooted cuttings and potted plants, greenhouses are heated with different combinations of renewable and non-renewable energy sources, among them wood, coal, gas, oil and geothermal energy. The transition to renewable energy sources, such as woodchips, heating based on geothermal energy or waste heat, can be considered innovative. Cultivars that require less heating have a positive influence on the GHG emission balance, as the reduction of one degree in heating corresponds to considerable energy savings. Some growers in Germany also adopted the Cool Morning–Warm Evening strategy for reducing energy requirements. Several other new technologies have been reported for energy saving in greenhouses, among them energy-efficient heat pumps, better insulating facade materials, innovative pre-heating and cooling ventilation technologies and underground-based heat storage [66]. Furthermore, a concept of low energy greenhouses (ZINEG) was developed that integrates new energy-saving techniques and strategies such as maximal thermal insulation, closed method of operation and using solar energy [67]. A study of the CF of poinsettia plant production in Germany showed that heating would be the highest contributor to GHG emissions, accounting for over 80% of the total emissions, if non-renewable fuels were used. The same study also demonstrated that adoption of the Cool Morning–Warm Evening strategy reduced the CF by 5% on average [9]. In a different study, it was found that emissions from heating of greenhouses in Austria are the major contributor for GHG emissions of most products, accounting for 84 to 90% of the total [47].

In the cultivation of stock plants, artificial light is applied only for certain plants such as poinsettia, to prevent flower induction. Artificial light is generally applied for the production of rooted cuttings and potted plants. The most commonly used technology is high-pressure sodium lamps. Innovative, light emitting diodes (LED) technology, considered more energy-efficient, is available for floricultural purposes. Furthermore, experimental results showed that a dynamic LED lighting system, adjusted to the radiation of solar light, consumes 21% less energy compared to the control LED system [68]. Nevertheless, LED technology is comparably more expensive, though its implementation reduces energy costs. Apart from the higher price, implementing LED technology requires expertise to achieve its full potential. Some growers reported that they experiment with LED technology. Prior studies emphasized that the energy consumption of lighting in the production of floricultural products can be reduced by efficient supplemental lighting sources, such as LED technology [9,69].

Plastic containers contribute to GHG emissions and also result in waste accumulation. Stock plants are cultivated in plastic containers, either bags or pots. In some propagation systems, bags or pots are discarded after every round of stock plants, other nurseries reported that they use bags from durable material, which can be re-used after disinfection by steaming. In this innovative system, bags can be re-used 6 to 7 times. Disinfecting by steaming also consumes energy; however, steaming must also be applied to the substrate and tables and the energy can come from renewable sources.

Rooted cuttings are cultivated in plastic plug trays. Some producers have introduced an innovative, deposit system for the plug trays. In this system, plug trays are collected from growers when shipping the next round of plants and the trays are re-used after cleaning and disinfecting. Other growers reported that used plug trays are returned to the tray producers where the plastic is recycled.

Potted plants are grown in plastic pots, which are then sold to the end consumer. Alternatives to petroleum based pots are a large diversity of biodegradable, compostable or recycled plastic containers designed to reduce plastic waste [70]. According to interviewees, the adoption of biodegradable or compostable containers in nurseries is still limited. Recycled plastic containers, on the other hand are frequently used. Interviewees referred to dark colored pots generally containing a percentage of recycled plastic. Nambuthiri et al. (2015), differentiated between biocontainers, which are designed for short periods (a few months) before degrading and compostable containers, which are designed for longer cultivation periods of one to three years [70]. Another challenge in implementing different types of containers, such as degradable and compostable containers, are the different irrigation and fertilizer requirements [70]. Recycled containers have the lowest direct costs, compared to the alternatives, which can explain their widespread acceptance among growers [26].

Different studies assessed the contribution of containers to the carbon footprint of potted plants. Results showed that the share of CO2e emissions of containers depends on the culture and the climatic requirements and can vary between 16% and over 50% of the total CF [30,69]. A few studies compared the CF of degradable containers. Comparing plastic and compostable rice hull pots, it was concluded that both have the highest contribution to CO2e emissions for poinsettia, zonal geranium and cyclamen; the plastic pots because of the material used for production and the rice pots due to transport from the production site [25]. Therefore, containers may account for a significant part of the CF; however, plastic alternatives do not necessarily offer a lower CF.

According to interviewees, stock plants are generally grown in substrate based on volcanic rock, which can be attained locally and has very good qualities, such as water permeability and a structure that allows sterilization. Some nurseries reported that they re-use the substrate after disinfection by steaming.

Rooted cuttings and potted plants are generally cultivated in peat-based substrate. Peat is the most common growing media in horticulture due to its unique qualities favorable for plant growth. But peat is a limited resource and its extraction is associated with negative environmental impacts, due to habitat destruction. Furthermore, peatlands are serving as carbon sinks and peat extraction contributes to greenhouse gas emissions [71]. Because of the negative impacts of peat use, peat substitutes were developed; however according to Barrett et al. (2016), few have been adopted commercially [11]. These authors further reported that the peat substitutes most commonly adopted by the horticultural industry are coir, pine bark and wood fiber. Indeed, some producers reported experimenting with peat substitutes such as cocos and rice as well as wood-based substrates and reported different levels of success. One producer reported that the use of rice chaff as growing media had failed. According to this grower, rice chaff and other peat substitutes bind nitrogen and therefore reduce the nitrogen availability for the plants grown. Barrett et al. (2016) explained that one of the barriers to adopting peat substitutes is because the growing media has to perform satisfactory across different plant species and under different cultivation conditions. The authors further emphasized the need to assess the sustainability of the different growing media to avoid adopting more environmentally damaging substrates [11]. Wandl and Haberl (2017) analyzed different floricultural products, including potted plants, for GHG emissions in Austria. According to their study, substrate is the second most important contributor to overall emissions and accounts for an average of 13% emissions of potted plants [47].

4.2.3. Distribution Stage

Sustainability challenges in the distribution stage are also related to the direct contributions to CF due to storage and transport. Harvested cuttings are packaged in cardboard boxes and stored in cold rooms until shipment. Cuttings are transported at the harvest day in air-conditioned trucks to a nearby airport. At the airport, cuttings are loaded onto passenger flights, with main destinations Amsterdam or Frankfurt. From the airport, cuttings are transported in climate-controlled vehicles (temperatures should not drop below freezing) and have to reach the rooting nursery within 3 to 5 days from harvest. To maintain their quality, cuttings require a temperature of 4 to 8 degrees during storage and transport. In general, harvested cuttings require lower temperatures compared to cut-roses to maintain their quality after harvest, which can contribute significantly to GHG emissions [20,29].

According to interviewees, despite air-shipment, producing cuttings in southern countries reduces CO2e emissions, compared to the alternative of producing in Germany or The Netherlands due to intensive heating and artificial lighting required. These claims are supported by several studies that compared the GHG emissions of cut flower production in The Netherlands to the production of flowers in Africa or Latin America [8,28,72]. Cuttings have relatively low weight, compared to cut flowers and can be packaged in large quantities in cardboard boxes. Moreover, in the current study, interviewees claimed that cuttings produced in Germany or The Netherlands will not reach the same quality as those produced in Africa or Central America in optimal temperature and light conditions.

Rooted cuttings are transported in climate-controlled vehicles for no more than three days until they reach the potted plant nursery. Some propagation nurseries make efforts to produce rooted cuttings locally by working together with sub-contractors. Other propagation nurseries cultivate rooted cuttings centrally, at the company headquarters. Finished plants are transported also in climate-controlled vehicles to a central logistic center. Some growers' organizations have regional logistic centers and try to source plants locally. At the center, they are stored under suitable temperature and lighting conditions. Some logistic centers use LED technology to reduce electricity costs. Other measures to reduce energy consumption include better building materials with better insolation and installation of solar panels. After a short period at the logistic center, plants are distributed to retail shops.

4.3. Social Sustainability Challenges and Sustainability-Driven Innovations along the Value Chain

The cultivation of propagation material (cuttings) is labor-intensive. Therefore, apart from optimal weather conditions, labor costs are an important factor in the choice of production location. Cuttings are produced almost exclusively in southern countries, in low-cost labor markets. Rooted cuttings for the German market are produced by propagation nurseries, collaborating contractors and independent growers in Germany and in The Netherlands. The majority of potted plants are cultivated within Germany. Nursery workers in Germany are subject to the German law in terms of working conditions, such as working hours, minimum wage and safety regulations. In African countries work regulations and standards are different from those in Europe. Moreover, national social security or health care systems that protect citizens from extreme poverty are missing. However, cutting farms are subsidiaries of the propagation nurseries in Europe and therefore the farm workers are direct employees of the European company. This gives the company a sense of responsibility for their employees because it can be directly accused of exploiting the workforce. Moreover, greenhouses of cutting farms are technologically more advanced compared to cut flower farms and partly offer better working conditions. For example, stock plants are grown on tables and not in the ground like roses. Therefore, workers do not need to bend down to the ground [29]. In addition, all propagation nurseries interviewed were socially certified (e.g., MPS Socially Qualified (SQ) or GLOBALG.A.P. GRASP). As most of the research on social conditions in Africa was published on cut-flowers, the social conditions reported by interviewees for cutting farms will be compared to the conditions in cut flower farms.

According to interviewees, stock plant nurseries contribute to the local economy by providing job opportunities and women are often the main workforce. Some interviewees claimed that cutting production is far more profitable than other agricultural products and therefore can support more people. This was supported by a different study, referring to cutting farms as more profitable than flower farms [29]. An average of 68% employment of women was found, among 20 flower and cutting farms in Ethiopia, Uganda, Kenya and Tanzania [34]. In Ethiopia, the floricultural industry employs 70% women [73,74]. Gobie (2019) also emphasized the importance of employment opportunities for women because earning wages allows women economic independence from their husbands and families [74]. In Kenya, jobs in the floriculture sector are considered more attractive than in other agricultural sectors, because of some benefits and securities offered to employees [21]. Nevertheless, communities in Ethiopia have stressed that changes in land use for floricultural farms have negative consequences. Floricultural farms took over agricultural land and tree plantations, which caused shortages and an increase in market prices of agricultural products and timber for construction and fire-wood [73].

Interviewees from propagation nurseries reported on regional development due to the presence of the cutting farms. They referred to road construction, connection of houses to electricity and community services, such as schools and health services. The owner of a propagation nursery reported that about 5000 people are employed in the floricultural production region close to Addis Abeba, Ethiopia. This region has developed well in the past 10 years, with new villages, schools, bakeries and electricity. A representative of a certification body explained that in many cases nursery employees are migrants, which also contributes to the regional development because of migrants' contributions to the local economy (see also [34]). It was explained that such workers cannot grow their own food because they do not have access to land or the time. Therefore, they must buy food and as a result boost the local markets. Regional development around floricultural farms can also have negative effects. In Lake Naivasha, the largest center of cut flower farms in Kenya, such development led to unplanned building of houses for the large number of migrants, unpaved roads and a lack of water supply and sanitation infrastructure [21]. But also in this example, some positive developments were observed such as connection of houses to electricity and building of shared pit toilets with cement slabs [21].

According to interviewees, nursery workers earn more than the average salaries in the region. Social certification (e.g., MPS Socially Qualified (SQ) or GLOBALG.A.P. GRASP) also increased the salaries at the nurseries. The GLOBALG.A.P. GRASP certification requires payment of at least national minimum wages or according to bargaining agreements (GRASP Guideline for Retailers). According to the MPS SQ standard, wages should at least meet the national or industry (CBA) minimum standards, whichever is higher and be sufficient to meet basic needs (MPS SQ certification scheme, p. 10). Higher wages were paid to flower farm workers compared to the minimum wage paid for agriculture employees in Kenya [21] and also workers in cutting farms in Uganda tend to earn better salaries than in flower farms [29]. According to a sustainability manager of a wholesale company the adoption of social certifications by propagation nurseries has improved the situation compared to four years ago. Kirigia et al. (2016), also confirms that the introduction of such certification standards, contributed to the improvement in working conditions in the floricultural industry in Eastern Africa.

Salaries paid to nursery workers in Germany and The Netherlands are above the minimum wage. Minimum wage was introduced in Germany in January 2015 [75]. Since then it was increased several times and the current hourly rate is 9.35 Euro. According to interviews, the adoption of Fairtrade standards for certain products such as potted poinsettia and pelargonium also meant better payment for nursery workers in Africa and higher prices for growers in Europe.

A representative of a propagation nursery stated that their workers in Africa generally work eight-hour days. During peak seasons, casual workers are recruited, and employees are expected to work overtime, which they are compensated for. In the cut flower industry, workers often have to work long hours due to the perishability of the product [76]. As cuttings have to be transported at the day of harvest, nursery managers are under pressure to harvest sufficient quantities. Therefore, harvest days have to be well planned with sufficient personnel to avoid overtime. In Kenya, flower farm employees work under a collective bargaining agreement stating 46 h per week, with 1.5 times overtime pay [21]. Comparable conditions were reported for cutting farms in Uganda as nursery workers are working six days a week, eight hours a day (Saturday only half-day) and overtime is voluntary [29]. In Germany, working hours can differ slightly between companies within the legal framework, which allows up to 48 h per week. One propagation nursery reported a 38.5-h work week.

