TUM School of Life Sciences

Sustainability Management at Farm Level - Preferences and Innovation

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Zusammenfassung

In Deutschland werden Managementstandards zur Verbesserung der Nachhaltigkeit in der Landwirtschaft bisher nur in geringem Maße angeboten und genutzt. Ziel dieser Dissertation ist es, auf der Basis von Erkenntnissen über Zusammenhänge und Einflussfaktoren auf den komplexen Entscheidungsprozessen der Landwirte die wichtigsten hemmenden Faktoren sowie Gestaltungsoptionen für solche Standards zu identifizieren. Dazu wurden vier Studien verfasst.

Die erste, explorative Studie untersucht den Prozess der Innovationsannahme für einen umfassenden, landwirtschaftlichen Nachhaltigkeitsmanagement-Standard bei deutschen Landwirten. Es wurde zur Datenerhebung die *Delphi-Methode* genutzt. Die Ergebnisse wurden mit den Entscheidungs-Vorphasen des *Innovations-Entscheidungs-Modells* verknüpft. Die Auswertungen zeigen, dass der relative Vorteil des Nachhaltigkeitsstandards aus Sicht der Befragten nicht ausreichend deutlich wird. Neben höheren Produktpreisen wird die Datengrundlage für die Nachhaltigkeitsbewertung als wichtigster Faktor für die Standardgestaltung identifiziert. Die zweite Studie fokussiert auf konkrete Ausgestaltungsvarianten. Hierzu wird mit einem *Discrete-Choice-Experiment* die Bereitschaft deutscher Landwirte untersucht einen Nachhaltigkeitsstandard zu übernehmen. Die Attribute des Standard-Designs wurden aus der ersten Studie abgeleitet, um einen fiktiven Standard zu modellieren. Die Befragten bevorzugen hier die Datenübernahme aus dem Integrierten Verwaltungs- und Kontrollsystem der EU, ein mittleres Nachhaltigkeitsniveau und die Möglichkeit Umweltprogramme zu integrieren.

In der dritten und vierten Studie wird die Rolle von Motivation und Risiko im komplexen Entscheidungsprozess der Landwirte tiefer untersucht. Studie 3 analysiert mit Hilfe des *Technologieakzeptanzmodells* den Einfluss sozialer, finanzieller und persönlicher Erwartungen auf die Absicht einen Standard zu nutzen. Die Ergebnisse des verwendeten *Strukturgleichungsmodells* bestätigen, dass die Benutzerfreundlichkeit den wichtigsten Aspekt darstellt. Studie 4 testet den Einfluss von drei *verschiedenen Risikomaßen* auf die angegebene Akzeptanz eines Nachhaltigkeitsstandards und kontrastiert diese Ergebnisse mit der angegebenen Höhe an Investitionen, welche die Landwirte in der Vergangenheit getätigt haben. Die Resultate deuten darauf hin, dass Selbsteinschätzungsfragen eher die Erwartungen an die Innovation selbst erfassen als tatsächliche Riskoapräferenzen. Dies bedeutet für Nachhaltigkeitsstandards, dass bessere Kenntnisse zu den Standards sowie Anwendungsbeispiele bei Landwirten eine wichtige Bedeutung für die Akzeptanz erwarten lassen, da diese das empfundene Risiko verringern können. Die Arbeit schließt mit einer Ergebnisdiskussion und der Ableitung von Handlungsempfehlungen.

Summary

In Germany, management standards for improving sustainability in agriculture have so far been offered and taken up only to a limited extent. The present work aims to identify the most important inhibiting factors as well as design options for such standards on the basis of findings on interrelationships and factors influencing the complex decision-making processes of farmers. This dissertation comprises the following four studies.

The first, explorative study investigates the process of innovation adoption for a comprehensive, agricultural sustainability management standard among German farmers. For this purpose, the *Delphi method* was used to collect data. The results were linked to the first stages of the *Model of Five Stages in the Innovation-Decision Process*. The results show that the relative advantage of the sustainability standard is not sufficiently clear from the point of view of the respondents. In addition to higher product prices, the data basis for the sustainability assessment is identified as the most important factor for optimizing a standard. The second study focuses on a possible standard design and uses a *discrete choice experiment* to investigate the willingness of German farmers to adopt a sustainability standard. For this purpose, attributes of the standard design were derived from the first study in order to model a notional standard. Respondents prefer the use of data based on the EUs Integrated Administration and Control System, a medium sustainability level and the possibility to integrate AES.

The third and fourth studies examine in depth the role of motivation and risk in the complex decision-making process of farmers. Study 3 uses the technology acceptance model to analyze the influence of social, financial and personal expectations on the intention to use a standard. The results of the structural equation model used confirm that ease of use is the most important aspect. Study 4 tests the influence of three different risk measures on the stated acceptability of a sustainability standard and contrasts these results with the level of investment farmers have made in the past. The results suggest that self-assessment questions are more likely to capture expectations about the innovation itself than actual risk preferences. The implication for sustainability standards is that better knowledge of the standards, as well as examples of use among farmers, is expected to be important for adoption, as these can reduce perceived risk. The paper concludes with a discussion of the results and the derivation of recommendations for action.

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Abbreviations

AES	Agri-Environmental Scheme
BMEL	Bundesministerium für Ernährung und Landwirtschaft
CAP	Common Agricultural Policy
DCE	Discrete Choice Experiment
EC	European Commission
EDP	Electronic Data Processing
EP	European Parliament
EU	European Union
GAEC	Good Agricultural and Ecological Condition of Land
IACS	Integrated Administration and Control System
ITC	International Trade Centre
PA	Precision Agriculture
RUM	Random Utility Maximization
SEM	Structural Equation Models
TAM	Technology Acceptance Model
TPB	Theory of Planned Behaviour
TRA	Theory of Reasoned Action
WBAE	Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection
WTA	Willingness-To-Accept
WTO	World Trade Organization

Part I: Introduction and Methods

1 Background and Research Questions

Agricultural production is currently a major driver of biodiversity loss and a significant source of greenhouse gas emissions (Tubiello et al. 2013; Dudley and Alexander 2017; IPCC 2019). Sustainable land use and food production could make a significant contribution to both biodiversity and climate protection (Pe'er et al. 2020). One possible way to improve this, which is still in its infancy, at least in Germany, is through the use of systematic sustainability management standards (Spiller et al. 2020a, pp 224). The first two chapters outline the political and societal background and different concepts for sustainability standards. Chapter 1.3 introduces elements of the organizational design of sustainability standards and Chapter 1.4 gives an overview of the literature on farmers' innovation adoption behavior. The section concludes with a description of the aims and structure of this dissertation in Chapter 1.5.

1.1 Sustainability Assessment in Agriculture

The issue of sustainability in agricultural production had already concerned experts before the publication of the Brundtland Report in 1987 (Douglass 1984; UN 1987). However, it is only since the mid-2000s that greater efforts have been made to increase food production worldwide while achieving enhanced sustainability (Buckwell et al. 2014). In the absence of a legal definition of sustainability in the context of agriculture to date, this thesis is guided by the definition provided by Allen et al. (1991). They offer the following concept: '*A sustainable agriculture is one that equitably balances concerns of environmental soundness, economic viability, and social justice among all sectors of society'* (Allen et al. 1991, p 37). Allen et al. emphasize that the whole-systems nature of agriculture must be recognized. Therefore, the entire impact of the agricultural system must be considered to improve long-term sustainability.

In view of increasingly drastic external effects of agriculture, which are becoming more and more evident against the background of climate change, all stakeholders face the challenge of finding efficient solutions as quickly as possible and making agriculture sustainable (Dudley and Alexander 2017; Balmford et al. 2018). Societies in Europe and Germany are becoming increasingly aware of the environmental problems of intensive farming systems. This is demonstrated at a number of different levels. In food purchases, consumers are making choices accordingly (Illichmann and Abdulai 2014; Profeta and Hamm 2019; Su and Canavari 2018). For example, sales of organic food increased by an average of 13.3% per year in Germany from 2018 to 2021 (BÖLW 2021; BÖLW 2022).

The European Union (EU) Commission's 2018 proposals to reform the Common Agricultural Policy (CAP) raised EU-level ambitions for sustainability and proposed in article 12 the obligation for a 'farm sustainability tool' as a Good Agricultural and Environmental Condition (GAEC) (EC 2018). In the course of the trilogue negotiations amongst European Commission, Council and Parliament, starting from 2020, article 12 was taken out (Metta and Lakner 2021). In the now adopted form of the EU Regulation 2021/2215, only Article 15 (4) includes the following requirements: *'The farm advisory services ... shall cover at least the following:... (g) sustainable management of nutrients, including at the latest as from 2024 the use of a Farm Sustainability Tool for Nutrients, which is any digital application that provides at least:(i) a balance of the main nutrients at field scale; (ii) the legal requirements on nutrients; (iii) soil data, based on available information and analyses; (iv) data from the integrated administration and control system (IACS) relevant for nutrient management' (EC 2021).* This highlights the need for urgent action, even though it has not yet been possible to reach political agreement at European level. The scientific report of the Advisory Board on Agricultural Policy, Food and Consumer Health Protection at the Federal Ministry of Food and Agriculture (WBAE) shows that in Germany sustainable farming is also a very topical and still unresolved challenge (Spiller et al. 2020b). The WBAE demands in its 2020 report that '*policies should support the development of intermediate forms of farming systems with greater sustainability that can compete with organic farming in terms of environmental performance but that achieve higher yields. Such approaches should, in the longer term, be developed towards a certifiable agricultural standard and a (possibly multi-level) label'* (Spiller et al. 2020b, p 19).

However, due to the multitude of requirements and dimensions of sustainability as well as the numerous interdependencies of management decisions in agriculture, measuring and assessing the sustainability of food production is a major challenge for which there is no harmonized framework in Germany so far (Spiller et al. 2020a). The various existing concepts and approaches for sustainability improvement in agricultural production systems differ fundamentally depending on their origin and addressees.

1.2 Agricultural Sustainability Standards

In the early 2000s, scientists in various European countries simultaneously began to search for indicators that form a basis for assessing sustainability in agriculture (Bockstaller et al. 2008; Lebacq et al. 2013). In Ireland (Louwagie et al. 2012), Italy (Pacchini et al. 2015), France (Thiollet-Scholtus and Bockstaller 2015), Switzerland (Häni et al. 2008), Germany (Hülsbergen and

Küstermann 2007; Doluschitz et al. 2009), and Belgium (Mey et al. 2011) indicator-sets and concepts for whole farms were developed and reviewed. The precision of the assessment and the system objectives differ significantly between the individual European approaches (Bockstaller et al. 2009; Schader et al. 2012; Marchand et al. 2014; Coteur et al. 2020). Consensus for standardization has not yet been reached (Olde et al. 2017a). In particular, the assessment of the ecological impact is still a crucial issue (Kelly et al. 2018; Dietz et al. 2021).

