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# A Doomed Technology? On Gene Editing in Bavarian Livestock Agriculture, Policy Field Conflicts and Responsible Research and Innovation

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The emergence of CRISPR-Cas9 has recently, for the first time, rendered the large-scale genetic modification of livestock animals such as cows, pigs, and chickens possible. Novel editing targets range from genes that curb disease vulnerabilities, increase muscle mass, or convey hornlessness, to the development of transgenic pigs for medical use. In this article, we discuss the efforts of a transdisciplinary research consortium in Bavaria, Germany, to test the technical and social feasibility of using CRISPR-Cas9-based gene editing as a novel technology in Bavarian small- to medium-scale livestock agriculture. The consortium comprised life scientists, local breeding associations, legal scholars, and social scientists from Science & Technology Studies (STS) and aimed to promote Responsible Research and Innovation (RRI) for gene editing technologies. Research focused on gene editing applications that improved animal health and all editing targets were co-developed with local breeding associations to meet the situated needs of small- to medium-scale livestock farmers in Bavaria. In this article, we discuss why the agricultural stakeholders in the project, that is, the representatives of local breeding associations, considered that, despite the project's success in generating positive research outcomes, it would be unlikely that results will be implemented in Bavarian livestock agriculture. We describe this situation in terms of a tension between agendas in the science and technology policy field and in the agricultural policy field in Bavaria that impacts local farmers' ability to adopt gene editing technologies. We further discuss what it might mean for RRI practices if public stakeholders are unlikely to benefit from the outcomes of RRI practices due to policy field conflicts or other contextual constraints and how STS scholars and other social scientists involved in RRI projects could adjust their practices to possibly redistribute benefits.

**Keywords: science and technology studies, agriculture, gene editing (CRISPR-Cas9), responsible research and innovation, policy field, Bavaria, Germany, livestock**

## INTRODUCTION

The emergence of CRISPR-Cas9 has recently, for the first time, rendered the large-scale genetic modification of livestock animals such as cows, pigs, and chickens possible (Lamas-Toranzo et al., 2017; Shriver and McConnachie, 2018). Prior techniques of genetic modification were effective on plants and smaller mammals such as laboratory mice; however, they were difficult to use in the larger mammals and birds typically found in livestock agriculture (Perisse et al., 2021). With the advent of CRISPR-Cas9, this has changed dramatically. While numerous questions still remain open, markedly the question of off-target effects (c.f. Middelveld and Macnaghten, 2021), CRISPR-Cas9 presents, for the first time, a technology that might allow scientists and breeders to engage in the large-scale genetic modification of agricultural livestock animals.

Historically, public debates about gene editing were largely focused on the genetic modification of agricultural plants and on biomedical applications. Only more recently, the genetic editing of livestock has become a topic of public discussion. While there has been some attention to the topic in mainstream media (see, e.g., WIRED, 2019 or New York Times, 2015), debates have significantly increased in the agricultural community and its public fora. Internationally, breeders have discussed gene editing with CRISPR-Cas9 as a new opportunity to accelerate and ensure success in breeding, particularly when it comes to breeding targets such as curbing disease vulnerabilities, increasing muscle mass or milk yields, or conveying other desirable traits, such as hornlessness in cows (Proudfoot et al., 2019; Yunes et al., 2019).

In this article, we discuss results from a research project that took shape amid these emergent debates. The project "FORTiGe – Forschungsverbund Tiergesundheit durch Genomik" (2018–2021) brought together a transdisciplinary research consortium in Bavaria, Germany, to test the technical and social feasibility of using CRISPR-Cas9-based gene editing as a novel technology in Bavarian livestock agriculture. The consortium was comprised of life scientists, legal scholars, and social scientists from the field of Science and Technology Studies (STS).