According to interviewees, both in African countries and in Europe most of the employees (about 75%) are permanently employed and temporary employees are hired for peak seasons. According to the MPS SQ standards employees must receive a binding, written employment contract (MPS SQ certification scheme, p. 9). Evers et al. (2014) also reported on 75% permanent employment and 25% temporary contracts for cutting farms in Uganda. The same study also pointed out that in farms that follow a Collective Bargaining Agreement (CBA) workers are employed on temporary contracts for up to six months upon recruitment, followed by yearly renewed contracts. Only workers with one-year contracts are entitled to the full benefits of the CBA [29]. According to the Kenyan CBA, the probation period of new employees is limited to two months followed by permanent work contracts [21]. High levels of workers' absence and turnover was reported on cutting farms, which was reduced with permanent (one-year) contracts and attendance bonuses [29]. However, during the hot rainy season a 10% level of absence remained due to malaria. Interviewees expressed their preference for workforce retention in order to benefit from trained and experienced employees. Security of employment was found a better incentive for workforce retention in Kenya rather than higher wages, under conditions of rising unemployment [5]. Among cut flower workers in Ethiopia, workforce retention was found to be related to job satisfaction. Positive evaluation of extrinsic organizational rewards (wages, job security and healthy environment) contributed to job satisfaction [44].

One of the central difficulties of nurseries in Germany according to interviewees is to recruit and retain employees. Bitsch et al. (2004) already identified the availability of qualified workers as a major challenge to the German horticultural industry [77]. Ludwig-Ohm and Dirksmeyer (2013) also reported a shortage of qualified, skilled workers in the horticultural sector in Germany [78]. According to one of the interviewees, the shortage in employees can be explained partly by the lack of prestige of the floricultural sector. Evidence for this claim came from an earlier study dealing with job satisfaction of apprentices, where Bitsch (1996) concluded that improving the image of the horticultural industry could help to attract qualified workers [22]. Ludwig-Ohm and Dirksmeyer (2013) further explained that the German society has little awareness of the sophisticated plant production systems and the high technical knowledge requirements for professionals in horticulture [78].

Improving different aspects related to job satisfaction offers the potential for attracting new qualified employees [38]. According to Bitsch (2007), job satisfaction is also important for staff retention and motivation. She found that among horticultural workers in the USA, achievement and recognition are the key components of job satisfaction. Other factors contributing to job satisfaction were job security, technical aspects of supervision and interpersonal relationships [23]. In the current study, a nursery manager in Germany spoke of retaining employees through promotions, support and motivation.

In African countries, providing employees with benefits can improve their quality of life and is a common practice to attract and retain the workforce. A manager of an international propagation nursery emphasized how important it is that employees are paid fairly and are happy to work for the company. Propagation nurseries with sites in Africa and Central America reported to provide different benefits for their employees. Among the benefits provided are health services such as clinics at the farm and access to nurses and physicians. Nurseries also generally provided daycare facilities, kindergartens and schools to employees' families. Daycare services allow mothers to go back to work and continue to financially support their families. Some nurseries provide financial services such as bank accounts to employees, small loans and a pension fund. Others provide accommodation at the farm, warm meals and clean drinking water. Some companies reported to also provide services to the community, such as support of schools and health services. This is supported by Kirigia et al. (2016), referring to services provided by the nurseries to the community, such as construction and renovation of schools, clean drinking water, health services and maintenance of roads [34]. Providing such benefits to employees and the community is innovative. On one hand it has a positive influence on attraction and retaining of employees; on the other hand, it contributes to the positive image of the company in the local community and for other stakeholders.

In Kenya, flower farms that signed CBAs offer benefits to their employees, such as cash allowances for housing and travel, paid sick leave, paid public holidays, paid annual leave and paid maternity leave of 3 months [21]. In Uganda, a similar arrangement was achieved, offering benefits to floriculture farm workers. In the latter CBA, some benefits, such as housing allowance, medical services and daycare are not included. However, most of the farms provided some of these benefits such as medical services, daycare and housing allowance, regardless of the agreement. Moreover, the quality of benefits in cutting farms was better than in flower farms [29]. According to Kirigia et al. (2016), some of the services mentioned above are requirements of certification standards [34]. In Germany, Bitsch et al. (2004), proposed a flexible benefit system as a low cost opportunity for horticultural workplaces to become more attractive [77].

Companies both in African countries and in Europe reported that they train their own employees to acquire new personnel and remain independent. According to Riisgaard and Gibbon (2014), this procedure of on-the-job training is typical for the cut flower sector in Kenya, with the explanation that for this type of job, skills are best acquired by exposure to the work environment [5]. Training on cutting farms is longer and more systematic compared to flower farms and workers with secondary education are preferred [29]. According to interviewees, some companies in Germany strive to retain employees and contribute to job satisfaction by offering special training programs, such as programs for training of nursery managers.

Interviewees reported that occupational health and safety standards in cutting farms are comparable to the European standards. Furthermore, all companies are certified, which obliges propagation nurseries to keep to standard safety measures and document all chemicals used. However, at least in the cut flower farms in Ethiopia, it was concluded that private standards did not improve the sustainability performance in terms of pesticide use [37]. Indeed, reports from flower farm in Ethiopia showed that local communities are concerned about workers' health, due to intensive application of chemicals [73]. Exposure to chemicals was reported as the main complaint of workers and communities around farms [34]. According to Franze and Ciroth (2011), workers' health in flower farms, in Ecuador, is at risk because of insufficient protection gear and the lack of time off after spraying pesticides [8]. In Uganda, workers are still exposed to chemicals, although some improvements have been made due to the CBA. This exposure is mostly during peak periods, when workers are required to enter the greenhouse too soon after spraying due to time pressure. Moreover, in both cutting and flower farms, workers' protective gloves are too short, which exposes them to chemicals. In addition, more chemicals are used in cutting farms because the growing media is fumigated with pesticides, before every new crop [29]. This practice contradicts the findings of the present study, where interviewees reported to steam the substrate for disinfection. In The Netherlands, health and safety is at low risk as workers use suitable protection gear and hazardous substances are applied using machinery [8].

Apart from chemicals, it was found that greenhouse workers on flower farms in Ethiopia are also exposed to high endotoxin levels, carried by organic dust, compared to field workers and suffer more frequently from respiratory symptoms [39]. High temperatures and humidity in greenhouses provide optimal conditions for a wide variety of fungi and bacteria. Moreover, the enclosed space and poor ventilation contributes to the high exposure of workers to dust. Exposure of workers to endotoxins, bacteria and fungi was also measured in Danish potted plant nurseries [45]. They found that the exposure levels depend on the tasks performed and that in 30% of the samples the endotoxin exposure limit was exceeded, which may have health implications for the employees [45].

The majority of potted plants sold in Germany are certified by either GLOBALG.A.P or MPS. Some propagation nurseries also reported that they are performing more controls for pesticides than required by the standards. GLOBALG.A.P. and MPS are business-to-business certifications and are designed to meet retailers' requirements. The end consumer is generally not informed about the certification of the products. According to a supply chain manager of a propagation nursery, consumers generally cannot know the origin of the plant and the cultivation conditions. Moreover, the end consumer has no information about traces of chemicals on the plant. On the other hand, positive developments, such as reduction in pesticide use, reduced energy consumption or social benefits for workers in Africa, are also not transparent to the end consumer. Since the interviews were conducted, both GLOBALG.A.P. and MPS have developed the consumer labels "GGN" and "follow your plant," offering consumers to track the origin of the plant by a specific identification number on the label [79,80]. However, currently, the extent of adoption of these labels is not known.

An exception are Fairtrade labeled pelargonium and poinsettia plants marketed by two propagation nurseries. According to interviewees, the Fairtrade label is a way for propagation nurseries to communicate to the consumer what they did anyway, even before the adoption of the Fairtrade certification. Another exception is bee-friendly labeled plants; the label indicates that plants have attractive flowers for pollinators and generally were treated with reduced levels of insecticides. However, as opposed to Fairtrade plants, there is no bee-friendly standard with clear requirements. Bee-friendly is rather a marketing innovation and the consumer has no certainty on what requirements bee-friendly plants must meet.

4.4. Economic Sustainability Challenges and Sustainability-Driven Innovations along the Value Chain

The issues discussed in this section represent the main economic difficulties of companies taking part in the value chain of flowering potted plants. According to interviewees, the price of potted plants in Germany is too low, partly because of price pressure from retailers. Other explanations interviewees offered for decreasing prices are overproduction of some products and high competition. On the other hand, interviewees reported that production costs such as wages and raw materials increase continuously. Moreover, this is a labor-intensive industry, in which labor costs amount to a major part of production costs. The propagation stages of stock plant cultivation and harvest of cuttings are especially labor-demanding. According to interviewees, propagation nurseries have witnessed an increase in salaries in Southern Europe and the Mediterranean region and therefore moved their cutting production sites to Africa and Central America. However, propagation chain actors are concerned that Africa will eventually also become too expensive for the production of cuttings, if prices continue to drop.

Because European legislation prohibits the import of plants of the Solanaceae family, stock plants of the Solanaceae family (e.g., petunia, calibrachoa) cannot be cultivated in Africa but in other regions mostly in Southern Europe and in other Mediterranean countries. This regulation is enforced to protect food crops such as tomatoes and potatoes from pathogen transmission [81]. However, production costs in countries such as Portugal, Tenerife and Israel are generally higher than in Africa.

The German market is perceived by interviewees as stable and not dynamic. Indeed, the German market has not changed much over the past 15 years with an average volume of 8.6 billion euros in retail prices [82]. Chain actors are concerned that generational changes will result in a reduction in the customer base, because young consumers have different preferences. According to interviewees, young consumers are not familiar with plant species, cannot judge plants' quality and invest less time in gardening. A different study predicted an increase in consumption, because the consumer groups spending most on ornamental plants (older than 55 and couples without children), are expected to grow [78].

According to interviewees, due to low margins and the stagnant market, some actors attempt to differentiate their products. In some cases, products are differentiated by means of sustainability labels. An example of marketing innovations of sustainable products for a premium price are Fairtrade potted plants. According to a marketing manager of a propagation nursery, the market price of Fairtrade plants was 30% higher, which also meant a higher profit. Another form of product differentiation are growers' organizations specializing in sustainable production of potted plants. Growers belonging to one of these organizations are committed to keep specific requirements, such as two third of renewable energy sources.

Unpredictable weather conditions affect plant maturation as well as consumer behavior. Although potted plants are mostly grown in protected environments, weather conditions can influence greenhouse production. For example, with above average temperatures in the winter, potted plants will mature too early. Moreover, the demand is also unpredictable and weather-dependent. Consumers are more likely to purchase outdoor plants when the weather is warm and sunny. Verdouw et al. (2010) also reported demand uncertainties due to weather-dependent sales in the floricultural sector [83].

To sell into retail channels, value chain actors are required to comply with different regulations. Private standards (e.g., MPS or GLOBALG.A.P.) are an innovative tool that has become a requirement from retail chains. According to a sales manager of a propagation nursery without complying with certain standards, they will be excluded from many business opportunities. Some propagation nurseries explained that adopting social and environmental certifications are a form of insurance, to prevent negative media attention typically brought upon them by Non-Governmental Organization (NGOs). According to interviewees, propagation nurseries also require from their contractor growers (of rooted cuttings) to be certified to either MPS or GLOBALG.A.P. Riisgaard (2009) also claimed that standards are a risk management strategy for brand protection of retailers or brand producers [76]. Although social standards were implemented generally as a strategy for risk management, some interviewees pointed out that standards positively influence the well-being of employees in African countries.

Another aspect relevant for economic sustainability of propagation nurseries is the long development of and the large investment in new cultivars. According to interviewees, because the development process takes many years, it is possible that when the new cultivar is finally ready, it is no longer attractive. Indeed, the market of potted plants is driven by consumers' growing demand for novelties and, therefore, research and development departments became increasingly important for competitive companies [60]. Still the development of new cultivars can take up to ten years and the popularity of novelties among consumers sometimes lasts only a few years.

According to some interviewees, there are solutions to many of the environmental and social sustainability challenges in the value chain of potted plants. However, interviewees further claimed that such sustainability solutions involve large investments and the costs cannot be compensated by the price. Nevertheless, some strategies such as increased energy efficiency contribute both to cost reduction as well as reductions in GHG emissions. Moreover, some costs such as the costs of compliance with standards cannot be avoided as non-compliance would be a market entry barrier.

4.5. Addressing the Sustainability Challenges Uncovered

Several environmental sustainability challenges have been identified in the value chain of flowering potted plants. Many of these challenges have available solutions, which include sustainability strategies and innovations. The challenge of water scarcity can be addressed by a combination of independent water sources, such as rainwater harvesting and water saving irrigation systems, such as close loop system. Closed irrigation systems are also a solution for fertilizer runoff and can reduce the amount of fertilizer applied.