Parallel to the assessment-based approaches that capture and evaluate the entire agricultural production processes (Breitschuh et al. 2008; Doluschitz et al. 2009), retailers initiated sustainability programs in response to increasing consumer demand for sustainable products (Ridoutt et al. 2016; Monastyrnaya et al. 2017). The property *'produced in a more sustainable way'* of an agricultural produce is a so called *Potemkin attribute* (Jahn et al. 2005). Jahn et al. describe such attributes as *'characterized by the fact that neither the buyer nor external institutions are able to carry out controls through laboratory analyses at the endproduct level'* (Jahn et al. 2005, p 55). Proof of the sustainable attribute for a product thus requires appropriate documentation and monitoring of the production processes themselves. Compliance is usually monitored by third parties. The willingness of consumers to pay additional money for the sustainable attribute does not allow for complex and cost-intensive sustainability management for the entire operation. Therefore, retail approaches in Germany focus mainly on individual sustainability aspects or individual products by means of so-called *'hotspot analysis'* and/or individual farm types or production chains (e.g. REWE Group 2015; Initiative Tierwohl 2016).

Currently, an increasing variety of approaches focus on different and often limited areas of evaluation (Meyerding et al. 2019; Schader et al. 2019; Mook and Overdevest 2021). We find examples for further developed assessment tools as well as retailer-initiated systems relevant for practitioners in Europe and the German-speaking countries (Coteur et al. 2020; Janker and Mann 2020). Established standards, e.g. the standard '*GLOBAL G.A.P.*', offer an add-on module for *'Farm Sustainability Assessment'* (Global G.A.P. 2020). In the remainder of this dissertation and the studies included within both types of approach to improving sustainability are addressed under the term '*sustainability standard'*[1]. However, this thesis focuses on approaches that consider the whole farm and all dimensions of sustainability.

[1] The World Trade Organization (WTO) defines a standard as follows: ‚*Document approved by a recognized body that provides, for common and repeated use, rules, guidelines, or characteristics for products or related processes and production methods, with which compliance is not mandatory. It may also include or deal exclusively with terminology, symbols, packaging, marking, or labelling requirements as they apply to a product, process, or production method'* (WTO 2014, p. 58).

A comprehensive recording and evaluation of the management of entire farms provide the most differentiated basis for assessing and improving the sustainability of the production. However, this is very time consuming and cost intensive due to the high effort required for data collection (Bockstaller et al. 2009; Olde et al. 2017b; Coteur et al. 2020). In addition, lower use of fertilizers or pesticides can lead to lower yields in the short term. On the other hand, sustainable farming practices can lead to lower input costs, better soil fertility, higher product prices, and better social acceptance (Kelly et al. 2018; De Steur et al. 2020). In many parts of Germany, traditional family farms still dominate. One might therefore assume that sustainable management is in their own interest. However, only about 40% of the agricultural land is owned by the farms, the rest is rented from third parties (Tietz et al. 2021). These landlords should have an equally strong interest in sustainable management, otherwise their capital would be consumed over time. Nevertheless, neither retail-oriented nor holistic approaches have yet become popular among German farmers. In this light, it is essential for policymakers and private providers to better understand farmers' perceptions and expectations of sustainability standard design.

The decision of a farmer to adopt farm sustainability management remains voluntary unless there are governmental regulations to the contrary. So far, there are no obligations in Germany regarding sustainability management that go beyond the defined *‚Good Agricultural Practices'* (BMEL 2021) or the so called *‚greening measures'* prescribed under EU directives (EC 2013). Farmers' adoption decisions are made in light of their individual production function, the benefits this innovation represents to the farmer, and their personal preferences. Possible reasons to explain the observed low acceptance of sustainability management systems in Germany are: farmers do not feel a need to change their actions or assume that current management is already sufficiently sustainable; the design of the standards offered so far, such as their incentives or content requirements inhibits adoption (e.g. limitation of fertilizer use); farmers do not know how to implement the required sustainable practices; and necessary changes do not fit into the farm management concept (Zapf et al. 2009; Luhmann et al. 2016; Griese et al. 2018). This dissertation investigates the influence of organizational design and its effect on farmer adoption.

1.3 Standard Design

In developing a standard, the interests of the stakeholders involved – such as farmers, owners of the standard, the inspection body and buyers or consumers – must be aligned through the criteria of the standard, its design and its organizational implementation. In doing so, contradictory requirements for a standard often collide, which also particularly affect the different

organizational implementation. This section illustrates findings of an initial analysis of farming standards from the *standards map* data base of the International Trade Centre (ITC)[2] combined with findings from literature. In the following paragraphs, the different areas of standard design are described and their respective effects from the farmers' point of view are presented. Table 1-1 gives an overview of potential sources of utility or impact of the various organizational design elements that can significantly influence farmers' acceptance of a standard.

Table 1-1 Organizational standard design elements by utility dimensions

Utility dimensions			
Transactional & direct costs	Market effects	Risk of application	Identification & social gains
data basis used for sustainability assessment	higher product *prices*	*management system* approach	*normative objectives*
technical support for data provision	*cooperation* for sales	*individual objectives*	includable *innovations*
offered *consulting* & information	standard *labelling*	*compliance* assessment	*involvement* in standard setting
direct standard related *costs*		*timeframe* for implementation	*geographical* coverage of *label*

Transactional and direct costs - Proof of sustainable management is provided by the farmers supplying information/data on the condition of their fields and their management measures. As with all standards, this information then forms the basis for an audit and certification (Jahn and Spiller 2005). Depending on the requirements of the standard, different levels of detail for sustainability assessment are required (see Chapter 1.2). More detailed information is associated with higher labor costs and possibly higher direct costs, e.g. soil testing for the farmer. Farmers distinguish between working time on the farm and in the office, whereby office work is often considered an additional bureaucratic burden and usually has a negative connotation (Falconer 2000; Jahn et al. 2003; Castellari et al. 2018). The standards also differ in terms of technical support for data provision or transfer of existing data. Automated transfer of existing data reduces the workload for the farmer (Bord Bia 2013). Some standards offer free advice, which in turn reduces the time required for data collection, but may also have an impact on the perceived risk associated with standard use (Morris et al. 2000; Garforth 2010). At the same

[2] ITC is a joint cooperation agency of the United Nations Conference on Trade and Development and the WTO. It provides an online data base that enabled to compare over 210 (as of 2017) international standards, codes of conduct and audit protocols (available at https://standardsmap.org).

time, some standards require some form of participation or membership fee, which are direct costs associated with standard use (Yiridoe and Marett 2004).

Market effects - The additional costs of more sustainable agricultural production partly have to be borne by consumers or buyers through higher product prices. It is, however, often not possible to pass on all of the additional costs to buyers (Trienekens and Zuurbier 2008; Janssen and Hamm 2012). From a producer's perspective, better market access or stable, secure trade relationships can be attractive for product sales, somewhat offsetting the necessary additional costs (Luhmann et al. 2016; Jantke et al. 2020). The definition of a standard as it appears on a product label is particularly important for consumers. In addition to specific content criteria (such as organic or quality requirements), the geographic origin of products is often indicated, e.g. national and regional indications of origin. Such regional indications of origin often make products even more attractive to consumers (Janßen and Langen 2017; De Steur et al. 2020).

Risk of failure under **application** - The diversity of standards and assessment methods illustrate that improving sustainability in agricultural production is not a trivial challenge. While the rules for organic farming and labelling are defined EU-wide (EP 2018), sustainability standards use both process-oriented and result-oriented criteria for sustainability assessment. This poses a risk for the farmers as they may not be able to demonstrate better results in an audit even if they tried to improve farm management. Some standards specify clear limits, e.g. for fertilization, others prescribe the use of certain techniques, and finally there are standards that focus on a continuous improvement process in the form of a management approach. Such improvement-oriented approaches make it possible, in coordination with the standard owner, for the user to define short-, medium- and long-term targets, which must then be achieved by the user individually. As a result, they reduce the risk of failure compared to standards with fixed target values. The degree to which the standard's requirements must be met can be assessed as pass or fail or relatively, e.g. as a percentage of goal achievement. Such relative assessment is more difficult to communicate to consumers, but more attractive to farmers because it gives them more freedom. Some standards allow transition periods at the beginning of the standard application, which also reduces the risk for the user and allows earlier cost compensation for the changed growing conditions (Olde et al. 2017a; Olde et al. 2017b).

Personal **identification and social gains** - There are standards like the Irish *Origin Green* that allow a farmer to set individual goals and to incorporate their own innovations (Bord Bia 2013). This can help users to identify more strongly with the standard and thus create additional benefits by means of social capital (Hunecke et al. 2017; Sutherland and Burton 2011; Burton

et al. 2008). In addition, greater user participation in standard setting is expected to have a positive impact on adoption (Rose et al. 2019) as is the geographical coverage of a label.

1.4 Farmers' Innovation Adoption Behavior

There have been few specific research on farmers' adoption of sustainably standards. Only the work of Luhmann et al. (2016), Naspetti et al. (2017) and De Steur et al. (2020) address similar issues. However, these were published after the data collection of this thesis and therefore could not provide a basis for the present research. Alternatively, literature on adoption of sustainable practices, agri-environmental programs, or conversion to organic farming was consulted, as these voluntary decisions are partly similar to the current challenge of innovation adoption (Coteur et al. 2020; Munz et al. 2020; Westerink et al. 2021; Kreft et al. 2021; Möhring and Finger 2022). The following is a brief overview of the literature on the most important factors.

Regarding the **characteristics of farms**, there are different findings on the role of farm size and innovativeness. Some studies have found a correlation between farm size and innovativeness, with larger farms being more innovative than smaller ones (Läpple and Kelley 2013; Läpple et al. 2015; Vecchio et al. 2022). This seems plausible for many innovations, since innovations are often accompanied by investments for which larger companies have more resources. However, many other studies have not been able to demonstrate this relationship (Trujillo-Barrera et al. 2016; Möhring and Finger 2022).

Socioeconomic characteristics of farmers and farms, have been citied in numerous studies as a cause of higher or lower likelihood of adoption of innovations. The studies of Padel (2001), Läpple and Kelley (2013), Läpple et al. (2015) and Pavlis et al. (2016) show that as a farmers' age increases, the likelihood of adopting agri-environmental schemes (AES) or organic farming decreases. In contrast, Lastra-Bravo et al. (2015) found exceptions, as shown by the studies of Defrancesco et al. (2007) and Barreiro-Hurlé et al. (2010). They explain that the AES studied were aimed at the (re-)implementation of traditional and less intensive practices with which younger farmers were no longer familiar. Moreover, we learn from these studies that farmers' formal education plays an equally ambivalent role. Läpple et al. (2015) confirmed Lin's (1991) earlier findings that farmers with agricultural education are more likely to adopt innovations. The meta-analysis by Barreiro-Hurlé et al. (2010) suggests that education per se does not lead to increased innovation adoption, but rather to increased access to information, which is then associated with a higher propensity to innovate. Pavlis et al. (2016) argues that

information is associated with knowledge about the innovation, which is an important aspect of innovation adoption (Lastra-Bravo et al. 2015; Läpple et al. 2015; Dessart et al. 2019).

