Algorithmic governance for environmental sustainability in Digital Agriculture Solutions –

The case of Digital Farm Advisory Services for small- and medium-scale farmers in the Global South

Marvin Léon Matheis

1017143

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MSc Thesis Environmental Policy Group

Dr. Sanneke Kloppenburg

Environmental Policy Group
WAGENINGEN UNIVERSITY

WAGENINGEN
UNIVERSITY & RESEARCH

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Author:

Marvin Léon Matheis (1017143)

MSc International Development Studies

Specialization “Politics and Governance of Development”

Honors track “Sustainable Development Diplomacy”

First Supervisor:

Dr. Sanneke Kloppenburg

Environmental Policy Group

Wageningen University

Second examiner:

Dr. Hilde Tonnen

Environmental Policy Group

Wageningen University

Informal supervisor:

Dr. Sander Jansen

Environmental Informatics and Earth Observation Unit

Wageningen Environmental Research

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Summary

Thus far, little has been written on environmental sustainability in Digital Agriculture Solutions (DAS). Yet, as DAS become increasingly deployed in the Global South's agriculture, their impact on the environment rises. Given the accelerating development and deployment of DAS, there is limited time for DAS designers to steer DAS development toward contributing to enhanced environmental sustainability. This situation is exacerbated by a lack of respective guidance for DAS designers.

Against this backdrop, this thesis sets out to answer the question: To which degree and by which ways can environmental sustainability be built into digital agriculture solutions? In drawing on the theory of algorithmic governance, a slightly adapted algorithmic governance framework, and the leverage point perspective, this thesis not only showcases that environmental sustainability can be built into DAS but also develops a novel analytical approach to render the ways by which this can be done visible.

In doing so, this thesis leverages the case study method and explores one specific DAS case, namely Digital Farm Advisory Services, through qualitative and theory-informed research. DFAS provide farmers with agricultural recommendations to improve their farming practices and thereby contribute to higher yields, farmer incomes, or other desirable outcomes such as enhanced environmental sustainability (cf. Fabregas et al., 2019).

By performing a secondary literature desk study and by conducting and evaluating fourteen interviews with DFAS designers, this thesis identifies 17 leverage points for building environmental sustainability into DFAS. These leverage points range from “Guaranteeing professional diversity of the experts that determine DFAS content” to “Pairing adoption of environmentally sustainable agricultural recommendations with financial inducement” (intervention) to “Integrating environmental sustainability in the cost function of the overall DFAS model” (see p. 70).

To better guide DFAS designers, this thesis then assesses said 17 leverage points regarding their depth, or put differently, regarding their effectiveness in contributing to enhanced environmental sustainability. Several “Deep”, “Medium Deep”, “Medium Shallow”, and “Shallow” leverage points are detected. By prioritizing the deepest leverage points, designers can contribute the most to enhanced environmental sustainability.

This thesis further scrutinizes the interdependences between leverage points, in single DFAS and beyond, so-called “chains of leverage”. It argues that “Deep” leverage points can positively impact “Shallow” leverage points and vice versa. In addition, DFAS-sustainability certification, and DFAS-carbon credit service bundles are identified as bundles with particularly high potential in contributing to enhanced environmental sustainability.

Ultimately, the established results and the utilized theoretical concepts and research methods are critically reflected and assessed. They are found to be suitable for guiding DAS designers to contribute to enhanced environmental sustainability in (digital) agriculture. Finally, this thesis concludes and proposes three venues for future environmental sustainability in DAS research: First, research on other DAS cases than DFAS, second, research on the identified and/or already considered leverage points in DFAS, and research on interdependences and combinations of leverage points.

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Foreword

The question of the extent to which digital solutions can improve development cooperation interests me for several years. That's why I have invested a great deal of time in learning about the various areas of this topic. The digitization of all areas of life is proceeding at a breathtaking pace. As a result, it is changing not only our daily lives but also the way certain professions are practiced and the means at their disposal. This includes the profession of development worker, wherein digital solutions are deployed to fight poverty and hunger and to improve the lives of poor people. I strongly believe that knowing about the right digital solutions to specific development problems can make development workers and development cooperation as a whole more effective. Being a “megatrend”, digitalization is meant to remain with us for the next several decades and therefore set to further alter development cooperation.

In parallel with the accelerating digitalization of all areas of life, including development cooperation, multiple environmental crises such as climate change, biodiversity loss, and land-system change are exacerbating. This negative trend has been perpetuated in the last decades and is equally projected to continue. Several actors such as the EU and the OECD have been calling for so-called “Twin Transitions” wherein the power of digital solutions is leveraged to resolve some of the most pressing sustainability-related issues. Grounded on my studies, I became to believe that Twin Transitions are a suitable way to adapt to and mitigate multiple environmental crises. I find it appealing that the idea of Twin Transitions accepts that digitalization is here to stay (sometimes in overly techno-deterministic tones though which I dislike) and that, besides bringing along several negative aspects, it also offers several opportunities. I am convinced that these opportunities need to be fostered and taped for enhanced environmental sustainability.

Yet, as stated earlier my mission for this thesis and beyond is not only to seek ways in which digital solutions can be utilized to combat environmental crises but also for ways in which digital solutions can contribute to improving the lives of poor people. Because agriculture is the sector in which most poor people work and because promoting agricultural development is one of the most secure and effective ways of alleviating poverty (World Bank, 2008), Digital Agriculture seemed to be a perfectly suited object of inquiry for this thesis. Besides, I am a passionate vegetable gardener myself. And had the chance to get good practical insights into larger-scale farming as well. This emotionally connected me to the topic and intrinsically motivated me to learn more about how agricultural development can be improved and made greener by the deployment of digital solutions. So, I set out on a journey to familiarize myself with this subject, permeate it analytically, and based upon this make useful recommendations to those who shape Digital Agriculture in the Global South, namely designers of Digital Agriculture Solutions.

On this journey, obstacles kept coming my way which I managed to clear out – one after the other. This is also due to my companions, who reliably stood by me even in difficult times: My supervisor Dr. Sanneke Kloppenburg, with whom I enjoyed working and who did an excellent job in challenging me academically and in teasing out my full academic potential, my parents, who supported me emotionally and financially so that I could concentrate my attention on my master thesis, and my partner and friends, who supported me both emotionally and intellectually, as sparring partners with whom I could argue over novel ideas. Without the support of these companions, this journey would not have been possible. For their help, I wish to express my utmost gratitude.

1. Introduction

Digital Agriculture Solutions (DAS) such as digital financial services, digital advisory services, or digital market-linkage services are increasingly used in agriculture to drive agricultural development and improve farmers' lives. DAS do so by various means, for example, by facilitating farmers' access to credit or insurance products, by advising farmers regarding crop-related agricultural practices, or by facilitating the transportation of locally produced agricultural goods to regional markets. Several terms have been coined to describe this growing integration of technology and agriculture: "Digital Agriculture" (e.g., FAO, 2022; USAID, 2022), "Digitalization for Agriculture (D4Ag)" (e.g., CTA, 2019b), "Agriculture 4.0" (e.g., Klerkx et al., 2019) and "Fourth Agricultural Revolution" (e.g., Rose et al., 2021). These terms suggest radical changes in the practice of agriculture. Such changes are likely to pose new opportunities and challenges for agricultural development, produce winners and losers among agricultural actors, and, if not attended to, might exacerbate existing crises in agriculture (Klerkx et al., 2019; Klerkx & Rose, 2020; Miles, 2019; Rose et al., 2021; van der Burg et al., 2019).

While the uptake of DAS in the Global North is accelerating, the pace of adoption in the Global South has been slower (Deichmann et al., 2016). However, the latest evidence shows that the Global South is catching up (GSMA, 2020, 2022). This means that designers of DAS have a limited time to steer DAS development in the Global South towards producing positive outcomes for people, production, and the environment while minimizing its risks (cf. Rose et al., 2021; Simelton & McCampbell, 2021). Yet, how designers of DAS could maximize their contributions to the environment remains particularly unclear. This is because designers lack the necessary tools and insights which would enable them to effectively build environmental sustainability into DAS.

One reason for this unsatisfactory condition is that environmental sustainability in DAS has been largely absent from rigorous scientific debate (Cobby, 2020). Admittedly, some scientific articles from digital agriculture literature relate to environmental sustainability. However, most articles either do so en passant (e.g., Basso & Antle, 2020; Ferdinand et al., 2021; Fraser & Campbell, 2019) or on overly techno-optimistic and techno-centric grounds – divining great reductions in agriculture's environmental footprint thanks to DAS (e.g., Bahn et al., 2021; Hrustek, 2020; cf. Cobby Avaria, 2020; Lajoie-O'Malley et al., 2020). Similarly, grey literature and big agribusiness sources promise starkly enhanced environmental sustainability due to DAS adoption (e.g., BASF, 2022; Bayer, 2022; CTA, 2019; FAO, 2019; GIZ, 2022; GSMA, 2019, 2021, 2022; UNEP, 2022; WEF & McKinsey, 2018; World Bank, 2019, 2021). Bayer, for instance, is convinced that "Digitalization in farming can help us deploy our resources efficiently and sustainably, enabling farmers to get the best out of their fields with minimal environmental impact."[1]

Yet, few of the identified articles and even fewer of the grey literature and big agribusiness sources substantiate their claims empirically (cf. Cobby Avaria, 2020; Klerkx & Rose, 2020; Lajoie-O'Malley et al., 2020). Given this, Porciello et al. (2021) have called for "swift action […] to address climate and environmental evidence gaps (p. 3)" in digital agriculture literature, while Cobby Avaria (2021) has prescribed "future researchers and developers […] to place sustainability at the center of their analyses […]" (p. 225). This thesis follows these calls.

[1] https://www.bayer.com/en/news-stories/digital-farming-driving-sustainability

Besides the environmental sustainability-related gap in digital agriculture literature, the angles, that the existing articles on the theme take, greatly differ. Lajoie-O'Malley et al. (2020), for instance, approach environmental sustainability in digital agriculture through "an analysis of high-level [digital agriculture] policy documents". The authors identify the socio-technical visions outlined in these documents and thereby wish to unveil the digital agriculture futures envisioned by policymakers. Opposed to this, Cobby Avaria (2021), examines literature reviews on digital agriculture and concludes that "most current reviews ignore [the environment]". He proposes the "fetishization of technology" and the "digital sublime" as possible causes for this ignorance (p. 229 et seq.).

In contrast, Kruk et al. (2021) and Forney & Epiney (2022) explore environmental sustainability in digital agriculture through a governance lens. To date, governance-focused perspectives have been widely neglected by digital agriculture scholars (Forney & Epiney, 2022). Kruk et al. (2021) examine the ways by which "digital environmental governance" (p. 2) is carried out in digital food sustainability initiatives for smallholder farmer participation. The authors argue that digital sustainability initiatives are "not only a tool but also a site of environmental governance" (Ibid.), pointing to the idea that politics, values, "normativities" (cf. Lee & Björklund Larsen, 2019), and, ultimately, a specific form of governance can be found within the inner workings of DAS (cf. Gritsenko & Wood, 2022; Just & Latzer, 2017; Lee & Björklund Larsen, 2019; Miles, 2019; Nissenbaum, 2011; Winner, 1980). Forney & Epiney (2022), in contrast, explore "the premises of an informational model of governance and the integration of a logic of big data into agri-environmental governance in Switzerland" (p. 173). They find that "digitization reinforces the bureaucratic approach to governance, and the contribution of digital technologies to the interests of the farmers themselves remains minimal" (Ibid.).

Another strain of digital agriculture literature focuses on designing DAS in such a way that high adoption rates are guaranteed and sound ethics are embraced (e.g., Bronson, 2018, 2019; Coggins et al., 2022; Eastwood et al., 2019; McCampbell et al., 2022; Rose & Chilvers, 2018; Simelton & McCampbell, 2021; van der Burg et al., 2019). Yet only Simelton & McCampbell (2021) put environmental sustainability at the center of their design analysis. They explore which "production systems [that] are promoted in climate service apps" and therefrom infer how these apps impact "national targets for sustainable development, ecosystem restoration, and climate resilience" (p. 1). Many articles from the design of digital agriculture literature resort to the Responsible Innovation Framework and consequently remain rather "broad and high-level", homogenous regarding their theoretical underpinnings, and hence of limited use for DAS designers (Jakku et al. 2022, p. 367). However, some articles from this strain of literature take a different approach, for example, the one of Ortiz-Crespo et al. (2021). Scrutinizing the ways by which digital advisory services can promote sustainable intensification, the authors leverage a "co-design methodology" and a "user-centered design approach" respectively (p. 566). In doing so, they develop their own advisory service for Tanzanian farmers. Based on their experiences, the authors finally deduce recommendations for future DAS designs. Yet, while the authors survey a multitude of important design aspects, they fail to conceptualize the mechanisms through which DAS design can contribute to environmental sustainability.

In summary, the existent literature on environmental sustainability in digital agriculture is small and heterogeneous. Some of the identified articles take a high-level perspective (Cobby Avaria, 2020; Lajoie-O'Malley et al., 2020), others relate to environmental governance (Forney & Epiney, 2022; Kruk et al., 2021), and yet others focus on improved designs for DAS (Ortiz-Crespo et al., 2021; Simelton & McCampbell, 2021). However, none of the existing articles provides the reader with a holistic perspective on how DAS can contribute to environmental sustainability in agriculture, or put differently, on how environmental sustainability can be built into DAS. Nor does any of the existing articles offer a methodological approach that would resolve this shortcoming. To fill this gap, and based upon this distill design hands-on recommendations for DAS designers, this thesis sets out to answer the following main research question:

To which degree and by which ways can environmental sustainability be built into digital agriculture solutions?

Yet, to render this rather general question answerable, one specific DAS case, namely Digital Farm Advisory Services (DFAS), is selected for in-depth analysis. DFAS are defined as services that provide agricultural recommendations to farmers in the hope to improve their farming practices and thereby contribute to higher yields, farmer incomes, or other desirable outcomes (cf. Fabregas et al., 2019).

To come to terms with the main research question, this thesis further makes several assumptions. First, that DAS attempt to govern agricultural actors; second, that these governance attempts and the resultant governance (referred to here as DAS/DFAS governance) originate from the design of DAS/DFAS; third, that such design-based DAS/DFAS governance can have different overall objectives; and fourth that environmental sustainability can be one of these objectives of design-based DAS/DFAS governance. Based on these assumptions, the following three case-tailored and simplified sub-research questions are distilled:

(1) How and through which ways do Digital Farm Advisory Services attempt to govern sustainability-related farmers' behavior?

(2) What are entry points for building environmental sustainability into Digital Farm Advisory Services?

(3) What are the most effective entry points for building environmental sustainability into Digital Farm Advisory Services?

To answer these sub-research questions this thesis starts by conceptualizing DFAS governance as algorithmic governance (cf. Eyert et al., 2022; Gritsenko & Wood, 2022; Just & Latzer, 2017; Katzenbach & Ulbricht, 2019; Kruk et al., 2021; Lee & Björklund Larsen, 2019; Miles, 2019). In drawing on the theory of algorithmic governance and a recently developed analytical framework, three general ways through which digital solutions such as DFAS seek to govern are identified: Governance through representation, governance through direction, and governance through intervention (see chapter 2). These three ways are examined by conducting an in-depth, theory-informed, and qualitative case study research, or put differently, an algorithmic governance analysis of DFAS. To execute the algorithmic governance analysis of DFAS, fourteen semi-structured interviews with DFAS designers were conducted and subsequently evaluated. Further, a secondary literature desk study was carried out (see chapter 3). The results of the algorithmic governance analysis of DFAS, which were obtained based on said methods, are presented concisely in chapter 4.

Based on the obtained results on DFAS governance and additional claims by the fourteen interviewees, and in drawing on the leverage point perspective, this thesis identifies entry points for building environmental sustainability into DFAS. These leverage points for building environmental sustainability into DFAS are identified alongside the three ways through which DFAS seek to govern farmers, namely representation, direction, and intervention. In reference to the leverage point perspective, said entry points are subsequently referred to as leverage points (Meadows, 1999) (see chapter 5).

In drawing on further concepts from the leverage point perspective, the identified leverage points for building environmental sustainability into DFAS are ultimately evaluated regarding their effectiveness in contributing to environmental sustainability. Several effective and less effective leverage points are classified. What's more, possible interactions between leverage points for building environmental sustainability into DFAS are discussed. Besides these rather results-based reflections, the theoretical underpinnings, and the methods used for the purpose of this thesis are assessed with respect to their appropriateness, representativeness, and other aspects (see chapter 6). Finally, the main research questions and the three sub-research questions are revisited, the contribution of this thesis is critically reflected, and three avenues for future digital agriculture and environmental sustainability research are proposed (see chapter 7).

In following these steps, this thesis identifies tailored and effective leverage points for building environmental sustainability into DFAS, or put differently, recommendations for environmentally sensitive DFAS designers. What´s more, it proposes and puts up for scientific debate a novel analytical approach to unveil such recommendations for DAS designers. In addition to these practical and theoretical-analytical efforts, this thesis seeks to provide DAS stakeholders with enhanced transparency about the inner workings of DAS. To date, these inner workings remain largely opaque (cf. Rotz et al., 2019). The author of this thesis is convinced that by providing DFAS stakeholders with greater transparency, they will be empowered to more critically assess DAS designs, and, based upon this, be able to set DFAS development towards producing positive outcomes for people, production, and the environment.

Finally, by demonstrating that DAS can enhance environmental sustainability, this thesis wishes to reconcile supposedly opposing positions of DAS proponents and proponents of environmentally sustainable agricultural approaches such as climate-smart, organic, and regenerative agriculture. To date, the latter remain largely skeptical of DAS or even oppose them (cf. Cobby, 2020; Klerkx et al., 2019), and thereby fail to tap the potential of DAS for enhanced environmental sustainability.

2. Theory

This thesis research is guided by two distinct theoretical perspectives: the theory of algorithmic regulation/governance and the leverage point perspective. These perspectives were chosen from a multitude of resembling theoretical perspectives such as the multi-level perspective (Geels & Schot, 2007) or the "informational governance of the environment" perspective (Mol, 2006). In combination, they were deemed apt for answering the posed research questions in this thesis. However, to date said theoretical perspectives have never been applied together. Hence, this thesis, besides inquiring about the ways by which DFAS seek to govern farmers and identifying leverage points for building environmental sustainability into DFAS, also probes this novel theoretical combination for the realm of digital agriculture.

In sections 2.1 and 2.2 of this chapter, the theory of algorithmic regulation/governance and Eyert et al.'s algorithmic regulation framework will be presented. The said framework is slightly adapted for this thesis to also cover algorithmic governance through DFAS. For this and other reasons such as readability and compatibility with existing scientific contemplations (cf. Forney & Epiney, 2022; Gritsenko & Wood, 2022; Hatanaka et al., 2022; Just & Latzer, 2017; Katzenbach & Ulbricht, 2019; Kloppenburg et al., 2022; Kruk et al., 2021) it is referred to "algorithmic governance", "algorithmic governance systems", "algorithmic governance framework", "algorithmic governance analysis" in the following. The algorithmic governance framework, in guiding the algorithmic governance analysis of DFAS, serves as the principal methodological tool in this thesis.

Yet, for answering sub-research questions (3) and (4), the theoretical as well as methodological contemplations subsumed under the term "Leverage point perspective" are similarly essential. Therefore, this perspective will be equally presented in this theory chapter (see section 2.3). In applying the theory of algorithmic governance, the algorithmic governance framework, and the leverage point perspective together, this thesis develops a new analytical approach (see section 2.4). This approach fills an important gap regarding the identification of environmental sustainability potentials in digital agriculture.

2.1 Theory of algorithmic governance

The theory of algorithmic governance draws on a mixture of disciplines such as quantification, science and technology, and governance studies (Eyert et al., 2022; Gritsenko & Wood, 2022). It mirrors the idea that digital solutions such as DAS, and the algorithms enabling their functioning, seek to govern the behavior of their users. The said theory is further based on the idea that algorithms (digital solutions) order society and produce what is referred to as "social ordering" (Gitsenko & Woods, 2022; Katzenbach & Ulbricht, 2019). In doing so, algorithms (digital solutions) exert power and shape reality in particular ways (Just et Latzner, 2017). However, algorithms (digital solutions) do not merely exist independently of humans. They are built by humans. These designers, in building said algorithms (digital solutions), make many normative decisions and thereupon built specific desirable outcomes into the governance emanating from them (Gitsenko & Woods, 2022; Lee & Björklund Larsen, 2019). Thus, the designers of algorithms (digital solutions) wield what is called here algorithmic governance power.

Opinions on the effect of increasingly algorithmically governed societies are divided. Some proponents see algorithmic governance as "a form of decentralized coordination and participation [which is capable] to process a high number of inputs and thus to tackle a high degree of complexity"(König, 2019; Schrape, 2019 in Katzenbach & Ulbricht, 2019, p. 5). Consequently, algorithmic governance is then perceived as "a mode of coordination that offers new opportunities for participation, social inclusiveness, diversity, and democratic responsiveness" (Ibid.). Opponents, however, see the increasing power of algorithms as a danger to social cohesion, social welfare, and democracy, just to name some of the raised concerns (Katzenbach & Ulbricht, 2019).

In this thesis, governance will be broadly understood as "coordination between actors based on rules" (Ibid.), while algorithms will be coarsely defined as "complex computer-based epistemic procedures" (Katzenbach 2019, p. 2) for solving a problem (cf. Gillespie 2014a, 2014b in Yeung, 2018, p. 2). Algorithmic governance is hence defined as the coordination of actors and the steering of their behavior by using "complex computer-based epistemic procedures" (algorithms) for solving a problem (Ibid.).

However, it should be taken into account that different professions operate with distinct definitions. While software engineers, for instance, view algorithms as a "logical series of steps for organizing and acting on a body of data to achieve a desired outcome quickly (Gillespie 2014a, 2014b; Dourish 2016 in Yeung, 2018, p. 2), the definition of social scientists is normally broader. They view algorithms as part of a sociotechnical assemblage that includes, beyond mere algorithms, computations networks, software architects & designers, data and users, enabling institutions, and resultant digital solutions (Yeung, 2018).

Following these contemplations, algorithmic governance analysis can be understood as an inquiry into how algorithms impact individual behavior, social interaction, and societal structure, and into who participates in this process, to what extent, and in which ways. To enable such an analysis, in the case of this thesis, DAS and DFAS are conceptualized as being perpetuated by algorithmic governance and underpinned by algorithmic governance systems (cf. Forney et Epiney, 2022). Such algorithmic governance systems are constituted by several system components which will be unveiled and distinctly dissected in this thesis. It is hoped, that based upon this, leverage points for building environmental sustainability into DFAS can be deduced (also see chapter 3).

Despite a growing body of algorithmic governance literature in recent years (e.g., Aneesh, 2009; Bellanova & de Goede, 2022; Eyert et al., 2022; Gritsenko & Wood, 2022; Johns & Compton, 2022; Just & Latzer, 2017; Katzenbach & Ulbricht, 2019; Kloppenburg et al., 2022; Kruk et al., 2021; Lee & Björklund Larsen, 2019; Yeung, 2018), algorithmic governance in DAS is to-date underexplored. However, as the theory of algorithmic governance is kept sufficiently broad to include all sectors in which digital technologies and algorithms are deployed and in which governance by algorithms consequently gains momentum, it can be also used for inquiring DAS.

2.2 Algorithmic Governance Framework

To date, only a few papers have provided analysts with methodological tools and frameworks to thoroughly capture algorithmic governance in digital solutions. While being inspired by the former works of Gritsenko & Wood (2022), Katzenbach et Ulbricht (2019), Yeung (2018), and others, the research in this thesis is mainly based on Eyert et al.'s (2022) algorithmic regulation framework. Yet, this framework is adapted, so that it also covers those actors who are only indirectly involved with shaping the ways in which digital solutions govern. These governing, however, not regulating actors, thus do not directly design the algorithmic governance systems underpinning digital solutions. However, they still have an impact on what kind of desired governance outcomes are designed into these systems and thus what kind of governance finally emanates from digital solutions. Due to these adaptations, Eyert et al's framework is renamed "algorithmic governance framework".

Eyert et al's framework was developed in 2022 and is based on Yeung's (2018) ideas. The authors' framework consists of three main ways through which the algorithms underpinning digital solutions seek to govern. These are "representation", "direction", and "intervention". Eyert et al. refer to these ways as "dimensions" of algorithmic governance. However, to remain generally understandable the term "ways" was used in the research questions. The term "ways" (by which it is algorithmically governed) was deemed to be more clearcut and more suitable for the practical purpose of this thesis than the analytical term "dimensions" (of algorithmic governance) which was perceived as being rather analytical and passive. Nevertheless, both terms "ways" and "dimensions" of algorithmic governance will be used quasi interchangeably hereafter.

The dimensions of algorithmic governance are a reinterpretation and terminological reconfiguration of what is seen as components of any control system by cybernetic scholars, namely "information-gathering", "standard-setting", and "behavior modification" (cf. Yeung, 2018). This reconfiguration is undertaken to bridge gaps between governance/regulation studies and adjacent social science research (Eyert et al., 2022).

Concerning the first dimension, originally, the "information-gathering component" of control systems, Eyert et al. propose to rather use the terminology of "representation" as this broadens the scope of analysis and at the same time does justice to the opaque and ambiguous ways in which algorithmic governance systems tend to overrepresent some while underrepresenting other aspects of the reality.

For the second dimension, originally the "standard-setting component" of control systems, Eyert et al. suggest using "direction", which they understand as the "entirety of normative choices inherent in the design of a regulatory system" (p. 6). This is justified with the argument that standards are just one way of attaining pre-defined and desired system goals and that hence a broader category is needed which also includes the operationalization of standards, for instance, in the form of indicators.

Finally, the dimension of "intervention" is proposed as a replacement for the "behavior modification" component. It is reasoned that "behavior modification" is predicated on the wrong assumption that "behavior is an object that can be adjusted at will" (p. 6). New research evidences that most attempts to steer behavior are prone to unintended effects and often fail to live up to their expectations. The latter has also been shown for digital agriculture (e.g., Coggins et al., 2022). Eyert et al. argue that the terminological reconfiguration from "behavior modification" to "intervention" allows for a more "symmetric perspective" as it includes "rather direct instruments" as well as "more indirect or long-term approaches" (Eyert et al. 2022, p. 6). As a consequence of the aforementioned terminological reconfigurations, the elaboration of new, analytical sub-dimensions becomes feasible.

2.1.2 Representation dimension

For the "representation"-dimension of algorithmic governance, Eyert et al. propose the sub-dimensions of "feature selection", "production of data points" and "interpretation of data". "Feature selection" describes the process of choosing specific data inputs over others. Thereby, representational priorities, through in- and exclusion, are set. The question after how, by whom, and with which purpose in mind data are produced is covered by the "production of data points”-sub-dimension. Finally, the “interpretation of data”-sub-dimension enables the analysis of data classification schemes, the identification of interpretative pathways, and thus the intentional or unintentional segmentation of the world according to said schemes and pathways.

All processes going hand in hand with “feature selection”, “production of data points”, and “interpretation of data” are highly value-laden and create what is being referred to here as digital representation-reality gaps. These processes reduce the reality of what ought to be seen. As a consequence, what ought to be seen can become the only aspects of reality that are seen and valued by the users of digital solutions.

In the case of DFAS, farmers are presented with a particular, distorted version of the world. Depending on the underlying version of the world, DFAS create different agricultural recommendations. This, in turn, governs farmers in a particular way. Thus, determining a specific digital representation is itself an act of governance. Creating DFAS with the help of a co-creational design approach is likely to allow farmers to understand or contribute to the way in which “feature selection”, “production of data points” and “data interpretation” distort reality and thereby govern (McCampbell et al., 2022; Ortiz-Crespo et al., 2021).

2.1.2 Direction dimension

As with the “representation”-dimension, Eyert et al. suggest three analytical sub-dimensions to explore the direction dimension of algorithmic governance. These are “general goals”, “standards”, and “indicators” (p. 9 ff.). While the “general goals” sub-dimension examines the ends to which regulation is performed – something often closely related to worldviews and values which are dominant in the larger social context –, the “standards” sub-dimension examines what kind of desired states need to be defined to make the pre-defined general goals attainable. Different standards or, put differently, definitions of desired states, are often intertwined and generate what is called “standard cascades” by the authors (p. 6, 9). Lastly, “indicators” – the third sub-dimension – are often being decided upon to make the achievement of standards measurable. Eyert et al. draw attention to the fact that numeric indicators prevail nowadays and that they become politized regularly, hinting at the societal controversies around the priorities inscribed into such “judgement devices” (p. 9). All in all, by setting specific general goals, standards, and indicators, algorithmic governance systems are anchored to a distinct normative governance direction. In the case of DFAS, the governance direction is conceptualized as being determined by the agricultural paradigm, specific agricultural standards, and the corresponding agricultural practices, that a specific DFAS seeks to promote.