Importantly, the project focused on exploring the possibility of using CRISPR-Cas9-based gene editing in the context of, and for use in, small- to medium-scale, local Bavarian livestock agriculture. This is why the consortium also included local breeding associations who co-developed the targets for editing together with the scientists. That is, editing targets were selected based on the needs of local farmers in livestock agriculture in Bavaria. The consortium thus focused exclusively on targets that would improve animal health, specifically focusing on disease resistances. Animal health is an important concern for small- and medium-scale farmers, who often lack the economic resources to bounce back from a disease outbreak in their herds. Concurrently, focusing on animal health allowed the consortium to take a specific stance in a German context that is historically characterized by a very negative public reception and strict regulation of genetic technologies in agriculture. This negative public opinion is not least due to a perception that genetic technologies mainly benefit large-scale agricultural corporation by increasing their yields and profits and have no benefits for local farmers (Levidow and Boschert, 2011). The consortium aimed to break this perception by focusing on animal health and local farmers' needs instead of yields and collaborations with larger corporations.

This specific research design successfully convinced a major Bavarian research funder to fund this project though they knew it would be a controversial topic. In recent years, Bavaria has made a distinct effort to cast itself as a high-tech state, investing significantly in research and innovation in Bavaria (High Tech Agenda Bayern, 2019). Concurrently and interestingly, Bavaria has also increased funding for interdisciplinary work that explores the social, political, and ethical aspects of emerging technologies, for example, through dedicated research institutes (see, e.g., the Bavarian Research Institute for Digital Transformation)[1] and strategic reorientations at some of its major universities (see, e.g. the TUM Agenda 2030)[2] toward "Responsible Research and Innovation" (RRI). RRI is both a research approach and a policy framework that proposes a multi-stakeholder approach toward innovation that is based on the principles of anticipation, inclusion, reflexivity and responsiveness (Stilgoe et al., 2013). Possible technology users and others affected by a potential innovation should be included in the innovation process in order to anticipate and reflect on its wider social, economic or political impacts and in order to responsively adjust research and innovation processes to avoid harm and increase benefits for society and public stakeholders. As Bavaria increasingly subscribes to an RRI framework as a preferred path for fostering innovation, funding a project on gene editing as an important emergent technology that is inter-and transdisciplinary in nature and promotes RRI is, hence, clearly in line with Bavaria's current science and technology policy profile.

However, in this article, we will examine what happens if the orientations and incentives put forward by science and technology policy are at odds with those of another policy field that is of equal or, in fact, greater relevance for the public actors involved in an RRI project. We will sketch how the incentives to promote gene editing in Bavaria in a transdisciplinary manner clash with the perceived incentives put forward by the agricultural policy field—incentives that significantly circumscribe the possibilities of practice of the agricultural partners in the project. Following critical research that explores the limitations and possibilities of putting RRI principles into practice in situated contexts (e.g., de Hoop et al., 2016; Macnaghten et al., 2022), we will analyze this conflict and discuss what these tensions imply for the possibility of practicing RRI "responsibly" in the field of gene editing in livestock agriculture in Bavaria and possibly in other fields of research, too.

## INCENTIVE CONFLICTS IN CONTEMPORARY AGRICULTURE

Agriculture is a contested field of human activity today. While without a doubt, human survival is dependent on agricultural

[1] https://www.bidt.digital/en/

[2] https://www.exzellenz.tum.de/en/exzellenz/university-of-excellence/

harvest, practices in agriculture have been criticized for their impact on the environment, their treatment of animals, and their contribution to climate change (Feola et al., 2015; Baur, 2020). This has led to increased attention to agriculture from policymakers, resulting in stricter regulations for animal welfare and environmental protection (Schmid and Kilchsperger, 2010; Vogeler, 2018) in some national contexts such as Germany and increased attention from researchers who aim to optimize agricultural practices through scientific and technological innovations. Meanwhile, market actors, such as large-scale retailers and supermarket chains, have also begun to respond to public debates about agricultural practices by introducing product lines and labels that offer agricultural products to consumers which adhere to stricter environmental and animal welfare standards (Vogeler, 2019). These are just some examples of current dynamics that showcase the complexities of agriculture as a policy field. Our understanding of "policy field" here follows a Bourdieuian conceptualization of social fields (Bourdieu and Wacquant, 1992; Fligstein and McAdam, 2012): we frame policy fields as social arenas where both state and non-state actors interact, collaborate, and struggle with each other in practices of meaning-making (c.f. Pohle et al., 2016).