Hunecke et al. measure human capital *'as educational level in years of schooling'* (Hunecke et al. 2017, p 224). They explain the higher likelihood to adopt irrigation systems among farmers with higher levels of education by the fact that human capital is associated with social capital and leads to larger **formal and informal social networks**. These social networks have a positive effect on the adoption of innovations (Warriner and Moul 1992; Moschitz et al. 2015). In a study on automated milking systems adoption in Europe, Sauer and Zilberman (2012) additionally found a significant positive effect of neighborhood/peer group behavior and technology density on technology adoption. Furthermore, very innovative farmers seem to have more extensive and supra-regional networks (Compagnone and Hellec 2015), whereby trust in the source of information seems to be particularly important (Hunecke et al. 2017). Overall, the opinion of peer groups is an important factor in an individual's evaluation of an innovation (Morris et al. 2000; Ambrosius et al. 2015)[3]. The work of Schaak and Mußhoff *'indicate that the farmer's beliefs and intentions are influenced by his or her perception of societal expectations'* (Schaak and Mußhoff 2018, p 237). Trujillo-Barrera et al. (2016) work examines the impact of expected economic, social, and personal rewards on the decision to invest in sustainable stables. They conclude that perceived risk is a major barrier to the adoption of innovation.

The perceived **risk associated with the innovation** from the farmers' point of view, as well as farmers' individual risk tolerance and risk aversion are also investigated in the studies by Roe (2015), Bozzola and Finger (2020), Iyer et al. (2020) and Sulewski et al. (2020). Risk tolerance is an individual factor that depends on the decision-makers age, education, gender, marital status and ethnic group (Sung and Hanna 1997). Risk aversion is mostly measured by simple questions or experiments and is mostly underestimated in non-payoff experiments (Holt and Laury 2002). Finally, the expectations that the potential user has of the innovation itself have to be considered in the context of risk evaluation. Sauer and Zilberman (2012) have shown that previous experiences with the adoption of innovations generally have a positive influence on the adoption of AMS, while Lastra-Bravo et al. (2015) and Yeboah et al. (2015) find that

[3] Some scholars have developed complete frameworks that additionally consider expectations and attitudes associated with the innovation adoption to approach the complexity of the adoption process. Amongst them the works of Dessart et al. 2019 and of Castro Campos 2022, which focus on the adoption of sustainable practices in general. These likewise derived the individual elements from the literature and do not allow an assessment of the weight of influence of each aspect.

previous experiences with the particular type of innovation (e.g. AES) have a positive influence on the adoption of other conservation programs.

1.5 Aim and Structure of this Thesis

Systematic sustainability management in agriculture is still a relatively new concept for which no harmonized regulation or standard has yet been established in Germany and Europe. It could in the near future, represent a new form of farm management between organic and conventional farming and thus contribute significantly to reducing the negative impacts of agriculture. In addition to the requirements regarding the farming practices, the organizational design of the standard plays a decisive role in the voluntary adoption of this form of innovation. This dissertation thesis examines German farmers' preferences and attitudes towards voluntary adoption of comprehensive sustainability management standards as a form of innovation adoption.

The aim of this work is to provide insights on the following questions:

- What benefits does systematic sustainability management offer users?
- Is process improvement perceived as a meaningful benefit and trusted?
- At what point does the innovation adoption process for this innovation currently fail?
- What price premium would be required to drive adoption?
- What impact does the organizational design of a sustainability standard have on adoption?
- Which target groups are more likely to adopt such an innovation?
- What influence do social environment, farmer attitudes, and ease-of-use have on adoption?
- What role do risk perception and risk aversion play in this context?

This thesis addresses these questions and presents four studies on the adoption of sustainability management as a form of innovation on farm level in Germany. The first of the studies is explorative and follows a qualitative approach (Fig. 1-1 indicated in blue). It identifies factors from existing literature that are expected to have a significant influence on farmers' behavior in the decision-making situation for or against the adoption of a standard. Based on farmers' previous experiences with similar approaches to improving agricultural sustainability, a two-stage Delphi study was conducted to identify and categorize barriers and facilitating factors to the adoption of standards. Likewise, the Delphi survey identifies a broad range of design options as well as participants' preferences for each option.

Based on the assumption of an individual *utility* of such an innovation for the user, a discrete choice experiment (DCE) was conducted to examine farmers' preferences for an improved

standard design, the relative importance of each design element, and the effect of possible higher prices for standard adoption. In the next step, while considering the socioeconomic context for standard adoption, farmer groups have been identified that are more likely to adopt a proposed standard. In a further analysis, the influence of farmers' personal perceptions, e.g. in terms of financial rewards or social environment, are analyzed using a structural equation model (SEM), which allows correlation between causal factors and effects on adoption decisions. Thus, the influence of expected benefits, social norms, and perceived ease-of-use on farmers' attitudes towards adopting a standard is examined in greater depth (Fig. 1-1, in-depth studies highlighted in green). Finally, because there are conflicting opinions in the literature about the role of risk perception and risk aversion in the adoption of standards, these two aspects have been further examined in relation to expressed attitudes towards the adoption of a standard (Fig. 1-1 indicated in yellow). On the one hand, the results of this work provide fundamental insights into the attitudes of German farmers towards systematic sustainability management and, on the other hand, they show the preferences in the design of such systems. This work then provides the basis to improve existing offerings as well as for designing policies based on farmers' voluntary acceptance of systematic sustainability management and improvement.

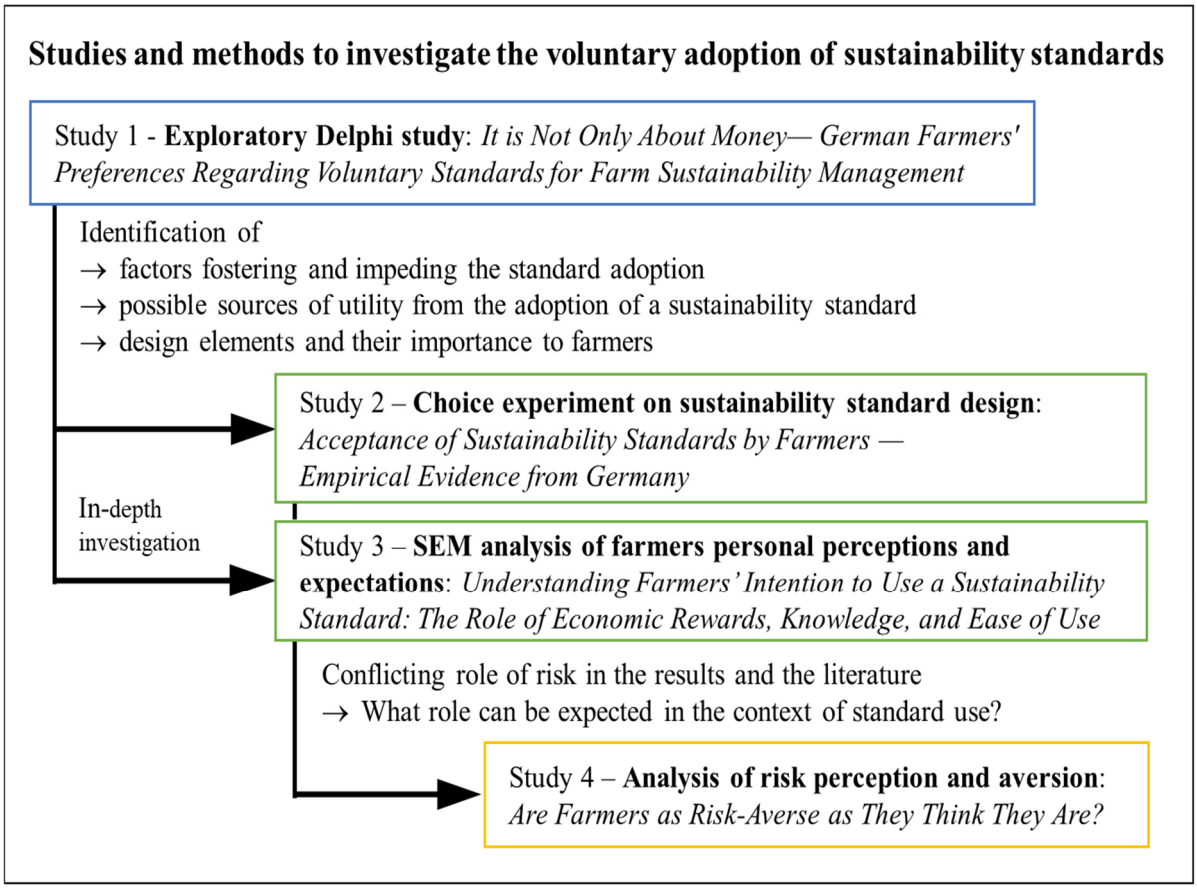

Figure 1-1 Overview of the studies included in the thesis (own illustration)

Chapter 2 below first provides an overview of the underlying concepts of innovation adoption behavior. It explains the underlying theoretical models for each study. Further, the research methods used and the econometric procedures employed are explained. Summaries of the individual studies are provided in Chapter 3, with the full publications included only in the appendix of the thesis to avoid copyright infringement[4]. Chapter 4 discusses the results, draws conclusions and makes policy recommendations based on the studies' findings.

2 Conceptual Framework and Applied Methods

The four studies examine and analyze different aspects in the complex decision making process of farmers for or against the adoption of a sustainability standard as a form of management innovation. The applied theories, concepts, and models, which have emerged from combining the formerly separate disciplines of social science, empirical economics, and behavioral psychology are nowadays referred to as behavioral economics. Chapter 2.1 first gives an overview of the underlying concepts of utility, rational choice and the integration of risk. Chapter 2.2 presents different theoretical models to explain innovation adoption. Chapter 2.3 presents the methods used and finally the methodological challenges are summarized in Chapter 2.4.

2.1 Theoretical Background

In the following, three key paradigms of scientific literature relevant to all four studies are briefly introduced: the concept of utility maximization; the assumption of rational choice; and the special role that risk in decision making has on the above principles.

2.1.1 Utility Maximization

The late 18th century English philosopher and political economist, Jeremy Bentham, adopted the approach of the early philosopher and economist, Adam Smith, to explaining decisions in terms of the utility associated with the decisions outcomes. Bentham generalized this approach away from the initially pure consumption theory to a much broader framework (Stigler 1950; Bentham 1890). He explained the utility of an action with the increase or decrease of pleasure and pain respectively, assuming that maximizing utility is the goal of every decision maker. However, he reached his limit when he tried to derive marginal utility from the monetary value of additional labor (Stigler 1950). His successor, John S. Mill, followed upon his work and they then jointly established an early utility maximization theory (Edwards 1954). Independently,

[4] The dissertation was submitted for grading with the appendix containing the full versions of the publications.

Mill's contemporaries, William S. Jevons, Léon Walras, and Carl Menger von Wolfensgrün, continued to work on the theory and calculation of marginal utility. They focused primarily on supply and demand functions, laying the foundation for modern utility theory in welfare economics (Stigler 1950; Edwards 1954). Francis Y. Edgeworth later introduced the notation of indifference curves, which for a long time formed the basis of the theory of riskless choices. However, this theory is based on the assumption that the decision maker, as *homo ecomonicus* or *economic man*, is completely informed, infinitely sensitive and rational (Edwards 1954). Modern theories no longer assume these set of values in the same way.

2.1.2 Rational Choice, Risk and Uncertainty

Herbert A. Simon's 1955 behavioral model of rational choice proposed an approach to *'replace the global rationality of economic man with a kind of rational behavior that is compatible with the access to information and the computational capacities that are actually possessed by organisms, including man*' to address the observed discrepancy in human choices (Simon 1955, p 99). He introduced the concept of *bounded rationality*, which is still valid and which includes outcomes that are not fixed a priori (Tversky and Kahneman 1989). A distinction must be made between randomness with known probabilities (risk) and randomness with indeterminable probabilities (uncertainty) (Knight 1921). A number of researchers have always been concerned with analyzing decision making in choices with indeterminate outcomes.