Energy consumption due to heating can be reduced by the choice of cultivars that require lower temperatures, implementing energy saving technologies and strategies such as "Cool Morning–Warm Evening." Moreover, heating with renewable energy sources can reduce the GHG emissions due to heating requirements significantly. Electricity consumption can be reduced by the choice of energy-efficient light technology such as LED technology. GHG emissions due to electricity can be reduced by sourcing electricity from renewable sources and own electricity production, for example, by installing solar panels. Energy consumption due to transportation can be reduced by regional production and sourcing of plants and transport with electric vehicles. Air-shipment of cuttings from producing countries is difficult to overcome, as production in closer locations is not economically feasible due to the relatively high cost production in Europe. Pesticide use is still a notable challenge in the industry, as the quality and appearance of the product is important to the end consumer. Application of an integrated pest management approach as well as biological pest control have reduced the use of chemicals. However, eliminating the use of pesticides seems unlikely, at this point.

Substituting peat as a growing medium is difficult. Although a large variety of innovative products are available on the market, the risk of adopting such alternatives is high. Successful cropping will require growers to test different substrates under different growing conditions and on a variety of plants before they can adopt peat alternatives with satisfactory results. Plastic containers at the early stages in the value chain can be re-used after cleaning, as was shown at the stock plant stage for innovative plastic bags or by the recollecting system of plug-trays. These innovations are already a common practice for some of the propagation nurseries interviewed. However, growers are more reluctant to adopt compostable or biodegradable containers at the potted plants stage. This involves a financial risk, because the costs of such containers are generally higher than plastic containers and successful cultivation is not guaranteed. In addition, the large diversity of products requires growers to test the containers first, in order to minimize the risk. Recycled plastic containers are widely accepted, due to their attractive price and similar qualities to the standard plastic containers. Furthermore, for both peat-free substrates as well as alternative pots, it is not clear whether the alternatives have indeed lower GHG emissions compared to peat or plastics.

Social challenges are different for Europe compared to Africa. Social challenges in Africa are related to low wages and general working conditions. Many of these challenges were addressed by the innovative social standards that have become a market requirement. For example, wages, employment relations and working hours are regulated in these standards. Health and safety issues are regulated further by the Good Agricultural Practice standards such as MPS or GLOBALG.A.P. Propagation nurseries make efforts to improve the lives of employees and their families as well as to contribute to local communities by provision of different benefits. Such benefits are provided to retain and attract workers, improve the image of the company in the local community but also improve the image other stakeholders, such as retailers, consumers and NGOs, perceive. Furthermore, many of the propagation nurseries are family businesses and part of their management vision is the responsibility for the wellbeing of all their employees.

The challenges of recruitment and retention of employees in Germany remain central for the industry. These challenges are related to the unfavorable image of horticulture in Germany and the generally low salaries of nursery workers compared to industrial production. Potted plants sold at large retail chains are generally certified. Adopting consumer labels for the certified products would improve the transparency of the finished product for the end consumer. The main economic challenges are related to the profitability of the product, due to low prices on the German market and relatively high labor costs. Actors deal with these challenges either by cost reduction or by product differentiation. Another economic challenge is the need to comply with standards (e.g., MPS or GLOBALG.A.P.), which serve as barrier to market entry. Adoption of standards also poses financial and administrative burdens. For small nurseries, implementation of such standards is, in some cases, not feasible, which excludes them from supplying to large retailers.

5. Conclusions

Sustainability driven innovations can address many of the sustainability challenges along the value chain. The implementation environmental innovations is generally associated with increased costs, production risk and complexity of implementation. Installation of LED technology, for instance, is associated with a large financial investment compared to the alternatives and effective implementation of LED technology requires knowhow. The adoption of peat-free substrate is associated with production risk and requires expertise as some crops cultivated using alternative substrates had failed. The adoption of social innovations as social standards is also associated with increased costs, however, they have become a market requirement and cannot be avoided. Other social innovations such as Fairtrade potted plants remain a niche product. Furthermore, addressing sustainability challenges may introduce tradeoffs between sustainability dimensions. Increase in salaries, for instance, will have a positive influence on the social dimension but is negative for the economic dimension, as it will affect profitability. However, the lack of transparency of the product prevents the transfer of sustainability costs to the consumer by offering a sustainable product for a premium price. This may change when more certified products are also labeled as such.

Several drivers influence actors to adopt sustainability innovations—(i) cost reduction in the case of reducing energy costs, (ii) barrier to market entry, such as the requirements from retail to adopt private standards, (iii) risk mitigation by adopting standards to prevent media attention, (iv) product differentiation by the adoption of sustainability labels such as Fairtrade, (v) management vision, such as "to become the most sustainable young plant company on the world" or "taking care of our employees" and (vi) company image, for instance by providing benefits to workers and the communities in Africa.

Business-to-business standards have generally had a positive influence on the adoption of specific sustainability innovations such as benefits to nursery workers in Africa. Moreover, by setting certification as an entry barrier for suppliers, retailers are becoming even more powerful chain actors. The involvement of NGOs influenced the adoption of social and environmental standards through pressure on chain actors such as retailers and propagation nurseries. However, pressure to stop using neonicotinoid insecticides also had a negative influence, as growers reported to have used other more harmful substances.

It is difficult to differentiate between social, economic and environmental innovations, as some innovations have impacts on all three dimensions. Private standards, for example, often influence social, environmental, as well as economic aspects. However, environmental innovations are generally technological innovations related to production processes and product qualities. Private companies or academic research institutes responding to market deficiencies generally develop such innovations as a business opportunity. Social and economic innovations, in many cases, are organizational or management tools and their implementation influences not only single actors but also the entire value chain. The development of such tools generally involves cross-sector dynamics and in this case, NGOs, chain actors and private agriculture and labor standards. However, the influence of each of these sectors is different. Some chain actors such as retailers are more powerful and can force other chain actors to comply. In this case, NGOs set the rules by placing particular sustainability challenges on the public agenda and forcing other chain actors and private standard organizations to react.

By investigating sustainability challenges along the value chain of flowering potted plants, the current study set the foundation for the development of sustainability assessment methods including environmental, social and economic dimensions. Indicator-based assessment can provide a reference for actors regarding their sustainability performance and will support them in making better decisions in order to improve their sustainability. Further research on sustainability innovations can help to determine how to better implement such innovations and to assess which innovations can considerably improve sustainability performance in the value chain. Moreover, the knowledge on where changes in the value chain are most urgently needed can promote research and development to contribute to addressing industry needs.

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Appendix A

Table A1. Main environmental, social and economic issues and the associated publications.

	No. of Publications [1]	References
Environmental aspects		
Water	11	Sahle and Potting (2013), De Vries (2010), Mekonnen et al. (2012), Russo, Scarascia Mugnozza and de Lucia Zeller (2008), Russo and de Lucia Zeller (2008), Lazzerini et al. (2018), [31] Ingram et al. (2018), Ingram et al. (2019), White et al. (2019), Kirigia et al. (2016), Knight et al. (2019)
Fertilizer	6	Russo, Buttol and Tarantini (2008), Sahle and Potting (2013), De Vries (2010), Mekonnen et al. (2012), Lazzerini et al. (2018), Ingram et al. (2019)
Plant protection agents and other Chemicals	3	Sahle and Potting (2013), Lazzerini et al. (2018), Mengistie et al. (2017)
Pots and containers	8	Russo, Buttol and Tarantini (2008), Lazzerini et al. (2015), Lazzerini et al. (2018), Bonaguro et al. (2016), Koeser et al. (2014), [30] Ingram et al. (2018), [31] Ingram et al. (2018), Ingram et al. (2019)
Growing media/substrate	7	Lazzerini et al. (2015), Lazzerini et al. (2018), Koeser et al. (2014), De Lucia et al. (2013) [30] Ingram et al. (2018), Ingram et al. (2019), Wandl and Haberl (2017)
Electricity, light and heating	9	Russo, Buttol and Tarantini (2008), [31] Ingram et al. (2018), Soode et al. (2013), Soode et al. (2015), Torrellas et al. (2012), Franze and Ciroth (2011), Koeser et al. (2014), Wandl and Haberl (2017), Abeliotis et al. (2016)
Transportation	4	Franze and Ciroth (2011), Abeliotis et al. (2016), De Vries (2010), Blonk et al. (2010)
Ecomomic aspects		
Cost benefit analysis	1	Torrellas et al. (2012)
Cost of production	2	Brumfield et al. 2018
Variable costs	4	Ingram et al. (2017), [30] Ingram et al. (2018), [31] Ingram et al. (2018), Ingram et al. (2019)
Value chain Governance	1	Evers et al. (2014)
Social aspects		
Health and safety	6	Nigatu et al. (2015), Thilsing et al. (2015), Franze and Ciroth (2011), Evers et al. (2014), Mengistie et al. (2017), Kirigia et al. (2016)
Working hours (work load)	3	Franze and Ciroth (2011), Evers et al. (2014), Kirigia et al. (2016)
Wages	4	Anker and Anker (2014), Franze and Ciroth (2011), De Vries (2010), Evers et al. (2014)
Employment relations	4	Riisgaard and Gibbon (2014), Franze and Ciroth (2011), Evers et al. (2014), Anker and Anker (2014)
Work satisfaction	4	Bitsch, (1996), Bitsch (2007), Staelens et al. (2018), Meyerding (2015)
Product responsibility	1	Franze and Ciroth (2011)
Community	3	Franze and Ciroth (2011), Anker and Anker (2014), Kirigia et al. (2016),
Local employment	3	Franze and Ciroth (2011), Evers et al. (2014), Kirigia et al. (2016)
Benefits to workers	3	Evers et al. (2014), Anker and Anker (2014), Kirigia et al. (2016)

[1] Publications could qualify for more than one dimension and more than one aspect.

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Framework for sustainability assessment of the value chain of flowering potted plants for the German market

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ABSTRACT

The value chain of flowering potted plants (FPP) is associated with environmental, social and economic sustainability challenges. Indicator-based assessment methods can provide insights into sustainability performance of agricultural value chains. The FPP value chain is not comparable to other agricultural systems and therefore cannot be assessed with existing indicator-based tools. In this study, a framework was developed for sustainability assessment of the FPP value chain, from breeding to distribution. The development of the framework involved defining sustainability themes and subthemes based on the characterization of the value chain and the investigation of social, environmental and economic sustainability challenges. The generic sustainability assessment tools, Sustainability Assessment of Food and Agriculture Systems (SAFA) and Response-Inducing Sustainability Evaluation (RISE), provided the foundation for indicator selection and development. The current study emphasized the need for a system-specific view, especially in unique systems such as the FPP value chain, because generic assessment tools, such as SAFA and RISE, do not cover all sustainability subthemes. Most of the indicators missing from generic assessment tools were environmental indicators. Environmental assessment is closely related to value chain stages and product-specific processes, therefore indicators were allocated according to the value chain stages, breeding, production and distribution. Social sustainability themes are influenced by national and regional socio-economic conditions, such as government provision of healthcare and a social safety net. Therefore, indicators are allocated based on geographical regions and stakeholder groups. The economic subthemes are determined by industry structure and sector-specific conditions. The ornamental sector is characterized by low margins and high uncertainty, related to profitability and vulnerability. Despite the initial evaluation performed in the current study, in the next step, industry actors need to determine the feasibility of the indicators. The implementation of the framework developed in the current study will provide further insights into the value chain, which will guide actors in taking actions for performance improvement and provide guidance for policy-makers in setting sustainability targets.

1. Introduction

Though the meaning and use of sustainability remain diverse, it is now widely accepted that sustainability should account for a balance between environmental, social and economic dimensions (Binder et al., 2010; Bitsch, 2016). Sustainability is increasingly considered by companies for setting their strategic goals and improving their competitive advantage (Closs et al., 2011; Qorri et al., 2018). Companies also need to manage related risks such as labor rights and pollution incidents (O'Rourke, 2014). Moreover, companies, taking part in global value chains are often held responsible for sustainability impacts related to their suppliers (Seuring and Müller, 2008).

Increasing sustainability in the agricultural sector requires insights into sustainability performance of agricultural systems. An agricultural system can be defined as a farm, or an entire supply chain. Indicator-based assessments are an effective tool to assess progress towards sustainability (van Cauwenbergh et al., 2007) and compare sustainability performance of systems. Indicator-based methods were developed as an alternative to direct impact measurements, which are more complex, time consuming, costly and in some cases impossible (Bockstaller et al.,

; FPP, Flowering Potted Plants; CFP, Carbon Footprint; GHG, Greenhouse Gas; LCA, Life Cycle Assessment; S-LCA, Social-Life Cycle Assessment.

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2009). Several indicator-based tools were developed for the agricultural sector. Some tools are branch-specific such as dairy, or arable crops, while others are "universal", aiming to serve all systems (Binder et al., 2010; Bonisoli et al., 2018; De Olde et al., 2016).

Ornamental plants are a branch of agriculture with economic and cultural significance. The global economic value of ornamentals was estimated 250–400 billion dollars (Chandler and Sanchez, 2012). Germany is the largest European market of ornamental plants, estimated 9.4 billion euros in retail price (2020) (Zentralverband Gartenbau e. V., 2021). Ornamental plants can be divided into cut-flowers and potted plants, consisting of green and flowering plants. In Germany, flowering potted plants (FPP), comprising of bedding and flowering indoor plants, are an important market segment with 33% of the total market volume (Zentralverband Gartenbau e. V., 2021).