To cover what and who impacts the governance direction of digital solutions more generally, the “direction”-dimension of algorithmic governance, as outlined by Eyert et al. (2022), is expanded by a fourth sub-dimension. Within this subdimension, which is named “Important general aspects and actors’ participation”, general aspects of direction as well as the participation and influence of different actors in determining the governance direction are explored (see section 4.1.2). Several authors have recently highlighted that exploring such aspects is essential in digitally enabled governance and/or digital agriculture (McCampbell et al., 2022; Kloppenburg et al., 2022; Kruk et al., 2021). Inclusion and exclusion processes play an important role in assessing the effects of DAS (Klerkx & Rose, 2020; Rose et al., 2021; Rotz et al., 2019). Several authors claim that for too long farmers have not been involved in the design of agricultural innovations (Klerkx & Rose, 2020; Rotz et al., 2019). What’s more, in adding a fourth sub-dimension that dedicates itself to said aspects, Eyert et al's framework is equipped to cover algorithmic governance instead of only covering algorithmic regulation.

2.1.3 Intervention dimension

The "intervention"-dimension of algorithmic governance, explores how the algorithmic governance systems underpinning digital solutions, make desired governance outcomes probable and undesired governance outcomes improbable. In short, it answers the question of how farmers are governed. This "intervention"-dimension is separated into the two sub-dimensions "degree of automation" and "strategies of influence".

The "degree of automation"-subdimension, analyses the degree to which governance in a digital solution is automated. In reference to Yeung (2018), Eyert et al. (2022) differentiate between two systems that automate governance, first, those that "automatically administer a specified sanction or decision, and [second], those that merely provide recommendations to human decision-makers (p.10)". Whereas in the first case, a high degree of automatic algorithmic decision-making leads to a high degree of governance automation, in the second case, algorithms merely provide human decision-makers with a decision-making basis. Thus, there is a lower degree of governance automation. It is not clear from Eyert et al.'s limited elaborations, what ought to be examined in the "degree of automation" sub-dimension. This thesis thus gives itself its own focus which is tailored to DFAS (see section 4.2.1).

The "strategies of influence" sub-dimension, identifies the strategies that are applied to achieve the desired governance outcomes (see "direction"-dimension). This thesis analyses five possible "strategies of influence" in DFAS: "coercion", "inducement", "re-interpretation", "influence through non-rational properties", and "architectural constraint" (p. 10 ff.). Yet, as will be seen later "re-interpretation" is the dominant "strategy of influence" used by DFAS (see section 4.2.2).

Strategies of influence of digital solutions	Coercion
	Inducement
	Re-interpretation
	Influence through non-rational properties
	Architectural constraint

Table 1: Types of strategies of influence according to Eyert et al. 2022, p. 10ff

The strategies of "influence through non-rational properties" and "architectural constraint" are especially found in algorithmic governance. Therefore, Eyert et al. (2022) added them to the algorithmic governance framework. "Influence through non-rational properties" via algorithmic governance systems, also referred to as "hypernudge" (Yeung, 2018, p. 12), uses biases and other non-rational properties. Behavioral economists and psychologists have identified these biases and non-rational properties throughout the last decades (e.g., gain-loss framing) (cf. Thaler & Sunstein, 2008). Large quantities of data help to find these biases and non-rational properties in sub-groups of the population such as farmers. "Architectural constraint", in contrast, allows or prohibits certain courses of action by design. This means that some pathways are built into, while others are not built into digital solutions. Requiring the user to enter a password is an example of such a "strategy of influence" type.

Main dimension of algorithmic governance systems	Sub-dimensions of algorithmic governance systems
1. Representation	1.1 Feature selection
	1.2 Production of data points
	1.3 Interpretation of data
2. Direction	2.1 Important general aspects and actors' participation
	2.2 General goals
	2.3 Standards
	2.4 Indicators
3. Intervention	3.1 Degrees of automation
	3.2 Strategies of influence

Table 2: Dimensions of algorithmic governance, adapted from Eyert et al., 2022, p. 12

All in all, Eyert et al's framework is intended to "[provide] the conceptual means for more detailed empirical research and systematic theory development" (p. 2). Further, it intends to stay sufficiently broad and at the same time detailed enough to allow for the analysis of a wide range of algorithmic governance systems, including the ones underpinning DAS. Due to its generality and applicability to DAS, and its targeted dimensions and sub-dimensions that allow for a clear, analytically sound dissection of various governance aspects in DAS, Eyert et al.'s framework is used to guide the following empirical research on algorithmic governance in DFAS (cf. Eyert et al., 2022) (see chapter 4).

2.3 Leverage point perspective

In contrast to the theory of algorithmic governance, the leverage point perspective stems from sustainability science. By aspiring to provide the analyst with entry points in a system where intervention is particularly effective to achieve environmental sustainability (Abson et al., 2017), the leverage point perspective takes a normative and action-oriented stance. This is because identified entry points are sufficiently concrete to deduce practical recommendations, for example for designers of DAS, from them.
Additionally, the leverage point perspective with its classification of leverage points according to their depth, or put differently, their effectiveness in changing an existent system toward environmental sustainability permits the comparison of various measures against one another (Fischer & Riechers, 2019). What's more, the leverage point perspective enables the analyst to shed light on sets of measures (Ibid.). For all those reasons, the leverage point was deemed apt to contribute to answering the research questions, in particular (2) What are entry points for building environmental sustainability into Digital Farm Advisory Services? (3) What are the most effective entry points for building environmental sustainability into Digital Farm Advisory Services?

The leverage point perspective is based on Donella Meadows' work from 1999. In this groundbreaking work, coined "Leverage Points – Places to Intervene in a System", Meadows identifies 12 types of leverage points for enhanced environmental sustainability in socio-ecological systems (Meadows, 1999). These range – in chronological order and grounded on the depth of interventions - from changes in "constants, parameters, and numbers" to "the power to transcend paradigms". Leverage points are broadly defined as "places within a complex system where a small shift in one thing can produce big changes in everything" (Ibid., p. 1).

No	Leverage point types
1	The power to transcend paradigms
2	The mindset/paradigm out of which the system arises
3	The goals of the system
4	The power to add, change, or self-organize system structure
5	The rules of the system (such as incentives and constraints)
6	The structure of information flows (access to information)
7	The gain around driving positive feedback loops
8	The strength of negative feedback loops
9	The length of delays, relative to the rate of system change
10	The structure of material stocks and flows
11	The size of buffer stocks, relative to their flows
12	Parameters (such as subsidies and taxes)

Table 3: Meadows' 12 leverage points

In the last few years, several authors from the emerging field of Sustainability Science – a field that has the practical usability of produced scientific knowledge at its heart – have further developed the leverage point perspective into a methodological approach called "leverage point analysis" (Abson et al., 2017; Fischer & Riechers, 2019; Leventon et al., 2021). This approach is more applicable and handier for research. It has been used by several authors to conduct empirical studies (Chan et al., 2020). Several of these studies have applied the leverage point analysis to the food system (Dorninger et al., 2020; Jiren et al., 2021; Manlosa et al., 2019).
Abson et al (2017) have condensed Meadows's 12 types of leverage points into four more general "leverage point categories" which they have called "parameters", "feedbacks", "design", and "intent" (p. 3). Fischer et Riechers (2019) have adopted said idea, yet they refer to the leverage point categories as "material" (parameters), "processes" (feedbacks), "design", and "intent" (see figure below).

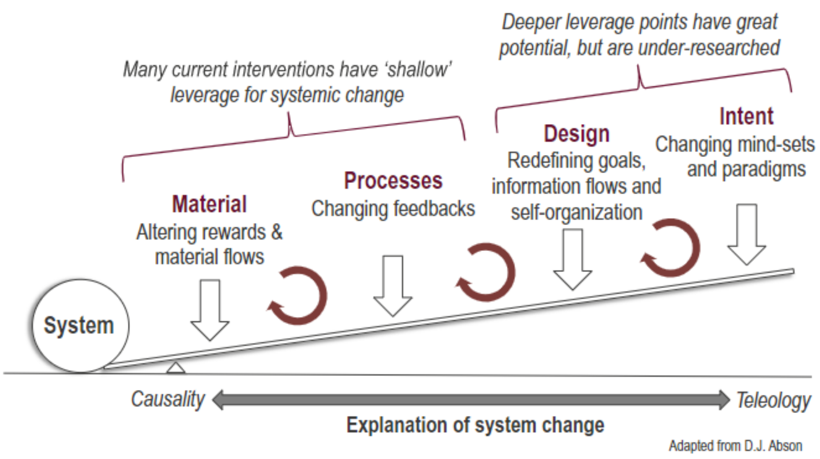


Figure 1: The four leverage points categories, from Fischer et Riechers, 2019, p. 117

Each of these categories subsumes three leverage point types. These leverage point categories are combined with the concept of shallow and deep leverage points which is equally introduced by Abson et al. (2017).

According to the authors, this differentiation is needed, to separate those areas for interventions with high potential for environmental sustainability (deep leverage points) from those with less potential (shallow leverage points). The authors define shallow leverage as “places where interventions are relatively easy to implement yet bring about relatively little change to the overall system”, whereas they define deep leverage points as “[places] that might be more difficult to alter but potentially result in transformational change” (p. 2).

The first six leverage point types are subsumed under the leverage point categories of “intent” and “design” and are classified as “deep”, whereas the last six leverage point types are subsumed under the leverage point categories of “parameters” and “feedbacks” and are classified as “shallow”. For the thesis at hand, the concept of depth of leverage points is finetuned. For a more precise classification of leverage points, the leverage point depth categories of “medium shallow” (leverage point categories 7-9) and “medium deep” (leverage point categories 4-6) are added as inter-stages to the stages “deep” and “shallow” (see table 3) and are matched with leverage point categories of “design” and “feedback” (processes) respectively.

No	Leverage point types	Leverage point category	Leverage point depth category
1	The power to transcend paradigms	Intent	Deep
2	The mindset/paradigm out of which the system arises		
3	The goals of the system		
4	The power to add, change, or self-organize system structure	Design	Medium Deep
5	The rules of the system (such as incentives and constraints)		
6	The structure of information flows (access to information)		
7	The gain around driving positive feedback loops	Feedbacks (Processes)	Medium Shallow
8	The strength of negative feedback loops		
9	The length of delays, relative to the rate of system change		
10	The structure of material stocks and flows	Parameters (Material)	Shallow
11	The size of buffer stocks, relative to their flows		
12	Parameters (such as subsidies and taxes)		

Table 3: Meadows’ 12 places to intervene in a system (leverage point types) and their respective leverage point (depth) categories (simplified and adapted based on Meadows (1999), Abson et al. (2017) & Fischer & Riechers (2019)

For their research on key levers and leverage points for socio-ecological transformation Chan et al, 2020, inter alia, analyze the question of “How might the levers and leverage points work together?” This resembles the question of interdependence, interplay, and synergies between different leverage points, be they shallow, medium shallow, medium deep, or deep, which is also raised by other authors. Fischers et Riechers (2019), for instance, caution that transformational change necessitates acting upon different leverage points at the same time. They write that studying “chains of leverage” or put differently “how one type of change in a system precipitates another, across different types of depth of leverage” could be fruitful for leverage point analysis.

Depending on the area of the food system that specific DAS target, there are more or fewer leverage points for building environmental sustainability into them. Digital market linkage services, for example, leverage faster transportation, and in some cases cold chains, for reduced food loss (GSMA, 2019a), while digital climate-smart advisory services, leverage climate-sensitive recommendations to help mitigate or adapt farms to adverse climate effects.

The algorithmic governance systems underpinning DAS, contain several leverage points which can be identified alongside the three dimensions of algorithmic governance outlined above.

While the leverage point perspective has shown to be fruitful for the analysis of phenomena in the analog world, healthy skepticism, and thorough thinking seem imperative when transferring and thus making it fruitful for the digital world. The leverage point perspective has, thus far, not yet been applied to digital solutions such as DAS and, as a general-purpose theory explaining socio-ecological transformation, was not necessarily intended to be applied in this realm. Yet, this is what this thesis does by identifying leverage points for building environmental sustainability into DFAS or put more precisely, into the algorithmic governance systems underpinning DFAS.

However, to be more tailored to the digital world, the leverage point perspective needs to be combined with a theory from informational/digital fields of study. After extensive explorative research the theory of algorithmic governance, as described above, has been identified as being well-suited for such a combination. Yet, as this novel combination is untrodden terrain it necessitates testing against an empirical case, in this thesis, the case of DFAS.

2.4 Conclusion: Combining Algorithmic Governance and Leverage point perspective

The algorithmic governance framework and the leverage point perspective, when applied together, complement each other in various ways. As has been shown above, the algorithmic governance framework captures governance through the three dimensions “representation”, “direction”, and “intervention”. Each of these dimensions has two to three sub-dimensions. The algorithmic governance framework thus enables the analyst to gain an understanding of the ways by which digital solutions such as DAS steer their users’ behavior.

Yet, while the framework is a well-suited analytical tool for taking stock of, shedding light on, and uncovering the inner workings of algorithmic systems active in DAS, it fails to give the analyst a normative grounding. However, this is needed to plan and undertake practical steps to build environmental sustainability into DAS. What’s more, the algorithmic governance framework does not allow the analyst to assess whether certain actions have the low, intermediate, or high potentiality to change algorithmic governance systems into a pre-defined - and thus inherently normative – direction, in this thesis, enhanced environmental sustainability. At the same time, the algorithmic governance framework does not explicitly carve out interdependences between the different dimensions of the algorithmic governance systems and thus does not allow for insights into possible synergies between leverage points of the same DAS and beyond.

The leverage point perspective can fill the pinpointed gaps and shortcomings in the algorithmic governance framework and analysis and thus serve as a complementary analytical tool. As has been shown above, the leverage point perspective takes a practical, action-oriented stance. By enabling the classification of leverage points according to Meadows’ 12 types of leverage points and the four corresponding leverage point categories “Deep”, “Medium Deep”, “Medium Shallow”, and “Shallow”, which indicate the effectiveness of a particular leverage point in changing a system, the leverage point equips the analysts with important practical tools. Said tools additionally capacitate the analyst to identify “chains of leverage”.

For the leverage point perspective to have its full complementary effect, a three-step process, wherein algorithmic governance systems are explored first (chapter 4), leverage points for building environmental sustainability into DFAS are identified second, and the depth of identified leverage points is assessed third, is applied. The methods selected for and applied throughout this three-step approach and the limitations of this research are elaborated on and reflected upon in the following “methods” chapter.

3. Methods

This chapter describes and justifies the methods used to make environmental sustainability in DFAS researchable. The case study method, wherein one case (here: DFAS) is thoroughly studied in the hope to be representative of a bigger whole (here: DAS), serves as the overall method (see section 3.1). Therefore, the case of DFAS is delimited by distinct research boundaries (see sections 3.1 and 3.2). To conduct the case study and enable triangulation of findings, the methods of secondary literature desk study, semi-structured interviews, and systematic interview evaluation are utilized (see section 3.3).

As opposed to grounded theory, wherein “open” coding is used, this thesis uses theory-informed codes. They are based on the algorithmic governance framework and the leverage point perspective. All in all, this thesis applies a qualitative, empirical, and theory-informed research approach.

3.1 Case study method

The case study method constitutes the principal and overall method of this thesis. It is used because it allows for generating early insights into novel phenomena and developments by analyzing single cases (Fidel, 1984). What’s more, the case study method is used because it serves as a good starting point for undertheorized and underexplored fields of research such as the one at hand: environmental sustainability in DAS (Cobby Avaria, 2020; Stake, 1978). Said field necessitates further contemplations and elaborations. Furthermore, the case study method also has practical advantages: It generates tangible results that are detailed enough to base broader real-world recommendations thereon (Fidel, 1984).

The literature differentiates three case study types: descriptive, explanatory, and exploratory (Mills et al., 2010a, 2010b, 2010c). This work takes on the exploratory approach, wherein initial insights into a broader phenomenon (here: building environmental sustainability into DAS) are generated (Ibid.). At the same time, elements of the descriptive case study approach, wherein “patterns and connections, in relation to theoretical constructs, to advance theory development (Ibid., p. 2)” are applied. The latter is particularly done throughout the analytical exploration of algorithmic governance systems. This exploration is heavily guided by Eyert et al’s (2022) algorithmic governance framework which was adapted for this thesis.

By using aspects of both case study types – explorative as well as descriptive –, it is hoped to gain first insights into the object of inquiry as well as to drive algorithmic governance theory development through the testing of the novel analytical algorithmic governance framework by Eyert et al. 2022 (cf. Ibid.). The selection of DFAS for in-depth analysis, as opposed to other DAS cases, was grounded on four main selection criteria (DAS case selection criteria), two of which are of practical nature (1,2) and two of which are content-based (3, 4) : (1) High visibility and prominence of DAS case/Relatively huge number of DAS case providers (CTA, 2019; GSMA, 2020) (2) Availability of information (in the form of website information, grey literature, scientific literature, etc. (for secondary literature desk research) (3) Relatively high potential to contribute to environmental sustainability in agriculture (cf. Fabregas, 2019)), and (4) Relatively high sophistication and maturity of DAS case as compared to other DAS cases (see figure 2).

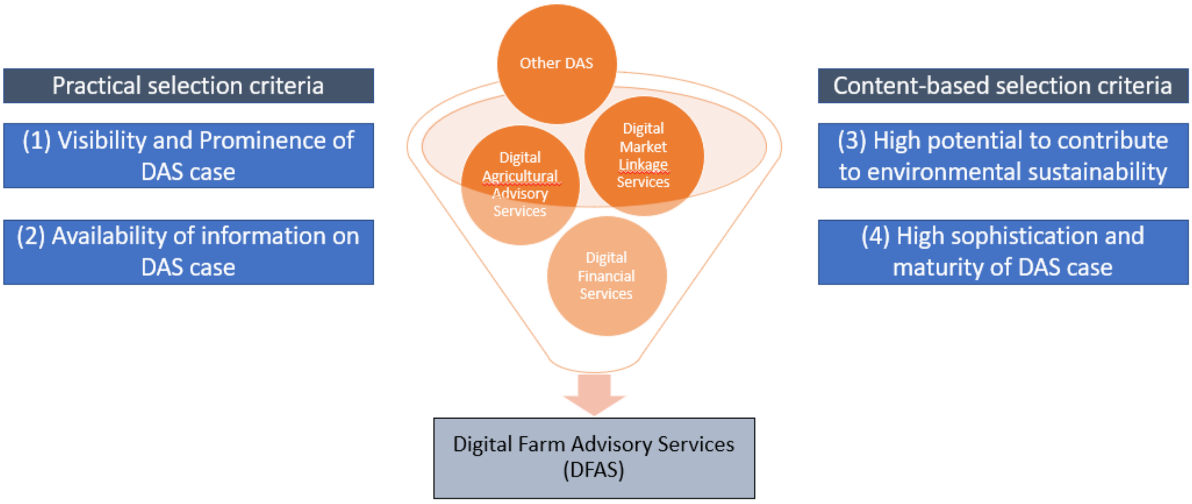


Figure 2: DAS case selection criteria & process

DAS case selection criterion (1) was applied because it was assumed that this would allow for better access to interviewees, (2) was applied because it was assumed that this would enable sound secondary literature desk research, (3) was applied because it was assumed that this would facilitate identifying leverage points for enhanced environmental sustainability, and DAS (4) was applied because it was assumed that this would enable better algorithmic governance system analysis as the likelihood of advanced DAS to be particularly algorithmically governing was thought to be higher (CTA, 2019a; GSMA, 2020). Applying all these DAS selection criteria to several DAS cases, yielded the case of DFAS. In how far DFAS are representative of DAS will be discussed in section 6.3.1.

To render the case of DFAS tangible, this thesis delimited itself to a specific set of DFAS providers with whom interviews were later conducted. DFAS providers are organizations whose employees either directly or indirectly contribute to the design and development of DFAS. Therefore, they are referred to as DFAS designers. DFAS providers as opposed to DFAS applications were chosen because first, DFAS providers were believed to have a more balanced, all-encompassing perspective on DFAS as most of them are involved with the provisioning of several DFAS (see table below), and second because DFAS applications were anyways not accessible to the author of this thesis and thus using them as an access point did not offer any practical, research-related advantages (e.g. analysis of user design).

The selection of DFAS providers (DFAS provider selection criteria) depended mainly on (1) their popularity, (2) access to interviewees of a specific DFAS provider, (3) the technology used to convey agricultural recommendations (only SMS, IVR, Apps), (4) the explicit target group of small-scale and medium-scale farmers in the Global South, and (5), later in the research process, the difference between new and already interviewed DFAS. The DFAS provider selection criteria (1) was applied because popular DFAS were deemed to have a higher impact on farmers and the environment, and are more visible, (2) was applied because it was deemed necessary to conduct several interviews to enrich secondary literature desk study, (3) was applied to limit the scope of the research and enable comparability between DFAS, (4) was applied because this target group is particularly vulnerable to consequences of adverse environmental effects, and (5) was applied to cover a wide range of different DFAS.

No	DFAS provider selection criterion	Justification of criterion
1	Popularity of DFAS provider	Ensures that DFAS have a comparatively high impact on farmers and environment
2	Access to interviewees of DFAS providers	Several interviews needed because of the novelty of the research
3	Technology used by DFAS provider	Limits the scope and enables comparability between DFAS providers
4	Target group of DFAS provider	Guarantees pro-poor focus of this work, comparability between DFAS providers
5	Difference between DFAS providers	Enable sufficiently broad insights into DFAS

Table 4: Justifications for DFAS provider selection criteria

It needs to be cautioned that some of these criteria became clear, after the conduction of the research. As can be seen in table 5 below, some DFAS providers provide one particular DFAS, while others provide several DFAS for different contexts. In the former case it was clear to which particular DFAS respondents were referring, while in the second case, this was not clear. However, it is assumed that respondents from DFAS providers with many active DFAS base their claims on several DFAS and thus hold a more general view of DFAS. In addition, it is assumed that analyzing a diverse set of DFAS cases enables their aggregation and ultimately allows for more general claims on DFAS as a whole.

DFAS provider type	Inter-viewee	Amount of DFAS delivered by provider	Description/Target area	Target group(s)	Target country/countries	Delivery technology
Public research institute	1	Three DFAS	better management of tropical vegetables (in cooperation with seed provider)	Small-scale farmers	Bangladesh	SMS (+ call center)
	1		better management of important crops (digitalization of government's "information packages")	Small-scale farmers	Ethiopia	SMS
	1			Small-scale farmers	Myanmar	SMS
Information provisioning company (with a focus on mobile communications & rural populations)	2	Several DFAS	Different foci; Always weather forecasts + (at least) basic crop information (in cooperation with mobile network operators)	Small-scale farmers	Many countries in the Global South	SMS, IVR (inbound & outbound), (+ call centers)
Dutch engineering company	3	One DFAS	Better management of rice (in cooperation with agribusiness)	Small- and medium-scale farmers	Vietnam	App
Weather and climate service company	4	Several DFAS	Better crop management, focus on weather and climate-informed services	Small-scale farmers	12 countries in the Global South, particularly in Africa	SMS, IVR, Apps
Kenyan agri-tech start-up	5	Not specified	Better crop management	Small- and medium-scale farmers	Kenya	App
Community and agricultural development organization	6	Several DFAS	Better crop management of most common crops	Small-scale farmers	Five countries in the Global South	App
Public research institute	8	Several DFAS	Alert service for potato farmers	Not specified	Bangladesh	SMS
	8		Better management of vegetables	Small- and medium-scale farmers	Indonesia	App
	8		Not specified (operated by government)	Small- and medium-scale farmers	Indonesia	App
Moroccan agri-tech start-up	9	Several DFAS	Better crop management (water, fertilizer, etc.)	Medium-scale farmers	Several African countries, particularly Morocco	App
International seed company	10	One DFAS	Better management of vegetables	Small- and medium-scale farmers	Indonesia	App

International agricultural development NGO	11	Several DFAS	Different crop-related advice foci	Small-scale farmers	10 countries in the Global South	SMS, IVR, Apps, and others
International agricultural development NGO	12	Several DFAS	Different crop-related advice foci	Small-scale farmers	Seven countries in the Global South, particularly India, and Ethiopia	SMS, IVR, Apps, and others

Table 5: Considered DFAS providers and their characteristics (Note: Interviewee 7 does not appear in the table because he holds general rather than DFAS-specific expertise; for an overview of all respondents, see appendix 2)

3.2 Object of inquiry

This thesis limits itself to the analysis of environmental sustainability in Digital Farm Advisory Services (DFAS). The limitation to DFAS was undertaken based on the four above-outlined DAS selection criteria. DFAS can be subsumed under the umbrella terminology "Digital Agricultural Advisory Services" (DAAS) (Precision Development, 2021). DAAS give different types of digital agricultural advice and can be distinguished, inter alia, along the scale and the target group that they serve, as well as the agricultural sub-system that they focus on. Concerning the scale, there are regional as well as farm-level DAAS. Regional DAAS are tailored to the needs of regional decision-makers (e.g., FAO or WFP), whereas farm-level DAAS are tailored to the needs of specific farmers (I 1). Target groups of DAAS are usually farmers, but can also be extension officers, agro-dealers, agricultural logistic companies, and many more. Furthermore, DAAS can target different agricultural sub-systems such as crop systems, agroforestry systems (e.g., Agroforestry-App for India)[2], livestock systems (e.g., agricultural recommendations in Mali)[3], and others.

DFAS as a specific DAAS are meant to provide farmers with practical information and recommendations on new, better, and locally suitable crop farming practices. Thereby, DFAS seek to facilitate their adoption (CTA, 2019a; GSMA, 2020). This thesis focuses on farm-level DFAS that offer their services to small- to medium-scale farmers in the Global South. Traditionally, farm advisory services were offered by extension officers. However, as extension officer-to-farmer ratios were low in the Global South (I 2), new agricultural information did not reach farmers, and adoption rates of improved agricultural practices consequently remained low. Against this backdrop, DFAS were developed. DFAS leverage the ever-increasing (smartphone) phone ownership rates among farmer populations and the steadily falling costs for telecommunication services. By taping the potential of mass communications - the spreading of new information to several thousand farmers at nearly the same time -, DFAS have starkly increased the outreach of extension (Fabregas et al., 2019).

To be inclusive, DFAS are delivered through various technologies, namely SMS, Interactive Voice Response (IVR), radio, TV, and lately also smartphone and tablet apps, social media, and chatbots (GSMA, 2020; I 12). This thesis limits itself to DFAS that are delivered by SMS, IVR, and Apps. Using these delivery technologies means that DFAS depend on mobile communications and thus need to collaborate with mobile network operators. DFAS are developed by the public as well as the private sector. On the side of public actors, it is often agricultural ministries, but also donors and academia that develop DFAS. They either do so within their own organizations or through the commissioning of third parties (CTA, 2019; GSMA, 2020). On the side of private actors, it is mainly agripreneurs, agribusinesses, NGOs, and mobile network operators that are involved with DFAS creation and delivery (CTA, 2019; ISF Advisors, 2021). Even though designers still improve several aspects of DFAS, there is some evidence that they have a positive impact on farmer productivity and incomes. Fabregas et al. (2019) write that "Meta-analyses suggest that providing agricultural information via digital technologies increased yields by 4% and the odds of adopting recommended inputs by 22% (p. 1)".

[2] https://www.worldagroforestry.org/blog/2022/01/24/agroforestry-app-set-accelerate-agroforestry-india
[3] https://snv.org/update/garbal-satellite-information-service-pastoralist-farmers-northern-mali

3.3 Other methods

While the case study method (with its explorative as well as descriptive elements), serves as the frame for the investigation at hand, other methods, namely secondary literature desk study, semi-structured interviews, and systemic interview evaluation in reference to algorithmic governance framework and leverage point perspective, serve as complementary methods.

The secondary literature desk study allowed for the acquisition of general knowledge on DAS and the selection of a DAS case, namely DFAS. Further, it hinted at existing knowledge gaps. The conducted semi-structured interviews filled many of said gaps and enriched the author's perspective with DFAS provider-specific insights. Last but not least, the systematic interview evaluation allowed for a structured and condensed representation of the obtained insights in the results chapter (see chapter 4). Altogether, this, finally, allowed for a discussion of results, theory, and methods.