In the 18th century mathematicians such as Daniel Bernoulli dealt with decisions under risk. He laid the foundation for the expected utility hypothesis, which assumes that a decision maker chooses between risky prospects by comparing expected utility values. But it was not until John von Morgenstern and Oskar Neumann (1944) presented their *Theory of Games and Economic Behavior* that decisions under uncertainty and risk became the focus of postwar economists. In the following years important contributions to the integration of uncertainty and risk in decision making have been made. Milton Friedman and L. Jimmy Savage (1948) contributed the concept of risk aversion to *Expected-Utility Theory*. The psychologists, Amos N. Tversky and Daniel Kahneman, presented in 1979 with their *Prospect Theory* a new model for decision making under risk, which is more in line with empirical findings from psychological experiments (Kahneman and Tversky 1979). About ten years later they presented their revised version, the *Cumulative Prospect-Theory,* which extends the theory to uncertain as well to risky prospects (Tversky and Kahneman 1992). This theory allows to explain phenomena such as framing effects, nonlinear preferences, source dependence, risk seeking, and loss aversion.

2.2 Explanatory Models

Against the backdrop of the fundamental relationships described above for the utility-maximizing decision-making behavior of people, scientists have developed various theoretical models that explain the spread of innovations (Chapter 2.2.1) and that relate factors influencing the decision-making process (Chapters 2.2.2 and 2.2.3).

2.2.1 Innovation-Decision Process

The *Model of Five Stages in the Innovation-Decision Process*, was first published in 1962 by the sociologist Everett M. Rogers in his book *Diffusion of Innovations*. It provides a systematic framework for analyzing the timing of individual steps in the process of innovation adoption (Rogers 2003). The model divides the decision-making process into five stages - *knowledge*, *persuasion*, *decision*, *implementation,* and *confirmation*. The prerequisite for this process are so-called *prior conditions*. These form the background against which innovation adoption can take place. The prior conditions include previous practices, felt needs/problems, innovativeness and the norms of the social system. In the first stage, knowledge, an individual or an organization learns about an innovation. A distinction is made as to whether it is a matter of awareness-knowledge that the innovation exists, or knowledge of how the innovation is used, or knowledge of the underlying principles on which the innovation is based. Knowledge is primarily influenced by the characteristics of the decision maker. These include socioeconomic characteristics, personality variables and his/her communication behavior. The next stage, persuasion, is significantly influenced by the perceived characteristics of the innovation itself, which can be broken down into five aspects: the so-called relative advantage of the innovation; innovations complexity; compatibility; trialability; and observability. Together these play an important role in explaining the adoption of innovations. In a study by Kearns (1992), 26% of innovation adoption could be statistically explained by these five factors of the persuasion phase. The first two phases lead to a decision (stage three) about whether to reject or adopt an innovation, which than leads to the implementation stage. The decision may later be confirmed or revised, so that once an innovation is adopted, it may not be used over time or may be adopted at a later date (confirmation stage). Rogers based his sociological model on numerous case studies, primarily from the fields of agriculture, health care, and international development programs. Even though the model is more than 50 years old, it is still used in various studies of the agricultural sector to analyze innovation adaptation processes (Meijer et al. 2015; Kuehne et al. 2017; Vecchio et al. 2020). The advantage of the approach is that inhibiting and promoting factors are

included on a very broad level, enabling a consideration of internal factors, the innovation environment and various aspects of the innovation itself (Ilbery et al. 2004; Arovuori and Kola 2005; Zabala et al. 2017). The *Model of Five Stages in the Innovation-Decision Process* was used as a guideline framework for the research in Study 1, which is presented in Section 3.1.

2.2.2 Random Utility Maximization Model

Jacob Marschak (1959) introduced psychometrist Louis L. Thurstone's *Law of Comparative Judgement* (Thurstone 1927), now known as the binomial probit model, into economics. He combined Thurestones idea of random utility with R. Ducan Luces *Theory of individual choice behavior* and defined his model of *Random Utility Maximization* (RUM) (Marschak 1959; McFadden 1986). Luce had 'introduced an *Independence form Irrelevant Alternatives* axiom that simplified experimental collection of choice data by allowing multinomial choice probabilities to be interfered from binomial choice experiments' (McFadden 2003, p 333).

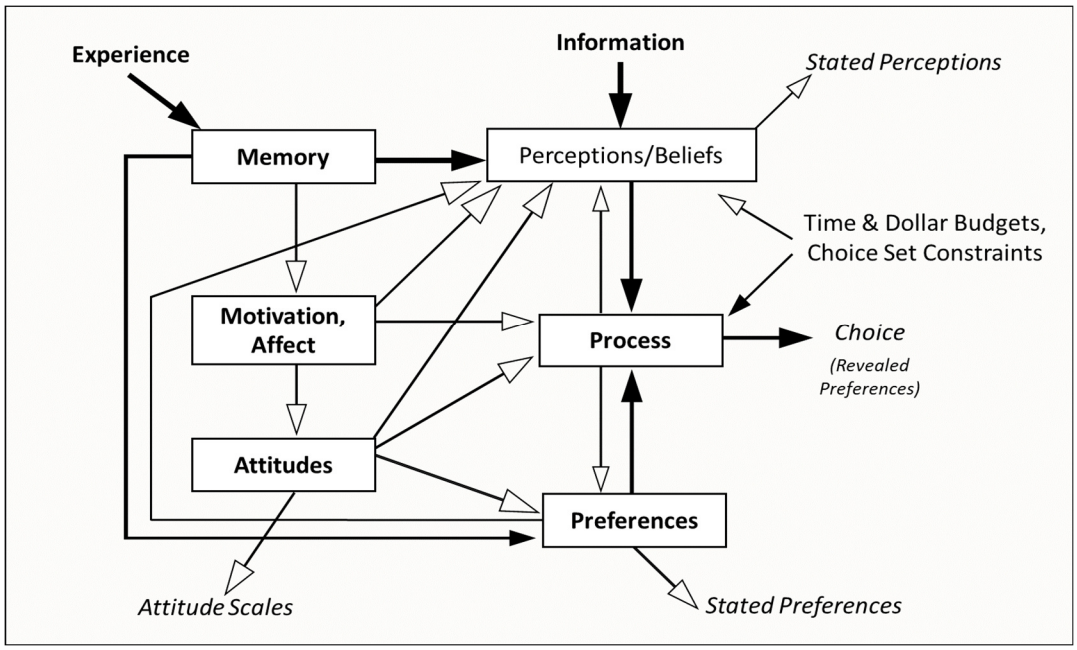

Figure 2-1 The choice process (adapted from D. McFadden 2003)

In doing so, he paved the way for Nobel Laureate, Daniel L. McFaddens' work on economic choices. McFadden generalized the model by extending the original approach of paired comparisons (i.e. decisions between two consumption alternatives) to multiple comparisons (McFadden 1973 and 1986). He incorporated Kelvin J. Lancaster's *New Approach to Consumer Theory*, which starts from the basic assumption that an alternative action is not chosen for its own sake, but on the basis of the benefits associated with the alternative. This utility is determined by the characteristics associated with the alternative action (Lancaster 1966). RUM thus

provides the theoretical basis for discrete choice decisions (see Chapter 2.3.2) which were used in the second Study included in this thesis (see Chapter 3.2). RUM has been extended over time to include various cognitive effects in decision making that have since come to light.

In 1998, a number of scholars collectively re-designed the decision process at a choice conference in Paris (see Figure 2-1) (Ben-Akiva et al. 1999; McFadden 2003). This forms the basis for further work and continued development of the choice model such as that of Morikawa et al. (2002) or McFadden (2003). The model depicts the factors that influence the choice process. The bold arrows represent the influence factors, which are consistent with previous choice models. The lighter arrows represent psychological constructs that play a role in decision making such as the effects of attitudes, perceptions, and motivation.

2.2.3 Technology adoption model

The technology adoption model (TAM) was developed by Fred D. Davis in 1985. The TAM describes the factors influencing technology adoption in particular (Davis 1989; Marangunić and Granić 2015). It is theoretically based on the *Theory of Reasoned Action* (TRA) (Fishbein and Ajzen 1975) and the *Theory of Planned Behavior* (TPB) (Ajzen 1991). TRA considers three factors: the *attitude towards behavior X* and the *subjective norm concerning behavior X*, which have an influence on the resulting *intention to perform behavior X* (Fishbein and Ajzen 1975, p 16). In addition, TPB introduces *perceived behavioral control*, which influences the intention to perform the behavior, ultimately leading to the behavior itself. Davis (1985, 1989) adapted TRA and TPB to technology use and included the two constructs *perceived ease-of-use* (PEU) and *perceived usefulness* (PU) in his TAM. The model also incorporates external variables, which are later specified in TAM 2, the work of Venkatesh and Davis (2000). In TAM 2, they consider subjective norm, image, job relevance, output quality, result demonstrability, experience and voluntariness to influence the perceived usefulness, which is critical to the intention to use, for example a computer, and is moderated by the perceived ease-of-use. A second revision of the model (TAM 3) followed in 2008 (Venkatesh and Bala 2008), addressing the deficiency criticized by Bagozzi, among others, with respect to the consideration of *'group, social, and cultural aspects of decision making'* (Bagozzi 2007, p 245). TAM 3 additionally includes anchor and adjustment factors (e.g. technology self-efficacy or anxiety), that are largely influenced by prior experience and affect perceived ease-of-use. The various models of technology adoption have served as the theoretical basis in many studies such as Aubert et al. (2012), Rota et al. (2013), Schaak and Mußhoff (2018), Llewellyn and Brown (2020) or Rezaei et al. (2020). It is a widely-used model to explain innovation adoption and is often statistically evaluated with

structural equation models. However, data collection for the many individual influencing factors is often a limiting aspect in practice. In this thesis the TAM has been used as the theoretical background for Study 3 included in Section 3.3.

2.3 Applied Qualitative and Quantitative Methods

This chapter describes the applied methods of the studies included in this dissertation thesis.

2.3.1 The Delphi Method

The Delphi method is a process of group communication in which the opinions of individuals on a complex issue or problem are solicited in several rounds of interviews, with the possibility of re-evaluating and qualifying individual opinions (Linstone and Turoff 2002). The method was first used and described by Norman C. Dalkey (1969), a contemporary and colleague of Herbert A. Simon. Both were concerned with people's choices and decision making and were influenced by each other (see Simon 1955). The now further developed method can be applied with different objectives (Linstone and Turoff 2002; Loë et al. 2016). Common elements of Delphi surveys are that the participants in the group are mutually anonymous and that they receive controlled feedback on the opinions of the other group members after each round of questioning. In this way, a cognitive process is set in motion that leads to a change or even a consolidation of one's own opinion, but in any case to an improvement of the group's judgment.