The value chain of FPP supplying the German market, can be divided into two main pathways, based on the propagation method, vegetative or generative (Fig. 1). The breeding stages generally take place at the propagation nursery headquarters, in European countries, the USA or Japan. Seeds are produced worldwide, whereas cuttings for the German market are mostly produced in African countries or in Central America. Solanaceae cuttings are generally grown in Mediterranean countries, due to EU regulations not permitting import of such plants from African countries, to prevent pathogen transmission to other agricultural crops. Young plants production generally takes place in the Netherlands and Germany. Finished plants for the German market are largely produced in Germany. Though the production of vegetative and generative propagation material is essentially different, in both cases, plants are container grown in protected environment (Havardi-Burger et al., 2020a).

The production of ornamental plants is associated with environmental and social burdens (Darras, 2020; Riisgaard and Gibbon, 2014; Sahle and Potting, 2013). Sustainability challenges linked to the vegetative value chain of FPP include greenhouse gas (GHG) emissions, pesticide use, water scarcity, low wages and profitability (Havardi-Burger et al., 2020b). Furthermore, there is growing consumer awareness of sustainability issues concerning ornamental plants, such as the use of peat and plastic. NGOs and retail chains also pressure actors such as propagation nurseries and growers in the value chain of FPP, to improve their sustainability performance (Havardi-Burger et al., 2020b). Thus, there is a growing need to assess the sustainability in the value chain of FPP to support improvements of the sustainability performance of the chain.

In prior work, the sustainability assessment of potted plants was generally focused on environmental aspects frequently implementing the standardized method of Life Cycle Assessment (LCA) (ISO 14040). In a recent study, Bonaguro et al. (2021) assessed environmental performance of production practices of cyclamen and zonal geranium using LCA. The study assessed six environmental impact categories in the production stages young plants (plug phase) and finished goods (Bonaguro et al., 2021). Other value chain stages such as the production of propagation material were not included in the assessment. LCA was also used to assess GHG emissions from the production of poinsettia. In addition, water consumption and variable costs were assessed in the production of young plants and finished goods (Ingram et al., 2019). Potted poinsettias were also assessed for carbon footprint (CFP) in the entire life cycle comparing three different assessment methods of product CFP standards (Soode et al., 2013). Nevertheless, non-sector specific methods, such as LCA, are too complex for implementation beyond research projects, that is by chain actors (O'Rourke, 2014).

An assessment method was developed for outdoor production of ornamental plants at the nursery level (Lazzerini et al., 2018). However, the method focuses on environmental aspects, neglecting economic and social aspects and does not consider other value chain stages. Social sustainability was assessed in cut-flowers production. For example, a social life cycle assessment method was implemented to compare cut-roses production in Ecuador and in the Netherlands. Social sustainability was largely neglected from the assessments of potted plants.

Numerous indicator-based assessment methods, such as REPRO, IDEA or INDIGO, were developed to assess agriculture's ecological impacts (Bockstaller et al., 2009). In recent years, more indicator-based methods also include social and economic dimensions. Indicator-based assessment tools differ also in their sustainability goals, target groups, and definitions of sustainable agriculture (Binder et al., 2010). De Olde et al. (2016) identified 48 sustainability assessment tools for the agricultural sector. Bonisoli et al. (2018) identified 15 assessment tools that evaluated at least the social, environmental, and economic dimensions. The majority of the tools are aimed at the farm level; few tools, such as SAFA, SSP and Avibio, allow to assess value chains (Binder et al., 2012; De Olde et al., 2016).

The value chain of FPP has unique characteristics compared to other agricultural systems, which include growing in containers in greenhouses. Furthermore, different production stages take place in different regions of the world. Thus, the available assessment methods developed for agricultural systems are not suitable for FPP. A context specific sustainability assessment method is required to assess the particular sustainably challenges in the value chain of FPP. Therefore, the study addresses the following objectives:

- Developing a method specifically for the value chain of FPP after the value chain was previously investigated in detail for processes and value adding activities.
- Determining sustainability themes according to the specific sustainability challenges associated with the value chain of FPP.
- Designing indicators in the new framework to assess important social and economic aspects in addition to environmental features; the former were so far mostly neglected in sustainability assessments of FPP.
- Including other value chain stages apart from the production stage, such as breeding, propagation and distribution often neglected from sustainability assessments in agriculture.

The framework is designed in accordance with the principles of

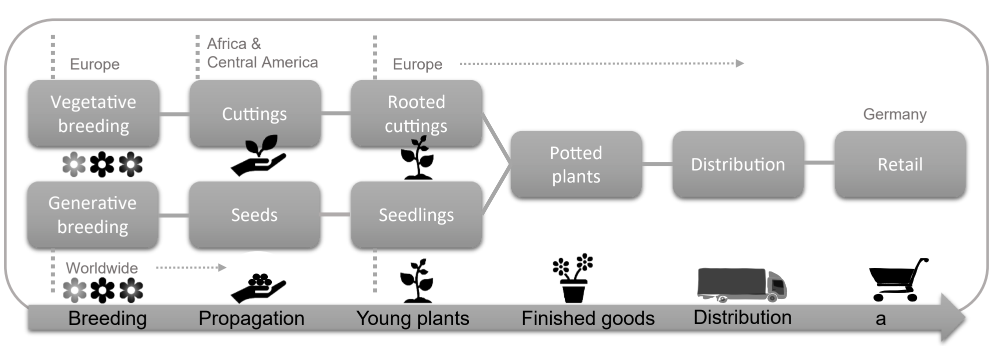

Fig. 1. Vegetative and generative value chain pathways as well as location of chain stages.

cleaner production because it is directed to businesses and considers sustainable development from the perspective of products and processes (Hens et al., 2018). Furthermore, considering the entire life cycle of the product, including product design in the form of breeding goals, containers and substrate also corresponds with both circular economy and cleaner production. Although the end of life at the consumer is not directly assessed, material choice of substrate and containers, which are included, considers use of renewable, degradable, re-used and recycled materials as well as the CFP, promotes conservation of resources and waste reduction. Product safety also considers potential pollution associated with the end of life of the product.

A framework for sustainability assessment is structured typically in at least three hierarchy levels. The first level is the most abstract, where sustainability principles or goals are defined. On the second level, goals and principles are broken down into specific areas of action also called themes or criteria. Indicators are the third level, which are used to assess sustainability performance in the specific area of action or theme (Bitsch, 2016; Bockstaller et al., 2015; De Olde et al., 2016; van Cauwenbergh et al., 2007). Measuring sustainability in value chains is even more challenging, because it requires analyzing activities, across different value chain stages and different sustainability dimensions (Qorri et al., 2018).

Therefore, the aim of this work is to develop a framework for sustainability assessment of the value chain of FPP. The specific research questions are (i) what aspects need to be included in the scope of the framework in terms of products, value chain stages and geographical scope? (ii) What are the relevant social, environmental and economic sustainability themes and subthemes? and (iii) which sustainability indicators are available in established sustainability frameworks to assess the identified subthemes and which indicators need to be developed in case no suitable indicators are available in prior work?

The article is structured as follows: following the introduction, section two presents the theoretical background for establishing sustainability frameworks and reviews the sustainability assessment tools considered as sources for indicators. Section 3 describes the methods applied for this study. The result section is dedicated to the sustainability themes identified and the indicators chosen, separated into the environmental, social and economic dimensions. In section 5, the discussion, findings are compared to published literature and section 6, conclusions, explores the significance of this work to chain actors, other stakeholders and policy-makers, and provides recommendations for future research.

2. Theoretical background for establishing sustainability frameworks

Sustainability assessment serves to provide information about the sustainability of relevant characteristics of a system. Assessing the current sustainability status of a system can help decision-makers and policy-makers to take informed actions concerning the adoption of strategies to improve sustainability performance (Binder et al., 2012; Sala et al., 2015).

The development of an assessment method includes different phases. van Cauwenbergh et al. (2007) proposed a framework of principles, criteria and indicators referred to as the Sustainability Assessment of Farming and the Environment (SAFE). Development of an assessment method following SAFE includes setting system boundaries and successively defining principles, criteria and indicators. Another step involves setting reference values for each indicator. An alternative to reference values are benchmarking approaches, which allow to compare different systems or monitor system changes over time (Binder et al., 2010). Deytieux et al. (2016) concluded that the assessment process is generally structured in four main steps: (1) definition of objectives, (2) system definition and description, (3) selection of the criteria and indicators, and estimation of each indicator from calculations or measurements, (4) final assessment, and using thresholds or reference values to determine system performance.

De Olde et al. (2017) emphasizes the importance of transparency in the development of sustainability assessment tools. To improve transparency, De Olde et al. (2017) suggested a development process that can be divided into six phases: (1) determining the purpose of the assessment and the system boundaries, (2) specifying the concept, definition of sustainability goals, themes and subthemes, (3) definition of indicators and evaluating their feasibility, validity and relevance, (4) reference values and translation into easily comparable scores, (5) data collection and assessment, (6) reflection on the process. Building on the listed prior work, a general procedure for the development of an assessment method was extracted (Fig. 2).

The current study focuses on the first four phases of establishing a framework for sustainability assessment. The scale and boundaries of a framework can be defined based on the product life cycle, spatial and temporal components (van Cauwenbergh et al., 2007). The assessment of a value chain needs to include all processes that are part of production or distribution and generate significant impacts on sustainability (FAO, 2014). Furthermore, prior work used a diverse terminology to describe the hierarchy levels of sustainability assessment frameworks (Appendix A). The current study uses the terminology goals, themes, subthemes, and indicators for the hierarchy levels of the sustainability framework.

The FAO council (1989) defined the concept of sustainable development in the agricultural sector focusing on environmental goals such as conservation of land, water, plant and animal genetic resources, social acceptance and economic viability (FAO, 2014). Goals for sustainable production of nursery products are to "reduce environmental degradation, maintain agricultural productivity, promote economic viability, conserve resources and energy and maintain stable communities and quality of life" (Krug et al., 2008, p. 43). The environmental sustainability themes for container greenhouse production include pollution from fertilizers and other chemicals, plastic waste, CFP due to heating and shipping, conservation of water and pesticide use. Social themes involve maintaining a safe working environment and supporting communities by hiring local residents and purchasing locally. The economic themes are to increase productivity and economic viability and account for consumer concerns regarding the product sources (Krug et al., 2008; Lopez et al., 2008). According to Binder et al. (2010), sufficient indicators should represent the complexity of the system but also indicators should be as few as possible to keep the assessment feasible.

To identify sustainability assessment tools that can serve as a source

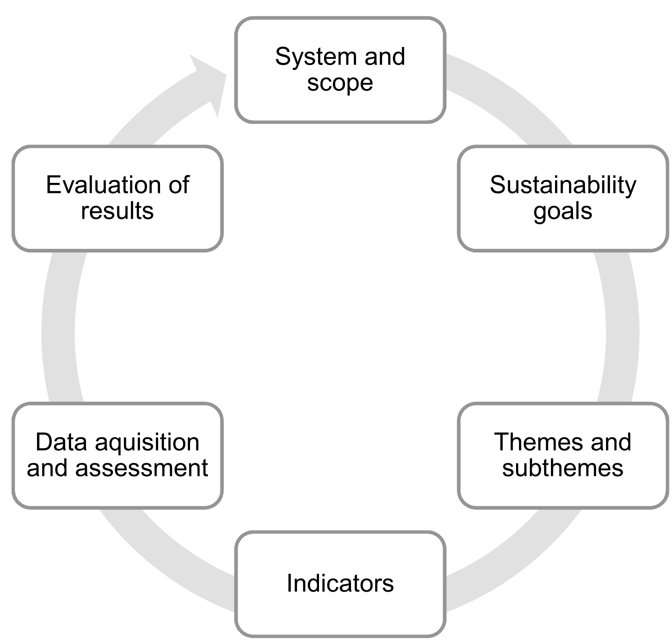

Fig. 2. Overview of the development of an assessment method.

of indicators, the current study investigated reviews comparing different agricultural sustainability assessment tools (Arulnathan et al., 2020; Bonisoli et al., 2018; Coteur et al., 2020; De Olde et al., 2016; Schader et al., 2014). The following criteria were used to select the tools: (i) universal framework for agriculture, or sector specific for ornamental plants, (ii) comprehensive collection of indicators preferably including all three dimensions, (iii) international tool, not country-specific, and (iv) availability of comprehensive explanations of the method in English. Three assessment tools seemed suited to serve as a basis for developing a framework for the assessment of the FPP chain: Sustainability assessment of food and agriculture systems (SAFA) and Response-Inducing Sustainability Evaluation (RISE) as non-specific (universal) tools, as well as Lazzerini et al. (2018), developed specifically for outdoor ornamental plants.

Both SAFA and RISE are top-down frameworks, with predetermined sets of indicators. They were developed with the aim of standardized assessments, and designed to fit different scales in different regions. Furthermore, both frameworks offer a software tool (Bonisoli et al., 2018). RISE and Lazzerini et al. (2018) were designed for assessment at the farm level. SAFA offers the possibility to assess entire value chains. Lazzerini et al. (2018) focuses on the environmental dimension whereas RISE and SAFA also analyze the social and economic dimensions. All methods offer explanations on the measurement methods in a manual or a scientific publication. All tools were implemented in case studies published in peer-reviewed scientific journals (Appendix B).