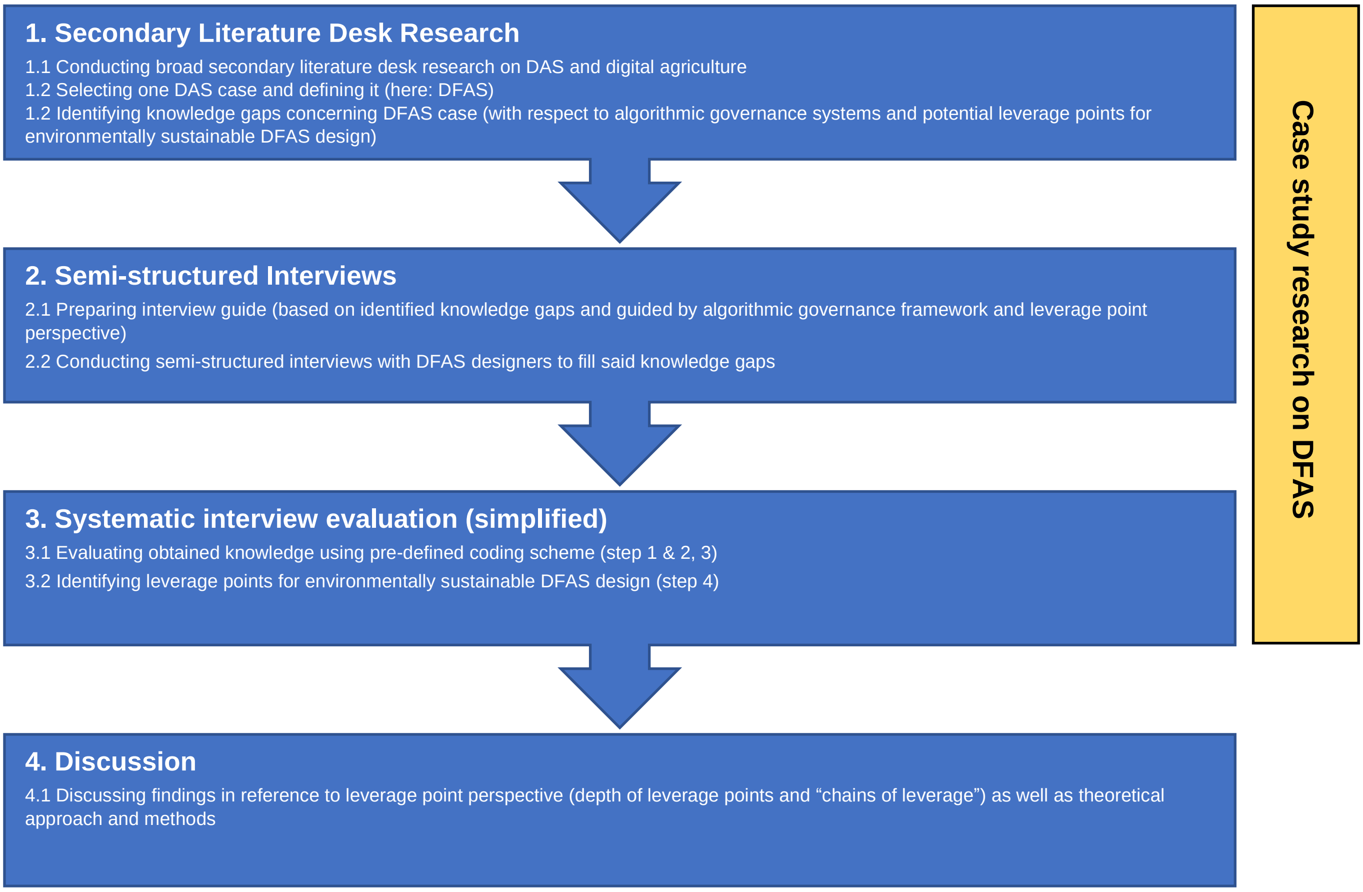


Figure 3: Methodological approach used to conduct case study research and answer research questions

3.3.1 Secondary literature desk study

For the secondary literature desk study, existing materials on DFAS and DAS more broadly in relation to environmental sustainability were identified through Google Scholar searches. Keywords such as "digital agriculture", "digital agricultural advisory services", "environmental sustainability", and "design" were utilized. Materials identified as relevant mainly included grey literature (reports) by interest groups and development agencies as well as scientific articles.

Grey literature was included for its contribution to segmenting and defining DAS cases clearly, for its contribution in proposing design-related, practically applicable measures (fitting the practical purpose of this thesis), as well as for its contribution to enhancing the authors' perspective on DAS and environmental sustainability more generally. Additionally, grey literature reports complemented scientific articles due to their timeliness, and, in some instants, their case-specificness (e.g., CTA, 2019a; GSMA, 2017). Several relatively recently published grey literature reports were found (CTA, 2019a, 2019b; GIZ, 2022; GSMA, 2017, 2019b, 2020, 2022; ISF Advisors, 2021; Porciello et al., 2021; WBCSD, 2021).

Similarly, several, but still a relatively small number of scientific articles, was identified (Bahn et al., 2021; Basso & Antle, 2020; Cobby Avaria, 2020; Fraser & Campbell, 2019; Hrustek, 2020; Kruk et al., 2021; Miles, 2019; Ortiz-Crespo et al., 2021; Rose & Chilvers, 2018; Simelton & McCampbell, 2021) References in these articles were checked for their potential contributions (snowballing).

Most of the identified materials showed vital gaps regarding environmental sustainability in DFAS and DAS more broadly, something that is also hinted at in some high-level reports and articles (e.g., Cobby, 2020; Lajoie-O'Malley et al., 2020). None of the found articles specifically addressed DFAS designers who wish to contribute to enhanced environmental sustainability, pointing to the fact that explorative empirical research is needed. Nevertheless, the secondary literature desk study enabled the delimitation and definition of a clear DAS case, namely DFAS. What's more, it yielded sufficient knowledge for preparing for the subsequent semi-structured interviews, including the interview guide (see Appendix 1). Further, the secondary literature desk study capacitated the author of this thesis to pose fitted follow-up questions to interviewees and to carry out more specific Google Scholar searches regarding distinct topics (Bernard, 2011).

3.3.2 Semi-structured interviews

Fourteen semi-structured interviews with different DFAS designers were conducted to fill the aforementioned knowledge gaps and to gain case-specific insights on the algorithmic governance systems underpinning DFAS (see appendix 2). The interviews were organized through cold emailing, leveraging work-related and university-related connections, and referral sampling. They were performed between May and August 2022. Two of them were excluded for not matching the afore-defined DFAS provider selection criteria (see section 3.1). In addition to the fourteen interviews, one background exchange with the principal author of the paper wherein the algorithmic governance framework is laid out was organized (Eyert et al, 2022). This was done to clarify aspects, which remained vague after perusal and to verify the suitability of the algorithmic governance framework for the analysis of hybridlike cases such as the one of DFAS (see chapter 4). Further, it helped to distinguish some of the algorithmic governance framework's dimensions and subdimensions more clearly and thus prepared the ground for a sound algorithmic governance analysis of DFAS.

Each of the fourteen interviews as well as the background exchange lasted between thirty minutes and one hour fifteen and thereby suited the busy daily lives of expert respondents (Bernard, 2011). All interviews were conducted in English. In the second interview (I 2) two respondents participated and took turns in answering the posed questions. Therefore, personal pronouns in direct citations differ. All interviews were taken remotely via *Microsoft Teams.* This might have limited rapport and narrative flow of respondents (Ibid.). However, remote interviews needed to be conducted because respondents reside in diverse geographic locations around the world.

The recording, as well as the transcription function in *Microsoft Teams,* was used. Prior to recording, all respondents were enlightened about the purpose of the interview and consented orally to be recorded. For privacy protection purposes and to meet good research practices and principles, an additional “Consent form” was sent out either before or after the conduction of interviews. The return rate of these forms has, as of the 4th of January, reached ≈70%.

The structure of the interviews was based on an interview guide which was closely guided by the algorithmic governance framework. Yet, for the interview guide, the order of the dimensions of the algorithmic governance framework (originally: representation, direction, intervention; see section 2.2) was changed (see Appendix 1). This was done for the purpose of guaranteeing a logical approach and ensuring the narrative flow of respondents. Interviews were therefore started with questions about the dimension deemed to be most overarching, obvious, and easily accessible by respondents, and ended with the dimension deemed to be most abstract, and hard to access. Applying these criteria resulted in a reordering of algorithmic governance framework dimensions to “direction”, “intervention”, and “representation”.

The interview guide was slightly refined after the first (pilot) interviews were conducted. The focus of interviews, mainly determined by the number of follow-up questions posed, differed throughout the interview phase, depending on the respondents’ expertise and the knowledge gaps which were most prevalent at a particular point in time. Yet, the core of the interviews stayed the same. In some rather general interviews, the authors’ own conceptualizations of DFAS – based on the secondary literature desk study and prior interviews – were put up for discussion. (cf. e.g., I 7). This was done for the sake of verification or falsification of obtained knowledge, and more generally to obtain a more detailed picture of environmental sustainability in DFAS. In the research methodology literature, this technique is also referred to as “Probing” (Bernard 2011, p. 161), wherein learned insights are put to a test. The contested probing type of “Probing by leading” (Ibid., p. 164), by some researchers perceived as unscientific, was used to clarify certain aspects that respondents did not touch upon naturally, but which were essential for pigeonholing obtained insights (Ibid.).

To cover various perspectives, designated DFAS designers from different professional backgrounds and organizations in the DAS realm such as international NGOs, universities, and startups were interviewed. Besides these considerations of knowledgeability and richness in perspectives, the experts were selected due to their familiarity with the author of this work (i.a., through work and academic relations) and snowballing.

The DFAS mentioned by experts were either designed by themselves, by other members of their team, or by partner organizations. All interviewed experts, except for I 9, who holds a position as “marketing lead”, were in one way or another involved with DFAS design. The explicitly mentioned DFAS operate across different countries in Africa, Asia, and Latin America (in order of representation). This geographical focus resulted by chance and was not chosen deliberately. Some respondents work in organizations that have designed a relatively huge number of DFAS (I 2, I 4, I 11, I 12), while others were directly responsible and/or contributed to the design of one or a couple of DFAS (I 1, I 3, I 5, I 6, I 8, I 9, I 10). One interview was conducted with an academic AI expert (I 7) who is not closely involved with DFAS design but enriched the perspective on the degree of automation in DFAS (see section 4.2.1).

3.3.3 Systematic interview evaluation

For systematic interview evaluation, the automatically generated interview transcriptions were relistened and manually improved at first. Particular attention was paid to interviews with respondents who had a strong English accent. This is because the transcriptions of these interviews were generally less precise. Smooth verbatim, wherein only very few corrections for improved understandability are made, was used as the transcription style. In a second step, the improved interview transcriptions were color-coded based on the seven sub-dimensions of the algorithmic governance framework (see table 1, p. 12) and the additional concepts of "leverage points" and "chains of leverage" (cf. section 2.3). In doing so, the computer program *ATLAS.ti* was used (see appendix 3).

In a third step, equally coded respondents' claims, relevant to the algorithmic governance analysis of DFAS, were compared, ordered, and evaluate. Similar claims were given a fine-tuned keyword among which they were later summarized for the different sections and sub-sections of the "results"- and "discussion"-chapters (cf. Bernard, 2011). In a fourth step, potential leverage points for building environmental sustainability into DFAS were identified for each algorithmic governance dimension. This identification was based on the prior algorithmic governance analysis as well as claims that were color-coded because they hinted at a probable leverage point for building environmental sustainability into DFAS.

Ultimately, the most plausible leverage points according to their power to change DFAS toward environmental sustainability were distilled. Then, the distilled leverage points were assessed regarding their depth and effectiveness respectively in reference to concepts from the leverage point perspective.

No.	Step
1	Revision and improvement of automatic transcriptions by *Microsoft Teams*
2	Color-coding of improved transcriptions in *ATLAS.ti*
3	Comparison and evaluation of similar respondents' claims, attribution of keyword, and summary of similar claims below keyword (see chapter 4)
4	Identification of leverage points based on algorithmic governance analysis and leverage point-related respondents' claims

Table 6: Steps that were undertaken for systematic interview evaluation

4. Algorithmic governance analysis of Digital Farm Advisory Services

Traditionally, extension officers sought to govern farmers' behavior and make them adopt certain agricultural practices. Yet, this has changed. Today, DFAS take on this governing role. This chapter investigates the ways by which DFAS seek to govern farmers' behavior, agricultural practices, and finally environmental sustainability in agriculture. As has been seen in chapter 2, according to Eyert et al. (2022) there are three ways (dimensions) by which algorithms seek to govern: "representation", "direction", and "intervention". In sync with the structure of the fourteen semi-structured interviews, this chapter first examines the "direction"-dimension then explores the "intervention"-dimension, and finally scrutinizes the "representation"-dimension.

4.1 Direction

The DFAS governance direction determines the purpose for which DFAS govern. The governance direction of DFAS is their overriding normative foundation. As such it impacts other DFAS governance through intervention and DFAS governance through representation. Most of the time there is not only one DFAS governance direction.

This section, beyond a general, "Important general aspects of DFAS governance direction" part (section 4.1.1.1) and a part on DFAS actors (section 4.1.1.2), looks at three areas wherein governance direction can be found: 1. The overall governance direction, which concerns the overall goals and standards that are sought to be enforced by most DFAS, 2. The content-related governance direction, which concerns the agricultural paradigm and the agricultural practices being promoted through DFAS, and 3. The service provision-related governance direction, which concerns the standards that DFAS set to govern the agricultural information space in a particular way.

4.1.1 Important general aspects and actors' participation

4.1.1.1 Important general aspects of DFAS governance direction

While intelligible agricultural information is normally shared with farmers digitally, the initial promotion of DFAS, personalized consultations, and the conveyance of more complex information are still supported by field visits in many DFAS projects (I 2). Thus, activities surrounding DFAS are carried out in the digital as well as the analog sphere. Consequently, direction can manifest in both spheres. For that reason, it is referred to as a "hybrid approach" to service delivery (Fabregas et al., 2019; Simelton & McCampbell, 2021). This work principally investigates the direction found digitally.

DFAS are often created (and delivered) through multi-stakeholder partnerships involving both off-the-ground and on-the-ground actors. These are local, national as well as international actors (cf. CTA, 2019a). I 12 explains: "[…] we work with the government agencies, we work with the local NGOs, [we work] with the social organizations […] (I 12)". I 11 echoes this by reporting: "We have projects that are in collaboration with, for example, various CGIARs, with the World Bank. So, each project is really a collaborative undertaking" (I 11). The different actors in such multi-stakeholder partnerships have commonalities and opposites in their directions (see section 4.1.1.2). These are combined and harmonized in a negotiation process throughout the design phase, wherein DFAS stakeholders decided upon the set of agricultural practices that should become promoted by a specific DFAS (I 11).

Planned iterations as well as external changes to the natural and sociopolitical environment of DFAS, can be seen as windows of opportunity for directional change (I 11, I 12). Theoretically, the direction could also change because of dynamic machine learning (Young, 2018). However, as the degree of automation is still low in many DFAS, this is only the case with very few DFAS to date (see chapter 4.3).

The way in which DFAS are created, either through a co-creational, bottom-up, or a technocratic, top-down approach, also impacts DFAS direction. The first approach is increasingly recognized as best practice and is referred to here as "farmer-centered DFAS design" (cf. Ferdinand et al., 2021; Hansen et al., 2019). Farmer-centered DFAS design comprises, amongst others, farmers' needs assessments with the help of focus group discussions and interviews as well as different test and piloting phases, and other feedback loops leading up to needs-based DFAS iterations (cf. Gbangou et al., 2020). It seems likely that, in co-creational DFAS projects, the dominant worldviews of participating farmers prevail in the final DFAS direction.

Additionally, the lead actor as well as the adopted business model impact DFAS direction (I 7). Some DFAS providers are business-to-business or business-to-government enterprises, meaning that they are supplying capabilities and tools to create DFAS to an intermediary client. In many cases, intermediary clients are national governments (GSMA, 2020; I 2, I 11, I 12). The power of business-to-business or business-to-government type DFAS providers over DFAS direction is limited. One of interviewed DFAS providers is an example of a business-to-business or business-to-government type DFAS provider. When asked about their influence on the direction, their respondent answered: "[Our company] is not necessarily influencing the content, it is subject partners who do this […]" (I 2). I 12, from an international non-profit NGO, similarly states: "largely content will be decided by the partner [intermediary client]" (I 12) ". Other DFAS providers are business-to-customer enterprises, meaning that they directly serve farmers. Therefore, they can have a bigger impact on DFAS governance direction.

What's more, the direction of a DFAS is also likely to depend on whether it rather gives general or personalized advice. Those DFAS giving general advice are sometimes also discussed under the terminology of "information services", whereas those giving personal advice are described as "advisory services" (GSMA, 2020). I 6 explains: "what we choose to do is to make sure that these general recommendations […] that that's being communicated to the farmers rather than personal advice" (I 6). In practice, it is difficult to make such a clear-cut divide between general and personal advice. Nevertheless, when staying with these archetypes for argumentative reasons, it can be claimed that information services are more straightforward in their direction as they consider rather general than farm-specific factors. The authority and gatekeeper function of selecting the "right" agricultural information, therefore, lies more with the DFAS provider.

In contrast, some personalized advisory services allow farmers to indicate their preferences which in turn adapts the service to these. Thereby, more power over DFAS governance direction is delegated to farmers. However, selecting preferences seems to be limited to some aspects of a specific DFAS, if existent at all. I 11 gives the example of DFAS customization in maize seed selection wherein farmers can indicate whether they are most interested in "taste", "early maturing" or "drought tolerance" (I 11). If indicating preferences is enabled at a higher level of DFAS customization (not only for seeds but rather for the agricultural paradigm underscoring all agricultural recommendations given by a DFAS), DFAS direction could theoretically fall increasingly into the realm of farmer decision-making. Yet, to date, such design innovations seem far away.

Lastly, some claims by respondents suggest that they seem to be rather uncritical, agnostic, or unaware of the potential direction that their DFAS exert – a circumstance that might have inhibited more pronounced results with respect to the algorithmic governance system analysis of DFAS. I 2, for example, stressed that he "[does not] think we're necessarily trying to steer in one direction or another, but just provide a variety of content that might be useful". He further goes on: "I don't think there was a particular standard [for good farming] used". I 4 cautions: Ultimately, it is above all what the farmers do anyway that is promoted" indicating that she does not think that her DFAS necessarily provokes profound directional changes in agricultural practices (I 4). She later states: "Technology companies tend not to want to influence practices (I 4).

It seems likely that in some companies there is truly little interest in governing farmers' behavior. I 12, for example, affirms that their DFAS tended to be "content agnostic" (I 12). She describes: "[…] initially we were content agnostic. We were like listening to our partners and promoting largely the content, what they wanted us to promote. Slowly, we started prescribing the contents" (I 12). I 11 highlights that her organization, when looking into climate adaptation, first identifies available strategies for a particular context. From those strategies, a particular strategy is then "very purposefully" chosen. This statement gives the impression that all options are always considered and finally the best strategy and thus direction is objectively selected. Even though this might be the case, it ignores the fact that any decision depends on the positionality of the decision-makers.

4.1.1.2 The role of different actors in DFAS direction

The actors impacting DFAS governance direction can be roughly grouped into seven groups: 1. technology designers (DFAS designers), 2. data providers, 3. outreach partners, 4. financiers, 5. international and national agricultural research institutions, 6. government institutions, and 7. other actors. Farmers could as an eighth group, yet in this thesis, their role in governance direction is not scrutinized (cf. CTA, 2019b). Depending on their size and in-house capabilities, one group often takes on several roles.

1. Technology designers (DFAS designers)

Technology designers, in this thesis also referred to as "DFAS designers", normally develop the backend as well as the front end of DFAS (I 11, I 12). They work at DFAS providers. Technology designers are the architects of the overall DFAS model and the algorithmic governance systems underpinning it. The overall DFAS model processes different types of data, either collected by technology designers themselves or data providers. Finally, agricultural recommendations are inferred from this model (I 12). While the organization of I 12 is provided with "raw content" externally, modeling that content as well as the programming of all algorithms is carried out internally. She explains: "[…] we take all the required raw content from them [partners] and then we build the algorithms. We design that entire flow […]" (I 12). In case content-related capabilities are existent in-house, particularly agronomic and/or communications knowledge, technology designers can also be engaged with curating the information utilized in agricultural recommendations (I 2, I 12). Due to their important tasks, it seems plausible that technology designers starkly impact DFAS governance direction.

2. Data providers

Data providers collect and provide raw and/or pre-processed data to technology designers. This data is then either directly visualized and displayed to the farmer or fed into the technology providers' (overall) DFAS model(s). I 9 explains: "we have external providers [data providers] that provide us with […] the weather and we transmit that to our clients (I 9)". Data providers can have command over storage, processing, analyzing, and modeling capacities (CTA, 2019a). What's more, they can be public or private. Weather data, for instance, is collected by public *National Meteorological Organizations (NMOs)* in many countries (Ferdinand et al., 2021; Hansen et al., 2019). Crop data can be produced publicly, for example, by agricultural research institutes, or privately, for example, by seed providers (I 1). Data providers often supply technological providers with application programming interfaces (APIs) that allow for data exchange (I 12). Data providers impact DFAS direction through the way they produce data. This includes aspects such as how, for whom, and which data is produced.

3. Outreach partners

Outreach partners are normally locally rooted NGOs and farmer organizations such as farmer cooperatives, associations, and/or agro-dealers, some of which have their own field staff (I 1, I 11). In case a DFAS is implemented together with the government, the government's extension department is likely to be involved in fulfilling the function of DFAS outreach partners (I 12). Outreach partners normally hold expertise in how to communicate with farmers effectively – be it digitally or analog. Thereby, they increase the probability of DFAS and ultimately agricultural recommendation adoption. This means, inter alia, that outreach partners speak the farmers' language, know their vocabulary, and are aware of indigenous concepts in agriculture (e.g., for the amount of rainfall) (Gbangou et al., 2020; Hansen et al., 2019).

Outreach partners use their networks for DFAS promotion and other information diffusion purposes. Besides NGOs, farmer organizations, and agro-dealers, mobile network operators are equally important outreach partners, however so, in the digital sphere. Mobile network operators provide farmers with mobile communications as well as mobile internet and thereby eventually enable DFAS. By setting the SMS price, IVR calls, and/or mobile data usage, mobile network operators greatly determine DFAS reach (Fabregas et al., 2019; I 2). The other aforementioned outreach partners rather exert a particular governance direction in the analog sphere. They feed important, locally obtained information into the DFAS design process. In co-creational DFAS projects, the outreach partners' impact on direction is bigger than in technocratic ones.

4. Financiers

DFAS financiers can be government institutions (e.g., agricultural ministry), but also international (development) organizations, agribusinesses, (impact) investors, or a combination of these (cf. public-private partnerships). Through the public *Netherland Space Office*, for instance, several grants were given to DFAS providers (I 3, I 5, I 8; also: https://g4aw.spaceoffice.nl/en/g4aw-projects/g4aw-projects). I 1 reports that he developed a DFAS in Bangladesh that is tied to and financed by a seed company (I 1). Another DFAS was financed by agribusiness company *Bayer* after the public funding ended (I 8). The DFAS that were developed by the interviewed information provisioning company for several developing countries are delivered and financed by different telecommunication providers (I 2). Other

DFAS are financed by (impact) investors (through series funding) or public "extension system funds" (I 11, I 12).

With the funding might come conditionality, possibly impacting DFAS direction (cf. I 1, I 8, I 12). I 7 cautions: "[For-profit DFAS providers] are really in it to make money […] and you don't know if they have any secondary use of the data that the farmers provide. […] if a large fertilizer company funds one of these startup advisory systems, you have a good idea in which direction their advice will go […]". Correspondingly, I 12 recalls a public-private partnership-based DFAS project wherein there was a conflict of interest concerning farmer data sharing. I 10 mentions that her organization is currently in talks with fertilizer and other agricultural companies regarding the sale of their big farmer and crop data. At the same time, seemingly contrary, she explains that, even though her DFAS is implemented and financed by a seed company, it does not seek to drive seed sales by giving seed-related agricultural recommendations (I 10).

DFAS accomplish revenues either directly or indirectly. Direct revenues usually come from farmer subscriptions, commissions, and/or in-service advertisements for agricultural products (CTA, 2019b). It stands to reason that while subscription-financed DFAS are relatively independent and act in the interests of farmers, commission and advertisement-financed DFAS are more dependent on either the party paying the commission or the advertising party. The latter could potentially bias agricultural recommendations and thus impact DFAS governance direction (I 12). Indirect revenues are realized from the sale of other products that show higher demand thanks to the DFAS offering. Some mobile network operators, for example, can increase their airtime and mobile data revenues by adding a free DFAS as an additional offering to their portfolio (GSMA, 2021). The prospect of indirect revenues could impact DFAS governance direction in case indirect revenues originate from agriculture-related fields.

In general, many DFAS providers operate under financial constraints, and some are even endangered to go bankrupt (CTA, 2019; GSMA, 2020, I 1, I 8, I 12). I 8 reports that his two DFAS projects for Indonesian farmers "both have hard times to develop [a] business case to keep running" (I 8). Financial constraints could enhance the financiers' leverage over DFAS direction.

5. Agricultural research organizations

International and national agricultural research organizations (often under the guidance of agricultural ministries) often supply technology designers with the most recent scientific agricultural information relevant to their computational processes. This scientific agricultural information can be, for example, on new varieties or new agricultural technologies. Potentially more important for the direction of DFAS is the fact, that agricultural research organizations often provide technology providers with a set of agricultural practices which can or ought to be considered for a DFAS for a specific region or country. It is likely that this set of agricultural practices indirectly depends on international agricultural research agendas. I 6 hints at the impact of research organizations when stating: "[…] we're not there to determine the good practices for Burundi, but we're following organizations like *ISABU* [Burdian Institute for Agronomy]" (I 6). I 9 likewise highlights how close their entanglement with research institutions is:"[…] we are working with the leading research centers. And our satellite imagery is directly compared to, you know, the models that they have and from that, we produce a result" (I 9). It seems plausible that research organizations, with the help of their objective, and scientific character, and by contributing a blueprint for the set of promoted agricultural practices, play an important role in content-related DFAS governance direction.

6. Governments

Government institutions, depending on the country, take on several of the aforementioned roles (I 1, I 2, I 12). In some countries, specialized governmental agencies and/or departments cover a broad range of roles that are necessary for DFAS design and operation. In other countries, government institutions only fulfill minor, but not necessarily unimportant roles, such as providing open and free weather data through their national meteorological organizations (Ferdinand et al., 2021; Hansen et al., 2019).

Often the agricultural ministry or another government authority controls the agricultural information space. I 2 substantiates this when saying that in many DFAS projects, "there is an [governmental] approval process on what can be put on the service (I 2)". I 11 reiterates that "they [government institutions] cross-check our advisory […] to make sure that […] they are happy with it […] (I 11)". I 6 goes further when making clear that, in the context of rigid, preservative governments, there is a limited probability for change in the agricultural practices that are promoted by DFAS (I 6).

In cases, in which the government is the commissioner, analog extension practices might merely become digitized for a DFAS as evidenced by I 1 and I 12. I 12 describes this form of cooperation: "there's a […] state government who wants to promote XYZ practices to the farmers and now they partner with *[our company]*, seeking their help in taking this to the farmers in different technologies [..]" (I 12). In some countries, several government departments and sub-departments are working in the agricultural extension realm (I 12). Accordingly, there can be different directions impacting DFAS design (I 12). Interestingly, some business-to-government DFAS providers aim at an integration of their DFAS into the bigger governmental extension system. This is facilitated by pieces of training for governmental extension staff (I 4, I 12). All given reasons create the impression that governments, as gatekeepers for information in the agricultural space and owners of many DFAS, starkly impact DFAS governance direction. However, governments heavily depend on the agricultural expertise of agricultural research organizations (see above) (I 11).

Other actors

Besides these concrete actors and their roles, several respondents mention that DFAS governance direction depends on the "partners" of technology providers. DFAS partners have normative preferences (I 2, I 4, I 11, I 12). This seems particularly the case with DFAS projects that are commissioned by third parties (I 2, I 4, I 11, I 12). I 4 explains: "the farming practices that are included are mostly based on what our partners suggest to include (I 4)". Therefore, the team of I 4, when choosing partners, makes sure that "[…] they are […] ethically, good partners." (I 4). In contrast to this, I 11 reports: "I wouldn't say [partners] influence. I would say we collaborate together (I 11)". I 6 cautions that a distinct uniformity in the communications with farmers is needed. He says "we align as much as possible to [the] best [agricultural] practices […] being communicated in Burundi. So that all organizations speak with one voice" (I 6). This points to the fact that an existent governance direction in agricultural development might become amplified by DFAS.

Regarding the profession of experts, DFAS governance direction is strongly influenced by "agronomists" (I 5, I 8, I 11). I 11 explains "[…] our agronomists on staff are really the lead in thinking about [the recommended agricultural practices] because they know the context very well and the specific geography and the farmers that we're working with […]". Given that sciences, including agronomy, tend to follow a specific scientific paradigm at a specific point in time (Kuhn, 1970), it is likely that the dominant thought in agronomy thus affects DFAS governance direction.

4.1.3 Overall DFAS governance direction: Improve livelihoods

The overall governance direction and general goal respectively of most DFAS is to improve the livelihoods of farmers (I 1, I 3). For-profit DFAS providers also pursue the goal of profit maximization. I 3 expresses that his DFAS project in Vietnam had "[…] [a] twofold purpose […] to eventually improve the lives of the rice farmers […] [and] to create a commercially viable information service in a way that the revenues generated […] cover the costs for providing it" (I 3). Some DFAS have a particular focus on poor and small-scale farmers (I 2, I 4). DFAS aim to realize improved livelihoods by contributing to higher incomes and yields (I 1, I 2, I 10), which are seen here – through the lens of algorithmic governance– as standards for the general goal (see chapter 2). Food security has been also raised as a standard for DFAS providers (I 10).