Novakowski and Wellar (2008) distinguish three types of Delphi studies: the normative Delphi, the political Delphi and the forecast Delphi. The normative Delphi determines group preferences for a development in the future based on participants' current knowledge. The political Delphi identifies opposing views and possible solutions to important political issues from a specific group of experts. In contrast, the forecasting Delphi attempts to bring the experts' opinions about an expected development in the various rounds to a consensus. Rikkonen and Tapio (2009) present another type, the argument Delphi, which also seeks to capture different opinions, but is more open in terms of the topic and flexible in terms of the group of experts. Depending on the number of respondents, a Delphi survey can be analyzed qualitatively or quantitatively. Chapter 3.1 presents a qualitative, argument-seeking Delphi survey with two rounds of interviews among German farmers as experts (Hannus and Sauer 2021a).

The method was chosen for three reasons. First, because it is an exploratory approach that avoids bias from the opinion leaders, unlike group discussion, for example. Second, because it allows for the inclusion of farmers who have other occupations or social obligations and who were not expected to travel long distances two or more times to participate in this survey. Third,

because the feedback round allowed for reflected opinions on an issue that may not have been thought about more deeply before the survey.

2.3.2 Discrete Choice Modelling

The discrete choice experiment (DCE) is a method to analyze revealed or stated preferences for decision alternatives, allowing statistically validated analyses of latent preference structures that are not directly observable. It enables monetary and non-monetary factors to be combined in the decision model (Colombo et al. 2009; Louviere et al. 2010; Hensher et al. 2015).

Table 2-1 Attributes and levels included in the DCE of Study 2

Attribute	Levels
Data provision	Data collection with questionnaire EDP* data transfer from digital crop field records EDP data transfer for the repeated application to the EU's IACS
Consultation	Free-of-charge once-a-year; Fee-based
Process optimization	Yes, No
Farm sustainability	Compliance with legal requirements Limits stricter than legal requirements Limits stricter than legal requirements plus additional measures
Price premium	None; 2%; 4%; 6%; 8%; 10%; 12%; 14%

* EDP = Electronic Data Processing

DCE is based on the work of Daniel L. McFadden on RUM and has been further developed over time by McFadden and Train (2000), Hensher and Rose (2009), Hess and Daly (2010), Bliemer and Rose (2010) and Rose et al. (2013) amongst others. In the DCE, the test subjects are presented with choice cards, which usually contain 2-3 choice alternatives. These are characterized by a series of attributes, which differ in their characteristics (level). Study 2 in Chapter 3.2 of this thesis includes a DCE to assess farmers' readiness to accept a sustainability standard and to analyze the impact of organizational elements in standard design (Hannus et al. 2020). Table 2-1 shows examples of the attributes used and their respective levels.

In the DCE, the utility U for a person n to choose an alternative j consists of a systematic variable V for the alternative $j \in$ {choice options} in the choice scenario t and an unexplained stochastic component ε (Louviere et al. 2010; Train 2009). The general notation of DCE is:

$$U_{njt} = V_{njt} + \varepsilon_{njt}. \quad \text{(Eq. 1)}$$

The utility U for a farmer n who chooses a standard j can be formulated as the sum of the influence values β'_n of the individual attributes, the person-specific influence weights x_{nj}, and

an unexplained proportion ε_{nj}. In the mixed logit model, this allows estimation of β' decomposed into a mean α' as a function of the influence weights x_{njt} and the associated standard deviation μ' as a function of the variable z_{njt} and an unexplained proportion ε_{nj} (Train 2009, p 159).

$$U_{njt} = \beta'_n x_{njt} + \varepsilon_{nj} = \alpha' x_{njt} + \mu'_n z_{njt} + \varepsilon_{nj} \quad \text{(Eq. 2)}$$

The analysis in Study 2 uses such a multinomial mixed logit model (also known as random parameter logit model) to account for the heterogeneity of farmers' preferences (Hole 2007). The relative effect of each attribute on the price premium necessary for farmers' adoption of a standard is referred to as 'willingness-to-accept' (WTA) and can be calculated easily with this base model. The estimation of a latent class conditional logit model allows the capture of latent preferences and establishment of relationships between sociodemographic or personal characteristics of participants and their decision behavior. DCE is an established method for measuring stated preferences, often used to investigate the adoption of agri-environmental programs (Birol et al. 2006; Espinosa-Goded et al. 2010; Santos et al. 2015; Chang et al. 2017). Some DCE studies examine organizational aspects of the systems too, such as the effects of technical assistance (Kuhfuss et al. 2015). DCE enables comparative measurement of the influence of individual design criteria and calculation of farmers' WTA. The method also allows the identification of latent preference groups and the calculation of which of the attributes were considered by participants and which were not.

2.3.3 Structural Equation Modelling

Structural equation models (SEM) are based on the assumption that a decision is influenced not by one but by a multitude of factors (items). Decision structures are mapped using SEM as a multivariate data analysis technique and a set of interrelated dependency relationships are estimated. The influencing items, which are statistically evaluated in a SEM, are very often specified theoretically with the TAM as a starting point (cf. Chapter 2.2.3). SEM combines several statistical methods, such as exploratory and confirmatory *factor analysis* (measurement of latent constructs with multiple items), correlations and multiple linear regressions (*structural path analysis*) (Kline 2016). It is a multivariate technique that makes it possible to estimate a system of equations including their errors. SEM can also be referred to as analysis of covariance structures, fitting models to observe covariance's and, where appropriate, means (Kline 2016). Factor analysis has its roots in the work of psychologist Charles Spearman, who sought to explain correlations between tests of mental ability explained by a general factor representing intelligence. It was L.L. Thurstone who enabled the detection of correlations with his models with different factors and by factor rotation (Kline 2016). Systems of simultaneous equations

and path analysis were developed in genetics, econometrics, and later in sociology.[5] The aim of the method is to test hypotheses about relationships between variables, including variables that are not directly measurable (latent variables). Since it is quite possible to estimate statistically valid SEMs with variables that are not causally related, the relationships between variables must be derived from theory or empirical studies for the application of the method to be meaningful. Equation 3 represents the general (structural) equation for a SEM (Stata 2021, p 575):

$$Y = BY + \Gamma X + \alpha + \zeta \quad \text{(Eq. 3)}$$

where the matrix of coefficients on endogenous variables that predict other endogenous variables is $B = [\beta_{ij}]$, the coefficients' matrix on exogenous variables is $\Gamma = [\gamma_{ij}]$, the vector of intercepts for the endogenous variables is $\alpha = [\alpha_i]$, and ζ is assumed to have the mean 0 and

$$Cov(X, \zeta) = 0 \quad \text{(Eq. 4).}$$

This approach is increasingly used in agricultural research, especially in adoption research (Hunecke et al. 2017; Naspetti et al. 2017; Schaak and Mußhoff 2018; Canavari et al. 2021; Bagheri et al. 2021). SEM is used here in Chapter 3.3 to test if the farmers stated intention to use a standard can be explained in the framework of TAM (Hannus and Sauer 2021b).

2.3.4 Risk Elicitation with Choice-Tasks

The number of studies examining the role of risk, risk aversion, and risk tolerance have increased rapidly in recent decades (c.f. Charness et al. 2013). Numerous methods for determining or estimating participants' risk aversion are based on hypothetical or non-hypothetical lottery choices (Holt and Laury 2002; Chavas 2004; Eckel and Grossman 2008). In addition, self-assessment questions are often used in surveys (Dohmen et al. 2011). However, it remains unclear which risk preference methods best predict actual risk behavior. There are a number of studies that use and compare different measures and/or combine them with measures of risk aversion and perception. These include the studies by Lönnqvist et al. (2011), Menapace et al. (2016) and Meraner and Finger (2019). In Study 4 in section 3.4, this approach has been followed and risk has been measured using a risk elicitation experiment based on Holt and Laury (2002),

[5] *'Sewall Wright, a geneticist, is credited with developing pathway analysis'* (Huber 2019). Wright published in 1918 his first paper using this method. Topic of the study were *'genetic causes associated with bone size in rabbits'*. He created path diagrams to show the assumed causal paths between variables, instead of simply estimating the correlations. In the following decades, both approaches were merged and further developed by various scholars a.o. Blalock 1967; Hauser and Goldberger 1971; Bagozzi 1977; Jöreskog and Sörbom 1982; Bagozzi and Yi 1989; Bollen 1989 to result in the present form of SEM.

combined with self-assessment questions and information on previous investment decisions (Hannus and Sauer 2020).

Holt and Laury's experiment to measure decision makers' risk aversion was first used in a study of U.S. undergraduates in 2002 (Holt and Laury 2002). In this lottery choice task, participants must indicate, given ten consecutive choices, which of two options they would choose in a real lottery. There are four more favorable choices for option A and six times the more favorable choice for option B. The proportion of 'safe' choice decisions a person makes indicates their risk aversion. The study was conducted as a hypothetical experiment as well as having real payoffs. The results show that as payout amounts increase, relative risk aversion increases and absolute risk aversion decreases. Thus, the behavior of subjects in all treatments is largely consistent with the predictions of this model. One of the authors' conclusions from these results is that, contrary to Kahneman and Tversky's (1979) assumption, subjects cannot imagine how they would actually behave under incentive-rich conditions when making hypothetical decisions. Here, participants generally underestimate the extent to which they will avoid risks. The method has become more widespread in recent years and is also applied in the agricultural context. Studies using this method in relation to farmers' decision making include e.g. Reynaud and Couture (2012), Menapace et al. (2016), Grüner (2017), and Rommel et al. (2019).

2.4 Challenges

The numerous European assessment approaches and concepts for sustainability management clearly show that researchers and practitioners expect great potential from these approaches. This has also been recognized at EU expert level, but not yet implemented politically. Systematic approaches for sustainability management have still not become generally practicable standards. Therefore, users could not recruited for the data collections. In addition, the description of a hypothetical standard had to be resorted to in order to empirically identify and further investigate inhibiting and promoting factors of a sustainability standard from the farmers' perspective. Taking into account the respective theoretical foundations and models, it was necessary to apply methods from different disciplines, each dealing in detail with individual aspects of the complex decision-making process. This broad spectrum of theories and methods from different research disciplines, as well as the limited access to German farmers for a representative data collection, represented the particular challenges for the present work. This also means that the results of the individual papers only point to partial solutions, and instead emphasize directions and needs for further research.

Part II: Empirical Studies

3 Summaries of the Empirical Studies

This chapter contains one-page summaries of the single publications of the dissertation. The complete, published articles are attached for review in the appendix and can be accessed online using the digital object identifier (doi) provided. The appendix also contains a data article '*Data on farmers' perception and acceptance of sustainability standards'* (Hannus 2020) as additional material, which is included in this dissertation at the end of the appendix. The data article describes the procedure, the questionnaire, the DCE, and the complete data analysis and thus forms the basis for the evaluations in the studies 2 to 4.

3.1 It is Not Only About Money— German Farmers' Preferences Regarding Voluntary Standards for Farm Sustainability Management

Against the background of biodiversity loss and negative climate impacts of agriculture, more sustainability is increasingly demanded from agriculture. This has led the scientific community to develop various approaches assessing the sustainability of conventional farming systems, which are now to be developed into sustainability standards for farms. Despite growing consumer demand and increasing political interest, none of the existing whole-farm, assessment-based sustainability standards have yet been able to gain wider acceptance in Germany.