RISE was developed at the Bern University of Applied Sciences based on goals for sustainable agriculture set out in the Agenda 21, and FAO, covering social, economic and environmental aspects (Grenz et al., 2016). Version 3 of RISE contains 10 sustainability themes and 47 subthemes, where each subtheme corresponds to an indicator. Although themes are not divided according to sustainability dimensions, five themes belong to the environmental dimension, two can be considered social and another two can be allocated to the economic dimension. Animal husbandry completes the list of 10 themes (Grenz et al., 2016), albeit not relevant for the present study.

SAFA, developed by FAO, targets businesses, organizations and other stakeholders that participate in crop, livestock, forestry, aquaculture and fishery value chains. The value chain stages involve production, processing, distribution and marketing of food and agricultural goods. Assessment does not include the consumer or end-of-life stages. The framework is designed hierarchically starting with four sustainability dimensions at the highest level: good governance, environmental integrity, economic resilience and social well-being. These are translated into 21 themes and 58 subthemes corresponding to the FAO principles of sustainable development. Sustainability objectives are measured through 116 indicators (FAO, 2014). The current study does not include the governance dimension because its issues were not found relevant to the FPP value chain.

Although outdoor cultivation is a different system than greenhouse cultivation, the indicators in Lazzerini et al. (2018) were considered for their suitability, because they were developed for an ornamental plant system. The assessment method has a set of six environmental indicators, selected from other frameworks. The method was tested on two production systems: (i) container production and (ii) open field production.

3. Methods

A six-step approach was followed in order to establish a framework for sustainability assessment for the FPP value chain (Fig. 3): (i) characterization of the chain, (ii) investigation of social, environmental and economic challenges, (iii) scope definition for the framework, (iv) determining social, environmental and economic themes, and subthemes, (v) selecting or developing suitable indicators and (vi) expert consultation to validate the feasibility and relevance of the newly developed indicators.

O'Rourke (2014) also proposed chain mapping as the first step in assessing sustainability of value chains and identifying the most important sustainability impacts along value chains as the following step. Monastyrnaya et al. (2017) argued that the analysis of a specific value chain is required to identify a set of relevant indicators, and this can be carried out by direct communication with stakeholders or literature review (Monastyrnaya et al., 2017).

Value chain characteristics as well as environmental, economic and social sustainability challenges along the value chain were investigated by conducting interviews with value chain actors, stakeholders and experts (Havardi-Burger et al., 2020a). Qualitative research is especially suitable to explore research topics that have not been previously studied in detail and to collect unanticipated data (Bitsch, 2005). Moreover, qualitative methods are applied in problem solving research (Bitsch, 2005). Since sustainability can be viewed as a wicked problem, and measurement system as a tool to manage the "problem" (Bitsch, 2016) the choice of qualitative methods for the current study is appropriate. In-depth interviews with actors provides rich and detailed information (Bitsch and Yakura, 2007), which is needed for the understanding of processes within a system and therefore especially suitable for characterizing value chains. Furthermore, diverse views and opinions of interviewees can offer a better understanding of the socio-economic political and cultural settings of the system and industry. Twenty semi-structured interviews took place in 2016 and 2017. The recorded interviews were transcribed and analyzed using qualitative content analysis. Furthermore, an extensive literature review was carried out on studies that assessed sustainability in ornamental plant systems. The sustainability challenges identified were further compared to the literature (Havardi-Burger et al., 2020b). In a literature review, O'Rourke (2014) suggested a similar approach. The sustainability theme of biodiversity was not investigated directly in the interviews mentioned above, but was included based on the literature review. Gasso et al. (2015) also followed a comparable approach to identify key sustainability issues in the value chain of Danish maize for German biogas, using interviews with stakeholder groups. In a different study, sustainability hotspots were defined by performing interviews with value chain actors of French pork chains (Petit et al., 2018). Schmitt et al. (2016) selected a set of sustainability attributes based on literature analysis and interviews with different actors in local and global cheese value chains.

Relevant sustainability themes were developed based on the

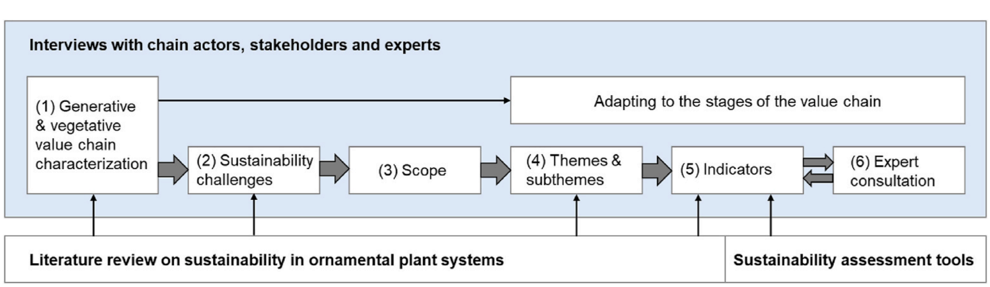

Fig. 3. Six-steps to establish sustainability assessment framework for the FPP value chain.

characterization of the value chain and the investigated challenges. Furthermore, the interviews analyzed continued to serve as a basis for the development of themes and subthemes and supported the selection of indicators (Fig. 3). Themes were broken into subthemes by specifying sustainability objectives. The subthemes correspond to the sustainability goals defined by FAO for sustainable development in agriculture, and the specific areas of action for greenhouse production of potted plants set by Krug et al. (2008). Based on the understanding of the FPP chain and the role of the different actors, it became clear that themes from the different sustainability dimensions should be allocated differently to the value chain stages.

The criteria used for indicator selection of sustainability assessment methods are broadly discussed in the literature. Binder et al. (2010) refers to three important criteria for choosing indicators: (i) goal orientation, (ii) system representation, and (iii) data availability. In a literature review, Bonisoli et al. (2018) identified nine criteria for indicator selection divided in intrinsic requirements and usefulness of the indicator. Intrinsic requirements include data availability, relevance, analytic validity, flexibility in case of changes and measurability. Criteria determining the usefulness of indicators are policy relevance, implementable by farmers, understandable and acceptable to users. Based on the criteria for indicator selection highlighted in the literature discussed above, in the current study, four criteria for indicator selection were used: (i) relevance, how well the indicator fits the sustainability objective, (ii) data availability, whether data is likely to be available for the assessment, (iii) understandability, whether the measurement method is clear, and (iv) applicability, whether the indicator is not too complicated, referred to as measurable by Bonisoli et al. (2018).

In the current study, the procedure for indicator selection for each subtheme started by determining which parameters needed to be measured. If a suitable indicator could be located, it was considered to qualify for the criteria relevance. Subsequently, it was examined for the clarity of method or understandability and applicability. Moreover, the likelihood and complexity of accessing data or data availability was estimated. In cases when no suitable indicator was found, new indicators were developed for the subtheme. Expert consultation was conducted to verify the validity of the newly developed indicators. Five experts were consulted regarding the relevance of sub-themes for assessing the sustainability of the chain and the feasibility of implementing the indicators. Interviewees included two experts for propagation nurseries and breeding, an expert for breeding methods and production technology of ornamental plants, an expert for production techniques of indoor and bedding flowering plants and another expert for horticultural production and innovations and ornamental breeding. Following the expert consultations, some of the indicators were further adjusted.

The hierarchy and the sequence for the development of themes, sustainability objectives and indicators are demonstrated in the example of the environmental theme “water use” (Fig. 4):

1. Setting the sustainability goal for each dimension (environment, society, or economy)
2. Identify sustainability challenges and define sustainability theme
3. Define sustainability objectives and subthemes for each sustainability theme
4. Selection or development of indicators to measure the subtheme

4. Results

The results are divided in four sections. The first section is dedicated to scope definition of the framework in terms of boundaries and intended users. The following three sections are dedicated to sustainability themes and indicators, separated in environmental, social and economic dimensions. For each sustainability dimension, an explanation is provided how themes are allocated across the value chain.

4.1. Scope of the framework

The aim of this assessment tool is for companies to assess their sustainability performance across the value chain. The FPP chain includes indoor and bedding flowering plants propagated with seeds or cuttings. The assessment is designed to assess chain performance, rather than product performance. The scope for the assessment includes value chain stages from breeding to distribution (Fig. 1). The stages retail and end of life at the consumer level are excluded. While the social dimension refers to the consumer as a stakeholder group, indicators relate to the quality of the finished product, rather than consumer behavior. The geographical scope includes breeding, propagation, production and distribution countries.

The assessment focuses on consequential impacts of the value chain and therefore fixed assets such as the construction of greenhouses, coldrooms, offices and equipment are neglected (Sahle and Potting, 2013). Nevertheless, certain aspects related to the structure of greenhouses such as insolation can influence GHG emissions for heating.

Both the generative and the vegetative pathways of the chain share similar sustainability challenges, if seed production takes place in containers in greenhouses. Field production is excluded from the scope of the assessment, because it involves different production systems. Sustainability themes from each dimension are allocated differently across the chain because they follow different patterns. Environmental themes are associated with processes in the different chain stages and therefore allocated to each stage. Socio-economic conditions in different geographic regions determine the allocation of social themes.

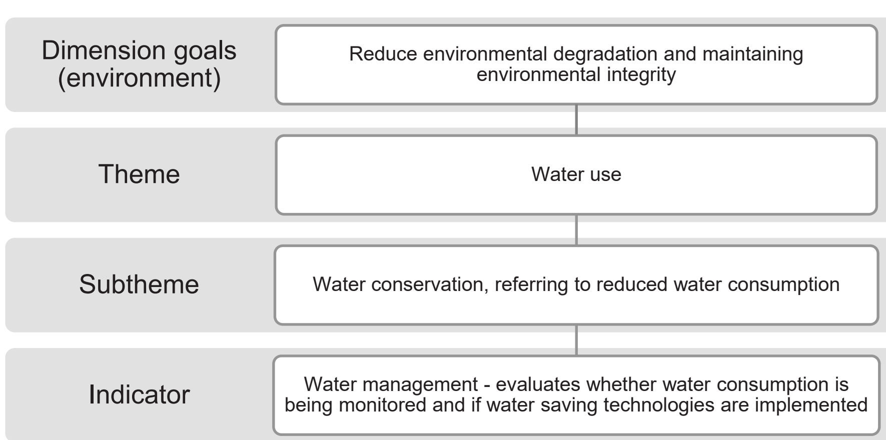

Fig. 4. Hierarchy levels of the sustainability framework for FPP, demonstrated by the theme “water use” as an example. The indicator water management was adopted from RISE.

Furthermore, three stakeholder groups (workers, local community, and consumers) were identified based on their susceptibility to different social impacts. Social sustainability themes are allocated accordingly to different stakeholder groups. The economic assessment is meant to assess the economic sustainability of businesses; therefore, themes are allocated according to the relevant actor groups.

4.2. Environmental themes and indicators

Environmental themes are adapted to each value chain stage (Table 1). Still, the production stages, propagation, young plants and potted plants all are associated with plant cultivation, share similar processes and, therefore, sustainability themes.

The following environmental themes have been identified for the FPP value chain. Breeding goals for ornamental plants are generally associated with productivity, efficiency, durability and esthetics of plants. Some of these goals can influence environmental performance such as GHG emissions by developing cultivars with lower temperature requirements. Cultivars with better disease tolerance can influence the need for pesticides in the production stages. Other examples for environmental sustainability goals are compact plants that reduce the need for application of growth regulators and cultivars with reduced water requirements. As no suitable indictor for the sustainability of breeding goals could be found, a newly developed indicator is suggested. The indicator measures the share of more environmentally sustainable cultivars developed in the last five years out of the total new cultivars. Additional information is provided on each indicator in Appendix C (Table C.1 to Table C.3) including the measured parameters, source and

Table 1
Environmental themes relevant to different value chain stages.

Value chain stages	Theme	Subtheme	Indicator
Breeding	Breeding goals	Sustainable cultivars	Share of sustainable cultivars
Propagation material Young plants Finished plants	Water use	Water conservation	Water management
		Secure water supply	Water supply
	Fertilizer runoff	Wastewater	Wastewater quality
	Plant protection	Chemicals application for plant protection	Plant protection practices
	Substrate and containers (material use)	Replacement of non-renewable materials	Material consumption practices
		CFP associated with production or transport	Choice of materials
		Non-degradable waste	Waste reduction practices
	Biodiversity	Invasive species	Invasive species risk
		Wild species populations in production areas	Species conservation practices
		Pollinator-friendly plants	(i) Insect-supporting varieties, and (ii) hazardous pesticides
	Energy use for production (heating, cooling and light) and shipment	Energy consumption and GHG emissions	Energy saving practices
		Percentage of non-renewable energy sources	Renewable energy
Distribution	Energy use for storage (temperature control and light) and shipment	Energy consumption and GHG emissions	Energy saving practices
		Renewable energy sources	Renewable energy

objectives. The breeding stage is generally not included in prior sustainability assessment frameworks. The SAFA framework, for example, includes all processes that are “part of production or distribution” (FAO, 2014, p. 16). However, SAFA’s scope also includes all processes “that generate significant impacts on sustainability” (p. 16), which indicates the need to include the breeding stage. Petit et al. (2018) had included the breeding stage for the assessment of French pork chains. However, issues identified for the breeding stage of pork are biodiversity of feeding species and pig performance. SAFA offers indicators for the theme agricultural biodiversity that are related to selection of breeds and their conservation, as well as the share of production of locally adapted or rare breeds (FAO, 2013). However, there are no indicators to measure the development of sustainable cultivars.