Higher incomes (Standard)

DFAS, amongst others, seek to contribute to higher incomes by improving the marketability of the farmers' crop portfolio (I 1, I 2). For that purpose, several DFAS connect their service to some form of marketability tools such as market price information and yield estimation (I 9, I 10, I 12). These tools can influence the decision for a type of crop and the amount of this crop being planted. They can also impact the timing of harvest and/or the market at which the crop is sold. What's more, marketability tools can steer the decision for a particular crop quality (I 12). The interviewed Moroccan start-up, for example, offers a service that estimates the harvest time of corn silage and another service that estimates yields (I 9). DFAS can additionally enable farmers […] to grow high-value crops" (I 2) or to diversify crops to realize higher incomes (I 1).

Higher yields (Standard)

High yields and/or agricultural productivity is another standard set by DFAS providers to improve farmers' livelihoods. I 5 describes her company's mission as being "able to give them [farmers] insights […] to ensure that they get the optimum yield (I 5)". I 9 similarly reports "our whole strategy is around optimizing a farming system from irrigation to harvest to yield and inputs (I 9)". I 10 highlights that making farmers use their inputs such as fertilizer, pesticides, and water "efficiently and productively" is one of her DFAS' desired contributions. "Input efficiency" can be named as an exemplary substandard for the standard of "high yields and/or agricultural productivity". Having the algorithmic governance framework in mind, these two standards, which are horizontally nested within one another, could be referred to as a "standard cascade" (Eyert et al. 2022, p. 9).

Indicators

Indicators serve as "judgment devices" (Eyert, p. 9) to verify in how far the aforementioned standards are accomplished. They come to the fore in impact studies and/or the reporting of DFAS providers (Fabregas et al. 2019; GSMA, 2017; I 6). Herein, yield, as well as income increases, are normally reported in "%-increases per season or year". A way in which agricultural productivity is usually measured on a more general level is the "yield gap"-indicator – the difference between the potential yield and the actual yield for a specific crop. Generally, as cautioned by I 1, I 6, I 8, I 10, and I 11, such (impact) measurements and the role of DFAS therein need to be approached with skepticism. Seasonally changing weather and the general conditions in which impact studies are carried out negatively influence their validity. Said conditions, inter alia, lead to observational effects and over-reporting (I 1, I 6, I 10, I 11). What's more, remote verification technologies such as remote sensing are impeded, for example, by cloudiness in the sub-tropics (I 8).

4.1.4 Content-related governance direction: Fostering a particular agricultural paradigm

In this section, the direction of the agricultural content that is integrated into DFAS is scrutinized. This includes particularly the agricultural practices which respondents referred to. From the mentioned agricultural practices, this thesis tries to infer the agricultural paradigms and thus overall content-related DFAS governance direction.

The content-related DFAS governance direction and the standards for good farming promoted through DFAS depend on the covered specific geography, value chain, and crop(s) (I 11). I 11 explains "[…] based off the specific agronomic conditions in and the value chains that we're working within each country we'll customize our advisory to what's most appropriate" (I 11). This gets mirrored by I 3 who illustrates the context of his company's DFAS for rice farmers in Vietnam: "Vietnam has a large history in using chemicals in agriculture. And they have a kind of mentality of better safe than sorry. So, there is quite an overuse of chemical use in rice production in Vietnam. So, that's one of the things that we advise them in. (I 3)".

Generally, DFAS aim to provide farmers with agricultural recommendations throughout different crop stages, "[…] starting from the pre-harvest until harvesting information" (I 10). Farmers are advised when to undertake which farming practice. What's more, some DFAS inform about irregularly upcoming events such as pests and diseases (I 8, 11). To identify suitable practices, aspects such as their impact on yields, associated labor costs, technological inputs, and land conditions are considered (I 11). Several respondents indicated that their DFAS seeks to strike a good balance between benefits for the environment and the farmer (I 3, I 9, I 11).

Based on the agricultural practices that respondents mentioned, it became clear that there is not one specific agricultural paradigm or form of carrying out agriculture that is being fostered through DFAS. I 11 substantiates this by saying […] we don't stick to one specific paradigm. It's really about understanding the soils and the specific environment that we're working in (I 11)". I 4 cautions that her company has paradigmatic preferences, but not necessarily a general strategy for implementing them (I 4).

In contrast, most DFAS seem to apply a mix of agricultural standards and practices that stem from different agricultural paradigms. I 11 underscores this hypothesis when saying: "[…] it's certainly not only organic or only conventional. It's sort of a mix of what is most appropriate for the specific farmers and geographies and value chains that we're working with (I 11)".
The possible DFAS governance directions are also limited by farmers' resources and existing backward and forward market linkages. I 6 estimates that due to these aspects, 50-80 % of Burundian farmers practice conservation agriculture. Yet, they never explicitly decided to do so (I 6). Correspondingly, I 4 mentions: "[…] since we focus on small-scale farmers, I would say it goes more towards the [governance] direction of organic farming (I 4)" pointing to the fact that the target group of a DFAS and the conditions of the very same also determine DFAS governance direction.

What's more, due to relatively open definitions and overlaps in agricultural practices, it is often impossible to distinguish promoted agricultural paradigms. To the question as to how far his DFAS promotes a particular idea of good farming, I 6 stresses: "I cannot point you to a textbook. But this to me, that's also a bit theoretical, like there's one solution for all (I 6)". Furthermore, most DFAS are evolving, meaning that they add new and/or eliminate old agricultural practices, some of which belong to different agricultural paradigms. I 8, for example, describes that their old DFAS version was conventional, whereas their new DFAS version contains an integrated pest management module, which points to an environmental sustainability-sensitive agricultural paradigm being promoted (I 8). A clear content-related governance direction further gets diluted by the magnitude of agricultural topics and aspects covered by one DFAS (I 8, I 11). "[Promoting] techniques that are different from traditional farming" (I 9) is named as a rather paradigm-agnostic governance direction.

Even though there is no clear overall content-related DFAS governance direction, several standards for good farming have been mentioned by respondents. These standards have been adopted by their particular DFAS. In the following, only the standards and substandards that have been raised by several respondents or have been strongly emphasized by individual respondents are enumerated. All presented standards and substandards are exemplary.

Three respondents refer to the usage of standards developed by international organizations (I 6, I 8, I 11). I 8 indicated that one of his DFAS uses the labeling of the *Food and Agriculture Organization (FAO)* regarding the toxicity of pesticides. I 6 states that his organization cooperates with the intergovernmental development and information organization *Centre for Agriculture and Bioscience International (CABI)* in matters concerning good agricultural standards and practices. With respect to pest and disease practices, he explains the CABI standard as follows: "[…] first it's about prevention, so you need to implement a number of things to make the risk lower and then see if you can use what they call green measures […] then there are the yellow measures where chemicals are involved […] (I 6)". Additionally, I 11 mentions that, in a project in India, her organization works together with the *Better Cotton initiative*, an international initiative that has established a sustainability standard for cotton farming.

Precision agriculture (Exemplary standard & substandards)

Moreover, several respondents explicitly name "precision agriculture" and/or insinuate the application of the very same (I 5, I 8, I 9, I 10). While I 9 explains: "[…] the farming practices that we promote are mostly in precision farming practices since what we do is to help optimize inputs […](I 9)", I 5 elucidates: [we] give them [farmers] insights, uh, or give recommendations on which areas to focus on […] because maybe they are lacking in water or nutrients […] (I 5)". Exemplary substandards to precision agriculture are optimized nutrient management and optimized irrigation scheduling. However, it needs to be cautioned that these substandards can also be practiced within agricultural paradigms or agricultural concepts other than precision agriculture.

Through promoting practices in the realm of optimized nutrient management, DFAS seek to contribute to maximizing yields and farmer profits and at the same time reduce adverse effects on the environment, for example, caused by nutrient leaching (I 9). I 9's startup developed an app that "give[s] you [the farmer] exactly what the land needs in terms of inputs (I 9)". Generally, DFAS that promote optimized nutrient management seek to inform farmers on the right amount, rate, place, and form of nutrient application throughout different crop stages (I 10). Seeking to establish the practice of optimized nutrient management means that DFAS govern farmers in this direction. To promote the usage of a specific input/fertilizer brand would be an even more tailored governance direction. I 10 reported that her DFAS is not trying to make farmers use a specific fertilizer brand, but that all accessible brands in a particular location are being promoted (I 10).

Another substandard of precision agriculture is optimized irrigation scheduling. The solution of I 9 "takes into account a farmer's water stock and it'll give you precise irrigation planning based on real crop needs (I 9)". I 9 further mentions that her company uses the sub-substandard of "deficit irrigation", wherein a balance between water availability and crop demand is stroked. I 5 elaborates that her company uses satellite imagery to identify the soil moisture on their clients' agricultural lands. This then allows focusing irrigation of those areas with low soil moisture.

Sustainable Agriculture (Exemplary Standard)

Other practices raised by respondents point to a DFAS governance direction that promotes the concept of "sustainable agriculture". Some DFAS recommend organic inputs only (I 5). Furthermore, several DFAS strive for a balance between improving farming results without exacerbating environmental conditions (I 5, I 9).
The raised standards of "alternate wetting and drying" (I 3), "drip and solar irrigation" (I 5), as well as "integrated pest management" (I 8) can be associated with sustainable agriculture. What's more, sustainable farming practices such as mulching, planting crops in pits (I 5), intercropping, and composting (I 6) are named. I 12 explains that in many of her projects, natural farming was the standard. She outlines that her DFAS promoted "[…] all these natural farming practices, which are basically, you know, chemical free and with zero cost of production, so basically, with the low input (I 12)". Other exemplary aspects that are considered in the natural farming standard, according to I 12, are soil fertility, farmers' debts, and climate sensitivity.

Other content-related standards

Other DFAS providers contend that they merely seek to improve existing practices (I 4, I 6). According to I 6, this is where the biggest leverage for livelihood improvements lies. There is, for example, a misconception among the farmers that his DFAS serves: Many farmers believe that putting more seeds into a planting pocket will lead to more plants. This neglects the fact of resource competition. His DFAS, therefore, delivers content to resolve such misconceptions. I 6 additionally mentions that his company has more complex sustainable agriculture concepts such as crop rotation at its disposal, which are, however, due to the current "knowledge level of farmers", not yet promoted. This points to the fact that DFAS which rigorously assess the preconditions of their target farmers and thus operate heavily demand-driven, putting farmers at the center, have limited content-related governance direction. They seem to rather reproduce and slightly improve what is already practiced by farmers.

Content-related indicators

Depending on the particular standard, several substandards are pursued by DFAS at the same time. Different indicators make the achievement of a standard measurable and allow for further improvements. For optimized nutrient management, for example, nutrient use efficiency and/or nitrogen use efficiency, are frequently used indicators. In contrast, for alternate wetting and drying, for instance, water efficiency can be a well-suited indicator.

4.1.5 Service provision-related governance direction: Controlling the agricultural information space

What is named "service provision-related governance direction" here, refers to principles and standards applied to the dissemination of agricultural information by DFAS. As new players in the agricultural information space, DFAS increasingly exert control over this space.

For some DFAS one of the general goals and/or standards is to provide free information and knowledge on agricultural practices (I 2, I 4, I 6, I 7, I 11). I 11 claims: "our services are free to anybody who uses them, and we are very committed to that (I 11)". This is particularly so, because "many farmers don't have the money to pay for those services (I 4)". Guaranteeing access to as many farmers as possible is also named a general goal (I 2). I 2, for instance, compares her companies' IVR services to a "Google for people who don't have access to [the] Internet (I 2)". "High impact and reach of the provided information" are additional standards that DFAS providers aim to live up to (I 2, I 11). What's more, it is mentioned that DFAS seek to keep pace with new agricultural developments and update recommendations continuously.

Additionally, some DFAS aim to enhance the amount of agricultural information available to individual farmers (I 9). An exemplary substandard to the former is the provision of scientific information. I 8 explains that one of the DFAS he helped set up contains "the best science-based information you can get as farmer (I 8)". This is echoed by I 9 stating that her company "give[s] them [farmers] modern techniques that are based on scientifically proven data (I 9)".

Some of the DFAS providers continuously measure the quality of their content and/or the receptiveness to their content in farmer populations. Therefore, they developed specific indicators. I 2, for example, mentioned that having at least 75 out of 100 farmers listen to a specific IVR message is his company's success measure. He states, "there are messages which generally do better than 75% and then there are messages which don't necessarily touch 75% (I 2)". Commissioned DFAS providers share such "performance data" with their commissioning party (I 2). Based on performance, agricultural recommendations are modified, placed elsewhere in the IVR menu, or removed. Similarly, I 12 reports that her non-profit tracks the success of messages and has developed success indicators such as "pick up rate" as well as "listen rate". These help, for example, to identify "how many farmers received […] an outbound IVR call (I 12)".

4.1.6 Summary: Governance through direction in DFAS

As has been shown above, several different actors play a role in determining DFAS governance direction. This is because DFAS are often developed in multistakeholder partnerships. National governments and their agricultural institutions as well as technology providers (DFAS providers) tend to be comparatively powerful in setting a particular DFAS governance direction. What's more, DFAS governance direction is influenced by the particular agricultural context for which a specific DFAS is developed.

As overall governance direction, "improving livelihoods" was identified. This is sought to be achieved through the standards of "higher incomes", "higher yields", and "agricultural productivity". For-profit DFAS parallelly aim for profit maximization. Based on the promoted agricultural practices, it is difficult to point to one specific content-related DFAS governance direction or put differently, to one agricultural paradigm that is explicitly being promoted by DFAS. A mix of promoted agricultural standards and practices was identified which is decided upon in the negotiation process between different DFAS stakeholders. Regarding the service provision-related DFAS governance direction, the standards of providing free, accessible, and scientific agricultural information to a large number of farmers was recognized.

1. Overall governance direction: Improving livelihoods/ (profit maximization)	2. Content-related governance direction: Fostering a particular agricultural paradigm	3. Service provision-related governance direction: Controlling informational space
Standards	Standards	Standards

• Higher incomes
  • Marketability
  • Diversification
• Higher yields
• Higher agricultural productivity
  • Input efficiency
	• Precision Agriculture
	  • e.g., Optimized fertilizer management
	  • e.g., Optimized irrigation scheduling
	• Sustainable Agriculture
	  • e.g. Alternate wetting and drying
	• Natural Farming
		• Free information
		• Accessible information
		• Scientific Information

Table 8: Overview of the three directional areas in the algorithmic governance systems underpinning DFAS and their standards and sub-standards

4.2 Intervention

The “intervention”-dimension, also referred to as “effective dimension” scrutinizes all way by which DFAS seek to move farmers towards contributing to pre-defined desirable states (see 4.1.3 and 4.1.4). Two aspects necessitate special attention when assessing how DFAS governance is carried out: 1. The “degree of automation” with which DFAS seek to govern, and 2. The “strategies of influence” which are applied to steer farmers’ behavior (cf. Eyert et al, 2022).

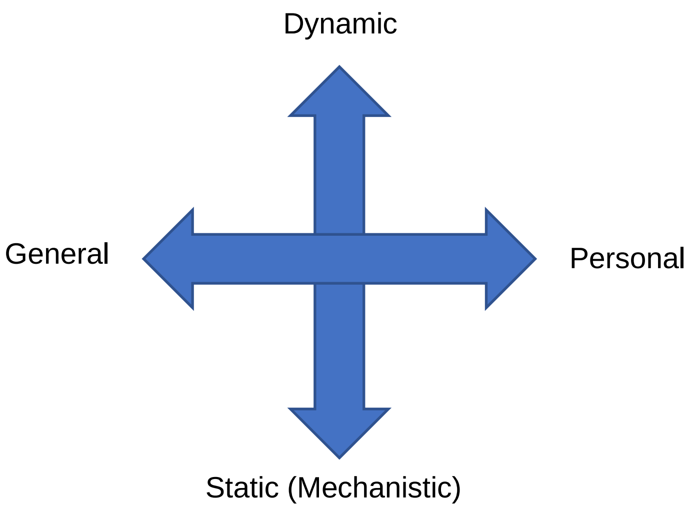
4.2.1 Degree of automation

In the context of the “degree of automation” sub-dimension, the degree of algorithmic decision-making in DFAS, and the ways by which DFAS designer attempt to automate DFAS governance, are analyzed. Eyert et al. (2022) leave many aspects that could be subsumed under the “degree of automation”-sub-dimension unmentioned. This thesis, therefore, chooses its own focus and concentrates on the degree of automation and the role of algorithms in creating agricultural recommendations. This focus is taken because agricultural recommendations are assumed to be one of the main sources of farmers’ governance. Based on this basic assumption, it is concluded that the automatic creation of agricultural recommendations is closely related to DFAS governance automation as a whole. Further, this thesis analyses the role of algorithmic decision-making in different phases of DFAS development.

The degree of algorithmic decision-making in DFAS varies. This thesis assumes that depending on the degree of algorithmic decision-making, either algorithmic or non-algorithmically governance emanates from DFAS. Which of the two is stronger, is beyond the scope of this work.

Generally, algorithmic decision-making in DFAS is mainly leveraged for the generation of agricultural recommendations. Implementing agricultural recommendations is the responsibility of the DFAS-facing farmers themselves. How much algorithmic decision-making is involved in the creation of agricultural recommendations depends on the types of agricultural recommendations that are delivered to farmers. The creation of general and static agricultural recommendations normally necessitates less algorithmic decision-making than the creation of personal and dynamic recommendations.

General agricultural recommendations are defined here as recommendations that are not tailored to particular farms, farmers, and their crops. Crop growth stages need to be assessed manually by farmers themselves. Grounded thereupon, the most suitable agricultural recommendations need to be equally identified self-independently. Static agricultural recommendations also referred to as "mechanistic" recommendations (I 7), are recommendations that neither explore data patterns between model inputs and outcomes nor do they automatically adapt thereupon. They still give crop-specific recommendations according to archetypical crop growth patterns. Personal agricultural recommendations are recommendations that are tailored to particular farms, farmers, and their crops, whereas dynamic agricultural recommendations are recommendations that, based on automatically assessed crop growth stages and machine learning algorithms, change dynamically and adapt continuously (for more detailed descriptions of different DFAS types, see chapter 4.3.2). Grounded on the types of agricultural recommendations they send out, DFAS can be characterized differently.



Main characteristics of different DFAS and agricultural recommendations respectively

According to I 1, automating the creation of agricultural recommendations is the only way for them to be personal and dynamic (I 1, I 4). He makes clear: "If you have 100,000 farmers on the system, you cannot manually start analyzing and interpreting certain data. That has to be done in an automated fashion because otherwise, it's undoable (I 1)". Based on the fact that many DFAS automate the generation of agricultural recommendations, and assuming that these recommendations then seek to govern farmers' behavior towards a certain notion of good agriculture (see Section 4.1), this thesis argues that farmer' governance itself is sought to be automated by DFAS.

In contrast to I 1, I 5 mentions that her startup is "still a bit manual". She sometimes uses emails to convey agricultural recommendations to her clients, whereas I 9 states "[Our DFAS] is fully automated. The decision rules are directly integrated into the models. So, for every analysis that's made, an advice is automatically generated for the farmer (I 9)". The latter points to the fact that a huge degree of algorithmic decision-making is at play in said DFAS. I 10 describes that her solution offers a pest and disease database including photos. However, to obtain agricultural recommendations concerning a specific pest or disease, farmers need to search the database and identify the pest or disease by "analog observation" (I 10).

Increased personalization and dynamization and thus algorithmic decision-making in DFAS is only possible when certain data, in particular crop and weather data, and particular agricultural models are available (see also chapter 4.3). I 8 illustrates: “Yeah, in Bangladesh, it's completely automated. […] there's a lot of weather forecasting [in the background]. We have a fungal disease model and remote sensing data about the crop development that also influences the spay advice [advice concerning pesticide application] and that's all automatic (I 8)”.

The degree of automation in DFAS is limited by external factors such as data availability. However, some DFAS providers have consciously decided to limit the automation of farmer governance through their DFAS. I 6, for example, cautions that due to low data quality, the automated generation of agricultural recommendations is prone to errors (I 6). It is likely that neglecting such factors and still sending out automatically produced, yet false agricultural recommendations could hurt the extent to which DFAS can govern farmers' behavior. Trust is an important prerequisite to being able to influence farmers as will be seen in the following section. Possibly for this and for other reasons I 6 pursues a rather low-tech approach with limited automation of farmer' governance. Other providers seek to find partners that can help dynamize their content and thus increase DFAS governance automation (I 2).

Automation needs to be also differentiated alongside different stages of DFAS development, which are described in an archetypical manner below. Hence, some aspects might, whereas others might not apply in an explicit DFAS development process. In the first stage of DFAS development, it is normally orally agreed upon a certain set of agricultural recommendations that will be promoted through a DFAS. Normally, the actors involved with DFAS development negotiate such an agreement. Algorithms play hardly any role in such negotiations. I 11 explains: […] we don't use algorithms to develop our agronomic advice (I 11)”.

In the second stage, the decided agricultural practices are digitized and modeled. This means that parameters that relate to specific agricultural practices are defined, relationships between parameters are determined and numerically formalized, and algorithms are written and integrated into an all-encompassing computer model (also “overall DFAS model”, see section 4.1.1). This process includes programming crop-specific thresholds into the model (e.g., point in time when the crop needs water). If thresholds are reached, as verified by continuous and automatic, model-based simulations including the computation of several relevant crop-related values, a message will be automatically generated and conveyed to the DFAS user (third stage) (I 1). The content of the messages is based on the computed values which are translated into understandable, entertaining, and actionable pieces of information for the farmer. Yet, there are some nuances regarding the automation of message generation. For their MUIIS project, for example, CTA automated the generation of messages, but agronomists had to approve and at times improve these before they were ultimately sent out to farmers (CTA, 2019).

Farmers finally decide whether they implement the recommended agricultural practices, and is thus an unautomated process (I 4, I 11). I 11 explains: “we can only do so much as presenting them with the information about what's available. But […], it's their ultimate decision what they do (I 11)”. Thus, there is human decision-making rather than algorithmic decision-making. DFAS can therefore also be referred to as “recommender systems” (also “decision support systems”) which are “intended to direct or guide an individual's decision-making processes in ways identified by the underlying software algorithm as optimal (Young 2018, p. 4)”. Two DFAS providers mentioned that they have internal digital platforms facilitating the second and third stage (I 11, I 12). I 11 states: "[…] the advisory that we're actually sending, we program into the platform, and that gets sent out. (I 11)".

If a DFAS has passed through the aforementioned three stages, it is operational. Many DFAS are, once agricultural recommendations are decided for and have been modeled, "kind of fixed", at least for a period of time (I 1). Yet, in a fourth stage, analog or automated revisions leading to a DFAS update, could possibly be made (I 7) (see also chapter 4.3.2)

Stage of DFAS development	Due tasks	Degree of automation (depends on aforementioned main characteristics of DFAS)
1. Pre-design phase	Negotiating a set of agricultural practices	Low
2. Design phase	Modeling of content/ agricultural practices	Medium
3. Delivery phase	Generation and sending out of agricultural recommendations	Medium - High
	Implementation of agricultural recommendations	Low
4. Iterations for improvement phase	Retraining models, reprogramming thresholds	Medium - High

Table 9: Degree of automation in different DFAS development stages

Additionally, as has been mentioned above, most DFAS are delivered in a "hybrid approach" (Fabregas et al., 2019; Simelton & McCampbell, 2021). Thus, there is an analog and digital arena wherein DFAS governance plays out. This approach, inter alia, is followed because conveying agricultural recommendations in an automated fashion risks farmers' non- or mal comprehension. In many contexts, DFAS have an insufficient impact, when merely sending out messages (Fabregras et al., 2021). This is because some agricultural recommendations necessitate further explanations, real-world demonstrations, and addressing farmers' worries to convince them of adoption. I 1 explains: […] when you get into […] more complex advisories […] you have to do that together with the extension system because they can better […] go to the field and they can discuss with the farmer to find out what the problem is (I 1)". I 9 adds that her company's on-the-ground agronomist teams, "[…] help farmers analyze the data that the digital platform gives them (I 9)".

Besides field staff, there are other venues through which additional explanations can be realized. Several DFAS, for example, operate call centers with agronomists which address farmers´ questions and worries (I 1). Others have added a chat function to their app, that allows farmers to communicate with researchers and other specialists (I 8). A relatively new development is the deployment of chatbots for farmers' "personal assistance (I 12). Contrary to the aforementioned ways of analog assistance, such algorithmically enabled assistance is based on a higher degree of automation. When asked about the limitations of automation, I 12 responds: "[…] there are certain limitations, but somewhere it has to be also a mix of things, say 70% of the digital, at least 20- 30% of analog should come in […] (I 12)", pointing to the suitability of a hybrid, not fully automated approach to DFAS design.

4.2.2 Strategies of influence

The most prevalent type of "strategy of influence", which is used by DFAS to govern farmers' behavior, is "initiation of re-interpretation" (cf. Eyert et al. 2022, p. 11). DFAS initiate reinterpretation by providing farmers with new agricultural information. This information allows farmers to compare and evaluate the advantages and disadvantages of the new, recommended agricultural practices against their habitual, old agricultural practices. This can lead to the adoption of potentially better new agricultural practices. Yet, the likelihood of re-interpretation and other strategies of influence heavily depend on the creation of convincing agricultural recommendations (see section 4.2.2.1), the usage of the right modalities and venues for communicating agricultural recommendations (see section 4.2.2.2), and the application of tailored meta-strategies. As will be seen later, all these strategies, if applied intelligently, are likely to augment DFAS governance.

However, due to the sophistication of DFAS and new modes of delivery, new "strategies of influence" are increasingly used and/or become increasingly available to DFAS designers. Among them are strategies that can be subsumed under the "influence through non-rational properties", the "inducement", and the "architectural constraint" types of "strategy of influence" (cf. I 2, I 11, Fabregas et al., 2019). "Influence through non-rational properties" is based on the exploitation of heuristics and cognitive biases in farmers to steer their behavior toward a desired direction. "Inducement" is based on a positive change in the incentive structure regarding a particular agricultural practice. Lastly, "Architectural constraint" is "[…] influence through the opening or closing of possible courses of action in environments to which regulatees [farmers] are exposed" (Eyert et al. 2022, p. 12). The "strategies of influence" available to a specific DFAS are grounded on its design. Sometimes several "strategies of influence" are combined for one purpose and applied at the same time (e.g., it stands to reason that determining the right timing of sending out agricultural recommendations leverages the "influence through re-interpretation" and "influence through non-rational properties" "strategy of influence"-type). Going into more depth here is beyond the scope of this thesis. This thesis merely identifies specific strategies rather than classifying each of these according to their archetypical "strategy of influence" types.

4.2.2.1 Characteristics of and strategies for influential *agricultural recommendations*

The most frequently raised characteristics of influential agricultural recommendations are understandability (I 2, I 4, I 5, I 6, I 9, I 11) and relevance for farmers (I 2, I 4, I 6, I 8, I 10, I 11). I 11 echoes this when stating that all DFAS providers "[…] have to make sure that the advisory […] is comprehensible […] and actionable (I 11)". A third strategy that was mentioned several times is "stylization of contents" (I 2, I 11, I 12).

Strategy of influence	**Important parameters**
Guarantee understandability of agricultural recommendations	• Match agricultural recommendations with farmers' educational level • Use simple language • Appeal to intuition • Convey agricultural recommendations in local languages • Use farmers' vocabulary and agricultural concepts • Present agricultural recommendations in a user-friendly way (visualization) • Keep agricultural recommendations short • Deliver agricultural recommendations consistently
Deliver relevant agricultural recommendations	• Guarantee that there is a real demand for agricultural recommendations • Formulate agricultural recommendations in a concrete way • Formulate agricultural recommendations in an actionable way • Enable timely relevant and sensitive agricultural recommendations • Customize agricultural recommendations for local crop-growing conditions

Make sure to stylize agricultural recommendations	• Make sure agricultural recommendations are engaging • Make sure agricultural recommendations are entertaining (e.g., story-telling) • Mare sure agricultural recommendations are non-instructional
Other strategies of influence	• Stay conservative, focus on existing agricultural practices • Be culturally sensitive, enable audience to relate • Use convincing framings (e.g., loss & gain framing)

Table 10: Strategies for influential agricultural recommendations

Guarantee understandability of agricultural recommendations

Understandability subsumes several aspects. It is given, when agricultural recommendations are created in a way, that they match the farmers' ability to understand them. Thus, aspects such as the education level of farmers need to be taken into account (I 11). As the educational level of many farmers in the Global South is relatively low, simple language appealing to the farmers' intuition increases understandability and hence DFAS' influence on farmers' agricultural practice adoption. I 4 underscores this when saying: "[…] we very much focus on keeping the information we communicate to farmers as simple and as intuitive as possible (I 4)". Delivering agricultural recommendations in the local language also contributes to understandability. Furthermore, understandability is achieved when DFAS farmers' vocabulary and linguistic concepts are considered. I 9 explains: […] we adopt the same type of language that they [farmers] use in farming. So, we keep technical terms very simple and adapt them to the way that they communicate, the way that they understand agriculture […] (I 9)".