This qualitative study first examines farmers' general attitudes towards sustainability in German agriculture. In the following, the drivers in the acceptance process and the farmers' preferences with regard to different design criteria of a standard are investigated. For this purpose, we link the results of a two-stage Delphi survey of German farmers to the first stages of Everett Rogers' (2003) innovation decision model. The explorative results show that from the perspective of the interviewed farmers, agriculture in Germany suffers from low social acceptance. At the same time – from the responding farmers' point of view – the demands on agriculture are continuously increasing. Further, they believe that sustainability of agricultural systems is an important topic and they feel a need for action. The most important benefits that the participants expect of standard, include process optimization and efficiency gains, as well as an improvement in social acceptance and better image of agriculture. High expected bureaucracy efforts and costs, as well as working time requirements represent the most important obstacles for standard use. In summary, the relative advantage of a standard is not clear for potential users. Regarding the design of a standard, the analysis reveals the positive effect on stated adoption of a possible price premium and that the data basis for sustainability assessment is very important for interested farmers. In addition, technical support and easy data transfer are highly

relevant, while the level of required sustainability (e.g. land management constraints) appear to be less important. Following the respondents, a standard should have a low level of complexity and be compatible with existing farm data and management practices. In particular, it should provide direct access to existing databases of sustainability assessment indicators.

The studies reveals that the design of most of the existing management standards does not meet the needs of practitioners. These insights can help policymakers in Germany and Europe when aiming at higher levels of farming sustainability in their agricultural policy. Further, it provides valuable starting points for in-depth analysis on the acceptability, the optimal configuration and specific target groups for voluntary agricultural sustainability standards.

Authors' contributions: Both authors designed the study and the methodology. Veronika Hannus realized the data collection, conducted the analysis, wrote and edited the manuscript. Johannes Sauer supervised the study. The authors thank the editor, Guy M. Robinson, and the two anonymous reviewers who provided helpful comments, as well as the German Farmers Association and all participating farmers for their support.

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3.2 Acceptance of Sustainability Standards by Farmers — Empirical Evidence from Germany

This study investigates empirically the willingness of German farmers to accept a sustainability standard. For this purpose, participating farmers were given a notional sustainability standard based on a whole-farm sustainability assessment approach in an online survey. In addition to questions on their attitudes, knowledge, and risk perceptions, a discrete choice experiment was used to examine the influence of five selected design criteria on farmers' willingness to accept (WTA) a standard. Specifically, we examine the effects of a number of attributes: We test various types (level) of data provision, consultation, process optimization, level of sustainability, and price premium required to motivate farmers to adopt a standard. The data from 492 participants are analyzed with a mixed multinomial logit model and latent class logit model to identify target groups and farm types that are more or less likely to adopt such a standard.

The results show three clusters of farmers that can be distinguished according to their general perception of sustainability standards: standard refusers (17%), risk-averse & interested farmers (29%) and standard supporters (55%). However, we could not confirm a significant difference in stated willingness to adopt a standard for these three groups in any statistical model. The DCE analyses confirm most of the effects of the design criteria, which we had previously derived from literature. A higher level of sustainability in agricultural processes – compared to compliance with legal requirements – requires an additional 11.3% price premium. The farmers prefer a standard that uses data from EU's Integrated Administration and Control System (IACS) over other forms of data provision. The payments needed to motivate farmers to adopt standards can be reduced by 6.2% if data provision via IACS is offered. If the standard additionally aims at process optimization, payments can be 1.5% lower. The estimation of a latent class model results two groups of farmers. One supports standard adoption, the other strictly rejects the use of a standard. The latter is characterized by farmers that run fattening farms (pig and poultry). They see a high risk associated with the introduction of a standard. A different sensitivity to price premiums is plausible, as income shares of EU direct payments in Germany range from 47.52% in specialized crop farms to 20.27% in fattening farms.

However, further research is needed to examine in detail specific hurdles (e.g. personal and social factors) and a more differentiated determination of the necessary prices for different farm types. Our data clearly show that farmers respond positively to targeted process optimization. An in-depth examination of the monetary and non-monetary effects of the process optimizations that can be expected from the implementation of such a sustainability standard would be helpful to quantify the 'utility' for the farmer. This could also form a basis for better future communication of the benefits of such types of standard.

Authors' contributions: The research question, research design and theoretical framework were developed by V. Hannus and J. Sauer. Veronika Hannus conducted the analysis and wrote the manuscript. Thomas Venus contributed to estimation strategies, interpretation and discussion of the results as well as to reviewing and editing of the manuscript. The authors thank the editor, Shigemi Kagawa, and two anonymous reviewers who provided helpful comments.

This choice-experimental study was published in Elsevier's Journal of Environmental Management in August 2020 following peer review. The post print version of the article: Hannus, V.; Venus, T. J.; Sauer, J. (2020): Acceptance of sustainability standards by farmers - empirical evidence from Germany. Journal of Environmental Management 267, 8/2020, 110617 is available online at: https://doi.org/10.1016/j.jenvman.2020.110617.

3.3 Understanding Farmers' Intention to Use a Sustainability Standard: The Role of Economic Rewards, Knowledge, and Ease-of-Use

Farmers' underlying decision model for their stated intention to adopt a sustainability standard is analyzed in this third study. Based on the initial Technology Adoption Model, a Structural Equation Model (SEM) is used to examine the underlying factors that influence the decision-making process. SEM enables to form so-called constructs from to two or more thematically related variables. In a second step in the analysis, interrelationships between the individual influencing factors can be uncovered and illustrated. The empirical data of 363 farmers fit very well to the theoretical model of technology adaptation. The results are based on a sample of larger-than-average German farms with farm managers younger than the German average. Thus, the sample represents a future-oriented share of farms in Germany.

The model confirms a positive influence of expected economic rewards on the *Perceived Usefulness* of a sustainability standard. Two separate constructs on *Economic Rewards* were identified, one regarding the process optimization and one regarding the financial aspects. This is a remarkable result, as it confirms the evaluation of Hannus et al. (2020), which indicated an influence of process improvement on the stated intention to use for the first time in the context of sustainability standards. Although, we expected differences in the impact of the two constructs, they do not differ in terms of the magnitude or direction. The *Subjective Norms* capture the perception of an innovation adoption in the society, and the *Personal Rewards*, i.e. the expected personal emotions arising from the use of such a standard. All of them affect the PU, they have a positive loading and are significant. However, *Perceived Ease-of-Use* emerges as the most important factor, as it is directly related to the stated intention to use a standard. Further, the data show a significant, and direct influence of previous knowledge about sustainability management in farming on the stated intention to use a standard. Given that most of our results are in line with the European literature on the topic, we assume that the results might not only be relevant for Germany. They may also be valid for other European or in particular Central European countries. In other cultural contexts, the weightings and effects of the individual influencing factors may be quite different. Our data model confirmed virtually all of the expected hypotheses of the developed theoretical model at a sufficient level of significance. The only exception is the effect of risk tolerance on the intention to adopt a sustainability standard, where no significant influence was found.

We conclude that amongst the younger generation of German farmers with larger farms, the intention to use a sustainability standard could be increased. In particular, an easily accessible

basis for sustainability assessment, e.g. using data from the EU's IACS, could provide a solution. Better farmer knowledge of comprehensive sustainability standards could also increase the likelihood of a farmer adopting a standard. In the development of policy instruments within the EU's CAP, member states have to focus on the one hand on a standard design that is simple to access and on the other hand on concepts and goals for the standards or tools that are easy to communicate. These findings can serve as a starting point to improve not only existing sustainability management systems, but also emerging farm management information systems, or agri-environmental schemes with the aim to make their use more attractive. However, further research is needed to verify the results by means of practical applications.

Authors' contributions: V. Hannus conceptualized the complete study, including methodology, data curation, formal analysis, and writing—original draft preparation and editing. Johannes Sauer supervised the whole working process. He contributed to the drafting and editing. All authors have read and agreed to the published version of the manuscript.

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3.4 Are Farmers as Risk-Averse as They Think They Are?

Risk preference is often cited as a key factor in the adoption of sustainable practices. The results of the first studies have all similarly shown that the risk has a substantial impact on decision making. In the farmer survey (see additional material in the Data Article), additional information was collected on the basic risk tolerance, risk aversion, and risk perception of participating farmers in a total of three different ways. First, a lottery task was used to measure risk aversion, which is commonly used in finance and management research. In addition, two indicators were derived from individual risk tolerance and risk perception questions using factor analysis and an explicit self-assessment question was included commonly used in behavioral studies. The effect on farmers' acceptance of a sustainability standard and on the reported level of investment made, were statistically tested using multinomial logistic regression.

The results compare whether differences were found between the proportion of farmers who wanted to use a standard and those who clearly reject a standard, and between farmers with high reported investments and those with low investments. In the case that risk tolerance and/or

risk aversion reflect a basic attitude of the decision maker, these were expected to have an equal influence on farmers' stated investment decisions as well as on the innovation decision. The same applies to the self-assessment of the impact of risk in entrepreneurial decisions. Only in the case of risk perception of a standard it would be expected that individuals who perceive the risk as high would decide against it. The self-assessment question on the importance of risk in corporate decision-making delivers a significant result in only one case. The risk aversion determined from the lottery is significant for farmers with higher investments as well as for standard adopters. In both cases, farmers with particularly low investments as well as clear standard adopters show higher aversion, which is, however, not significant in either case. The determined factor for risk perception is significant in connection with standard use for both rejecters and adopters. The results of our analysis suggest that farmers' risk perception responses reflect their expectations of the innovation itself, while the results of the lottery tasks seem to correspond to a factor for risk acceptance. In contrast, risk tolerance appears to capture a different underlying dispositional factor than the measure of risk aversion from the lottery task. This implies that risk-averse behavior must be distinguished from risk-seeking decisions in general.

On this preliminary basis, we suggest that researchers should focus on the specific impacts expected from the introduction of, for example, a sustainability standard on agricultural production. This may help to better understand the underlying causes of perceived risk. Lottery games should be used if one is really interested in the disposition patterns of decision makers. Decision makers' self-reported risk perceptions do net seem to reflect their actual risk attitudes.

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Part III: Discussion and Conclusions

4 Discussion and Conclusions

This chapter first presents and discusses the results of the studies against the background of the current literature. Then, it highlights the limitations of the studies, the transferability of the results, and points to further research potential. The thesis concludes with a reflection of the results with regard to the design of a German sustainability standard and policy implications.