In the light of climate change, water scarcity is becoming more severe not only in arid regions of the world but also in humid countries such as Germany. Therefore, the general objective is to reduce water consumption. An additional objective is to secure water supply while preventing regional over-use of aquifers or surface waterbodies. Water conservation efforts are assessed by the chosen RISE indicator, water management (whether water consumption is monitored) and by assessing the implementation of water saving measures. The indicator water supply was chosen to assess water availability in the region to secure long-term water supply and prevent water-associated conflicts. Different online tools such as the WWF’s “Water Risk Filter” or WRI “Aqueduct” can provide an estimate on the regional water risk based on the location of a company (World Resources Institute; WWF). The alternative indicator ground and surface water withdrawals (SAFA) measures the water use of the company in relation to the regionally available freshwater. However, the indicator requires to determine water scarcity, for all watersheds used by the company. This seems challenging, as noted in the limitation section of the indicator. The indicator water balance is designed to measure the amount of recovered irrigation water compared to the total amount of irrigation water (Lazzerini et al., 2018). Data has to be collected through extensive field surveys. Though the indicator provides a good estimate for water re-use, it is specific for a certain irrigation system and does not fit other systems.

Fertilizer is mostly applied with the irrigation water. Some growers might apply solid fertilizer in the potting mix. Whether liquid or solid, fertilizer runoff is associated with the irrigation system. For example, nitrate emissions to soil and eventually to water bodies can lead to algal blooms in water bodies as well as acidification of soil and water (Sahle and Potting, 2013). In closed irrigation systems, where irrigation water is circulated, nutrients are generally not discharged. As not all irrigation systems in use are closed systems, fertilizer runoff is relevant for the assessment. In such systems, drainage water should be treated for removal of nutrients. According to interviewees, wetlands have been constructed for wastewater treatment from irrigation water in stock plant nurseries to remove wastewater contaminants. The removal of nitrogen and phosphorus is variable depending on the wetland system and other conditions (Majsztrik et al., 2017), therefore, water control after treatment is desirable. The SAFA indicator chosen to assess wastewater quality, measures concentration of nitrate and orthophosphate directly in wastewater. The indicator nitrogen surplus indirectly assesses the leaching potential of nitrogen by calculating the ratio of nitrogen uptake of plants, compared to the nitrogen available in the fertilizer (Lazzerini et al., 2018). This indicator is not suitable, because it is assumed that the remaining nitrogen, not used by the plants leaches into the environment. The indicator fertilization (RISE) is designed for field production, as it measures fertilizer application compared to nutrients in the soil and crop requirements for optimal yield (Grenz et al., 2016).

Plant protection agents are in frequent use in the cultivation of FPP. To prevent environmental exposure, the use of chemical agents should be limited to a minimum with preference to less harmful substances. The chosen indicator, plant protection practices adopted from RISE, measures whether the application of plant protection agents complies with the principles of integrated plant protection. Integrated plant protection assures that harmful substances are used only when strictly necessary (RISE). Nevertheless, it should be noted that the indicator also evaluates GMO cultivation, which is generally not relevant for pest control in ornamental crops. The indicator environmental exposure pesticide-water measures the persistence of pesticides in the soil (Lazzerini et al., 2018), which is more suitable in field production than in protected environments. To measure environmental exposure to pesticides the indicator wastewater quality (SAFA) can be further implemented to measure pesticide residues in the discharged water.

Reduced environmental burdens associated with substrate and containers used in the FPP production can be achieved through (i) reduced use of non-renewable materials such as plastic or peat or use of alternative recycled or renewable materials, (ii) reduced CFP associated with production or transport, and (iii) reduction of non-degradable waste such as plastic or substrate (perlite). The chosen indicator material consumption practices (SAFA) aims to assess the replacement of non-renewable materials by recycled and renewable materials. To avoid sourcing less sustainable materials, the CFP associated with the production (reported by the supplier) and an estimate of transport CFP should be taken into consideration. Such an indicator is not part of the SAFA, RISE or Lazzerini et al. (2018) indicator lists and therefore was developed for the current framework. The indicator, waste reduction practices (SAFA), chosen for the current framework, is an indicator aiming to measure practices, such as re-use and recycle processes, which are especially relevant for the early production stages of propagation material and young plants, where container and substrate can in some cases be re-used. The indicator recycled green waste in the substrates measures its percentage in potting mixes (Lazzerini et al., 2018). However, the indicator does not measure recycling of other materials such as containers or other types of substrate. RISE suggests the indicator material flows that also determines the degree of fulfilling the recycling potential, but the focus is on self-sufficiency and local sourcing of fertilizers and feed.

Several issues are associated with biodiversity or the goal of preservation of wild populations of species, and the FPP value chain: (i) the risk of invasive ornamental species, (ii) creation of ecological niches in the surroundings of greenhouses, to support the natural populations of species such as insects and birds, and (iii) pollinator-friendly plants (insecticide-free and nectar and pollen-rich). According to Hanspach et al. (2008), about 30% of all invasive plant species in Germany were introduced for ornamental purposes. The majority of invasive plants have been introduced through cultivation in private and public gardens (van Kleunen et al., 2018). According to Hanspach et al. (2008), 95% of all invasive plants species that originated from ornamentals in Germany are perennials. Furthermore, species have a high probability to become naturalized when planted in gardens, and relatively resistant to frost or showing high winter hardiness (Hanspach et al., 2008). Bechtloff et al. (2019) considered woody plant species as especially invasive, which are not in the scope of this study. A risk assessment is recommended to determine whether a species should be accepted or rejected from sale (Hulme et al., 2018). German-Austrian black list information system (GABLIS) was introduced as a risk assessment tool (Essl et al., 2011). The indicator invasive species risk measures whether an introduced ornamental species went through a risk assessment before the approval for sale. Both SAFA and RISE include biodiversity as a sustainability theme, but do not offer a risk indicator.

Diversified land use in non-productive areas, surrounding the greenhouses can support wild species populations. Supporting biodiversity by creation of ecological niches in open areas around the greenhouses, was mentioned by an interviewee as an important aspect of environmental sustainability. Measures to support wild species and habitat connectivity, can include the construction of ecological infrastructures and niches such as stone and wood heaps, trees and hedgerows and flower strips (FAO, 2013). The chosen indicator species conservation practices was designed to assess which activities and practices have been implemented to support wild population of plants and animals on company land. Ecological infrastructures (RISE) measures the percentage of the agricultural area that has a high ecological value, but the scoring system is designed for farmland, which cannot be easily applied to ornamental production.

Ornamental plants rich in nectar and pollen can support pollinator insects and comply with the objective "encouraging pollinator populations". Pollinators generally suffer from worldwide decline with consequences to agricultural production and ecosystems stability (Jachuła et al., 2019). The choice of ornamental plant varieties for production and marketing can influence wildlife conservation of pollinator insects. However, the ornamental plant assortments sold in garden centers in the UK was unattractive to flower visiting insects (Garbuzov et al., 2017). Furthermore, it was shown that pesticide residues on ornamental plants had health implications for insects (Lentola et al., 2017). Thus apart from choice of plants rich in nectar and pollen, plants should be free of insecticides. This is especially relevant to bedding plants planted in gardens and on balconies.

The indicator insect supporting varieties is designed to measure the share of production and marketing of varieties that can support pollinators. The indicator was developed based on a SAFA indicator measuring the share of locally adapted varieties. Lists of plants can help to determine which plant species or varieties are insect friendly (Garbuzov and Ratnieks, 2014). To assess the risk to traces of insecticides harmful to pollinators, the indicator hazardous pesticides is implemented. The indicator hazardous pesticides serves both environmental and social themes, safety to pollinators and consumer safety (see product responsibility). The alternative indicator species conservation practices (SAFA) measures practices to protect wildlife populations on or close to the enterprise land, but not the support of the product for insect populations.

Two aspects have to be considered for the theme of energy consumption in the production and distribution stages: (i) reduced energy consumption and GHG emissions, and (ii) reduction in the percentage of non-renewable energy sources and transfer towards sustainable, renewable energy. Efforts to reduce energy requirements are assessed using the indicator energy saving practices (SAFA). The indicator measures the share of the energy saving practices implemented, compared to a list of feasible practices not yet implemented. The indicator renewable energy (SAFA) assesses the share of renewable and sustainable energy over total energy use. The alternative RISE indicator energy intensity also calculates the percentage of non-renewable energy. However, the indicator gives a score, which is a result of a function based on data gathered on agricultural farms, which is not comparable to ornamental production, distribution or storage requirements. Lazzerini et al. (2018) suggested the indicator carbon dioxide equivalent, taken from a LCA and adjusted to 1 ha of nursery surface for one year. This approach is not suitable to a value chain assessment, which also assesses the distribution stages. Furthermore, the calculation is too complex to implement by value chain actors.

4.3. Social themes and indicators

Social conditions along the FPP value chain differ in the geographical regions, Europe as opposed to Africa and Central America (Havardi-Burger et al., 2020b). Seed production takes place in different regions of the world. Therefore, the distinction between the regions can be generalized into industrialized countries as oppose to low labor cost countries. Furthermore, an overview of the value chain based on the interviews allowed to identify stakeholder groups to be considered for social sustainability. Accordingly, social themes should be allocated differently based on (i) the geographical region, and (ii) the three stakeholder groups, production or nursery workers, local community and consumers (Table 2). Workers' sustainability themes are assessed for all geographical regions. However, due to differences in terms of social security and health care, equality and medical care are only

Table 2
Social sustainability themes and the relevant regions.

Stakeholder group/ themes	Subthemes	Indicator	Region
Workers/ employment relations	Employment agreement, contract	Employment relations	All
	Workload	Working hours	
	Wages	Wage level	
Workers/welfare	Occupational health and safety	Safety and health trainings	All
		Safety of workplace	
	Job satisfaction	Capacity development	
	Equality	Gender equality	Low labor cost countries
	Medical care	Health coverage and access to medical care	
Local community/ regional development	Support of local communities	Community investment	Low labor cost countries
	Regional employment	Regional workforce	
Consumer/product responsibility	Consumer safety	Hazardous pesticides	Germany
	Transparency	Product labelling	

assessed in low labor cost countries. Similarly, the local community themes are relevant only to communities in low labor cost countries. Such communities are often subject to poverty, poor infrastructure and unemployment, leading to the examination of the contribution of the company to the local community. The theme product responsibility is only relevant to the consumer and therefore assessed in the consumption country, Germany. In cases where an enterprise has production sites in different regions, such as in Africa and Europe, each site should be evaluated separately.

According to the interviewees, ornamental production for some species (e.g., poinsettia) is characterized by seasonality of production. Though the majority of employees are permanent, temporary workers are generally hired at peak seasons. Legally binding contracts insure commitment of both employers and employees, and protect workers' social and financial rights. Furthermore, permanent contracts reduce turnover and provide security of employment. The chosen indicator employment relations (SAFA) measures whether the enterprise has a written agreement with their employees (Appendix C, Table C.2). The contract should follow national or international labor treaties and include specifications regarding working hours, vacation and social security provision. The alternative RISE indicator personnel management also assesses whether written employment contracts are in place, but it also assesses many other aspects and therefore is less suitable. At peak seasons, workers are often expected to work over-time. The chosen indicator working hours (RISE) measures whether or not working hours and vacations are recorded. It also evaluates the working hours against regional standards. The alternative indicator, right to quality of life (SAFA) assesses working hours and other aspects, such as the freedom to speak languages, practice religion and culture, which were not identified as sustainability challenges in the FPP value chain. Furthermore, vacation time is not assessed in the SAFA indicator. Therefore, this indicator it is not suitable here.

Wages paid in Africa to nursery workers on cutting farms are generally higher than in cut flower farms. Also in Germany and the Netherlands, nursery workers generally earn more than the countries' minimum wages. Still, wages are considered rather low. The indicator wage and income level (RISE) is designed to compare the wage to the financial needs. However, it is not clear how financial needs can be determined. The chosen indicator wage level measures the percentage of employees paid at least or above the regionally calculated living wage. According to FAO (2013, p. 223), living wage is the amount paid to employees within a standard workweek that meets basic needs for subsistence. The regional living wage can be determined by online calculators (e.g., Global Living Wage Coalition, 2011; WageIndicator Foundation, 2003). In Germany, living wage, calculated for a single person is lower than the net minimum wage. Therefore, the minimum wage is considered as the baseline in Germany.