A user-friendly, simple DFAS design/interface also facilitates the adoption of DFAS' recommendations because of better understandability (I 5). Some DFAS providers seek to guarantee the latter by visualizing agricultural recommendations, for example, in easily interpretable multi-colored crop (suitability) maps or activity timers (I 4, I 5, I 6). Additionally, a convenient number and length of messages to convey agricultural recommendations, something that is tested by some DFAS providers (I 11), adds to understandability. It further impacts information retention. Voice-and/or video-based DFAS keep their messages to a maximum of two minutes as this, inter alia, allows farmers to jump back and forth and deliberately listen and/or relisten to specific audio(visual) contents (I 2, I 6, I 12). I 5 explains: "[…] you click on the video, and you see it and then you go to the next step […] if you missed a step you just need 30 seconds and then you've seen it (I 5)".

Sending out consistent messages, in the text- as well as voice-based DFAS, is another strategy used to enhance the probability of understandability and thereby "influence through reinterpretation". Consistency in voice-based DFAS pertains to the protagonists as well as the conversations that they are having. Assigning so-called "green scores" to different agricultural practices is named as another means of facilitating farmers' understanding and decision-making regarding environmentally sustainable agricultural practice adoption (I 9).

Deliver relevant agricultural recommendations

Supplying farmers with relevant agricultural recommendations is another strategy that is leveraged to make farmers adopt these. Relevance contains different aspects such as real demand/need for a specific agricultural recommendation, concreteness, actionability, and finally usefulness of an agricultural recommendations at a specific point in time and for a specific place (I 2, I 6, I 8, I 10, I 11, I 12). Finding out what is relevant to farmers in a specific context, is enabled by designing with the farmer (cf. farmer-centered design approach) (I 11, I

12). Such an approach to DFAS design unveils farmers' constraints and barriers to agricultural practice adoption and finally leads to recommendations that are "actionable and realistic" (I 11). I 6 cautions: "you [DFAS designers] need to find tricks and methods to communicate advice in a way that is actually useful […] (I 6)".

Actionability of agricultural recommendations allows farmers to act out the recommendations without further consultations. Concerning weather forecasting, I 8 explains that "farmers need to have an action perspective […] because they do not know what it [the weather forecast] means (I 8)". Often actionability is also given if recommendations are conveyed in a stepwise manner which can be followed chronologically by the farmer (I 11). Further, to be actionable, recommendations need to be timely-relevant, and -sensitive (I 2). In the case of weather forecasts and alerts, this means that they need to be released with sufficient anticipation so that the farmers can prepare their fields accordingly. What's more, time relevance can also relate to the time of the day when the agricultural recommendations is sent out. At best, the arrival time of messages matches the routine of farmers. Listening to the weather forecast, for example, is something that many farmers do every morning (I 2). Thus, DFAS have more influence if they approach farmers with such pieces of information in the morning, be it through text- or voice-based messages. Concerning the timing of messages, I 11 describes: "[…] for certain people you don't want to message them or send them a voice call at the beginning of the day, they're out in the field and they're busy. For other people, the end of the day is worse because they might be commuting back from another occupation or dealing with children […] (I 11)". As the best time is often difficult to know from observation only, some DFAS have determined it through experiments for different recommendations (I 11).

Relevance and actionability of agricultural recommendations and thus DFAS' influence on farmers' behavior is also augmented by hyperlocal customization of recommendations, meaning that agricultural recommendations are precisely adapted to the type and growth stage of the planted crop, the location of a specific farm, and its agro-climatic as well as other agronomic conditions. Customization can be established based on farmer information and preferences (indicated throughout the set-up of a DFAS), but also based on historical farmer data that a specific DFAS holds (I 2). Two respondents mention that they are actively exploring ways to further customize their recommendations to farmers (I 2, I 10), while another respondent explains: "[…] we really take the exact location of the farmer and provide a forecast for this location and also climate advice for this certain location (I 4)", pointing to the fact that her company is already sending out customized recommendations. I 2 describes the planned customization of their voice-based DFAS as a "muti-stage process" and continues by elaborating on his company's plans: "[…] at the moment we're just making sure that we know enough about our users to build those [farmer] personas, then, the second step would be adapting the UX based on the personas and then the third step would be creating that sort of a content recommendation engine based on who the users are […]". Customization is not only a strategy of influence through its more detailed guidance of farmers, but also due to enabling a closer relationship between the farmer and the DFAS provider. I 10 circumscribes this as follows: […] we want to develop it to make it personalized recommendation for each farmer. So, I think that way the farmers feels like they belong to [our DFAS]".

A sense of "relevance" can also be created by DFAS themselves. By communicating the benefits and risks of specific agricultural practices and DFAS usage more broadly, a strategy of influence that has been mentioned by several respondents (I 2, I 3, I 5, I 8, I 11), relevance can be ascribed. I 3 explains: "[…] we said, well, if you use the app, then your life gets better because you get more yields, you get higher quality rice, you get less costs for chemicals (I 3)" while I 11 cautions: […] you have to really think about how you're communicating the profit. So, the potential benefit to them […]. Ascribing relevance to the usage of DFAS or implementation of recommended agricultural practices thus enhances DFAS governance.

Make sure to stylize agricultural recommendations

Another strategy that increases the probability of agricultural recommendations' adoption, besides understandability and relevance, is their "stylization" in an entertaining, engaging, and non-instructional manner (I 2, I 11, I 12). Besides information retention, this stimulates frequent and active DFAS usage (I 2, I 12). I 2 states regarding their voice-based DFAS: "we don't want people to drop off, right? We wanna keep them on the phone, so the message really needs to be engaging (I 2)". For that reason, and in particular, in the case of voice-based DFAS, methods such as storytelling with different protagonists or conveying agricultural recommendations in form of radio announcements are leveraged as strategies of influence. I 2 explains that in one project it was tried to "[…] represent a farming household where there was a farmer, his wife would also help him across the agriculture activities, they had a kid who was going to some sort of agriculture institute and bringing back important knowledge as well […] and you had these little sounds playing in the background that would represent what you would normally hear in a village […] (I 2)". Using sounds that "you would normally hear in a village" points to the fact that, making the audience (auditorily) relate to the content and being culturally sensitive are other strategies of influence that make agricultural practice adoption more probable and thus increase DFAS' influence over farmer behavior. These strategies are also named by other respondents (I 6, 12). Another way of being engaging and entertaining and thus influential is "gamification", a strategy that is also used by some DFAS providers (I 2).

Other strategies of influence

What's more, respondents caution that agricultural recommendations should be rather conservative and stick to what is already being practiced rather than promoting novel, unknown practices. This is because farmers tend to be skeptical of new practices (I 4, I 9, I 10). I 4 expresses: "It could be weird or the demand for advisories could be lower if you don't advertise what already exists." (I 4). I 6 reiterates this when sharing his conviction: "I'm a strong believer in getting these [traditional] practices right and helping the farmers to implement no regrets-, practical-measures which they can relate to, and which are very easy to understand (I 6)".
In addition, strategies stemming from behavioral economics such as loss and gain framing are used for augmented agricultural recommendations adoption (I 11). Loss and gain framing based on the framing effect, a cognitive bias, wherein people decide on a specific option based on the connotations attached to it rather than based on what is rationally the best option.

4.2.2.2 Different modalities and venues for communicating agricultural recommendations

To truly impact farmers' behavior, sending out SMS, calling farmers via outbound IVR calls, or sending push-up messages via apps to farmers does not suffice. There are different constraints in the aforementioned approach such as limited trust vis-à-vis DFAS by farmers which make it necessary to detect and leverage additional modalities and venues for communicating agricultural recommendations. This is likely to increase DFAS governance and power over agricultural practice adoption.

Table 11: Overview of modality and venue-related strategies of influence

Modality and venue-related strategies of influence	Combine digital with analog advice
	Approach farmers actively
	Enable two-way communications
	Order displayed information
	Develop alternative informational formats & Incentivize adoption with financial incentives

Combine digital with analog advice

As has been mentioned above, DFAS are often combined with on-the-ground presence and analog advice – a strategy of influence mentioned by many interviewed DFAS providers (I 2, I 3, I 5, I 6, I 9, I 12). The on-the-ground staff helps with the introduction of the DFAS (I 3, I 6, I 9) and explanations in the farmers' local languages (I 9, 10). This increases uptake, understandability, and sometimes even relevance of agricultural recommendations as field staff can tailor agricultural recommendations to a specific farm and farmer. I 5 explains that her startup uses on-the-ground staff to "reach the farmer through a familiar voice […]". This points to the fact that the on-the-ground partner should be locally rooted. This seems particularly important since farmers in rural areas traditionally do not trust unknown organizations. I 9 reports that there are "issues with farmers that don't trust the technology". I 2 mentions that his company often works with governments to overcome the trust issue as "farmers typically do trust the government extension workers […] [and therefore] associating their name to the content goes a long way in in the adoption […] (I 2)".

Approach farmers actively

Another strategy of influence is actively approaching farmers rather than passively awaiting their requests for agricultural recommendations (I 2, I 8, I 9, I 10, I 12). For that purpose, many IVR-based DFAS have or are currently adding an outbound call component. This allows DFAS to automatically call farmers from their system. I 2 reasons: "[…] it [is] more convenient to them. […] We've seen through data that users who receive these calls, they have higher engagement levels on the platform (I 2)". Outbound calls thus not only make DFAS more impactful through reaching out in specific instants but also by increasing farmers' general interest and usage of a DFAS.

Text-based DFAS leverage (push-up) notifications as well as reminders to influence farmers to adopt agricultural recommendations (I 8, I 9, I 10). I 9 explains: […] they [farmers] get daily notifications on what has to be done and reminders (I 9)". This is also substantiated by Fabregas et al. (2019) who state that DFAS use "reminders and other nudges to address behavioral biases" (p. 1). However, designers need to be cautious when designing such strategies into DFAS because there is a danger that "farmers may begin to ignore reminders or nudges if they are repeated too often" (Ibid., p. 3).

Enable two-way communications

Two-way communications, allowing for engagement with the digital platforms that send out agricultural recommendations or other venues such as call centers or chat functionality, is another DFAS strategy of influence (Coggins et al., 2022; I 1, I 3, I 8, I 11, I 12). It allows farmers to actively engage with the DFAS and obtain needed information self-independently. In this context, I 12 refers to "push- and pull-based advisory" (I 12). In the former, the advisory is pushed to the farmers, whereas in the latter, the farmers themselves pull information from the DFAS provider. Grounded on the agricultural development in some geographies, a pull-based advisory has become more appealing to farmers. This is because in these areas: "[…] farmer[s] are so well equipped with the information, they want choices to make and get […] particular information about the crop […] (I 12)". Two-way communications, besides increasing DFAS usage (I 3), lead to higher adoption rates as they appeal to the "volition" of farmers (I 11). What´s more, two-way communications are said to increase a feeling of "[DFAS] ownership" among farmer populations (I 12) (cf. Coggins et al., 2022).

Order displayed information

The order of contents in IVR systems or apps was also mentioned by some respondents as a strategy of influence (I 2, I 8). This strategy corresponds to "influence through non-rational properties", but also to "architectural constraints" wherein the electronic architecture is designed in a way that favors some options over others. I 2 illustrates, for example, that new content is sometimes moved to the top of the IVR menu. Thereby, it is promoted. Similarly, I 8 states that in his app-based DFAS, farmers are first provided with the Integrated Pest Management-based agricultural practice, and only if this does not work, receive agrochemical pesticide advice.

Develop alternative informational formats & Incentivize adoption with financial incentives

Two respondents also report that they developed alternative informational formats for their DFAS (I 2, I 12). The company of I 2, for example, has developed a format that allows farmers to listen to several IVR-based agricultural recommendations in one go rather than first navigating through the IVR menu. Others DFAS providers have experimented with IVR groups to enable farmer-to-farmer extension (I 12). It is also experimented with financial incentives as a strategy of influence (I 2, I 11). I 2 notes "[…] obviously financial incentives are always a big one […] (I 2)". However, it is cautioned that this adds "a different dynamic to the behavior change mechanism than just information". Financial incentives correspond to the strategy of "inducement" (cf. Eyert et al. 2022, p. 11).

The importance of a "mix of solutions" is stressed as a more general rule for DFAS interventions (I 12). I 12 explains: "Whenever you come up with this solution, you should come up with different strategies, have a mix of solutions, not just one shot for all. There should be a mix of in-person, IVR, chatbot, and different formats like a mix of analog and digital (I 12)".

4.2.2.3 Meta-strategies of influence

Besides the aforementioned strategies which relate to the content of agricultural recommendations and the modalities and venues through which they are communicated, there are what is referred to here as "meta-strategies of influence". "Meta-strategies of influence" are not limited to one DFAS area. They can be applied to all areas of DFAS. In sync with the other "strategy of influence" types, the three identified meta-strategies of influence seek to enhance DFAS governance.

Conduct experiments and research continuously

One of these meta-strategies is continuously conducting experiments, and research during DFAS design and delivery (I 11, I 12). I 11 highlights: […] we do a lot of testing. We do a lot of experiments (I 11)". Research can be used to answer many important questions regarding effective service delivery. I 12's non-profit NGO, for example, has done multiple experiments to determine the delivery format with which farmers are most comfortable. The result was recorded voice-based messages. Research is normally underpinned by monitoring and evaluation systems. These are based on pre-defined benchmarks, something that is referred to as “performance metrics” (I 2).

Adapt DFAS to contextual changes continuously

The results of experiments and research allow for improvements of DFAS. Making these improvements to DFAS is hence a second strategy that can be circumscribed as “continuous adaptations”. I 2 explains regarding the adaptability of DFAS: [that] it's a constant case of making sure that the messages are highly receptive, highly engaging […]. He further declares: “[those messages] that people listen to more often are given the limelight in the service […] (I 2)”. Continuous research and adaptations are particularly necessary in the face of frequent contextual changes. Regarding DFAS such frequent changes usually happen in the realm of technology or with respect to socioeconomic factors (I 12).

Ensure DFAS usage for a minimum duration

Establishing a minimum duration for DFAS projects, in case they are funded by governments and alike, is another meta strategy of influence. This is because DFAS only unfold their real impact after several seasons. I 12 illustrates: “[…] one season, no way you can see the results because majority of the time goes into the preparatory work and all. Season two, you start seeing some results. Season three, […] We can start seeing very evidently the results [of DFAS] (I 2)”. What’s more, “bundling DFAS” is also reported as a strategy by respondents (see section 6.1.2).

4.2.3 Summary: Governance through intervention in DFAS

As has been shown above, DFAS governance is amplified by governance automation and by leveraging “strategies of influence”. Governance automation was analyzed regarding the creation of agricultural recommendations and regarding different DFAS development phases. It was focused on the automatic creation of agricultural recommendations because agricultural recommendations are believed to be one of the main sources of the farmers’ governance emanating from DFAS. There are four types of agricultural recommendations: general, static, personal, and dynamic agricultural recommendations. The creation of general agricultural recommendations is the least automated, while the creation of dynamic agricultural recommendations is the most automated.

Besides the automatic creation of agricultural recommendations, there is automation in different phases of DFAS development. Four phases, namely, pre-design phase, design phase, delivery phase, and iterations for improvement phase, were distinguished. The degree of automation in these phases is either low, medium, or high. What´s more, the degree of automation also always depends on the specific DFAS. Generally, to date, most DFAS are still carried out in a hybrid format, wherein there is digital/algorithmic as well as analog governance. It has been shown that there are several good reasons for DFAS designers to pursue such a hybrid approach to DFAS delivery.

In addition to DFAS governance automation, DFAS leverage a magnitude of strategies of influence for enhanced DFAS governance through intervention. These strategies are carried out throughout the design as well as the delivery phase of DFAS. There are agricultural recommendations-specific, modality-, and venue-specific as well as meta-strategies of influence. The agricultural recommendations-specific strategies of influence seek to ameliorate the reception of agricultural recommendations. The modality and venue-specific strategies concern the channels and modi for transmitting agricultural recommendations. And lastly, the meta-strategies are strategies on an overall level that secure continuous DFAS enhancements. All these strategies aim at enhancing DFAS governance. Which strategies are leveraged depends on factors such as the technology selected, the resources and sophistication of a specific DFAS, and many more. The table below gives an overview of all identified strategies of influence leverage by DFAS.

Table 12: Overview of identified strategies of influence by DFAS

"Strategy of Influence" type	Strategies of influence
Agricultural recommendations-specific strategies of influence	Guarantee understandability of agricultural recommendations • Match agricultural recommendations with farmers' educational level • Use simple language • Appeal to intuition • Convey agricultural recommendations in local languages • Use farmers' vocabulary and agricultural concepts • Present agricultural recommendations in a user-friendly way (visualization) • Keep agricultural recommendations short • Deliver agricultural recommendations consistently
	Deliver relevant agricultural recommendations • Guarantee that there is a real demand for agricultural recommendations • Formulate agricultural recommendations in a concrete way • Formulate agricultural recommendations in an actionable way • Enable timely relevant and sensitive agricultural recommendations • Customize agricultural recommendations for local crop-growing conditions
	Make sure to stylize agricultural recommendations • Make sure agricultural recommendations are engaging • Make sure agricultural recommendations are entertaining (e.g., story-telling) • Mare sure agricultural recommendations are non-instructional
	Other strategies of influence • Stay conservative, focus on existing agricultural practices • Be culturally sensitive, enable audience to relate • Use convincing framings (e.g., loss & gain framing)
Modality and venue-specific strategies of influence	Combine digital and analog advice
	Partner with trusted, locally rooted organizations
	Approach farmers actively
	Enable two-way communications
	Order displayed information
	Develop alternative informational formats
	Incentive adoption with financial incentives
Meta-strategies of influence	Conduct experiments and research continuously
	Adapt DFAS to contextual changes continuously
	Ensure DFAS usage for a minimum duration

4.3 Representation

To identify how DFAS govern through representation, the digital representation of farms, farmers, and crops in DFAS needs to be studied. Eyert et al. (2022) propose that governance through representation is exercised on the governed subjects by three ways: feature selection, data production, and data interpretation. In the case of DFAS, feature selection, data production, and data interpretation, lead to a particular digital representation of farms, farmers, and crops. This representation is shaped by what is referred to here as digital representation-reality gaps. These gaps and the reduction of complexity that goes hand in hand with them, only render the (automatic) creation of agricultural recommendations feasible, and, based on this, farmers' governance possible. This chapter seeks to explore the digital representation of farms, farmers, and crops in DFAS, and to pinpoint digital representation-reality gaps. Thereby, this chapter hopes to generate insights into how DFAS govern through representation (via agricultural recommendations).

Feature selection refers to the specific types of data about farms, farmers, and crops that are considered for agricultural recommendations by DFAS. The production of agricultural data points refers to the sometimes fuzzy and ambiguous process by which agricultural phenomena are measured and by which data is subsequently collected and processed. Agricultural data is produced through certain (measurement) procedures using specific technologies. This production is embedded into "complicated socio-technical networks" (Eyert et al., 2022, p. 7). Lastly, agricultural data interpretation pertains to the process of rendering the produced agricultural data actionable. In the case of DFAS, the ultimate interpretation of agriculture data results in understandable, relevant, and actionable agricultural recommendations. For consistency and reading flow, feature selection and production of data points are addressed in one section (see section 4.3.1). Hereafter, three forms of data interpretation in DFAS are showcased (see section 4.3.2).

For analytical purposes, it is helpful to distinguish DFAS along with the type of agricultural recommendations that they produce. These agricultural recommendations can be pigeonholed into two continua: the "general-personal" and the "static-dynamic" continuum (cf. section 4.2.1). This thesis argues that personal and dynamic agricultural recommendations are based on a relatively accurate digital representation of individual, site-specific farming systems. In contrast, general and static agricultural recommendations are based on coarse, rather regional digital representations of farming systems. Thus, for highly general and static advice, crop developments and needs are not site-specifically determined, but rather correspond with historical averages (observed throughout various seasons in the selected region).

4.3.1 Feature selection and production of data points

The features that are selected for DFAS and the data points which are later produced concern weather and climate, soil, crops, farmer, as well as farming activities and results. Many of these features are selected because they are needed for specific agricultural models (I 1, I 4, I 8). These models help to digitally simulate and approximate the reality of farms or the factors, in particular weather, which are impacting or will impact farms in the future. The selection of features is dependent on data availability. I 4 reports: […] our partners […] want us to include as many different layers [features] in the algorithm as possible, but then it always comes down to: Is there data available?" She further states: "Due to lack of data availability, the advisories are not particularly sophisticated" (I 4). I 8 cautions that selecting features from data that are produced by satellites, even though they are possibly available, is not always useful because the pixels tend to be too coarse to mimic the realities of small farms (data accuracy) (I 8).

Data availability and accuracy are dependent on the existing measurement infrastructure. This infrastructure enables the production of data points for a particular context. I 6 illustrates existing, elementary measurement bottlenecks that hamper DFAS offerings: […] if farmers don't have a measuring tape and they have a piece of land full of crops. How are you going to make a planting plan in a[n] understandable manner? (I 6)”.

Much data is produced through domestic and international research organizations, some of which are sharing this data through application programming interfaces (APIs) (I 11, I 12). Generally, in the past and within traditional extension systems, data was produced through field trials, while today there is a mixture between on-the-ground data production and data production through remote data collection technologies as well as digital models, algorithms, and predictive AI (I 7). I 4 explains how some algorithms segment agricultural lands into grid points and subsequently compute a value for each grid point: “[…] in such an algorithm you have to overlay different data layers, basically. So, you can basically lie a grid on a map and then in each grid point you get a value, and a farmer is located in one of those grid points and you can get climate and meteorological data for each grid point and calculate certain variables. And then you can add a next layer, like, let's say, the soil type and then you get a new result for this grid cell (I 4)”. This algorithmically computed data is also referred to as “gridded data” (Araghi et al., 2022). It is used in cases in which measurement infrastructure does not cover the areas for which data is required. In some cases, features are selected, and data is produced for validation of input data only (control variables) (I 3).

When approaching “feature selection” not merely in a digital sense, but rather as a process of reducing complexity more generally, the set of selected agricultural practices could also be viewed as selected features. This set is selected from a magnitude of possible agricultural practices, a process in which some practices are ascribed more usefulness than others. After the selection of agricultural practices (DFAS content) that should become promoted in a DFAS, DFAS providers, through expert discussions, determine which features (parameters) are linked to these [practices] (I 11). I 11 explains this by giving a specific example: “Let's say there's a ground nut content, but for me to send out this ground nut content to the farmers, there are many other parameters which are required to make it more personalized, more specific. So, then I need a soil health data (I 12)”. This points to the fact that it is first decided upon a specific crop and agricultural practices which are deemed useful regarding this crop. And that second, features become selected and data points become produced. The value-laden process of feature selection and data production depends on the governance direction which is agreed upon by DFAS stakeholders (see section 4.1).

To (consciously or unconsciously) keep up the pretense of objectivity and veil the normative character of DFAS governance, DFAS stakeholders leverage “justification-techniques” such as cost-benefit analysis (I 11) and established models, such as crop growth models, that promise to mimic reality. As has been mentioned earlier, normally features regarding weather, soil, crop, farm, and farmers, and farmer activity and results are selected by DFAS for the subsequent creation of agricultural recommendations.

Table 13: Different types of agricultural data and features selected by DFAS

Type of agricultural data	Selected features
Weather data	• minimum and maximum temperature • wind speed • solar radiation • length of daylight • precipitation
Soil data	• Soil type • Soil state • Soil fertility
Crop data	• Crop type • Crop cultivar (variety) • Planted area
Farm & farmer data	• Location • Personal information (e.g., name, age, gender)
Farm activity and results data	• Sowing/planting and harvesting date • crops planted • input usage (fertilizer, pesticides, herbicides, fungicides), • irrigation information, • yield information

Weather data

Regarding the weather, features such as "minimum and maximum temperature", "wind speed", "solar radiation", "length of daylight", "precipitation", and others are selected (I 1, I 4). "The solar radiation/length of daylight"-feature, for example, is needed for the growing degree days heuristic (model) which allows for predicting flower blooming and/or crop maturity (I 4). "Onset of the rainy season" is another selected feature that is mentioned (I 4). To make claims about historical weather patterns (climate), several of these features are collected over 30 years. Some DFAS providers provide farmers with historical climate data in the front end (I 9), while others merely leverage it for back-end calculations. Weather data is normally produced by automated weather stations, weather radar, and weather satellites. Recently, commercial microwave links (CML) have become more popular as means to produce high-resolution precipitation data (GSMA, 2021). Generally, the measurement of weather-related variables (features) is guided by standards as defined by the World Meteorological Organization and other meteorological standard-setting organizations. Whether these standards are and can be followed depends on several factors, for example, the condition of the weather measurement infrastructure. This impacts the quality of weather data.

Both, weather data quality and weather data density, determine the quality and granularity of weather forecasts for a specific location. I 2 reports the following on the weather forecasts of his DCAS: "I wouldn't say it's hyper-localized weather condition. We provide weather on a district level in most countries […] (I 2)". In developing countries, the data point density regarding the weather is low, because the measurement infrastructure is often inadequately developed and underfinanced. What's more, there is often not sufficient (digitized) historical weather data (Ferdinand et al., 2021; Hansen et al., 2019). I 6 explains the overall dilemma in which DCAS providers operate: "You need to get the weather data right and […] below the Sahara there are hardly any weather measurements. In Burundi, there's one automated weather station […]. In addition to the aforementioned constraints, for many countries, there are no locally adapted weather models, so forecasts need to be computed with less precise, global models (I 6).

As agriculture is highly weather-dependent, weather data and forecasts are at the heart of any DFAS (I 1, I 8). However, all the aforementioned preconditions lead to relatively inaccurate weather forecasts and as a consequence hamper the quality of agricultural recommendations. Given that the climate is changing and extreme weather events become more likely, one respondent has mentioned that her DFAS has changed the way of producing forecasts, taking less historical weather data into account (I 4). Seemingly in contrast, I 7 argues that more data is needed to cover extreme weather events (I 7). Despite all these constraints, some DFAS providers provide weather forecasts that are more precise than the ones of most weather apps or those broadcasted through radio (I 4). All in all, it is still very likely that the digital representation of weather in DFAS differs (relatively starkly) from reality.

Soil data

Concerning the soil, the "soil type", the "soil state" and "soil fertility" are selected features (I 4, I 9). The difficulty with which different soil properties can be assessed highly varies (van Evert, 2020). While some soil properties are easily assessable, others are hardly assessable. Additionally, the interactions between soil components are still relatively poorly understood. Yet, five respondents recognized the importance of soil data (I 1, I 4, I 5, I 8, I 12) and are either planning to integrate them into their algorithms or have already attempted to do so (I 4, I 5, I 8).

Several DFAS providers conduct on-the-ground soil tests, sometimes with the help of partner organizations (I 5, I 9, I 10). One respondent mentioned that her DFAS uses an existing digital soil database from the government (I 12), while another respondent cautioned that soil databases are rarely available in developing countries (I 4). For that reason, some DFAS providers establish their own soil database (using the tests that they have taken) and develop soil models based on that (I 10). I 10 explains: "So, we have like a soil model based on the several soil sample[s] that we take all over in Java and Sumatra. […] we try to do the sampling and make a soil model […] fertilizer recommendations come from that soil model (I 10)."

For the soil models, the spotty soil test results from specific farms are extrapolated to larger areas of agricultural land. It is hoped that in the long run, the soil model can replace manual soil testing (I 10). Which rules are applied for the extrapolation remains unclear. As with any extrapolation, the complexity of reality is reduced, leading to a digital representation that differs from reality. Approximating soil realities becomes even more challenging, given their horizontally as well as vertically changing character (van Evert, 2020). This is recognized by the DFAS of I 10, which explains that her organization seeks to retake soil samples and thereupon update their soil model every five years. Yet, soil conditions might change faster than that in some intensive farming locations, again impacting the digital representation-reality-gap. The soil conditions particularly impact nutrient management-related agricultural recommendations. To date, few soil models capture nutrient carry-over effects from previous seasons in soils. The common practice is to reset the soil condition for the new agricultural season (Boote, 2020).

Crop data

Regarding the crop, features such as "crop type", "cultivar type" (also variety and/or seed type), and "size of the planted area" are selected (I 1, I 9, I 10, I 11). While indicating the planted crop type is relatively easy, indicating the planted cultivar type is challenging in some contexts (I 1). This is because some cultivar types are not officially recorded and scientifically described. They are only locally known and have often been grown over generations (I 6). To guarantee that there is some knowledge of the cultivar, the purchase of seed packages is coupled with the offer to use a seed-tailored DFAS that sends out cultivar-specific agricultural recommendations (I 1).