Table 4-1 Overview of the empirical studies and analysis of the dissertation

Study	Research problem	Method and data used	Core findings
Study 1 / Chap. 3.1	Identification of **factors and design elements fostering or impeding** the adoption of farm sustainability standards	Exploratory research on socio-economic aspects, personal prerequisites and attitudes of selected farmers to identify factors influencing the adoption of a sustainability management system; The analysis is based on the initial stages of the innovation decision process by E. Rogers (2003); Data: own data from a two round online survey following the Delphi approach described e.g. by Novakowski and Wellar (2008)	The results, even for participants with innovation-positive conditions, show: The 'relative advantage' of the standard is not transparent, it is a complex innovation that is not easily triable easily, and it lacks communication of its benefits. In the design of a standard participants would like: higher product prices, easy data transfer of existing farm data, and a geographic label.
Study 2 / Chap. 3.2	**Preference measurement** among farmers regarding the adoption and impact of design elements in farm sustainability standards	Data of a discrete choice experiment (McFadden 2003) was evaluated using a mixed multinomial logit model (Hole 2007) and latent class analysis (Pacifico and Yoo 2013) of stated preferences including farmer characteristics; Data: own data from an online survey with DCE amongst German farmers	The surveyed farmers would meet additional sustainability requirements for a price premium of about 11%. They prefer a standard with data transfer from the EU Integrated Administration and Control System and a medium level sustainability required.
Study 3 / Chap. 3.3	**The role of** (personal, social and economic) **expected rewards** in the decision making process regarding the adoption of a farm sustainability standard	Psychometric measurements of preference statements on reward expectations (cf. Trujillo-Barrera et al. 2016) with confirmatory factor analysis and structural equation modelling of the adoption decision (Bagozzi and Yi 2012; Bagozzi 1977); Data: own data from an online survey	Expected economic rewards and subjective norms show high impact on the perceived usefulness of this innovation, but the ease-of-use is most important, and along with prior knowledge, has a high, significant impact on the stated intention to use a standard.
Study 4 / Chap. 3.4	**Comparison of different risk measures** (from an experiment and stated risk preferences) in farmers' decision-making	Holt and Laury experiment (Holt and Laury 2002) and multinomial logistic regression models to measure the impact of different risk variables on stated standard adoption and on realized investment decisions; Data: own data from an online survey including a Holt-and-Laury experiment	Our lottery-task results are consistent with risk-friendly behavior, measured by the realized investments, while the self-assessment questions on risk-taking behavior result to be more likely capturing other aspects such as farmers' expectations of the innovation itself

The overall objective of the thesis was to investigate why German farmers have hardly used voluntary sustainability standards so far and to identify pathways for adapting standards to user requirements. Therefore, the prerequisites, preferences and attitudes of farmers as well as the design options of sustainability management standards were comprehensively investigated and evaluated in four studies. Table 4-1 provides a summary overview of the studies and presents the respective research problems, data bases, used methods, and key findings.

4.1 Discussion of the Studies

The first study shows that the low acceptance of sustainability management systems among German farmers is not due to farmers' lack of awareness of a sustainability problem in farming. In the expert group of the Delphi study, most farmers were of the opinion that German agriculture in general is not very sustainable and that this is an important issue, both for the future of agriculture and for society. They agree with the statement that in this regard society's demands are constantly increasing and that economic and ecological sustainability in agriculture in Germany needs to be improved. Many of the study participants are aware that their own farm management could also be improved in some aspects of sustainability. These findings are in line with the results of the second data collection. Here, more than 83% of the respondents were generally positive about a sustainability standard. In the second study, a cluster analysis revealed three groups of participating farmers: about 17% generally reject a standard; around 28% could be classified as 'risk averse, however interested in a standard'; and 55% are standard supporters. The results confirm the findings of Luhmann et al. (2016) on sustainability standards in dairy farming and Schukat et al. (2020), who provided analogous results on the German Integrated Animal Welfare Standard.

According to the experts of the Delphi study, the benefits of standards lie in: process optimization through systematic analyses and improvement of processes; economic efficiency gains; better social acceptance; and improved image (in descending order). The data analyses from the second and third study confirm that process optimization is a particularly important driver for the acceptance of a sustainability management standard. The DCE resulted in a price premium of 11.3% for products in order for farmers to take on a sustainability standard that requires a level of threshold limitations stricter than the legal requirements. This premium could be reduced by 2.8% if the criterion of process optimization is taken into account in the design of the standard. Study 3 shows that farmers' expectations regarding financial rewards from

using a standard has the same size and similar loading on the perceived usefulness of this innovation as the expected rewards from process optimizations. This is consistent with recent findings on the impact and potential benefits of sustainability standards and sustainability assessment tools (Trujillo-Barrera et al. 2016; Coteur et al. 2020). A study by De Steur et al. (2020) identifies the improvement of individual work steps as motivating for using a standard, however the overall concept is neither addressed nor investigated in depth in their paper. The studies included in this thesis are the first works to address and examine the process optimization component so explicitly. The impact of a standard focused on continuous process improvement needs to be investigated further.

The analysis of the results of the first study, following the model of Rogers, shows that even among the participating farmers with positive preconditions for innovation adaptation, the relative advantage of this innovation is not clear enough to be convincing. One explanation could lie in the complex interrelationships in agriculture and often temporal offset of cultivation and negative consequences. However, the extent to which the participating farmers have already experienced negative consequences of 'unsustainable' agriculture themselves (e.g. in the form of erosion, reduced water retention capacity or fertility of the soil) was not investigated in any of our studies. It would be important to investigate this aspect and to determine whether farmers associate negative developments on their land with their own farming practices. Personal experiences of this kind and concrete measures for improvements could be important motivating factors to change one's farming practices and perceive systematic farm management as beneficial, as suggested by the research of Rose et al. (2019). However, this can only be captured through studies of specific agricultural management constraints and not by a general approach such as the one used in the present work.

In the first study, several aspects were identified as being a hindrance to the adoption of a sustainability standard. Poor measurability of the benefits is amongst them. This is a common problem of environmental management systems which envisage a continuous improvement process (Alberti et al. 2000; Zutshi and Sohal 2004). These systems have only been investigated in the agricultural context in Germany about 20 years ago (c.f. Zellmann et al. 2000b, 2000a). The expected high bureaucracy, the associated high costs and the high time requirements were identified as amongst the most important hindering aspects. Results from Greiner et al. (2014) and Falconer (2000) on AES, from Castellari et al. (2018) on the acceptance of standards and De Steur et al. (2020) on the acceptance of sustainable practices provided analogous results.

These findings are supported by the results of evaluating different design elements of a sustainability standard. The evaluation shows that product price is the most important design criterion, closely followed by the data basis used for sustainability assessment and technical support for data submission. Equally important to the participants is a label indicating a geographical area of origin and free advice on how to apply the standard. Among the five criteria rated as most important, there are three that have an impact on time and bureaucracy requirements. A simplification in data provision − using existing IACS data as the basis for sustainability assessment − would reduce the required price premium for sustainable products by 6.1%. Free consulting from the standard-setting body once a year could lead to an additional 1.9% reduction in the price premium. DCE attempts to make each of the attributes comparable by using monetary units. This does not mean, however, that a sufficiently high price leads to the desired acceptance in practice. Studies of AES adoption have already found that in certain cases farmers do not participate in the scheme even when it appears financially lucrative (Burton et al. 2008).

The third study supports the assumption that an additional price premium should not be overestimated as a factor in the adoption process. Rather, it adds another significant aspect. The SEM shows that the different influencing factors, financial, personal or social expectations have a significant influence on perceived usefulness. However, these factors do not have nearly as much influence on the intention to use a standard as perceived ease-of-use and prior knowledge. This suggests that while process improvement may reduce the calculated price increase required for standard adoption, even then ease-of-use and a personal knowledge of the standard have a greater impact. The importance of technological support for adoption lies not solely in a POSSIBLE impact on price premiums, but in its significant impact on the ease-of-use. According to Rogers (2003), a distinction must be made as to what type of knowledge is involved. Knowledge is primarily influenced by the characteristics of the decision maker, such as socio-economic characteristics, personality variables, and his or her communication behavior. In this study, the focus is on awareness-knowledge that the innovation exists and knowledge of how the innovation is used. A significant influence of knowledge on innovation adoption is found in several publications, amongst them the studies of Läpple and Kelley (2013) related to conversion to organic farming and Canavari et al. (2021) on the adoption of variable rate irrigation. In conclusion, the results are consistent with the expectations from reviewing the literature. Further research is encouraged to identify how ‘Learning and Innovation Networks for Sustainable Agriculture’ could be targeted to increase knowledge and support this innovation (Moschitz et al. 2015; Warriner and Moul 1992).

The influence of the social environment and farmers' attitudes on the innovation adaptation decision was mainly investigated in the third study and partly also in the second study. Cluster analysis identified three groups of participants that differ in terms of attitude, knowledge, risk perception, and awareness of a sustainability standard. However, analysis of the DCE data with latent class analysis showed that only two groups could be statistically identified from the experiment. Farmers who are significantly more likely to accept a standard make up about one-third of the participants. They are under 40 years of age, have higher levels of education, positive attitudes toward sustainability standards, already participate in AES, and rate the risk as low. This supports the expected results from the studies of Läpple and van Rensburg (2011) and Läpple et al. (2015). A differences could be identified for owners of swine and poultry farms. The DCE showed that their concerns are stronger than those of the rest of the group, which are mainly arable, mixed, and dairy farms. Furthermore, the Delphi results suggest that this is due to substantive requirements of a potential standard, e.g. regarding N limits. This can also be explained by the different income shares of direct payments in Germany, ranging from 20.27% in fattening farms to 47.52% in special crop farms (c.f. Hannus et al. 2020). Farms with a higher share of income from direct payments are likely to be less sensitive to price markups, i.e. those where a lot is earned through prices. Again, further investigation of the exact relationships is needed. Nonetheless, the results provide clear evidence of underlying decision patterns.

The fourth study examines the role of risk perception and risk aversion in this context. In addition to the basic attitude − i.e. the risk aversion of the individual decision-makers − the risk perception is important but depends on the decision-making situation. The comparison of the farmers' perception of the risk associated with a standard and their stated adoption decision showed a significant correlation with high risk perception for the rejecters of the innovation. For some farms, therefore, such an innovation is ‘absolutely not under discussion’. This is supported by the results of the structural equation model. According to the SEM analysis, risk perception has an effect on the ease-of-use and thus indirectly on both the perceived usefulness and the intention to use a standard. A lower risk perception was not found on a significant level among the possible standard adopters, but a fundamentally lower risk aversion could be identified on a significant level. The great complexity of such systems and the unproven benefits, found as inhibiting factors in the Delphi study, may serve as a possible explanation. Mohan's results show that in developing countries, farmers who are more risk averse have a higher propensity to get organic certification (Mohan 2020). This contrasts with the previous assumption that less risk averse farmers seek organic certification from works in the UK (Läpple and van

Rensburg 2011). This suggests that it is necessary to consider the degree of diffusion of standards or certification schemes in the respective region. In our case, for the adoption of sustainability standards, it is assumed that for this early adoption of innovation, risk-taking farmers are needed (Läpple and van Rensburg 2011).

In recent years, much research has examined the adoption of precision agriculture (PA) and smart farming technologies. Pathak et al. (2019) found '*that many of the determinants of innovation diffusion that have been examined in other industry contexts were absent in the PA technologies adoption literature, and that the complexity and multidimensional nature of the adoption process was very poorly represented'* (Pathak et al. 2019, p 1311). In contrast, the present studies have attempted to paint a larger picture of the challenges of innovation diffusion in sustainability standards. To summarize: the process of innovation adoption for this form of innovation is currently not failing due to the general attitude of farmers towards sustainability standards. The need to act seems to be generally recognized. Nevertheless, it was not the aim of the present study to investigate on this in-depth. Further empirical research on farmer intentions and general attitudes toward improving the sustainability of their own agricultural practices is urgently needed. The adoption of sustainability standards currently fails due to the lack of a clear relative advantage of using a standard over working without one. This does not mean that farmers are not striving to work more sustainably in the future. However, it does indicate that the benefits cited from systematic sustainability management are not compelling when compared to the inhibiting factors, such as the bureaucratic burden of process documentation, cost, and time requirements. Process improvement was cited as the most important reason for using a standard, ahead of economic efficiency and social acceptability, and was also confirmed in the other two studies as a key factor in the acceptance of a standard. Significant improvements are needed in EDP-based transfer of data used as the basis for sustainability assessment. In this respect, many of the farmers surveyed are in favor of using existing IACS data. Additional advice and the possibility of combining a standard with AES seem to make its use even more attractive. Greater ease-of-use not only has the potential to reduce the prices or payments required to accept a standard, but is a key prerequisite for many farmers to consider adopting a sustainability standard. Younger dairy, arable or mixed farmers with a high level of education, a generally positive attitude towards sustainability management, a lower risk aversion and perception represent the most suitable target group with the highest probability of adoption. The risk assessment depends on the innovation itself, whereby the correlation with prior knowledge has not yet been evaluated. Knowledge has a direct influence on the intention to use a standard,

while the associated risk has only an indirect influence via the ease-of-use. About half of the farmers consider the risk associated with adopting a standard to be high and this half mostly reject the use of a standard. The group who assess the risk as low would use a standard much more frequently and has a lower general risk aversion overall.