Occupational health and safety is relevant in the different production stages of FPP, especially because of pesticide use (Mrema et al., 2017; Tsimbiri et al., 2015). Training and education of the employees as well as strict regulations of application can prevent exposure of employees to chemicals. Two indicators are suggested to measure occupational health and safety standards in companies. Safety and health trainings (SAFA) measures the existence of safety trainings and their effectiveness. Furthermore, understanding safety hazards through trainings can empower employees (FAO, 2013). Safety of workplace (SAFA) determines safe, clean and healthy work environment, and specifically work with toxic substances according to protocols ensuring safety. An alternative is offered by the indicator safety at work (RISE), which measures the frequency of work-related accidents and cases of illness. However, it does not refer directly to working procedures with chemicals with their potential long-term health hazards.

According to interviewees, a central difficulty of enterprises in Europe is to recruit and retain employees. Producers in Africa also expressed their preference to retain trained employees. Improving job satisfaction can help retaining and motivating employees as well as increase the potential to attract new employees (Bitsch, 2007; Meyerding, 2015). One aspect of job satisfaction is the development opportunities for employees. The chosen indicator capacity development measures opportunities of employees for development and advancement within the company, and therefore can indicate the potential for job satisfaction of employees. The alternative indicators occupation and training (RISE) measures employee satisfaction considering different aspects at work. However, questions are not specified, which makes the assessment rather subjective, with difficulties to assess the general conditions for employees. Thus, the understandability and applicability of the indicator is questionable.

Women are central to the workforce in propagation nurseries in Africa. This allows them financial independence, and to support their families. For mothers, to be able to continue to work, provision of maternity leave and support in daycare is needed. The chosen indicator, gender equality, assesses the provision of adequate resources to support rights of women before, during and after pregnancy among other discrimination issues.

Communities in low labor cost countries are often deprived of affordable and accessible medical care. To compensate for the absence of state medical care provision, employers in these countries are expected to provide affordable health care services to their employees. The chosen indicator, health coverage and access to medical care (SAFA), indicates whether medical care is provided to employees. The alternative indicator, health (RISE), assesses whether personnel are satisfied with their health situation, but not whether health care is provided by the employer.

Job opportunities can also attract migrants, and contribute to a growing community. Investment in local schools or the development of infrastructure, for example, can support the needs of a growing community. The indicator community investment (SAFA) measures investment of the enterprise to meet local community needs whereas the indicator regional workforce (SAFA) measures whether the enterprise hires local employees. Hiring a regional workforce indicates support for the local community rather than encouraging migration to the region.

For the consumers, the themes focus on product responsibility regarding consumer safety and reliable information for consumers. The indicator hazardous pesticides (SAFA) is designed to assess the risk of traces of harmful pesticides on plants. This indicator specifically measures which pesticides were used, and determines their risk through lists of hazardous pesticides published by the World Health Organization. The indicator product labelling (SAFA) was chosen to encourage reliable labelling by measuring compliance with standards. The indicators tractability system and certified production (SAFA) are less relevant because the majority of potted plants are already certified (Havardi--Burger et al., 2020a). However, it is important for consumers to be informed on aspects such as certified production (GlobalGAP or MPS-A, B or C), social certification in Africa or Latin America, production location, and properties of substrate and containers.

4.4. Economic themes and indicators

The economic sustainability themes are viewed from the company perspective, for all actors participating in the value chain. The majority of subthemes are relevant to all actor groups, but two subthemes, stable production and cost of production, are only relevant to companies in the production stages (Table 3). Furthermore, economic indicators are defined at a higher level of abstraction, because they are general to business. Nevertheless, the choice of themes, subthemes and indicators is specific for sustainability challenges of companies in the FPP value chain.

As stated by interviewees, the sector suffers from low margins because of increasing production costs, mainly due to labor costs, and decreasing prices. Therefore, for producers, profitability is a major sustainability theme. There are different measures to assess short and long-term profitability of a business. According to Deytieux et al., (2016), profitability performance of cropping systems is generally calculated by either gross profit or net income. Net income is one of a set of SAFA indicators. SAFA's net income was chosen to measure whether the revenues in the last five years associated with producing goods and services exceeds the total expenses including interests and taxes (Appendix C, Table C.3). The net income is generally calculated for the income statement of a company and therefore the indicator is easily applicable. Another relevant indicator, cost of production, assesses production costs per product unit of specific products and allows to calculate the break-even point. The break-even point is the point at which production costs per unit are equal to the price per unit sold. The alternative profitability indicator in the RISE framework measures the operating cash flow to sales ratio. However, this indicates if a company is able to generate cash from its sales, rather than the profitability of a business.

According to interviewees, actors in the value chain are vulnerable due to several factors influencing the quality, quantity and the maturation time of plants. The indicator production risk adopted from SAFA is designed to measure the implementation of mechanisms to ensure the quality and quantity of yields in order to mitigate risks such as unpredictable weather conditions and pathogen infestation. Interviewees also referred to other difficulties of the business such as demand uncertainty or workforce shortage. The chosen indicator risk management measures the preparation of a business to deal with external and internal risks, by risk assessment and the implementation of different mechanisms to withstand potential risks. An alternative RISE indicator also deals with risk management, focusing on specific threats to farm livelihood, which is not suitable to assess risks in the FPP value chain. This indicator is less suitable because it refers to farm risks in general and the measurement method is vague.

Table 3
Economic sustainability themes, subthemes, indicators, and the relevant value chain stages.

Theme	Subtheme	Indicator	Actor group
Profitability	Profitability	Net income	All
	Profitability per unit product	Cost of production (per unit product)	Producers
Vulnerability	Stable production	Production risk	Producers
	Assortment	Product diversification	All
	Diversified income	Stability of market	All
	Internal and external risk management	Risk management	All
	Liquidity	Financial liquidity	All
Accountability	Product traceability	Traceability system	All

Intense competition, over-production and price pressure from retail contribute to low prices and market uncertainty. The indicator product diversification (SAFA) measures the number and the development of products, assuming that diversified products reduce risk and contribute to additional market potential. Stability of market (SAFA) measures diversified income structure to ensure sufficient numbers of buyers and marketing channels. Secure buyer-supplier relationships are especially important in the supply of perishable products. The indicator stability (RISE) assesses farm financial stability including aspects such as diversified income sources but also farm specific aspects such as guaranteed land access and the maintenance of infrastructure, which are less relevant for the current assessment.

The floricultural sector is more vulnerable in times of economic recessions compared to other horticultural and agricultural sectors, because it can be seen as a luxury product, as opposed to necessity goods, such as food products. The vulnerability of the sector was demonstrated during the COVID-19 crisis and lockdown in Germany, in the spring of 2020. During this period, all specialized retailers such as garden centers and nurseries were closed. The only open channel were supermarket chains. Moreover, due to the interruption in international flights, the value chain was disrupted, and propagation material such as cuttings, could not be delivered from production locations to Europe. Under such circumstances, liquidity is vital. The chosen indicator financial liquidity adopted from RISE accommodates both SAFA indicators net cash flow and safety nets by assessing the ratio of cash reserves including liquid assets and the available credit lines to average weekly expenditure. The calculation yields the period, for which the business can continue to pay its expenditures.

Actors along the value chain have to account for the products they produce and sell. This can be seen, for example, in the form of requirements for business-to-business certification. Such standards also entail the traceability of the product. Traceability is another form of risk management, for example, in the case of pesticide application that can have consequences on product safety but also workers' safety. To deal with accusations of irresponsible application of pesticides, producers can use a traceability system to account for the use of pesticides on specific products. The indicator traceability system (SAFA) measures the share of production that can be tracked along the value chain.

5. Discussion

In the present study, a concept was developed for assessing sustainability across FPP value chains. The concept differentiates between social, environmental and economic themes, allocated to value chain stages, stakeholder groups, chain actors and geographical regions. In prior work, the perception was that different value chain stages are associated with different sustainability impacts, and therefore, each value chain stage should be assessed according to the related impacts. For example, different environmental and social impacts are associated with different supply chain stages in the apparel supply chain, such as land use in the cultivation of cotton and labor practices in the manufacturing of clothing (O'Rourke, 2014). Environmental themes identified in the current study follow the above concept, as their allocation is differentiated based on the different value chain stages. Petit et al. (2018) also identified different sustainability themes from the three dimensions, across six value chain stages, where some themes such as "water" are relevant in several value chain stages. However, different from the present study, no specific pattern was identified by Petit et al. (2018), for theme allocation to value chain stages.

The milk value chain described by Binder et al. (2012) includes five stages, with the first stage referring to feed producers, considered only for environmental impact on biodiversity and the last stage being consumers, assessed only for their social acceptance. The three stages in between, producers, processors and retailers, share the same economic indicators, with the exception of one additional indicator, subsidies, which is only relevant at the production stage. In the current study, economic themes are also allocated to different chain actors. Similar to Binder et al. (2012), additional indicators are required to assess producers. The allocation of environmental indicators across the value chain stages are also comparable to the current study. Binder et al. (2012) allocated social indicators evenly across the value chain stages, producers, processors and retailers. Such homogeneity was not possible in the current study due to the global character of the value chain with part of the production taking place in low labor cost countries and others in industrialized countries, as well as the consideration of different stakeholder groups.

van Cauwenbergh et al. (2007) divided social themes by relating to farming communities and the society. Social themes are also divided between stakeholder groups in the assessment method for social-LCA (S-LCA). In the S-LCA method five stakeholder groups are considered, workers, consumers, local communities, society, and chain actors, each assessed with different themes (Benoît et al., 2010). In a recent study, only three stakeholder groups were considered for a S-LCA framework, developed for assessing wood-based products in Germany (Siebert et al., 2018a). Two groups, workers and local communities, are comparable to the ones considered in the present study. The third group the "national society" is different from consumers considered for the current study. Consumers are a direct stakeholder in the FPP value chain, and can be affected by sustainability impacts, whereas the direct implications for the national society are vague and difficult to determine.

In a study applying S-LCA, Franze and Ciroth (2011) showed dramatic differences between social impacts of cut-roses produced in Ecuador compared to the Netherlands. This result emphasized the difference in the requirements for social assessment between low labor cost countries and Europe. Moreover, social performance of a nation or a region is dependent on the form of government and government policies. For example, in the USA, the government does not fund healthcare and therefore corporations have a role in provision of healthcare to employees (Hutchins and Sutherland, 2008). Healthcare is an interesting example, because it also emphasizes, differences between European countries and the USA in the need for social assessment. Siebert et al. (2018b) also observed the need for a regional perspective regarding social implications. Taking into consideration the national and regional socio-economic conditions, Siebert et al. (2018b) developed a regional S-LCA for wood based products to a specific region within Germany.

Categorizing sustainability themes as social or economic is in some cases challenging. An example is the theme job satisfaction and the subtheme attract and retain employees. Attracting and retaining employees is associated with the welfare of employees, and thus a social challenge. Nevertheless, the implications of worker shortages are an economic issue. Another example relates to the subthemes product traceability and transparency. Though traceability and transparency are closely related, product traceability was allocated as an economic subtheme, related to risk management and transparency as a social subtheme associated with responsibility to the consumer. According to van Cauwenbergh et al. (2007), marketing activities are an economic theme whereas safety and security in provision of goods belong to the social dimension. In the S-LCA, transparency is also allocated as a social subcategory targeting consumers. In SAFA, both indicators product labelling and traceability system (adopted in the current study) are allocated under the economic subtheme product information.

The majority of indicators were chosen from the SAFA framework. This can be partly explained by the comprehensiveness of SAFA including 116 indicators compared to 47 RISE indicators and only 6 indicators in Lazzerini et al. (2018). This is comparable to findings of De Olde et al. (2017) concluding that SAFA has a high coverage of the majority of subthemes compared to the other assessment tools evaluated, including RISE. The understandability of the SAFA indicators are generally better as the measurement method is clearly explained. Furthermore, the RISE indicators are in some cases unclear, regarding what is actually measured and measurement method. De Olde et al. (2016) also claimed that SAFA calculations are more transparent than RISE, partly because the RISE's calculations are more complex and it is not clear how they are computed. Nevertheless, the SAFA indicators are in some cases too complex for measurement by chain actors, as evident by the indicator ground and surface water withdrawals. The environmental indicators suggested in Lazzerini et al. (2018) were found unsuitable for the sustainability assessment of the FPP value chain. This can be explained partly because they are designed to assess field production rather than production in a protected environment and because other indicators, such as water balance, target a specific production system and, therefore, exclude the assessment of other systems.

The majority of context-specific indicators that had to be developed specifically for the assessment of FPP value chains assess environmental subthemes. Indicators assessing social and economic subthemes were adopted from either SAFA or RISE. These results contradict the findings of Gasso et al. (2015), claiming that generic sustainability frameworks such as SAFA cover environmental subthemes well, but fail to cover sustainability issues related to social and economic dimensions. For example, an indicator for breeding goals had to be developed, because breeding is not part of the scope of SAFA or RISE. The theme substrate and containers is specific for FPP cultivation, which gave rise to the need for specific indicators. The perspective on biodiversity is also very different to other agricultural value chains and required new specific indicators. Social and economic subthemes are not specific to FPP value chains, but rather the combination of subthemes is specific.