Crop type and cultivar type data, together with other data, allow DFAS to estimate and simulate crop development and determine the current phenological stage of a planted crop. For this purpose, so-called crop (growth) models are used (Boote et al., 2010; I 1; Wenkel et al., 2017). Knowing the phenological stage allows for determining the necessary agricultural practices at a given point in time. However, if the cultivar is not known or not well described, a less accurate, more general crop growth model needs to be used. In the case of the latter, the digitally simulated crop growth stage can deviate from the real crop growth stage. The probability that inaccurate agricultural recommendations are given increases.

Some DFAS also aim at assessing the phenological stages of crops and the crops' biomass production respectively through satellite data (I 3). However, it is cautioned that there are some practical issues with this (I 1, I 8). For instance, satellite data does not allow us to identify the reasons for delayed crop growth. The more general and static DFAS are based on the typical crop development in a region and give recommendations regarding crop management practices according to the archetypical phenological stages therein. I 6 explains concerning his company's general and static DFAS: "If crops are selected, an activity timer for each crop is created. It is a seven-week window which includes all the activities that are relevant in this time (I 6)". The farmers themselves then must compare the given recommendations against the actual status of their crops and decide which agricultural practices to undertake (I 6).

Farm and farmer data

With respect to the farm and farmer data, the features of "location" as well as "personal information" including contract info, farmer's name, age, and planted crops are selected (I 1, I 5, I 9, I 10, I 11). DFAS providers normally have databases containing their farmer users (I 12). As locations are not always easy to describe in developing countries, for instance, due to a lack of street names, sometimes locations are indicated by the farmer on a coarse administrative zone level (I 8). Other DAS, use creative ways to approximate farmers' location, for example, by letting farmers indicate the closest school. This information is subsequently matched with a geo-referenced school database resulting in an approximated farm location. Some more sophisticated, app-based DFAS use phone-internal GPS sensors for determining farm locations. They additionally make farmers indicate their farms' boundaries on maps. I 5 underscores this by saying: "[…] for the location, the application allows you to use Google Maps to show the boundaries of your farm […]. I 9 echoes: […] [the app will] ask you to encircle your farm, so there's a map (I 9)". Some DFAS realize the registration process, in which the aforementioned basic data is collected, by leveraging call centers, while others use in-serve data entry (I 1).

To date, few DFAS allow farmers to indicate their crop-related preferences (I 11). Generally, the farm and farmer data are relatively limited. The exact farm location, for example, often remains unknown, making it impossible to simulate site-specific weather and crop growth conditions (I 6). This points to digital representation-reality gaps which make it difficult for DFAS to give accurate agricultural recommendations.

Farm activity and results data

"Sowing/planting and harvesting date", "crops planted", "input usage" (fertilizer, pesticides, herbicides, fungicides), "irrigation information", and "yield information" are the features collected regarding farm activity and results (I 1, I 3, I 4, I 5, I 7, I 8, I 9, I 10). The farm activity and results data help ameliorate agricultural recommendations for a specific season, but, potentially more importantly, in the medium- and long run allow for the calibration and (re-) training of specific and overall DFAS models (I 4, I 7).

The "sowing/planting date" allows DFAS to tune the crop growth models to a specific point of time of the season and is therefore of high importance. The indication of the harvesting date, in contrast, can help improve future recommendations concerning the best time to harvest (I 7). Indicating the crops planted on a specific patch of agricultural land results in a crop history, based upon which, for example, different options for crop rotation can be recommended in the future. Fertilizer usage data, combined with weather, soil, and crop data, allows the DFAS to estimate nutrient availability and recommend the point in time and amount for renewed fertilizer application as well as the ideal fertilizer composition. Similarly, pesticide usage data allows for targeted pest recommendations (I 8). Irrigation information combined with other data allows for tailored irrigation scheduling and recommendations concerning the amount of water to be applied (I 9). Finally, yield data, as the ultimate output data, can help to train and improve DFAS models (I 7).

Several DFAS providers are already collecting farm activity and results data, while others want to increasingly do so in the future (I 4, I 7, I 9, I 10, I 11). However, there can be some data accuracy issues as farmers usually input data themselves. I 7 explains: […] you need the real input from the farmers […] usually, they tend to report things in their favor […]. If you train the model on that type of input, then it's not reality anymore […] (I 7). I 11 mentions that her company is "increasingly experimenting with SMS surveys (I 11)". However, she also cautions that: "There's different, you know, obviously accuracy and reliability issues that come into play when you don't visit someone in person." I 10 reports that farmers have limited incentives to regularly input their data into the DFAS system, normally resulting in a lack of the needed data.

4.3.2 Interpretation of data

The features deemed relevant, and the data on a farming system produced accordingly are finally being interpreted into actionable agricultural recommendations by the overall DFAS model. Normally, there is a chronological sequence of data interpretation that ends with the farmer-facing agricultural recommendations. Several models such as weather forecasting, water, soil, crop growth, and pest and disease models can be leveraged in such an interpretative process. Generally, a modular approach to model development, which allows for plug- and play functionality, and improvements to existing modules as well as the addition of new modules is pursued since the 90s/early 2000s (Boote et al., 2010). Which modules are added to the overall DFAS model depends on data availability, but also the approach and governance direction a particular DFAS provider follows. Approaches can be distinguished along the archetypes of low- and high-tech DFAS (I 6), each having their advantages and disadvantages. I 6 cautions: "[…] most tech organizations are really technology driven, whereas, yeah, from my perspective, technology is a challenge, but it's not a problem. It is a behavioral change [that] you need to accommodate. So, there's much more needed than just providing technology". Another differentiation of DFAS and agricultural recommendations more specifically can be undertaken along the aforementioned general-personal and static-dynamic continua. Grounded on these considerations, in the following, DFAS will be segmented into

“General DFAS”, “Personalized, but mechanistic DFAS” and “Personalized and dynamic DFAS”. And the varying data interpretation in each of these DFAS types are illustrated.

General DFAS

“General DFAS”, sometimes also referred to as informational services (GSMA, 2020) provide farmers with general information and/or agricultural recommendations. The degree of automation and the number of used algorithms is low. Few models and if so, general models (based on past experiences) are utilized. For general DFAS, analog information materials and contents are digitized (I 2). Yet, these contents are not modeled and tailored to the farmer. The information and agricultural recommendations are presented in a static and/or strictly chronological way and are matched with the different crop growth stages. Farmers, if at all, only input little amounts of data into DFAS, and thus “General DFAS” have very limited information on the farmers they are serving. Much of the interpretative work must be undertaken by the farmer. At the same time, farmers can freely select the information they are interested in (I 6). I 8 illustrates farmers’ interpretation concerning disease detection in general DFAS: “[…] the app has pictures of insects and diseases so that they [farmers] recognize the disease and then the app also provides then what type of fungicide or insecticide they need to apply (I 8).

Personalized, but static DFAS

“Personalized, but static DFAS” are tuned to a particular farmer during the set-up phase of DFAS. Therefore, usually, basic information such as location, crop type planted, and other data are collected from the farmer. Then, the DFAS delivers personalized and tailored agricultural recommendations (personalization). The degree of automation is higher than in “General DFAS”, meaning that more decisions are taken by the algorithms. What´s more, more agricultural, crop-specific models are utilized. Analog agricultural contents, that were created, based on data that have often been collected for several decades, are digitized and modeled for “Personalized, but static DFAS” (I 7).

Basically, and similar to the “General DFAS”, in many “Personalized, but static DFAS”, the phenological stages of a crop are connected to stage-specific agricultural recommendations (I 1). I 4 explains: […] you have different stages, crop growth stages, and during each stage, there are certain activities that are more or less needed (I 4)”. However, in “Personalized, but static DFAS”, algorithms (as opposed to the farmers), based on pre-defined thresholds and fixed decision rules respectively, decide whether a specific phenological stage is reached and/or whether a particular agricultural activity needs to be undertaken (e.g., irrigation due to limited rainfall). Fixed decision rules also referred to as “expert rules” (I 7) are defined and integrated into the algorithms of personalized, but static DFAS in its set-up phase (I 7, I 8). I 7 explains: “The decision rules are directly integrated into the models. So, for every analysis that's made, an advice is automatically generated for the farmer (I 9)”. Because of the fixation of algorithmic decision rules and thresholds respectively before the running of the DFAS, these DFAS are referred to as “Personalized, but static DFAS” here.

To decide whether a phenological stage is, based on said rules and thresholds, reached, “Personalized, but static DFAS” simulate crop growth, weather, etc. continuously and automatically (I 7, I 8). If a certain decision rule or threshold or several decision rules and thresholds are fulfilled, as computed by an algorithm, a decision rule or threshold-specific message is sent out to the farmer (I 1, I 4, I 8). In some text-based DFAS, there is a database with text elements in the back end. These text elements can be automatically assembled to match one or several reached decision rules and thresholds respectively (I 4).

Farmers can normally input some data into “Personalized, but static DFAS”. Yet, the options are limited. All in all, much of the interpretation is conducted by the DFAS and not the farmer. As with all recommender systems (also decision support systems) and thus all analyzed DFAS, the farmer finally decides if he wants to adopt a particular agricultural practice. Due to the low data accuracy and quality, there is some probability that DFAS recommend non-suitable practices for a certain point in time.

Personalized and dynamic DFAS

The “Personalized and dynamic DFAS” resemble the “Personalized, but static DFAS”. I 7 suggests that a combination of the two might allow for leveraging the advantages of both. The “Personalized, but static DFAS”, for example, are based on elaborated models that contain rich agronomic knowledge. These sophisticated agronomic models can serve as a good starting point for “Personalized and dynamic DFAS” (I 7). “Personalized and dynamic DFAS” use several agricultural models and machine learning algorithms to learn from model inputs as well as model outcomes. Some analysts circumscribe said DFAS as “AI-based systems” (I 7). The main difference between “Personalized, but static DFAS” and “Personalized and dynamic DFAS” is that the latter can adapt themselves in the face of new data (I 7), whereas the former DFAS are “kind of fixed” (I 1). New data for adaptions of “Personalized and dynamic DFAS” are normally obtained, amongst others, from farmers and/or by satellites. I 7 explains new developments regarding DFAS: “[…] it moves a bit more towards data science and using AI instead of these mechanistic [static] models to do predictions and to generate advice. […] in the past it was more like these mechanistic [static] models and expert rules that we used, from the agronomists. And now these new AI-based systems, they just look at the data from lots of farmers and then use these learning algorithms, algorithms to train models based on this data. And these models then can generate the advice following historical patterns that they learned from the data (I 7)".

In contrast, in “Personalized, but static DFAS”, an expert is needed to interpret new data, formulate decision rules based on that, and “manually” add these new rules to the algorithms of the DFAS. Thus, making changes to “Personalized, but static DFAS” is much more time-intensive and costly than having a model that retrains itself. For that reason, adaptations regarding crop management and agricultural recommendations are normally only undertaken sporadically. This can lead to missing out on particular agriculturally relevant phenomena (I 1).

How and what the “Personalized and dynamic DFAS” learn, depends on their priorities. These priorities are defined in what is being called the “cost function” of the machine learning algorithms. The cost function optimizes for a specific value. Traditionally this has been “yield” (I 7). Whether dynamic DFAS will become more commonplace in the coming years remains unclear as there are still many limitations, in particular regarding data availability and accuracy. I 9 reports that “all our algorithms [of her DFAS] use machine learning systems (I 9)”, while I 4 reflects on the further development of her DFAS: “a next step in the future could be to apply a machine learning algorithm (I 4)” and then cautions: “This especially works well for situations where there is a lot of data, but it would take a long time because you may have one or two rainy seasons a year, depending on the location (I 4)”.

4.3.3 Summary: Governance through representation in DFAS

It has been shown above that, DFAS select particular agricultural features while neglecting others, that DFAS produce agricultural data in specific ways while ignoring others, and that DFAS interpret agricultural data distinctly while disregarding other interpretative pathways. All these processes are, inter alia, based on value-laden decisions of DFAS designers, data providers, and other DFAS stakeholders. By digitally representing agricultural systems in particular ways, DFAS govern. This thesis contends that this is because the agricultural recommendations inferred from the overall DFAS models depend on these very same digital representations. This means that particular combinations of feature selection, data production, and data interpretation lead to specific governance directions of DFAS. However, determining, for example, which set of selected features leads to which agricultural recommendations and subsequently to which governance direction is beyond the scope of this work. Yet, the basis for governance through representation rests on the aspects mentioned above and summarized below:

Most DFAS select relatively basic features such as minimum and maximum temperature, soil type, and crop type. Due to low data availability, granularity, and accuracy in the Global South, many DFAS designers rather focus on getting DFAS to work than designing a highly sophisticated DFAS (I 1). This however is likely to compromise the reliability of deduced agricultural recommendations (I 6).

The data point production is starkly dependent on farmers' input (e.g., farm location) and agricultural model outcomes. However, digital agricultural models remain relatively immature in developing country contexts. Despite seeking to mimic real-world farming, they often produce digital representation-reality gaps. These gaps are compounded when several inaccurate datasets and model outcomes are combined in the overall DFAS models. While some agricultural data is produced by the DFAS providers themselves, other data is provided by third parties and withdrawn from their databases via application programming interfaces (APIs) (I 9, I 12, van Evert, 2020)

The digital representation-reality gaps are likely to negatively impact the accuracy of agricultural recommendations. This is because agricultural recommendations are based on the digital representation of agricultural systems. Agricultural recommendations are created through the interpretation of available agricultural data. DFAS convey general, personalized, static, and/or dynamic agricultural recommendations. Producing general agricultural recommendations necessitates relatively few algorithms and agricultural models. By contrast, producing static/dynamic agricultural recommendations necessitates many agricultural data, algorithms, and agricultural models. What´s more, the overall DFAS model, from which agricultural recommendations are inferred (data interpretation), needs to be more complex.

In newer, high-tech DFAS, which are usually intended for larger, more profitable farms, satellite data, as well as low-cost in-situ field sensors, are increasingly leveraged for agricultural data verification and additional agricultural data production purposes (Gracia et al., 2020; I 7; van Evert, 2020). Potentially, these additional agricultural data collection technologies can close some of the aforementioned digital representation-reality gaps and make agricultural recommendations more accurate. In addition, the increasing prevalence of personalized and static, and even dynamic DFAS which leverage machine learning algorithms could make important contributions in the very same area.

The insights gathered throughout this chapter on how and by which ways DFAS govern farmers' behavior, give an impetus to continue thinking about how these sustainability-related "governance ways" can be deployed to advance environmental sustainability. They evoke questions such as "How do the governance systems underpinning DFAS need to be changed to enable environmentally sustainable DFAS governance direction?", "Which strategies of influence are particularly effective in making DFAS contribute to enhanced environmental sustainability?", or "How do agricultural systems need to be digitally represented in DFAS, so that DFAS promote their environmental sustainability?". This thesis seeks to solve these and similar questions by applying the leverage point perspective and by identifying leverage points along the three governance dimensions "direction", "intervention", and "representation" of DFAS as outlined in this chapter.

5. Leverage points for environmental sustainability in Digital Farm Advisory Services

In this chapter, leverage points for building environmental sustainability into DFAS will be presented. In evaluating the conducted interviews, and in making further plausibility conclusions, said leverage points were identified along the subdimensions of the algorithmic governance framework (see chapter 4). Subsequently, the depth of identified leverage points is assessed (see chapter 6). It needs to be cautioned that some of the identified leverage points for building environmental sustainability into DFAS rest on a thin empirical data basis and thus necessitate testing against reality or further empirical studies.

5.1 Direction

There is an overall, content-related, and service provision-related direction. Leverage points for building sustainability in DFAS are only identified for the first two directions as these appear to be particularly relevant regarding environmental sustainability. To become more environmentally sustainable, enabling environmental sustainability needs to become a primary standard for the overall goal of "improving farmers' livelihoods" of many DFAS. Therefore, DFAS need to be perceived as means to achieve better environmental outcomes in crop farming, rather than only as contributing to higher incomes and yields. Such a shift in thinking about DFAS could contribute to increased environmental sustainability in two ways. First, DFAS designers could increasingly focus on the agricultural realms that most negatively impact the environment and then design environmentally sustainable DFAS to fix them (e.g., irrigation scheduling for highly water-scarce regions). Second, DFAS designers could tweak already existing DFAS in a way that they prioritize the most environmentally sustainable crop management practices. The latter relates to the set of agricultural practices (and the agricultural paradigm) that is decided upon in negotiation processes between different DFAS stakeholders.

Generally, there are agricultural practices that are recognized as particularly environmentally sustainable such as practicing silvopasture, green manuring, or growing cover crops (Sova et al., 2018). At the same time, some agricultural paradigms, which subsume specific agricultural practices, have been recognized as particularly environmentally sustainable, one of which is regenerative agriculture (Reichhuber et al., 2021). Some of the explicitly environmentally sustainable practices might be relatively complicated to explain (e.g., agroforestry), in particular, if not yet practiced (I 12). Yet, integrating such complex, but environmentally friendly agricultural practices and complex farming systems more broadly into DFAS might be another leverage point for enhanced environmental sustainability in DFAS.

Generally, for those environmentally sustainable practices to be put on the DFAS, there needs to be a strong intention and high commitment for the very same by DFAS stakeholders. I 12 reports that her business-to-business DFAS provider used to be content agnostic. However, this has changed, and climate sensitivity has become a "hardcore value". Therefore, this topic is always highlighted in the negotiation processes with partners leading up to the final DFAS (I 12). I 1, in contrast, remarks that, during the design processes for some of his DFAS projects, environmental sustainability was not explicitly looked at. He also recalls a project in Ethiopia wherein environmental sustainability played a role. However, he stresses: "I doubt whether this was a big part of the advisory system itself or, let's say, an explicit goal of the advisory system (I 1)". One of the main reasons for the disregard of environmental sustainability aspects is that other challenges of DFAS such as business sustainability are prioritized over environmental sustainability (I 1). Another bottleneck is that environmental sustainability is not always clearly defined for DFAS and more broadly (I 10).

Four factors have been insinuated as possibly impacting some of the aforementioned aspects: DFAS partner selection, diversity in the people negotiating DFAS content, the size of investments in environmental sustainability-focused agricultural R&D, and external shocks (I 4, I 11, I 12). DFAS partners have a strong impact on DFAS direction, in particular, if they are governments. Thus, only collaborating with partners that wish to promote environmentally sustainable agricultural practices is a leverage point for environmental sustainability. I 4 highlights that her organization already checks potential partners and whether "[they] are in line with the kind of values we [DFAS company of I 4] have and that they are not promoting any practices that we don't agree with (I 4). I 12 highlights that the overall goal of DFAS providers and partners should be the same. When asked about conflicts of interest, she recalls a collaborative DFAS project with a for-profit partner that put his business interests first. Increased diversity in the people negotiating DFAS content, referring to the professions of negotiators and the school of thought they belong to, might also serve as a leverage point. As has been shown in section 4.1, a lot of responsibility in the negotiation processes leading up to DFAS content is delegated to agronomists. However, agronomy is not an objective and politically neutral science, even though it likes to present itself as such. Power and politics influence which cropping systems and agricultural practices are viewed as favorable in a specific context (Moseley, 2021). What's more, in conventional agronomic approaches, the complex cropping systems, that many smallholder farmers in the Global South manage, are paid insufficient attention to (Sinclair & Coe, 2019). Including various scientific disciplines and agronomic schools of thought, also those which are not dominant, in DFAS negotiation processes could facilitate more holistic perspectives and allow for more environmental sustainability in DFAS.

An additional leverage point lies in financing more agricultural R&D, in particular R&D that puts farmers' livelihood improvements as well as environmental sustainability at the center. The obtained knowledge should either be integrated into existing crop growth models or should inform the development of new crop growth models that consider environmental parameters and sustainable agricultural practices (Wenkel et al., 2017) (also see section 5.3).

External shocks, or put differently, unexpected major events impacting the farming context, could also serve as a leverage point for building environmental sustainability into DFAS. External shocks can mold the conditions under which decisions for specific standards were originally taken. This, in turn, can enable major changes, including paradigmatic changes. I 11 describes that, due to "exploding" chemical fertilizer prices, animal manure as an alternative nutrient source was closer investigated for a project in Kenya. I 12 reported that the COVID-19 pandemic changed how their DFAS were delivered. However, as extern shocks cannot be provoked intentionally, they rather serve as indirect leverage points and are thus not further enumerated below (see table 13 below).

5.2 Intervention

Above, the degree of automation in DFAS has been understood as the degree of algorithmic decision-making in different DFAS development phases. Emphasis has been put on the creation of the agricultural recommendations-phase as it strongly determines DFAS governance.

Regarding several aspects, it remains unclear how a higher degree of automation in DFAS impacts environmental sustainability. The agricultural practices and paradigm promoted by DFAS could, for example, be either selected by farmers based on an automatic pre-selection or could be fully automatically assigned to farmers (in a specific location). However, which of the two ways would lead to better environmental outcomes would highly depend on farmers' agricultural practices and paradigm selection. Similarly, while personalized and dynamic agricultural recommendations are based on smaller digital representation-reality gaps on average, it remains uncertain whether they contribute to more environmentally sustainable agricultural systems than the general and personalized, but static type of agricultural recommendations. Case- and phase-specific future research is needed to profoundly unveil the relationship between the degree of automation and environmental sustainability in DFAS.

Concerning the strategies of influence that are used in traditional DFAS, it seems likely that many of them can be also used for environmentally sustainable DFAS. This is because strategies such as "guaranteeing understandability of agricultural recommendations" are content-neutral. I 12 reported, for example, that her DFAS seeks to communicate concepts such as the "365 crop cover concept", traditionally recognized as an environmentally sustainable concept, in an easy and user-friendly way.

As additional and particularly environmental sustainable strategies of influence and thus leverage points for building environmental sustainability into DFAS four are raised by respondents: the communication of the long-term benefits of sustainable practices, the promotion of practices that result in win-win outcomes for farmers, and the environment, the highlighting of environmental sustainability practices in DFAS, and the incentivizing of environmental sustainability practices by bundling (I 3, I 4, I 8, I 9, I 11).

I 4 cautions that promoting sustainable practices through DFAS requires delivering more information to farmers, while I 3 explains: "[…] you can really promote sustainability to them, but they are more concerned about their livelihoods, so you need to take into account both". I 11 cautions that considering farmers 'context is even more important concerning environmentally sustainable DFAS because "practices might not have immediate yield benefits or profit benefits and in fact might be very costly for the farmer to implement". I 8 illustrates, that in his DFAS, farmers are first provided the environmentally friendly and then the environmentally less friendly crop management option, pointing to the fact that the order in which agricultural recommendations are provided matters. Denoting practices that contribute to environmental sustainability explicitly is another strategy of influence that one respondent insinuates (I 9). Pairing environmentally sustainable practices with financial inducement, and thus bundling DFAS with other digital agriculture services, could also heighten environmental sustainability through DFAS (see section 6.1.2).

5.3 Representation

The accuracy and the consideration of representative elements important to environmental sustainability vary in the digital representations of DFAS. Thus, representation-reality gaps equally differ. Theoretically, there is no limit to the complexity of the digital representation of farming systems. Ever more features (variables) and accurate data could be inputted into ever more complex overall DFAS models resulting in ever more precise digital representations of agricultural systems (I 4, Wallach et al., 2018). However, often there are practical issues regarding data availability. What´s more, many interactions between different agricultural features (agricultural variables) remain unclear to date. Hence, more research, based upon which model improvements can be undertaken, is needed. Missing knowledge makes what is called parameterization, difficult or impossible. Nevertheless, there are some leverage points, on a general as well as on a sub-dimensional level, which are likely to positively impact the environmental sustainability of DFAS through representation.

Increasingly representing the interactions between different factors, for example, could serve as one leverage point for building environmental sustainability into DFAS. On the farm level, this would mean extending crop models tailored to specific fields to farm models. These farm models should not only consider agronomic variables, but also agroecological variables that are related to environmental sustainability. On an even broader level, beyond the farming system, the agroecosystem, into which the farming system is embedded, should increasingly be taken into account in digital representations. This is because there is an ecologically important interplay between the farming system and the agroecosystem. Boote et al (2020) write “Most of our models are fairly robust when we focus on the role of agriculture in provisioning […] however, the linkage of specific management practices to regulatory, cultural or supporting ecosystem functions needs substantial improvement” (p. 355).

Besides this extension of the spatial scale, the temporal scale should also be extended. This would allow capturing several seasons and the (nutrient) carry-over effects from one season to the other. Such a practice would contrast with the commonly used practice of resetting model values at the beginning of each season (Asseng et al., 2020). Agricultural recommendations inferred from such multi-season models could potentially also facilitate more strategic, long-term decisions as opposed to operational decisions of present DFAS (I 1). It is likely that such an extension on the temporal scale, contributes to environmental sustainability, a concept that is itself (by definition) predicated on a longer time horizon. Crop rotation, a relatively environmentally sustainable practice, is an exemplary practice that could become enabled by multi-season models.

Selecting more and other features than the ones which are selected for current DFAS only has a positive impact if they are related to environmental sustainability. What´s more, they need to be available and clearly relatable to the other variables. Such features could include, for example, the crop cultivar allowing for better adaptations of general models. However, as has been shown above, often such data is not available.

Apart from crop data, (non-homogenous) soil data is named as an important component for any DFAS supporting environmental sustainability and agricultural production more broadly (I 5, I 10; cf. Wallach et al., 2018). More accurate soil and weather data, for example, enables more precise input recommendations and applications leading to enhanced environmental sustainability (I 4, I 5). The production of related data points could be undertaken by governments. These could later be shared through open and free data repositories. Such repositories could serve as a foundational data layer for all DFAS developers.

For improved weather data, the cornerstone for any DFAS, public and/or private investment in the weather measurement infrastructure including the set-up of automated weather stations and other measurement devices is needed (Ferdinand et al., 2021). The generation of new weather data could be complemented by the digitization of old paper-based weather data. What’s more, more and better farm activity and results data would be needed for tailored agricultural recommendations. This would, for example, allow for pesticide advice that considers the farmers’ pesticide history and therefore is sensitive to the interplay between different types of pesticides and their impact on crops and soil (I 8). Yet, as farmer activity and results data are reported by the farmers themselves, there have been some inaccuracies. Thus, attempts to increasingly use this type of data for enhanced environmental sustainability would require ensuring data quality. Incentivizing and communicating the importance of more accurate data entry as well as regularly validating data entry through field visits or remote measuring devices could be ways to improve farmer input data.

Besides farmer activity and result data, the data that is collected on farmer characteristics and farms is equally limited. Yet, the characteristics of each farmer and farm impact which agricultural practice is found to be most suitable for the particular context, also with regard to environmental sustainability (Sinclair & Coe, 2019). Environmentally-sustainable practices are said to be more time intensive in the initial phase, leading to a perception that they are inappropriate and unsuitable for poor farmers who need to allocate their time to income-generating activities (I 12). Collecting information on labor availability on a particular farm could underpin this assumption with data and possibly impact resultant agricultural recommendations, just to name one exemplary and neglected feature that could improve environmental sustainability in DFAS.

Generally, the environmental sustainability-sensitive digital representation is by large impacted by the direction of agricultural R&DD investments which also include model research, development, and deployment. In some respects, model research has not advanced much in the last decades (e.g., regarding root zone modeling), and thus more innovation is needed (Boote et al., 2010). Different papers recognized the importance of transdisciplinary collaboration, including social science, in such agricultural model-related research processes (Boote, 2020, Boote et al., 2010, Wenkel et al., 2017), another aspect that could, if being taken up, increasingly contribute to environmental sustainability in DFAS.

For models to come up with more environmentally sustainable agricultural recommendations, besides the integration of more environmental sustainability-related variables, it would be also necessary to express sustainability in their cost function, especially in personalized, dynamic DFAS. This would allow the models not only to learn about how to optimize for better yield but also how to optimize for the most sustainable farming practices (I 7). Yet, this would mean that environmental aspects are represented numerically in the models to enable comparability between different relevant aspects. A monetary value could result as the ultimate, numerical unit. Along with the concept of ecosystem services comes an attempt to represent nature in monetary value. Based on the experience that the original irrigation plannings “weren't at all aligned with what the farms could produce, in terms of water”, I 9 reports that her DFAS added the variable of “farm’s water stock” leading to diverging, more environmentally sustainable irrigation plannings. Additionally, I 9 explains that her company has introduced a green scoring system that assigns points to farming activities. This system encompasses calculations on consumed energy, carbon footprint, and water consumption (I 9). All these undertakings can be seen as leverage points for environmental sustainability in the representative algorithmic governance dimension.