However, in this article, we are not focusing on analyzing the specific make-up and dynamics of this policy field in Bavaria. This beyond the scope and the data of the project at hand. Rather, we are interested in understanding how agricultural stakeholders—in our case, representatives of local Bavarian livestock breeding associations—understand the complexities of this policy field from their situated perspective and how they interpret its incentives. We further aim to understand how they articulate these incentives together or in tension with incentives and opportunities formulated by science and technology policy, available and relevant to them through long-standing ties and collaborations with local life science researchers and their involvement in the RRI-oriented research project at hand.

With our analysis, we first aim to contribute to the recently growing literature around incentive conflicts in agriculture, particularly with regard to "right vs. right" conflicts. Baur (2020) elucidates the problem of incentive conflicts in agriculture by discussing how farmers in California have responded to concurrent calls to increase the food safety of their products and to develop more sustainable and climate-friendly practices—both calls that many farmers find important and agree with in terms of their personal value-orientations. Baur shows that a majority of farmers, however, opt for increasing food safety rather than focusing on climate-friendly farming practices because increasing food safety is "perceive[d] as most feasible within the bounds imposed by their institutional environment and [. . . ] aligns more consistently with multiple institutional drivers than does environmental sustainability. While food safety finds broad support in comprehensive rules, standards, and market mechanisms, sustainability is often implicitly discouraged by market mechanisms and receives only disjointed support from fragmentary rules and standards." (Baur, 2020, p. 1185).

Baur here shows that choices in agriculture are poorly understood through a pure analysis of value orientations or preferences. He suggests instead "that each choice belongs to complete, but divergent, institutional logics, each with its own set of constitutive institutional carriers" (Baur, 2020, p.1178) and must be understood and analyzed as such. Importantly, drawing on Feola et al.'s work (Feola et al., 2015), he argues that farmers tend to comply in particular with incentives put forward "by powerful social actors whom they believe are beyond their ability to influence" (Feola et al., 2015)—such as, in the case of food safety, retail and supermarket chains who dictate strict food safety rules and hold farmers accountable for outbreaks. This analysis of how constrained choice emerges holds particularly true for small and medium-scale farmers, who often have less wiggle room to respond to multiple calls to action at once than larger businesses and have to choose carefully where they invest their resources.

We will show that, in our case, similar tensions between diverging incentives and diverging visions for the future of agriculture in Bavaria and the possible role of genetic technologies within it are at work. Each vision is advocated for by a different actor constellation, whose ability to shape the future has to be assessed by farmers, breeders, and their representatives in order to forge their own path forward. Part of this complex field of tension is a misalignment of science and technology policies and agricultural policies in the Bavarian context, which we will explore in our empirical analysis. We will argue that careful attention to these tensions between incentives from different policy fields is important for RRI practitioners who aim to practice RRI responsibly as these tensions can significantly circumscribe the possibility for public stakeholders, such as in our case the agricultural stakeholders from local breeding associations, to benefit from RRI projects. We will discuss possible implications for RRI practices, particularly, how STS scholars and other social scientists involved in RRI might be able to respond to such challenging situations, which is where we locate the second key contribution of this paper to the current literature.