The indicator selection process emphasized trade-offs between the need to reduce the number of indicators for feasibility and the full representation of relevant sustainability themes. Binder et al. (2010) described this tension, referring to parsimony for striving to simple representation of the system and sufficiency for the representation of the complexity of the system. One approach is indicators that accommodate several sustainability aspects. However, in such cases, it might become unclear what is actually being measured. An example is the indicator stability (RISE) that aims to assess the financial stability of a farm. The indicator measures farm infrastructure, long-term access to land, the number of customers, and main source of income. In other cases, putting more aspects together offered an added value, such as in the case of the indicator liquidity (RISE), which combines two SAFA indicators, net cash flow and safety nets, and gives a concrete measure illustrating how long a business can survive under financial stress.

Another strategy to reduce the number of indicators is to use the same indicator to assess different subthemes. For example, wastewater quality can assess nutrient load and pollution from pesticides in wastewater. The indicator hazardous pesticides is relevant to both the social and environmental dimensions. It assesses consumer safety but also safety to pollinator insects and the protection of biodiversity. In such cases, different parameters might be measured and compared to different threshold values (Appendix C). In the example of the indicator hazardous pesticides, different black lists are available for pesticides highly toxic to humans and pesticides highly toxic to insects.

6. Conclusions

The conclusion section is divided into three sub-sections. The first section refers to the contribution of the current study to the theory behind assessing agricultural value chains and the differences in assessing social, environmental and economic aspects. Section 6.2 is dedicated to the empirical limitations and suggestions for future research, whereas section 6.3 offers practical implications for chain actors and policy-makers.

6.1. Theoretical implications

Agricultural value chains can differ substantially, and therefore generic sustainability assessment methods such as SAFA and RISE, cannot cover all sustainability subthemes relevant in different agricultural systems. The current study emphasized the need for a system-specific view, especially in unique systems such as FPP value chains. Different from the expectations based on prior work, most of the indicators missing from generic assessment tools are environmental indicators. The need for a system-specific assessment method is demonstrated also by the attempt to adopt indicators from the assessment method developed by Lazzerini et al. (2018). Though specific for a different ornamental plant system, it was not suitable for FPP value chains.

The value chain view offers a different perspective on the differences between the dimensions of sustainability. Social sustainability in a value chain perspective is more influenced by the national and regional socio-economic conditions, rather that the sector or the product. In the current study, several geographical regions with different requirements for social assessment exist in the same value chain. Instead of referring to specific geographical regions, the criteria to differentiate between regions could be government provision (or equivalent) of healthcare and a social safety net. This allows a more general view of the assessment framework, which could then be implemented across geographical regions. The subtheme wage should also be assessed regionally, because the reference value, either living wage or minimum wage, is determined regionally.

Geographical regions do not play an important role in the economic assessment, as it is viewed from a business perspective. Differences might raise from different kinds of risks businesses have to face. For example, location can determine the risk of climate change implications. Furthermore, certain regions might be at higher risk of political instabilities, as was reported in some African countries (Havardi-Burger et al., 2020a). The economic dimension and the associated subthemes are determined by the industry structure and the conditions in the specific sector. The ornamental sector can be characterized by its relatively low margins due to intense competition and pressure from retailers. Moreover, the sector is susceptible to high demand uncertainty, partly because it can be considered producing luxury products. Therefore, the economic assessment focuses mainly on subthemes associated with profitability and vulnerability of the business.

Environmental assessment is closely related to the value chain stages and the specific processes. Environmental assessment is dependent on the specific processes associated with the product, and therefore sustainability themes are divided according to value chain stages. Although the production stages share the same sustainability themes, differences can be found due to different production systems. The indicators chosen assess a wide range of production systems, such as close and open irrigation systems. However, due to the implementation of different systems in different regions, different regions may suffer from different sustainability impacts. For example, the need to heat greenhouses in Europe may result in higher GHG emissions; open irrigation systems in Africa may lead to leaching of nutrients and pesticides into the environment through wastewater.

6.2. Empirical implications

The framework presented here can serve as a basis for a sustainability assessment tool specific for FPP value chains. The indicators presented in the framework were evaluated for their suitability. Applying the indicators in practical operations is beyond the scope of this study, as the focus of the current study was to establish a specific sustainability framework, by determining sustainability themes, subthemes, indicators and the assessment need along the value chain. Therefore, the application of the indicators by users will be necessary for a final determination of the feasibility of single indicators, in terms of data availability, as well as their validity and relevance. After such an evaluation, a final set of indicators can be determined and a measurement system established. Furthermore, to provide improvement guidance for users, sector and region-specific reference values have to be established or alternatively a benchmarking system.

Future research should address the question whether the framework can be implemented to assess similar value chains, in other regions, taking into account regional socio-economic differences. Alternatively, the method can be tested on similar products, such as green potted plants or potted herbs and young vegetable plants for consumers. Moreover, the propositions determined here for the different allocation of social, economic and environmental indicators across value chains can be further tested on value chains from other sectors or industries.

6.3. Practical implications

The current study emphasized the need for policy-makers to distinguish between different agricultural systems in the implementation of suitable assessment frameworks, either generic or system-specific. Implementation of the framework developed in the current study will provide further insights into the value chain to direct actors and policy-makers. Sustainability assessment can support chain actors in taking strategic decisions by prioritizing where to invest and which measures to adopt in order to improve their sustainability performance.

To support practical decision-making, further research is required to assess which alternative sustainability innovations are preferable. For instance, there is a need to determine which growing media have better sustainability performance and lower CFP compared to peat based growing media. Such assessments can help chain actors make an informed choice to improve sustainability performance. Sustainability assessment in the value chain of FPP can also direct policy-makers in setting environmental, social and economic sustainability targets and develop suitable incentives for the adoption of sustainable practices. Furthermore, adopting the framework as a measurement tool can guide future regulation in the specific sector or help regulators to develop specific sustainability standards for ornamental plants.

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CRediT authorship contribution statement

Nirit Havardi-Burger: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Heike Mempel:** Conceptualization, Validation, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Vera Bitsch:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Hierarchy levels in sustainability assessment method based on the literature

Hierarchy level	Definition and alternative terminology
Concept	Specifying the concept of sustainability (De Olde et al., 2017) Terminology: Concept (De Olde et al., 2017), goal (van Cauwenbergh et al., 2007)
Goals	Principles of sustainability agreed upon in international treaties, standards or agreements (Bitsch, 2016) The challenge is to take the general concept of sustainable development and focusing on the specific problems of agriculture (Binder et al., 2010). Terminology: Principles (Bitsch, 2016), goals (De Olde et al., 2017)
Themes and subthemes	Specific objectives derived from the principles or sustainability concept, and should be selected based on detailed knowledge of the system (van Cauwenbergh et al., 2007). Terminology: Themes and subthemes (SAFA, Bockstaller et al., 2015), areas of action (Bitsch, 2016), principle (van Cauwenbergh et al., 2007), criteria (Bitsch, 2016; van Cauwenbergh et al., 2007) Key issues (Gasso et al., 2015), hotspots (Petit et al., 2018), impact categories (Haas et al., 2000), subcategories (Benoît et al., 2010), attributes (Van Calker et al., 2006; Schmitt et al., 2016)
Indicators	Indicators are variables that can assess the system objectively and give an indication of the state of the system (van Cauwenbergh et al., 2007).

Appendix B. Suitable sustainability assessment methods as potential sources for indicator selection

Method	Sector	Dimension	Assessment level	Source	References for case studies
Lazzerini et al. (2018)	Ornamental plants	Environmental	Nursery, container and open field production	Lazzerini et al. (2018)	Lazzerini et al. (2018)
RISE	Universal for agriculture	Environmental, economic, social	Farm	RISE 3.0 - Manual (Grenz et al., 2016)	(De Olde et al., 2016)
SAFA	Universal for agriculture	Environmental, economic, social, governance	Supply chain	SAFA Guidelines, SAFA Indicators and SAFA Tool FAO (2014)	Bonisoli et al. (2019)

Appendix C. Themes and indicators

Table C.1
Environmental themes and indicators

Theme	Sustainability objectives	Indicators	Indicator source	Measured parameters
Breeding goals	Development of more sustainable cultivars (reduced heating requirement, reduced chemical applications for pest control)	Share of sustainable cultivars	own	Share of new environmentally sustainable cultivars developed out of the total new cultivars
Water use	Water conservation	Water management	RISE	Monitoring of water consumption and implementation of water saving measures
	Secure water supply (without compromising aquifers or surface waterbodies)	Water Supply	RISE	Assessment of regional watershed level
Fertilizer runoff	Prevent fertilizer runoff by wastewater treatment and control of nutrient load in treated water	Wastewater quality	SAFA	Concentration of nitrate and orthophosphate
Plant protection	Reduce application of crop protection chemicals to minimum, prevent environmental exposure	Plant protection practices [1]	RISE	Compliance with principles of integrated plant protection
Substrate and containers	Reduced use of non- renewable materials (e.g., plastic, peat)	Material consumption practices	SAFA	Replacement of non-renewable materials by recycled and renewable materials
	Sourcing substrate or containers with lower CFP associated in production and transport	Choice of materials	own	Evidence for consideration of CFP (supplier) and transport associated CFP
	Reduce non-degradable waste such as plastic or substrate (perlite)	Waste reduction practices	SAFA	Implemented practices to reduce waste
Biodiversity	Prevent introduction and spread of alien invasive ornamental species	Invasive species risk	own	Invasiveness risk assessment of new ornamental species before approval for sale
	Preserve and support wild population of species in production areas	Species conservation practices	SAFA	Capture biodiversity enhancing practices to support wild population of plants and animals
	Encouraging pollinator populations by choice of ornamental plants varieties	Insect supporting varieties	Own adjusted from SAFA (E 4.3.3)	Share of production and marketing of insect supporting varieties determined by number of plants [2]
Energy use (temperature control/ heating and storage as well as transport)	Reduced energy consumption and GHG emissions	Energy saving practices	SAFA	Share of implemented energy saving practices
	Reduced dependency in non-renewable energy sources	Renewable energy	SAFA	Share of renewable and sustainable energy carriers of total net energy use

[1]Originally “Plant protection” in the RISE framework.
[2]See social indicators “hazardous pesticides” to assess the risk of exposure of pollinators to insecticides.

Table C.2
Social sustainability themes and indicators

Subtheme	Sustainability objectives	Indicators	Indicator source	Measured parameters
Employment agreement/ contract	Workers have secure workplace and stability through binding legal contracts	Employment relations	SAFA	Written agreements with employees
Workload	Workload allows quality of life, overtime compensated	Working hours	RISE	Working hours and vacations recorded and evaluated against standards
Wages	Wages provide reasonable life quality for workers and their families	Wage level	SAFA	Percent of employees that are paid living wage or above
Occupational health and safety	Employees trained for health and safety issues	Safety and health trainings	SAFA	Existence and effectiveness of employees' health and safety training
	Safe working environment	Safety of workplace	SAFA	Determining safe, clean and healthy workplace
Job satisfaction	Attract and retain employees	Capacity development	SAFA	Opportunities for employees' capacity development and advancement
Gender equality	No gender discrimination, including support of working mothers through provision of maternity leave	Gender equality	SAFA	Provision of adequate resources to support rights of women before, during and after pregnancy
Medical care	Access to affordable medical care for employees	Health coverage and access to medical care	SAFA	Provision of medical care for employees
Benefits to/investment in local communities	Support of/invest in local communities	Community investment	SAFA	Investment to meet local community needs
Employment	Contribution to regional employment	Regional workforce	SAFA	History of preferential hiring of local employees when possible
Consumer safety	Product free of highly hazardous pesticides	Hazardous pesticides	SAFA	Any highly hazardous and other pesticides used (safety to consumers and pollinators)
Transparency	Consumer informed on product quality through a reliable labeling system	Product labelling	SAFA	Products are labeled in compliance with standards

Table C.3
Economic sustainability themes and indicators

Theme	Subtheme	Sustainability objective	Indicators	Indicator source	Measured parameters
Profitability	Net income	Maintain short and long term profitability of the business	Net income	SAFA	Total revenue in the last five years associated with producing goods and services exceeds the total expenses (including interests and taxes)
	Profitability per unit product	Costs of unit production are lower than the price per unit of product sold	Cost of production	SAFA	Cost of the products sold per unit of production, break-even point
Vulnerability	Stable production	Mitigating production risk such as unpredictably weather conditions and pathogen infestation	Production risk[1]	SAFA	Implementation of mechanisms to prevent disruption of volume or quality
	Assortment	Diversified products to ensure market growth, product differentiation and reduced risk (market, weather, price)	Product diversification	SAFA	Number and type of products as well as development of new products
	Diversified income	Diversified income structure (marketing channels and buyers) and production contract with buyers	Stability of market	SAFA	Activities to diversify marketing channels and stabilize prices
	Risk management	Internal and external risks (e.g., demand uncertainty, shortage in workforce)	Risk management	SAFA	Existence of a plan or a strategy to reduce risks and adapt
	Liquidity	Financial liquidity to withstand shocks	Financial liquidity[2]	RISE	Cash flow plus available credit lines divided by average weekly expenditure
Accountability	Product traceability	Products can be traced along the value chain	Traceability system	SAFA	Share of production that can be traced along the value chain

[1]Originally "guaranty of production levels" in the SAFA framework.
[2]Originally "liquidity" in the RISE framework.

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