Table 14: Overview of leverage points for environmental sustainability in DFAS (based on the precedent section)

Dimensions of Algorithmic governance	**Leverage point for environmental sustainability**
Direction	1. Establishment of environmental sustainability as an additional standard to the overall “improvement of livelihoods” direction
	2. Embracing complex, but environmentally sustainable agricultural practices and farming systems more broadly
	3. Selection of DFAS partners for which environmental sustainability is important
	4. Diversity in the professionals that determine DFAS content
	5. Increased investment in environmental sustainability-focused agricultural R&D
Intervention	1. Leverage same strategies as in traditional DFAS for environmentally sustainable agricultural recommendations (e.g. understandability)
	2. Communication of long-term benefits of environmental sustainability practices
	3. Promotion of win-win practices, consideration of farmers and the environment
	4. Highlighting environmentally sustainable agricultural recommendations, put these first in the service
	5. Pairing adoption of environmentally sustainable agricultural recommendations with financial inducement, bundling of DFAS with other digital agricultural services
Representation	1. Extend the spatial and temporal scale that DFAS models are covering
	2. Consider variables that are explicitly related to environmental sustainability in DFAS models (such as soil data)
	3. Make improvements to weather measurement infrastructure
	4. Leverage farmers’ data entry while ensuring data quality
	5. Consider variables beyond agronomic ones that allow for a better representation of farmers and farms
	6. Augment R&DD investments concerning environmental sustainability-sensitive models
	7. Integrate environmental sustainability in the cost function of the overall DFAS model

6. Discussion

This discussion chapter is divided into three sections. Guiding questions structure each section. Said questions relate to the results generated through algorithmic governance analysis (section 5.1), the identified leverage points for building environmental sustainability into DFAS (section 5.2), and the methods used to generate results (section 5.3). The discussion aims to critically reflect upon and assess the obtained results, the utilized theoretical perspectives as well as the applied methods.

6.1 Results

To guide DFAS designers that wish to design environmentally sustainable DFAS, it is paramount to know which leverage points and “chains of leverage” they should prioritize (cf. section 2.3). This section, therefore, discusses *How deep (or shallow) individual leverage points in the three algorithmic governance dimensions are* and *In how far they can produce “chains of leverage” in and beyond DFAS?*

6.1.1 How deep (or shallow) are individual leverage points in the three algorithmic governance dimensions?

The question around the depth of leverage points is a question about the best places where to intervene to move DFAS toward contributing to environmental sustainability. It is therefore highly relevant for DFAS designers. Shallow leverage points are defined as “places where interventions are relatively easy to implement yet bring about relatively little change to the overall system”, whereas deep leverage points are defined as “[places] that might be more difficult to alter but potentially result in transformational change” (Abson et al 2017, p. 2). For this thesis, Meadows’ twelve leverage point types were, according to the four leverage point categories (intent, design, feedback, parameter), classified as either “Deep”, “Medium deep”, “Medium shallow” or “Shallow” (see table 14 in memory of section 2.3). The deeper a leverage point is, the higher the probability that it, when leveraged, positively impacts environmental sustainability in DFAS.

Table 15: Meadows’ 12 places to intervene in a system (leverage point types) and their respective leverage point (depth) categories (simplified and adapted based on Meadows (1999), Abson et al. (2017) & Fischer & Riechers (2019)

No	leverage point types	Leverage point category	Leverage point depth category
1	The power to transcend paradigms	Intent	Deep
2	The mindset/paradigm out of which the system arises		
3	The goals of the system		
4	The power to add, change, or self-organize system structure	Design	Medium Deep
5	The rules of the system (such as incentives and constraints)		
6	The structure of information flows (access to information)		
7	The gain around driving positive feedback loops	Feedbacks (Processes)	Medium Shallow
8	The strength of negative feedback loops		
9	The length of delays, relative to the rate of system change		
10	The structure of material stocks and flows	Parameters (Material)	Shallow
11	The size of buffer stocks, relative to their flows		
12	Parameters (such as subsidies and taxes)		

"Deep", "Medium deep", "Medium shallow", as well as "Shallow" leverage points can be found in DFAS. Some leverage points appear to be DFAS-specific, while others are more general and thus could trigger changes to environmental sustainability in DAS more generally. As DFAS are only "recommender systems" (Yeung 2018) and can therefore not directly influence how agricultural practices are carried out (see section 4.2.1), leverage points can only transform algorithmic governance systems and their resulting agricultural recommendations, but not necessarily impact farmer users' behavior.

Leverage points for building environmental sustainability into DFAS have different degrees of depth in different algorithmic governance dimensions and DFAS development phases respectively. The direction dimension plays out from the start of DFAS development processes through to DFAS delivery and finally DFAS iterations. The intervention dimension has a role in DFAS design and particularly in DFAS delivery. The representation dimension is important in the design phase (modeling of content) and is less ostensibly in the delivery phase see (section 4.2.1). As the direction's impact and the impact of directional leverage points are so grave, they also influence the other two dimensions and their leverage points. Therefore, it could be claimed that leverage points on different dimensions are horizontally nested with one another (cf. Leventon et al., 2021)

Direction dimension

In the "direction"-dimension, the leverage points "Guaranteeing professional diversity of the experts that determine DFAS content" and "Selecting DFAS partners for whom environmental sustainability is important" have characteristics that are touched upon Meadows "2. The mindset/paradigm out of which the system arises" leverage point category. If there is professional diversity among DFAS designers, meaning that besides agronomists also professionals such as ecologists or social scientists are involved with DFAS design, it is likely that the mindset/paradigm with which DFAS are designed changes (cf. Boote, 2020, Boote et al., 2010, Wenkel et al., 2017). A similar impact has the establishment of environmental sustainability-sensitive multi-stakeholder DFAS collaborations through environmental sustainability-sensitive partner selection. Yet, the latter seems to even starker ensure environmental sustainability-positive change as environmental sustainability is explicitly considered. As both leverage points directly influence the "intent" of the system, they can be classified as "Deep" (cf. Abson et al., 2017).

In contrast, the leverage point "Establishing environmental sustainability as an additional standard for the overall "improvement of livelihoods" direction" corresponds with Meadows' "3. The goals of the system"-leverage point category. To make system goals achievable, desired states are formulated in the form of standards. As soon as standards are defined, (algorithmic) governing systems move regulatees in the direction of those standards (Eyert et al. 2022; Just & Latzner, 2017). In the case of DFAS design, a standard/goal-based directional change towards environmental sustainability through leveraging said leverage point is likely to be grounded on the negotiation processes determining DFAS' set of promoted agricultural practices. System goal changes can be viewed as profound and said leverage point is therefore "Deep".

The leverage point "Embracing complex, but environmentally sustainable agricultural practices and farming systems more broadly" is classified here as "Medium Deep". It holds characteristics of what Meadows describes as "5. The rules of the system". Traditionally, one rule to DFAS design was to make it work and get services operational relatively quickly (I 1). However, under this rule, the complexity of agricultural systems and practices was neglected.

If DFAS want to increasingly contribute to environmental sustainability in agriculture, embracing more complex practices is vital. This is because environmentally sustainable practices (e.g., crop rotation or agroforestry) are in some cases comparatively more complex. Lastly, “Increasing investment in environmental sustainability-focused agricultural R&D” is a “Shallow” leverage point that best matches the leverage point category of "12. Parameters”. This is because an increase in the investment rate for environmental sustainability-focused agricultural R&D is merely a numeric change that does not change algorithmic governance system behavior as it neither stabilizes nor breaks existing DFAS (Meadows 1999). Yet, augmenting environmental sustainability-sensitive investments might kick off processes that may be leading up to the changes on a higher system level.

Intervention dimension

In the “intervention”-dimension, leverage points are generally less deep and thus correspond with leverage point categories which are lower on Meadows’ “list”. “Bundling adoption of environmentally sustainable agricultural recommendations with financial inducement, or with other digital agricultural services” as the highest leverage point in the “intervention”-dimension addresses the “rules of the system”. It does so by changing the incentive structure for environmentally sustainable agricultural practice adoption because farmers who adopt such practices receive a (financial) reward for doing so. In contrast, one could also argue that the aforementioned leverage point rather falls into the category of “The gain around driving positive feedbacks” as financial inducement reinforces the positive impact of adopting environmental sustainability practices for the farmer. Besides the farmer, the environment would be a “winner” of such a process (cf. Meadows 1999). Yet, this would mean that the depth of the leverage point would be “degraded” from “Medium deep” to “Medium shallow”.

The second deepest leverage point in the “intervention”-dimension is “Highlighting environmentally sustainable agricultural recommendations & putting these first in the service”. DFAS designed in such a way have changed the present “structure of information flows” (leverage point category 6) in favor of environmental sustainability information. Therefore, the leverage point can be classified as “Medium deep”. The leverage point “Communicating the long-term benefits of environmental sustainability practices” also alters information flows and therefore falls into the very same leverage point category.

The leverage point “Promoting win-win practices, considering the farmers and the environment” by contrast could be said to trigger “positive feedback loops” (cf. leverage point category 7) and could therefore be classified as “Medium Shallow”. It is likely that gains regarding farmers’ livelihoods as well as gains concerning the environment positively influence each other and lead to “success to the successful”-loops, wherein improvements to livelihoods and the environment lead to more improvements to the very same areas (Meadows, 1999).

The last and shallowest leverage point “Leveraging same strategies as in traditional DFAS for environmentally sustainable agricultural recommendations (e.g., understandability)” in the intervention dimension is not clearly allocatable to a specific leverage point category as it comprises many different strategies which can be leveraged for the creation of susceptible agricultural recommendations.

Representation dimension

In the “representation”-dimension, the deepest leverage point is “Integrating environmental sustainability in the cost function of the overall DFAS model”. It is classified as “Deep”. Being leveraged, this leverage point would impact the goal of the system. This is because the cost function formalizes what goal a(n) (relatively sophisticated) algorithm or a set of algorithms should optimize for (I 7). Complex cost functions particularly exist in machine learning algorithms and AI-based systems. As such algorithms and systems produce new knowledge based on data inputs and outputs and potentially even create new system structures and behaviors. For the latter reason, it could be also claimed that the aforementioned leverage point falls into the leverage point category of “4. The power to add, change or self-organize system structure” (cf. Meadows 1999). What’s more, the leverage point resembles the third leverage point in the direction dimension (3. Establishing “environmental sustainability” as an additional standard for the overall “improvement of livelihoods” direction). However, it rather targets the algorithmic governance system directly through a more environmental sustainability-sensitive digital representation of farming systems, whereas the similar leverage point in the “direction”- dimension targets the bigger socio-technical structure into which algorithmic governance systems are embedded.

The leverage point “Extending the spatial and temporal scale of DFAS models” corresponds with the leverage point category “The rule of the system” and can thus be classified as ”Medium deep”. Traditionally, the rule for DFAS (and for DFAS designers alike) was something like “give (program) season-based agricultural recommendations for a specific crop (in isolation)”. Such a rule ignored spatial spillover effects (between fields) as well as long-term effects of specific practices (also referred to as carry-over effects, cf. Asseng et al., 2020). Extending the spatial and temporal lens through which the environment is viewed, resonates with the concept of environmental sustainability.

The three next and shallower leverage points in the “representation”-dimension are: “Considering features (variables) that are explicitly related to environmental sustainability in DFAS models (such as soil data)”, “Leveraging farmers’ data entry while ensuring data quality”, and “Considering non-agronomic features (variables) for a better representation of farmers and farms”. They all match with the “6. The structure of information flows”-leverage point category and are therefore classified as “Medium deep”. When being leveraged, these leverage points add new information loops to the existing ones and thereby either directly positively influence environmental sustainability in the algorithmic governance systems underpinning DFAS or indirectly knock on other leverage points for environmental sustainability. It could be argued, for instance, that the second, aforementioned leverage point could facilitate the incremental application of machine learning algorithms and thereby enable algorithmic governance systems “to [increasingly] add, change or self-organize system structure” (cf. leverage point category 4).

“Making improvements to the weather measurement infrastructure” leads to a change in the physical infrastructure on which DFAS depend. Tendentially, such changes are relatively costly. It is argued here that this leverage point corresponds with the “The structure of material stocks and flows”-leverage point category. At a later stage, the newly improved infrastructure could improve information flows (cf. leverage point category 6) and enhance the foundational agricultural data layer on which DFAS designers highly depend. A more robust, quality foundational agricultural data layer could lower digital representation-reality gaps (cf. I 4, I 6). Said leverage point was lately prominently raised and ascribed high importance for the betterment of weather services (including DFAS) (cf. Ferdinand et al., 2021). Yet, staying within the theoretical limits of the leverage point perspective, this leverage point can only be classified as “Medium shallow" or “Shallow”.

Lastly, “Augmenting R&DD investments concerning environmental sustainability-sensitive models” is a leverage point that is rather “Shallow”. Similar to the last leverage point in the direction dimension, this leverage point falls into the leverage point category of “Parameters”. The leverage point is grounded on the idea that more investments will allow DFAS designers to dedicate more time to the search for environmental sustainability-sensitive models, testing them, and finally improving them. Probably, such an undertaking would also require on-the-ground, agronomic experiments. For that reason, it is claimed here that said leverage point should be leveraged together with the similar leverage point “Increasing investment in environmental sustainability-focused agricultural R&D” in the “direction”-dimension.

Table 15 gives an overview of all identified leverage points. The deeper a leverage point is the greener its background color.

Table 16: Overview of leverage points in DFAS, ordered according to their leverage point category and thus depth

Dimension of algorithmic governance	Leverage point in DFAS	Leverage point type	Leverage point' depth category
Direction	1. Guaranteeing professional diversity of the experts that determine DFAS content	The mindset/paradigm out of which the system arises	Deep
	2. Selecting DFAS partners for whom environmental sustainability is important	The mindset/paradigm out of which the system arises	Deep
	3. Establishing "environmental sustainability" as an additional standard for the overall "improvement of livelihoods" direction	The goals of the system	Deep
	4. Embracing complex, but environmentally sustainable agricultural practices and farming systems more broadly	The rules of the system	Medium deep
	5. Increasing investment in environmental sustainability-focused agricultural R&D	Parameters	Shallow
Intervention	1. Pairing adoption of environmentally sustainable agricultural recommendations with financial inducement, e.g., through bundling with other DAS	The rules of the system	Medium deep-Medium shallow
	2. Highlighting environmentally sustainable agricultural recommendations, putting these first in the service	The structure of information flows	Medium deep
	3. Communicating the long-term benefits of environmental sustainability practices	The structure of information flows	Medium deep
	4. Promoting win-win practices, considering the farmers and the environment	The gain around positive feedback loops	Medium deep
	5. Leveraging same strategies as in traditional DFAS for environmentally sustainable agricultural recommendations (e.g., understandability)	Not clearly allocatable	Medium Shallow
Representation	1. Integrating environmental sustainability in the cost function of the overall DFAS model	The goals of the system; The power to add, change, or self-organize system structure	Deep
	2. Extending the spatial and temporal scale of DFAS models	The rules of the system	Medium deep
	3. Considering features (variables) that are explicitly related to environmental sustainability in DFAS models (such as soil data)	The structure of information flows	Medium deep
	4. Leveraging farmers' data entry while ensuring data quality	The structure of information flows	Medium deep
	5. Considering non-agronomic features (variables) for a better representation of farmers and farms	The structure of information flows	Medium deep

	6. Making improvements to the weather measurement infrastructure	The structure of material stocks and flows	Medium shallow - Shallow
	7. Augmenting R&DD investments concerning environmental sustainability-sensitive models	Parameter	Shallow

As has been shown above, the deepest leverage points for building environmental sustainability into DFAS can be found in the “direction”-dimension. It is followed by the “representation”- and “intervention”-dimensions. This thesis argues that DFAS designers should focus on leveraging “Deep” and “Medium deep” leverage points. This is because these leverage points are most effective in changing DFAS toward contributing to environmental sustainability. Yet, some “Shallow” leverage points might knock on deeper leverage points, producing what is referred to as a “chain of leverage” (cf. section 2.3). Against this backdrop and keeping the question of the cost-effectiveness of DFAS interventions in mind, it needs consequentially to be asked:

6.1.2 In how far can leverage points in DFAS and beyond produce “chains of leverage”?

“Chains of leverage” describe the interdependences between different leverage points, or put differently, how leveraging one leverage point can precipitate another leverage point (cf. Fischer & Riechers, 2019). This is particularly interesting as it is assumed that many “Deep” leverage points are difficult to leverage and necessitate some “groundwork” first. It is put up for debate here that once the process of change is kick-started said “chains of leverage” can lead to truly transformational change (Ibid.).

There is probably a difference in the degree to which leverage points in DFAS need to be leveraged to produce “know-on effects” on other leverage points. Possibly there are varying thresholds to this which are likely to depend on the agricultural context and specific DFAS environment. For the collected environmental sustainability-sensitive data, for example, there is likely to be a specific amount of data that is needed to knock on the deeper leverage point of “Integrating environmental sustainability in the cost function of the overall DFAS model”. In this specific case, this is because a certain amount of environmentally sensitive agricultural data only makes DFAS designers think about the opportunity of leveraging said leverage point.

While Meadows seems to be convinced that changes to deep leverage points will invoke “further changes down the line” (cf. Meadows, 1999), this thesis argues that “chains of leverage” in DFAS (and beyond) can also be bidirectional, meaning that deep leverage points can not only contribute to leveraging shallow leverage points, but also the other way around. Using the same example as above it can be claimed that having more environmental sustainability-sensitive agricultural data at their disposal, for example, could lead DFAS designers to integrate environmental sustainability into the cost function of the overall DFAS. Yet, on the other hand, aiming at designing environmental sustainability into the cost function could make DFAS designers consider the bolstered usage of new environmental sustainability-enabling measurement devices such as soil sensors to obtain said data. To substantiate the aforementioned claim beyond single, yet plausible examples such as the one at hand, more and especially geared empirical research is needed. Generally, many more “chains of leverage” between leverage points within DFAS are conceivable. However, this thesis wishes to particularly bring more light on how such “chains of leverage“ can be formed beyond the leverage points of a single DFAS only.

“Bundling”, wherein a DFAS is combined with one or more other (D)AS could be understood as a strategy to produce such “chains of leverage” beyond DFAS. Bundling has been recognized by several recent publications as a way of improving the impact of DAS, including the one of DFAS (cf. CTA, 2019b; Porciello et al, 2021). This thesis argues that this increased impact is realized because by bundling DFAS with other DAS their respective leverage points are equally bundled, constituting what is referred to here as “DAS-overarching chains of leverage”.

For the case of DFAS, the aim of bundling is likely to be “higher adoption rates of the recommended agricultural practices”, or put more generally, amplifying the governance emanating from DFAS”. CTA (2019b) substantiates this when arguing that by bundling advisory services with “higher-margin services like market linkage […] increased farmer registrations, deeper farmer engagement, and in some cases stronger economics (p.41)” were achieved.

Bundling results in bundles or, viewed through the leverage point perspective, in new combinations of leverage points. Against this backdrop, this thesis argues that some bundles, which contain enough leverage points, can improve the environmental sustainability performance of DFAS and the services they are bundled with. In practice, however, the reasons for bundling are manifold and do not necessarily relate to enhanced environmental sustainability. While I 1 mentions that bundling is undertaken to improve the business sustainability of DFAS, I 6 explains that “the nature of the problems is so complex that it doesn't make much difference if you just change one thing”, pointing to the fact that bundling is necessary to get a handle on the challenges in agricultural development in the Global South.

What’s more, the types of bundles differ. There are, for example, what is referred to here as “digital agricultural service bundles”, wherein two DAS are bundled, as well as “digital-analog service bundles”, wherein one DAS and one analog agricultural service are bundled. In addition, the number of services in one bundle can differ. While bundling two services is the minimum requirement to accomplish a “bundle” per definitionem, bundling several (digital) services, something that is, inter alia, done in so-called digital agriculture platforms, is also possible. I 6 describes that his company pursues a “platform approach”. Other providers rather have different standalone products which are linked weakly (I 9), pointing to varying degrees of DAS integration in bundles. Coming up with precise definitions and a well-rounded “bundle-typology” is beyond this thesis which focuses first and foremost on DFAS.

In practice, DFAS can be bundled with financial services. Several respondents reported being currently looking into such DFAS-financial service bundles (I 2, I 6, I 8, I 9). Financial services can range from the (digitally-enabled) facilitation of saving groups to index-based crop insurance and market price information. I 11 states “I think bundling some type of insurance product with our advisory could be a very promising avenue. And other types of financial products like insurance, I think could make a lot of sense” (I 11).

DFAS-insurance bundles are increasingly been seen in the D4Ag realm (CTA, 2019). This thesis argues that bundling DFAS to index-based crop insurance could possibly facilitate the adoption of new, costly, and potentially “risky”, but environmentally sustainable agricultural practices. However, this is only possible if various leverage points for environmental sustainability in both services are leveraged. Else, bundling could also lead to worse outcomes for the environment (e.g., through the unthoughtful, risk-free application of huge amounts of fertilizers).

Other bundles that could potentially increase environmental sustainability through the combination of different leverage points for environmental sustainability are DFAS-sustainability certification and DFAS-carbon credit service bundles. I 3 and I 11, report to be looking into the former. I 11 explains: “[…] product premium pricing, that's something we're exploring as well. For example, in India, we have a project on cotton and we're working with several partners, including the Better Cotton initiative, thinking about standards for cotton. You know, how can we, you know, help farmers produce cotton in a more responsible way, but then achieve a higher price for the product that they're producing (I 11)". I 2 and I 11, in contrast, are looking into (digital) carbon credit services, which reward farmers monetarily for entrenching agricultural practices that store CO2 in their soils and woody perennials. Combined with advice through DFAS, such (digital) carbon credit services could enhance environmental sustainability.

This work argues that beyond these exemplary bundles, there are many more bundles for enhanced environmental sustainability in DAS. This thesis contends that identifying these bundles and their respective "chains of leverage" and taking advantage of them in the design process, will make a positive contribution to environmental sustainability in DAS. This is because leveraging effective bundles enhaces DAS governance and thereby gives allows DAS designers to better steer farmers toward desired environmental-sensitive outcomes in agriculture.

6.2 Theory

In this thesis, the theory of governance and the respective algorithmic governance framework were utilized to investigate the ways by which DFAS can govern farmers' behavior. Based on that, through the identification of leverage points, the potentials of said DFAS governance in contributing to environmental sustainability were determined. Finally, the depth of leverage points and possible "chains of leverage" were made visible and discussed with the help of the leverage point perspective. The taken approach is novel in many ways. First, Eyert et al´s (2022) algorithmic governance framework has not yet been thoroughly applied to an empirical case such as DFAS. Second, the leverage point perspective has not yet been applied to digital/algorithmic systems, or more precisely, hybridlike systems such as the ones underpinning DFAS. And third, the algorithmic governance framework and the leverage point perspective have not yet been applied together. Besides the practical methodological challenges that this caused, it also prompted the questions as to *whether the algorithmic governance framework (as laid out by Eyert et al (2022) is suitable to describe (algorithmic) governance by DFAS and DAS more generally*, as to *whether the leverage point perspective is useful to determine potentials for environmental sustainability in digital/algorithmic systems*, and as to *whether it is productive to use the algorithmic governance framework and leverage point perspective together (to analyze DAS).* Answering these questions naturally implies suggesting theoretical as well as methodological improvements.

6.2.1 Is the algorithmic governance framework suitable to describe (algorithmic) governance by DFAS and DAS more generally?

For this thesis, not all aspects of Eyert et al´s (2022) algorithmic governance framework were used. In particular, those that are deemed to serve as starting points for a critique of the present mode of algorithmic governance in DFAS, namely the properties of "Adaptability" and "Opacity", have been left out. This was done purposefully to, conversely, follow a hands-on, practical approach, focusing on concrete and possible DFAS changes toward environmental sustainability rather than a broad critique of algorithmic governance in DFAS and its sociopolitical implications. Still, this thesis attempts to critically dissect algorithmic governance analytically, something done by very few authors (cf. O'Reilly, 2013). What's more, this thesis, seeks to profoundly uncover data types as well as "data practices" (Lupton, 2016) including the analysis of the "[…] kinds of data used […], how they are produced, and how they are linked to the objects that they seek to represent (Eyert et al., p. 2)", and thus departs from the, to-date relatively common practice in technology studies, wherein it is not clearly differentiated between different aspects of algorithmic governance systems (cf. Input-throughput-output model by Just & Latzer et al., 2017, p. 241; Eyert et al., 2022). Last but not least, this thesis, as opposed to other strains of literature (e.g., Reidenberg, 1998; Lessing, 1999; Aneesh, 2009), does not look at algorithmic governance through the lens of code only but instead takes a more encompassing view, also including algorithmic governance facilitated through socio-technical assemblages.

Beyond this more general, theoretical reflection, the practical application of the algorithmic governance framework to DAS and DFAS more specifically, which forms part of the methodological approach, yielded some valuable insights into their algorithmic governance systems. This points to the fact that the algorithmic governance framework is applicable to hybridlike systems (analog as well as algorithmic governance) such as DFAS and thus evidences Eyert et al's claim that their frameworks "dimensions and subdimension […] apply to any kind of regulation [governance systems] (p. 4). Yet, the hybrid character of DFAS resulted in a less clear-cut and straightforward empirical analysis, something that was exacerbated by the varying degrees of automation and algorithmic governance present in different DFAS development phases (see table 8, p. 47).

It seems plausible that the algorithmic governance framework is suitable for the analysis of other DAS as well and is thus generalizable. However, the algorithmic governance effect is likely stronger in some other DAS. This is particularly likely for DAS on which farmers are highly dependent for their livelihoods (e.g., market linkage services). Nevertheless, it is likely that even in these cases there will still be some form of analog governance. This thesis argues that the remaining presence of analog governance is grounded on the relatively complex, unstructured environments on which agriculture in the Global South is predicated. Complex, unstructured environments as opposed to simple, structured environments such as greenhouses, it is argued, hinder algorithms to unfold their full governing effect.

The practical application of the algorithmic governance framework was further exacerbated by the fact that its "three dimensions should not be understood as successive stages and are by no means isolated, but rather empirically intertwined (Eyert et al 2022, p.11)". This empirical conflation of dimensions combined with the ambiguous definitions of those dimensions by Eyert et al. leads to the perception of overlap. It was, for example, empirically challenging to distinguish the subdimensions of "Degree of automation" and "Interpretation of data" as well as the subdimensions of "Production of data points" and "Interpretation of data". The latter seems to overlap particularly in sophisticated DFAS. This is because in such DFAS several loops of data production and/or interpretation are carried out before a final model outcome (agricultural recommendation) is generated. Hence, it remains unclear if intermediate results from single models (e.g., weather forecasting model outcomes) as opposed to final results from the overall DFAS model (normally agricultural recommendations) out to be analyzed within the "data production" or "data interpretation"-subdimension. What's more, some difficulties occurred when trying to match some of the identified "strategies of influence" in DFAS with the archetypical "types of strategies of influence" as outlined and defined by Eyert et al. (2022) (p.10ff.) (e.g., coercion or inducement). First, there was a mixture of algorithmically enabled and non-algorithmically enabled strategies of influence (e.g., time-sensitive sending out of agricultural recommendations vs. understanding of farmers' context). Second, some of the identified strategies of influence were not clearly allocatable to one of the archetypical strategies of influence.

In addition, the algorithmic governance framework showed some gaps regarding the collaborative multistakeholder efforts that facilitate the development of the algorithmic governance systems underpinning DFAS. What comes before and during the development of algorithmic governance systems seems to be – consciously or unconsciously – neglected by Eyert et al (2022). This creates the impression that algorithmic governance only happens when algorithmic governance systems are in place.

For cases of hybrid multistakeholder governance such as the one at hand (see section 4.1.1), which is starkly based on the norms and values of individual actors and actor constellations coming together in analog governance spaces to negotiate (algorithmic) governance in DFAS, this thesis proposes to add a fourth "Participation and Engagement/Influence (of different actors)" dimension to the existing framework (cf. Kloppenburg et al., 2022). This thesis argues that such an additional dimension would offer sufficient room to identify all involved (algorithmically) governing actors, and to determine their power vis-à-vis, other actors.

Subsuming all actor-related aspects under the "direction"-dimension as was done for this research does not allow for enough differentiation between, in reality similar, but still varying aspects of algorithmic governance. Particularly as new algorithmically governing actors, due to a power shift from public to private actors, emerge in the agricultural development realms (I 7), adding an additional dimension to the algorithmic governance framework seems timely. It appears to be plausible that the advancing digitalization of DAS and increased bundling and platformization of DAS will accelerate said development (due to positive network effects) (cf. Just & Latzer, 2017).

In addition, this thesis suggests adding the special strategy of "bundling" to the "strategies of influence"-types. "Bundling", wherein two or more DAS are combined, involves huge changes to an existing DAS. To impact farmers' behavior most profoundly, designers normally ground bundles on different "strategy of influence"-types The specific DFAS-carbon credit services bundle, for example, leverages the (monetary) "inducement" "strategy of influence"-type. Generally, bundles enlarge the functionality of a single DAS and thereby leverage the "architectural constraint" "influence of strategy-type" (e.g., by merging two or more DAS interfaces into one interface). Yet, as opposed to the typical "architectural constraint" "influence of strategy-type, bundles do not limit the possible actions of DAS users but rather enable them.

The two aforementioned suggestions for changes to the theoretical algorithmic governance framework do justice to Eyert et al. who, at the end of their article, make clear that "the subdimensions are not exhaustive and can be complemented by further aspects should empirical research suggest any (p.11)".

6.2.2 Is the leverage point perspective useful to determine potentials for environmental sustainability in digital/algorithmic systems (such as the ones underpinning DFAS or DAS more broadly)?