4.2 Research Limitations and Recommendations

The methodological approach of the first qualitative study was very ambitious from the beginning. This led to a challenging analysis and publication process of the results. The study design set out that information on more than one aspect had to be collected simultaneously in a single data collection. The decision to design the study in this way was made because of the paucity of available preliminary works on, and the large number of conceivable barriers to, such standards. Alternatively, it would have been possible to examine the individual parts separately, which would have taken considerable extra time. The Q-method could also have been used to record the pro and con aspects as well as the evaluation of the organizational design elements (Brown 1993). The advantage of the chosen method, however, is that by including open-ended questions, a very broad spectrum of influencing factors could be narrowed down. The participants of the first study were deliberately selected from expert farmers who had additional qualifications and were already familiar with the topic. It was challenging to find suitable participants who had already studied the topic and were willing to take part in such a survey.

The resulting sample size in the Delphi study was not suitable for quantitative analysis, which are often desired in consensus-seeking Delphi studies (Novakowski and Wellar 2008). However, the argumentative nature of the Delphi procedure chosen (c.f. Rikkonen and Tapio 2009) obviously provided a good basis for further work, as all of the other studies produced results that were consistent with the findings of this preliminary qualitative study. The effort for the stepwise comparison with the five stages of Rogers' model of the innovation adaptation process was relatively high (c.f. Hannus and Sauer 2021a). It served to define the further research direction and showed that even for farmers with positive preconditions, the design and organization of standards is the main problem. The first study clearly showed what inhibiting and facilitating factors might exist from the perspective of decision makers with very positive preconditions; it did not capture what proportion of farmers in Germany this corresponds to. Further studies are needed to determine how large the target group is for a sustainability standard with comparably positive preconditions and how these could be addressed.

For the other studies, data from a single very large data collection was used (Hannus 2020). The composition of the participants in the second data collection was intended to reflect as closely as possible the average of German farmers and farms. Since the survey was conducted in cooperation with a professional farmers' association, the resulting sample is not entirely representative. There is a slight discrepancy with regard to the age of the farmers and the size of the farms. The resulting sample consists of younger farmers with larger farms compared to the German average (Destatis 2016a; Destatis 2016b). However, the spatial distribution across Germany and the composition by farm type are representative. Around 600 farmers completed the survey, 550 completed the selection experiment, and 470 adequately answered the item questions used in the SEM. There was only one notable dropout in the risk selection and risk questions. Overall, both the design of the survey, its implementation, and the survey results obtained can be rated as very good, and it provided a sufficiently large and representative sample for the various analyses conducted.

For the first part of research questions to be answered, conducting a DCE was exactly the right choice of method. It is a proven method that has often delivered valuable results in comparable cases, also in connection with agriculture (e.g. Glenk and Colombo 2013; Schulz et al. 2014; Schreiner and Latacz-Lohmann 2015). In quasi-experimental DCE, as in the one performed, bias must be accounted for in order to interpret the results correctly. This means that in the DCE it must be assumed that the actual WTA is lower than what the results show from the experiment (Murphy et al. 2011; Loomis 2014). Another part of the research questions that emerged from the literature was investigated with a SEM. In general, SEM uncovers essential interrelationships in decision-making processes, but can always only provide as good and detailed insight as the collected variables and the given objectives allow. Desires to act, individual reactions, social identity, and collective intentions all contribute to the adoption processes. They are only partially considered in the TAM employed and are integrated via intention-to-use as well as the ease-of-use (Bagozzi 2007). A more accurate picture of the psychological construct underlying decision making related to the adoption of sustainability standards could be obtained if the influencing factors were captured and queried separately via even more individual and detailed item-questions.

With respect to the applied SEM method a limitations is its poor suitability for non-normally distributed response variables. The Satorra-Bentler adjusted maximum likelihood SEM estimate for categorical variables tends to overestimate the model fit for the common fit indices (RMSEA = Root Mean Square Error of Approximation, CFI = Comparative Fit Index, TLI =

Tucker–Lewis Index). Thus, a better model fit is assumed than actually exists (Xia and Yang 2019). *'In addition, even a well-fitting SEM model can have problematic lower-order components and omit important variables'* (Tomarken and Waller 2005, p 56). This is a general but important limitation that must always be taken into account when interpreting the results of structural equation models. Nevertheless, most of the results of Study 3 are consistent with the European literature (Läpple and Kelley 2013; Caffaro et al. 2020; Naspetti et al. 2017; Trujillo-Barrera et al. 2016; Canavari et al. 2021). Therefore, it is assumed that the results are also valid for other European or, in particular, Central European countries. However, the weights and effects of the individual influencing factors may be quite different in other cultural contexts.

In Study 4, the data on risk perception as well as risk aversion have so far only been preliminarily analyzed and compared with the literature. Therefore, there are numerous limitations in the interpretation of the results. These include: a self-selection bias due to the very long questionnaire, which had the risk elicitation choice task at its very end and a resulting small biased sample for the choice task. There is still potential for a data analysis that includes several of the additional variables. A bivariate probit model or a further structural equation model, which accounts for the correlation of the different risk factors on the two different decisions on investment and on standard adoption, could shed light on further intended structures.

In all studies, the farmer were intentionally not presented with a specific standard, but were given examples of the type of basic standard that was meant. This could be seen as a limitation of the work. However, we used it so that in the first study we could point to the possibility of systematically improving sustainability on farms. This served to find out whether or not farmers in the two data collections perceived the benefits of continuous improvement processes. Here, more reliable results could certainly have been expected, and also more specific ones, if the questions asked were directed at a standard that is actually on the market. Nevertheless, in the case of existing standards that relate to different types of operations and to operations as a whole, the number of experts were too small to be included in the first study. In the second data collection, only a very small number of farmers would have been approached if a specific standard had been used. Therefore, a conscious decision was made not to ask for a specific standard. The results obtained are therefore of a general nature and studies on individual standards and their relative benefits in terms of bureaucratic burden and higher prices, etc. need to be studied individually in future works.

4.3 Policy Implications

In agriculture in Germany and many other European countries, there is an urgent need for action, not only to reduce GHG emissions, which are very difficult to measure and calculate, especially on a farm-wide basis (Zehetmeier et al. 2014; Tsakiridis et al. 2020), but also to promote biodiversity and protect groundwater (Spiller et al. 2020a). Even though the EU member states have not yet been able to agree on the mandatory introduction of a '*Farm Sustainability Tool for Nutrients'* (EC 2021; EC 2018, p 45) governments are challenged to act. At present, they lack the courage to do anything other than hesitate to expect market mechanisms to regulate through consumer decisions, as could be seen in the trilogue negotiations (Metta and Lakner 2021). However, market mechanisms might not be successful, because in recent years other crises and issues have often pushed the problems of agriculture, at least in Germany, into the background. Consumers' will to act is not very strong at the moment, as the Corona pandemic, the war in Ukraine, supply shortages and high energy costs claim their full attention.

This is where politics is called upon to act, because agriculture in Germany urgently needs to become more sustainable (Pe'er et al. 2020), with a view to achieving climate targets (UBA 2020), but also in view of the impending decline in biodiversity (Dudley and Alexander 2017) and the still high pollution of some water bodies with nitrogen inputs (UBA 2015). If policymakers continue to focus only on conversion to organic farming and this increases at the current rate, it will take another 50 years before 50% of the agricultural land in Germany is farmed organically (c.f. German Federal Ministry of Food and Agriculture 2021). Even that would only be possible with renewed massive subsidies or country-specific regulations. In this context, sustainability standards, which are introduced on a broad level in agriculture, can possibly make a massive contribution to improvement more quickly.

As the second study has shown, there are about 65% of the farmers surveyed who generally see a need for action and are very positive about more sustainable land management. They are also part of German society and want to manage their farms in an economically sustainable way. Since this group includes, in particular, farmers under 40 with higher education who already use AES, one of the most important prerequisites for the acceptance of such a standard is, of course, financial viability. Therefore, financial compensation for the additional time spent on documentation and office work is obligatory for a standard. The present work has not investigated consumers' willingness to pay or the consumer perception of domestic sustainable products − these are issues to be addressed further. However, the studies show that the product price increases needed for such a standard can be significantly reduced by a clever development and

organizational design of the standard. This starts with farmers' involvement in the development of the standard, a geographic focus for the standard label, and the opportunity to incorporate farmers' own innovations into self-defined annual improvement goals and thus implement continuous optimization processes on the farms.

If change in Germany is truly desired, the obligations for land cultivation must be increased in various dimensions, or sustainable agriculture must be established on a broad basis as an alternative to organic farming. An assessment of sustainability could be based on the information in EUs' so called '*multiple application form'* as well as on field and farm balances, whereby a direct data transfer between the systems must be possible, so that the additional effort for the farmers is kept as low as possible. In addition, competent and supportive advice must be offered free of charge. In order to achieve voluntary participation of farmers, different target groups should be deliberately addressed first. These include, in the first instance, dairy farms as well as mixed and crop farms. Likewise, attempts should be made to initially recruit and support younger, highly-educated farmers who are innovators as pilot farms for a longer period of time. These could later serve as demonstration farms and be used for data collection.

In addition, individuals that can act as multipliers could be targeted, who can then further promote the dissemination of the innovation in their communication within the target group. It has been demonstrated with the promotion of organic farming in Germany that large funding programs that address many areas and are interlinked can move a major change. It would be possible to gather experience and collect data on actual savings on different types of farms in an initial phase with demonstration farms. In this way, the actual successes of sustainability management could be demonstrated and used to build up a network of knowledge and experience. Compliance with nitrogen and emission balances, for example, is particularly difficult for fattening livestock farms with pigs and poultry as could be expected. These also have the strongest reservations about the application of new environmental requirements or standards. They could also be better supported in establishing changes within a specified period of time with such a standard, which is aimed at continuous improvement, than if the farms constantly see their existence threatened again by mandatory changes in the framework conditions.

Overall, this work shows that a large proportion of German farmers have a positive attitude toward sustainability management standards in agriculture and are open to this innovation. There is still a great need for improvement in the organizational design of the comprehensive sustainablity standards. In addition, the commitment of users must be supported by society through additional payments or through higher revenues from pricing.

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Part IV: Appendix with Full Publications

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Data Article:	Data on farmers' perception and acceptance of sustainability standards	59 Pages

The appendix with the complete publications is not included in the online publication to avoid copyright infringement.