Grounded on the reviewed leverage point perspective literature (Abson et al., 2017; Birney, 2021; Chan et al., 2020; Dorninger et al., 2020; Fischer & Riechers, 2019; Jiren et al., 2021; Leventon et al., 2021; Manlosa et al., 2019; Meadows, 1999; Meadows D, 2009) it stands to reason that the leverage point perspective was originally designed to analyze relatively big and analog systems. One could think of a "food system" as having the appropriate size for leverage point analysis. Yet, this thesis takes a small-scale approach and investigates the relatively small, and additionally digital/algorithmic governance systems underpinning DFAS. This approach is grounded on the belief that systems are hierarchically nested within one another, that small system changes, in sum, cause bigger system changes and vice versa, and that therefore the size of the analyzed system is negligible.

This thesis, in accordance with Abson et al., views "systems" rather as epistemological tools "[…] through which sustainability issues can be addressed (p. 3)". It is therefore further believed that whether the "systems" causing sustainability issues are mediated through analog or digital means is equally negligible. However, what sticks out from the results is, that almost all leverage points for environmental sustainability in the algorithmic governance systems underpinning DFAS are to be found in leverage point categories that are rather non-material (informational). Particularly, the leverage point category of "The structure of information flows" is identified several times. Given that the digital sphere is often only perceived as being non-material (Crawford, 2021), and given that this work delimits itself while looking into some aspects beyond the digital sphere (e.g., weather measurement infrastructure), to this very same sphere, the latter seems logical.

Besides these conspicuities, this thesis contends that the leverage point perspective is appropriate to identify environmental sustainability potentials in digital/algorithmic governance systems underpinning DFAS and DAS more broadly. Yet, analysts should be cautious that results concerning environmental sustainability potentials in the physical world will be less pronounced or even totally neglected (e.g., resource usage such as metals, and energy for running DFAS) (cf. Crawford, 2021).

What's more, it needs to be cautioned that this thesis sees defining environmental sustainability in (digital) agriculture precisely and subsequently operating with a thorough and critical environmental sustainability definition as being beyond the scope of this thesis. This estimation was made because there is a lot of scientific debate around what can be called environmentally sustainable agriculture and/or what are environmental sustainability agricultural practices (e.g., Ritchie, 2017). At the same time, this approach is in sync with other empirical studies on leverage points wherein environmental sustainability is equally not delineated thoroughly (cf. Chan et al., 2020; Dorninger et al., 2020; West et al., 2014.)

6.2.3 Is it productive to use algorithmic governance framework and leverage point perspective together (to analyze DAS)?

Based on the results of the descriptive algorithmic governance system analysis (see chapter 3), some interview questions relating to the leverage point perspective, and thorough contemplations, leverage points for building environmental sustainability into DFAS were identified and assessed in their respective depth. Thereby, two theories which are both inspired by system and complexity thinking were combined: The algorithmic governance theory which explicitly sheds light on algorithmic governance systems that are part of larger (socio-) technological systems (Eyert et al., 2022; Just & Latzer, 2017; Yeung, 2018) and the leverage point perspective which explicitly sheds light on ecological sustainability in socio-economic systems, and which in the case of this thesis was applied to the socio-biological system of agriculture. It needs to be cautioned though, that the leverage point perspective is not applied to agricultural systems directly, but rather indirectly to the algorithmic governance systems underpinning DFAS. DFAS, in turn, seek to govern agricultural systems by steering farmers' behavior.

Grounded on the belief that the concept of "system" serves, first and foremost, as an epistemic tool, this thesis argues that the algorithmic governance framework and the leverage point perspective can be used together in an enriching manner. This belief is also substantiated by the fact that the used approach proved applicable to render algorithmic governance systems underpinning DAS and the potentials for environmental sustainability therein visible, and that it thus could be used to increasingly shed light on the relationship between DAS and environmental sustainability. Ultimately, this could supply DAS designers with the right tools for in-depth, to effectively build environmental sustainability into DAS. Yet, it needs to be cautioned that the approach at hand needs to be undertaken consecutively, meaning that first the algorithmic governance system needs to be unveiled and described, and second, leverage points need to be identified and assessed. Attempts to come up with a unified single analytical framework that combines the three dimensions of the algorithmic governance framework with the four leverage point categories of the leverage point perspective failed.

What's more, much more research and some analytical refinements would, amongst others, further evidence the preliminary proof of concept (proof that the analytical approach works) and increase the feasibility of future studies. It would be conceivable, for instance, to adapt Meadows' language of leverage points to the non-material, informational realities found in digital/algorithmic governance systems and thereby make it less cryptic and more practical for analysts.

6.3 Methods

Given the lack of scientific research in the field of DFAS, DAS, and environmental sustainability, elements of the explorative as well as descriptive case study method were used as the principal method and as starting point to "generate early insights on novel phenomena and developments by analyzing single cases" (cf. Methodology chapter; Fidel, 1984). Further, the case study method sought to advance theoretical development. To enable a thorough case study research, the supportive and additional methods of secondary literature desk study, semi-structured interviews, and systematic interview evaluation were leveraged (see "Other methods" section). What's more, as has been shown above, the analytical approach used is novel.

These aspects prompt the questions as to whether the case study method is suitable for analyzing DFAS/DAS and for identifying environmental sustainability potentials therein, and as to whether the methods enabling DFAS case study research were well chosen, and as to whether the applied analytical approach shows sufficient analytical potential to be used in future research.

6.3.1 Is the case study method suitable for analyzing DFAS/DAS and for identifying environmental sustainability potentials therein?

A has been seen, using the case study method yielded some good results on the specific DAS case of DFAS and leverage points for environmental sustainability therein. Yet, it is questionable whether these findings are generalizable and thus transferable to other DAS cases. This is because different DAS tackle different challenges of agricultural development and consequently have varying characteristics. DAS which enable market linkages, for example, dominantly tackle agricultural logistics and infrastructure challenges which is very much in contrast to DFAS, which dominantly tackle knowledge gaps of farmers. However, some more general findings such as high-level leverage points for building environmental sustainability into DFAS are likely to also apply to other DAS cases. "Increasing investment in environmental sustainability-focused agricultural R&D" or leverage points that contribute to a robust foundational agricultural data layer (e.g., "Making improvements to the weather measurement infrastructure") are examples of such high-level leverage points. Data from the foundational agricultural data layer can theoretically be used unlimitedly across DAS cases as it is a non-rivalrous good (cf. World Bank, 2021).

The DFAS provider selection criteria as outlined in section 3.1, also contributed to the suitability of the case study method. Said criteria have allowed for insights that are sufficiently broad to speak for most DFAS for small- and medium-scale farmers in the Global South and sufficiently narrow to have enabled thorough analysis. This is because they have covered a relatively high number of DFAS cases (also due to the inclusion of serial providers of DFAS), which stretch over several continents, serve different target groups and agricultural value chains, and utilize varying delivery technologies. Yet, it would be conceivable to further limit research boundaries, for instance, to one DFAS and/or DAS delivery technology. In particular, regarding the strategies of influence of a particular DFAS type a technology-based restriction would have yielded more fine-grained results as technology is an important enabler of "strategies of influence".

6.3.2 Were the methods, which enabled DFAS case study research, well-chosen?

It is deemed that the secondary literature desk study served its purpose. Yet, it needs to be cautioned that due to the accelerating emergence of the field of study in which this thesis is located ever more articles are published on an almost daily basis. This bears the risk that newly published articles are not sufficiently taken into account. A Google Scholar search in November 2022, using the same search words as outlined in section 3.3.1, resulted in several more "hits" than the searches conducted earlier. Another risk lies in the stark usage of grey literature as it can lead the analysts to slip into a rather uncritical, "technological-fix" position. Once having taken such a position, questions about narratives and values underscoring particular future visions for DFAS and DAS fade into the background while solutionist ideas come to the fore. Regular withdrawals from the field of study to ask the originally intended questions and reflect one's positionality for safeguarding against said phenomenon should therefore be pursued by those who research said field of study.

The semi-structured interviews with DFAS designers posed several challenges. Even though most of the interviewed respondents held extensive knowledge of technical aspects of DFAS, it was sometimes difficult for them to reflect upon normative, social, and/or environmental aspects of DFAS. This thesis assumes that this is because of two reasons: First because of increased professional specialization, differentiation, and (organizational) complexity in the DAS realm which makes it harder for experts to relate to other perspectives and maintain a birds-eye perspective, and second because the "language" of the interviewer did not always coincide with the "language" of respondents. This has likely limited mutual understanding despite the knowledgeability of respondents. I 1 summed the challenges in interviews up in cautioning: "Your questions are very abstract, high level and sometimes […] [it is] difficult to assess what the relationship is between, let's say, environmental sustainability, on the one hand, and certain agricultural advisories, on the other hand (I 1)".

To be more specific: It was, for instance, not very helpful to directly mention concepts such as "algorithmic governance" or ask for "strategies of influence" throughout the interviews as this was irritating for respondents. Many DFAS designers seemed to be rather unconscious or agnostic regarding the governance effect exerted by their DFAS. Similarly, only a few respondents could respond to the question as to whether they leverage "strategies of influence". Thus, possible strategies (e.g., inducement, coercion, etc.) had to be first presented, at times by giving examples, which bears the danger of being overly suggestive and consequently bias results. Inquiring respondents about normative aspects such as agricultural paradigms/standards promoted by their DFAS was equally challenging because the concept of “agricultural paradigms”/ “standards” remained difficult to understand and because definitions of agricultural paradigms/standards differ and/or overlap. This results in, inter alia, several standards being pursued at the same time by DFAS, rendering the question about which standards a particular DFAS providers leverages unanswerable.

The interview guide was, based on the above-noted contemplations, revised for better understandability several times. This resolved some of the aforementioned challenges. However, some more fundamental challenges remained. The challenges were additionally amplified by the fact that the author of this thesis was not able to assess environmental sustainability in DFAS through code/algorithms. In turn, this led to a substantial dependence on DFAS designers and respondents respectively.

Last but not least, the theory-informed interview evaluation which was based on fixed coding allowed for a relatively structured and systematic evaluation. At the same time, however, this approach endangers, as opposed to a grounded theory approach, to be self-referential and stay within the same, and fixed frame. Another less-fixed approach is likely to have yielded very different results. At the same time, it is assumed that following such an approach would have made it considerably more difficult to combine the evolving field of algorithmic governance with the field of study that utilizes the leverage points perspective as theoretical grounding. Therefore, this approach was deliberately excluded.

7. Conclusion and Outlook

7.1 Conclusion

Against the backdrop of a rising DAS uptake in the Global South, the absence of environmental sustainability from digital agriculture debate and literature, and the non-existence of practical, and sufficiently detailed recommendations for DAS designers who wish to design environmental sustainability into DAS, this thesis set out to answer the following main research question:

To which degree and by which ways can environmental sustainability be designed into Digital Agriculture Solutions?

To answer this question, this thesis, drew on the theory of algorithmic governance, the algorithmic governance framework by Eyert et al. (2022), and the leverage point perspective. Further, existing articles on DAS and environmental sustainability, particularly those related to governance and improved design of DAS were used as sources of inspiration. In drawing on said concepts and the existent literature, this thesis developed a novel analytical approach to render effective leverage points for building environmental sustainability into DAS visible. To permeate the object of inquiry thoroughly, one DAS case, namely DFAS was selected for qualitative, theory-informed, and case-study research. Further, the main research question was broken into three, case-specific sub-research questions:

(1) How and through which ways do Digital Farm Advisory Services attempt to govern sustainability-related farmers' behavior?

(2) What are entry points for building environmental sustainability into Digital Farm Advisory Services?

(3) What are the most effective entry points for building environmental sustainability into Digital Farm Advisory Services?

These three sub-research questions were resolved chronologically (see chapters 4, 5, and 6). To capture environmental sustainability in DFAS, DFAS were conceptualized as vehicles for farmers' governance. It was assumed this governance, which was referred to as DFAS governance, is embedded in DFAS design. Further, it was contended that by steering farmers' behavior through DFAS governance, DFAS influence farmers' agricultural practices and finally environmental sustainability of their farming practice.

To answer the first sub-research question, Eyert et al.`s (2022) analytical framework was extended by the subdimension "Important general aspects and actors' participation" to cover DFAS governance more intensively. Eyert et al's framework provided three ways by which DFAS impact farmers' behavior, agricultural practices, and finally the environmental sustainability of their farming practice. These are direction, intervention, and representation (see section 2.2). The adapted algorithmic governance framework provided the means to conduct an algorithmic governance analysis (see chapter 4). To answer the second sub-research question, this thesis drew on concepts from the leverage point perspective (section 2.3) and the results generated from algorithmic governance analysis (see chapter 4). This allowed for pinpointing leverage points for building environmental sustainability into DFAS. Leverage points were identified alongside the three ways by which DFAS impact famers' behavior, agricultural practices, and ultimately environmental sustainability (chapter 5). To answer the third sub-research question, the identified leverage points were matched with the twelve leverage point types and the four leverage point categories “Shallow”, “Medium Shallow”, “Medium Deep”, and “Deep” as outlined in section 2.1. Next, possible chains of leverage were identified and assessed for their effectiveness to contribute to enhanced environmental sustainability in agriculture (chapter 6). For answering all the aforementioned research questions, a secondary literature desk study, 14 semi-structured interviews with DFAS designers, and a systematic interview evaluation were conducted (chapter 3).

Regarding (1) “How and through which ways do Digital Farm Advisory Services attempt to govern sustainability-related farmers’ behavior?” it could be shown that DFAS govern sustainability-related farmers’ behavior by setting goals and standards for desirable farming, by automating different processes such as the creation of agricultural recommendations, by leveraging a multitude of strategies of influence (e.g., the creation of influential agricultural recommendations, the usage of various modalities and venues to convey these), by selecting some agricultural features over others, and by producing and interpreting agricultural data in distinct ways. In short, it was shown that DFAS seek to govern sustainability-related farmers’ behavior through direction, intervention, and representation.

These various ways by which DFAS govern, are based on the design of DFAS or put differently, the design of the algorithmic governance systems underpinning DFAS. During this design process of DFAS, different DFAS designers wield different degrees of power over designing governance into DFAS. Technology designers and governments generally wield comparatively much power. The role of algorithms in governing farmers’ behavior starkly varies between different DFAS, and between different DFAS design phases. In the negotiations around the set of agricultural practices that should become promoted through a DFAS, a phase that has an important impact on the environmental sustainability in DFAS, for instance, algorithms only play a subordinate role. Yet, in other phases such as the creation of agricultural recommendations, algorithms and thus algorithmic governance are starkly involved.

Given the fact that the ideas on how to govern farmers’ behavior are often already existent in the heads of DFAS designers prior to DFAS design, this thesis argues, that DFAS only reproduce, reinforce, and/or amplify normative, inherently political, and analog ideas and values of DFAS designers (cf. Just & Latzer, 2017; Nissenbaum, 2011; Toyama, 2011). Yet, since DFAS are often the results of multi-stakeholder collaborations, combinations of these “governance ideas” need to be negotiated. The ideas of those actors with the most power are likely to prevail. They thus set the course for governing farmers’ behavior in a distinct manner and produce specific environmental outcomes.

By answering the first sub-research question, this work contributed to filling the governance-related gap in digital literature agriculture. Further, it stimulated thought on how to conceptualize the ways by which DAS govern sustainability-related farmers’ behavior, agricultural practices, and finally environmental sustainability in agriculture. The theory of algorithmic governance and the corresponding algorithmic governance framework were proposed as promising means to this end. Empirical evidence suggests that they are appropriate for capturing governance in DFAS. It appears likely that these concepts can also be utilized for the analysis of other DAS.

Regarding (2) “What are entry points for building environmental sustainability into Digital Farm Advisory Services?” 17 entry points could be detected. In drawing on the leverage point perspective, said entry points were referred to as leverage points. Five leverage points for building environmental sustainability into DFAS were identified with respect to the general goals, standards, and indicators of DFAS (direction dimension). Five leverage points were identified with respect to automation and strategies of influences in DFAS (intervention dimension). And seven leverage points were identified with respect to features selected, data production, and data interpretation (representation).

The identified leverage points for building environmental sustainability into DFAS ranged from "Guaranteeing professional diversity of the experts that determine DFAS content" (direction) over "Pairing adoption of environmentally sustainable agricultural recommendations with financial inducement" (intervention) to "Integrating environmental sustainability in the cost function of the overall DFAS model" (representation). All leverage points resemble general design recommendations for DAS designers. Yet, they are relatively DFAS case-specific.

By unveiling leverage points for building environmental sustainability into DFAS, this thesis contributes to filling gaps in the design-related digital agriculture literature. Most existing literature gives recommendations regarding the DAS design process by comparing already conducted design processes against ideal-typical concepts and frameworks such as "Human-centered design" or "Responsible Innovation". However, the present thesis went beyond the comparatively visible and easily identifiable areas of improvement revealed as a result of such endeavors. By utilizing an entirely different approach that renders the inner algorithmic workings of DFAS visible, detailed, tangible, and hands-on recommendations become givable.

Stepping one step back and taking a bird's eye perspective, the identified leverage points for building environmental sustainability into DFAS, in combination with the utilized algorithmic governance framework and the leverage point perspective, could serve as means to derive more general design recommendations. These recommendations could be like, for example, the Principles of Digital Development[4] or Google's Building for Billions[5] recommendations. Opposed to the latter, they could yet be tailored to the realm of DAS and explicitly target designers that wish to design DAS for enhanced environmental sustainability. Exemplary recommendations could then read "Design for environmentally sustainable agricultural paradigm/mindset change" or "Design for environmentally sensitive farm' representation".

Regarding (3) "What are the most effective entry points for building environmental sustainability into Digital Farm Advisory Services?" it could be shown that the deepest and thus most effective entry points (leverage points) can be found in the "direction"-dimension, wherein three leverage points were labeled "Deep" and one was labeled "Medium Deep". It was argued that this is because DFAS direction impacts all other DFAS development phases. The initial directionality, it was argued, will directly impact the two other dimensions of algorithmic governance systems.
The "direction"-dimension was followed by the "representation"-dimension, wherein one leverage point was classified as "Deep" and four leverage points were classified as "Medium Deep". It was argued that this is because the agricultural recommendations, which ultimately impact farmers' behavior, agricultural practices, and thus environmental sustainability, are heavily dependent on the digital representation of farms, farmers, and the environment. Emphasizing an environmentally sensitive digital representation and narrowing down digital representation-reality gaps thus holds relatively great leverage for enhanced environmental sustainability in DFAS.

[4] https://digitalprinciples.org/
[5] https://developers.google.com/

The ”intervention”-dimension was placed third concerning its possible contribution to enhanced environmental sustainability in DFAS. None of the identified leverage points for building environmental sustainability into DFAS in this dimension was found to be “Deep”. Yet, four leverage points were found to be “Medium Deep”. It was argued that this is because most of the “strategies of influence” are relatively content-neutral, meaning that they can be leveraged for enhancing or weakening environmental sustainability.
More specifically, the three deepest identified leverage points per dimension, which DFAS designers should consequently prioritize as they are likely to have to biggest positive impact toward environmental sustainability in DFAS, were:

Direction

1. Guaranteeing professional diversity of the experts that determine DFAS content
2. Selecting DFAS partners for whom environmental sustainability is important
3. Establishing “environmental sustainability” as an additional standard for the overall “improvement of livelihoods” direction

Representation

1. Integrating environmental sustainability in the cost function of the overall DFAS model
2. Extending the spatial and temporal scale of DFAS models
3. Considering features (variables) that are explicitly related to environmental sustainability in DFAS models (such as soil data)

Intervention

1. Pairing adoption of environmentally sustainable agricultural recommendations with financial inducement, e.g., through bundling with other DAS
2. Highlighting environmentally sustainable agricultural recommendations, putting these first in the service
3. Communicating the long-term benefits of environmental sustainability practices

More leverage points can be found in table 13 (p. 78). Based on the identified leverage points for building environmental sustainability into DFAS it was reasoned that deep as well as shallow leverage points in DFAS precipitate one another. Further, it was contended that transformational change towards environmental sustainability in DFAS necessitates leveraging several leverage points in parallel and/or leveraging so-called “chains of leverage”. It was shown that such “chains of leverage” exist in single DFAS, but also beyond single DFAS, in bundles, wherein DFAS is combined with one or more DAS. DFAS-financial service, DFAS-sustainability certification, and DFAS-carbon credit service bundles were identified as such “chain of leverage”-constituting bundles. The last two bundles were found to hold particularly great potential in contributing to enhanced environmental sustainably. Yet, to substantiate the aforementioned claims and show how different leverage points influence each other and how chains of leverage can effectively be formed, much more research is needed.

By answering the third research question, this thesis enables DFAS designers to prioritize the deepest and thus most effective leverage points in changing DFAS toward contributing to enhanced environmental sustainability. What’s more, by introducing the concept of “leverage point categories, and by adding the interstage leverage point categories of “Medium deep” and “Medium shallow”, this thesis provided DFAS designers with (more calibrated) tools to assess leverage points for building environmental sustainability into DFAS thoroughly. Given that DFAS designers have limited time to steer DFAS development in the Global South towards producing positive outcomes for people, production, and the environment, this thesis hopes to not only have filled gaps in digital agriculture literature, but also to have provided DFAS designers to make quick, informed, effective, and environmentally sensitive design decisions in the future.

Regarding the main research question “To which degree and by which ways can environmental sustainability be designed into digital agriculture solutions?”, it can be reasoned, based on the empirical case study research of DFAS, that DAS can be effectively tweaked towards environmental sustainability by capitalizing on the deepest leverage points. The deepest leverage points for building environmental sustainability into DFAS can be identified through algorithmic governance and leverage point analysis alongside the three ways (dimensions) direction, intervention, and representation. It is by these ways that DAS impact farmers’ behavior, agricultural practices, and the environmental sustainability of their farming practice.

Yet, it seems likely that environmental sustainability can be designed into different DAS through these three ways to different degrees. In the case of DFAS, this thesis estimates that this degree is medium-sized. This is because what farmers finally do with the agricultural recommendations which are sent to them by DFAS is dependent on them. It remains relatively uncertain if such recommendations translate into the adoption of environmentally sustainable agricultural practices. In other DAS cases, wherein the farmers are more dependent on complying with DAS’ guidelines to reap DAS’ benefits (e.g., in the case of digital market linkage services), the “(algorithmic) governance effect” is likely to be bigger. And thus, environmental sustainability designed into such DAS governance is likely to have a bigger impact. Despite the limitations of several DAS to directly impact farmers’ behavior and environmental sustainability, this thesis is convinced that DFAS developers should increasingly envision and realize environmentally sustainable DAS beyond the ones already existing today. Such visions and best practice cases, it is hoped, will lead to a more environmentally sustainable digital agriculture sector in the future.

In addition to studying governance in digital agriculture and design improvements for environmental sustainability and thereby contributing to filling literature gaps, this thesis has also contributed methodologically. It proved that the newly adopted analytical approach that drew on the theory of algorithmic governance, Eyert et al’s (2022) algorithmic governance framework and leverage point perspective, is fit for purpose. It allows scholars and practitioners to conceptualize the ways by which DAS govern farmers and to identify effective leverage points for building environmental sustainability into DAS.

7.2 Outlook

Yet, to stay up to date and to become increasingly suitable for the realm of DAS, the utilized novel analytical approach needs to be constantly refined in further research encounters. This is even more so because digital agriculture is under constant change. Firstly, there are changes in the availability of agricultural data due to new agricultural data infrastructures (e.g., multi-spectral satellites, low-cost sensors; cf. (Angelopoulou et al., 2019; Garcia et al., 2020) evoking small agricultural data practices which might shift to big agricultural data practices in the long run. Such increases in agricultural data availability and intensity are likely to also enable increasingly digitized governance of agriculture as well as the environment (Forney & Epiney, 2022). Secondly, new receiver technologies (e.g., smartphones) and delivery technologies (e.g., chatbots) become available to a higher number of farmers (I 12). This will, amongst others, impact the possible “degree of automation” and “strategies of influence”. And thirdly, DFAS become ever more fine-grained, tailored, and tuned to local contexts, specific varieties, and individual farms and farmers (GSMA, 2020; 2022). Thus, DFAS will be more adapted and personalized to the actual needs of farmers at a particular point in time. Against the backdrop of these changes and the limited scope of this thesis which left many important questions unanswered, three avenues for future research are proposed:

First, future research should investigate algorithmic governance for environmental sustainability in other DAS cases than DFAS, alongside one specific delivery technology (e.g., Interactive Voice Response) or one specific crop value chain (e.g., orange sweet potato). This would allow for comparability between different DAS cases, DAS delivery technologies, and DAS value chains as differently pronounced results along the three algorithmic governance dimensions are likely to result from such research. What's more, the object of inquiry could be shifted to farmers and thus foreground the analysis of their interaction with DAS. This would allow for insights into the "micro-governance" of DAS and the responsive "micro-practices" of farmers.

Second, future research should examine how identified leverage points, if integrated into new DFAS designs, will impact the resultant environmental sustainability in agriculture. This would verify or falsify some of the claims made in this thesis and possibly show varying degrees of effectiveness of specific leverage points in contributing to environmental sustainability. Another way of studying this could be to first identify several existing DFAS that are already embracing one or more of the identified leverage points, analyze them, and then compare their resultant impact on environmental sustainability.

And third, future research should scrutinize the interactions between leverage points of varying depth within and beyond a single DFAS and the impact of leverage point combinations on environmental sustainability in agriculture. This will allow us to determine which leverage points and leverage point combinations to build into DFAS first, and to identify potent DAS-overarching bundles, or put differently leverage point combinations beyond a singles DAS.

It is hoped that realizing such research encounters would not only contribute to filling pinpointed literature gaps in digital agriculture literature, but also to reconciling proponents of DAS and proponents of environmentally sustainable agricultural approaches such as climate-smart, organic, and regenerative agriculture. This thesis serves as a headstart.

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Appendices

Appendix 1: Interview Guide - Digital Farm Advisory Services designers/experts

1. **<u>General part on DAS/Digital Agriculture</u>**

- Could you give a short and general summary of what your DFAS is doing? (types of services, target group & region, evolvement over time)
- What kind of DFAS are there and how do they differ?

2. **<u>Specific part</u>**

2.1 AG systems of DFAS

Direction

  - What kind of farming practices are being promoted through your DFAS? (indicators)
  - Are there any common principles for "good" farming that underlie these practices? (standards)
  - What farming system results if farmers adopt the promoted practices and principles? What characteristics does this farming system have? (general goals)
  - What do DFAS aim for? (general goals)
- In how far is environmental sustainability being considered for the promoted farming practices and principles?

Intervention

- What strategies do DFAS use to make farmers adopt recommended agricultural practices? (Strategies of influence)
  - What role do algorithms play in these strategies?
- How do you think environmental sustainability can be fostered through the chosen strategies?
- To which degree are these strategies automated? (Degree of automation)

Representation

- Which variables are considered in the models underpinning DFAS? (feature selection)
- What connection do the selected variables have to environmental sustainability?
- How are advisories inferred from the variables and models underpinning DFAS? (interpretation of data)
- How do DFAS need to be designed so that they promote environmental sustainability/ sustainable agriculture practices?

2.2 Chain of leverage

- How could the bundling of different digital agriculture services foster environmental sustainability in digital agriculture?

3. **<u>End</u>**

- Could you link me up with other interviewees who could contribute to my thesis?
- Sending of "Informed consent"
- Appreciation & thanking – finished thesis will be sent out

Appendix 2: List with respondents and their characteristics

Reference	Company of respondent	Role/Position of respondent
I 1	Public research institute	Academic researcher and DFAS developer
I 2	Information provisioning company (with a focus on mobile communications & rural populations)	Regional Implementation Manager, East & Southern Africa Lead Product Manager
I 3	Dutch engineering company	Business Manager of Integrated Water Management
I 4	Weather and climate service company	Meteorology and Climate Change Consultant
I 5	Kenyan agri-tech start-up	Technology Lead
I 6	Community and agricultural development organization	Agricultural Program Manager
I 7	Public research institute	Academic researcher and AI expert
I 8	Public research institute	Agronomic researcher
I 9	Moroccan agri-tech start-up	Marketing Lead
I 10	International seed company	Data and Knowledge Coordinator
I 11	International agricultural development NGO	Research Manager Climate
I 12	International agricultural development NGO	Former State Head

Appendix 3: Codes used for color-coding transcripts of semi-structured DFAS expert interviews (Screenshot from ATLAS.Ti)

Name	Häufigkeit	Dichte	Gruppen
1. Direction	21	0	
1.1 General Goals	44	0	[Normative dimension]
1.2 Standards	14	0	[Normative dimension]
1.3 Indicators	3	0	[Normative dimension]
2.1 Degree of automation	17	0	[Effective dimension]
2.2 Strategies of influence	58	0	[Effective dimension]
2.Intervention	1	0	
3. Representation	5	0	
3.1 Features selected	21	0	[Representational dimension]
3.2 Production of data points	37	0	[Representational dimension]
3.3 Interpretation of data	41	0	[Representational dimension]
4. Chain of Leverage	9	0	
5. Leverage points for ES	22	0	
Governed Agricultural Practices	2	0	