## MATERIALS AND METHODS

For our analysis, we draw on a range of materials which we collected as embedded social scientists in the FORTiGe project (2018–2021). As discussed above, the FORTiGe project was conducted by a transdisciplinary research consortium consisting of life scientists, legal scholars, and social scientists from the field of Science & Technology Studies (STS) as well as representatives of local breeding associations. The project focused on exploring the possibility of using CRISPR-Cas9-based gene editing for use in small- to medium-scale, local Bavarian livestock agriculture and focused exclusively on targets that would improve animal health by mediating disease resistances.

Our STS project component aimed to explore the perspectives of two different publics on gene editing in Bavarian livestock agriculture: the wider Bavarian public and small- to medium-scale Bavarian farmers. As a basis for engaging these publics, we developed a range of scenarios based on gene editing applications that were considered possible and beneficial

by the life scientists and the representatives of local breeding associations. Project methods included:

- Semi-structured interviews with researchers and agricultural stakeholders in Bavaria within and beyond the project consortium
- Scenario-based focus groups with members of the lay public that discussed possibilities of using CRISPR-Cas9 for gene editing in Bavarian livestock agriculture
- Semi-structured interviews with Bavarian small- and medium-scale farmers about these possibilities
- Participant observations of project meetings and related public events
- A workshop where we presented results from the focus groups and the interviews with farmers to the project consortium, including the agricultural stakeholders, and discussed, in terms of RRI, what our results might mean for the socially responsible development of livestock gene editing in Bavaria

For this specific article, we draw upon all empirical materials that specifically engaged agricultural stakeholders in the project consortium, i.e., the representatives of local breeding and farming associations in Bavaria. These stakeholders are particularly aware of the dynamics in the agricultural policy field in Bavaria and frequently related and evaluated the project's goals within this context. These materials specifically include the semi-structured interviews with agricultural stakeholders in Bavaria who were project members and with some of their colleagues (seven persons), observations at project meetings over the course of 3 years as well as, importantly, the discussions of our results and future possibilities for livestock gene editing in Bavaria at our final project workshop. All interviews were recorded, transcribed, and informed consent was obtained before each interview. At project meetings, field notes were taken. The final workshop was recorded and transcribed for analysis, including break-out groups where researchers, agricultural stakeholders, social scientists, and legal scholars discussed the possible futures of livestock gene editing in Bavaria and what it could mean to develop and use this technology in a responsible manner. The topic of tensions between the efforts of the project and the agricultural policy landscape in Bavaria emerged as an important theme at this final workshop. It served as a sensitizing concept (Blumer, 1954) in the consequent grounded theory analysis (Charmaz, 2006) of all relevant materials. We performed multiple rounds of open and focused coding in the project team, which consisted of three team members, shared coding results to improve intercoder reliability, and discussed emergent themes and coder memos in order to allow the nascent results to inform the ongoing analysis. The results of this analysis are present in this article.

Below, we outline the results of this analysis. We draw particular attention to two moments in the project that showcased the tensions between the project's goals, funded and supported by key actors in the Bavarian science & technology policy field, and the agricultural stakeholders' perceptions of the agricultural policy field and their room to maneuver within it, tensions which had significant implications for the possible meanings of RRI in the project context. The first moment arose already during the formation of the consortium and contestations surrounding its design and funding; the second moment concerned the agricultural stakeholders' reception of and response to the results of the STS project component, i.e., the results of the focus groups with the lay public and the interviews with farmers.

## A CONSORTIUM IS FORMED

In order to adequately contextualize the results of the FORTiGe project, it is important to start by discussing the tensions that surrounded its inception. The project was conceived by highly esteemed researchers at a renowned university in Bavaria. Having had a long and successful track record in animal biotechnology and livestock breeding, they recognized that CRISPR-Cas9 could be a game-changer, not only for their research, but also for developing real-world applications for livestock agriculture. The two most senior researchers of the group had both lived through the vehement rejection of genetic technologies for agricultural use, mainly plant breeding, in Germany in the 1990s and early 2000s. Because of these histories and what they perceived to be an unchanged public attitude toward green biotechnologies, both were concerned that CRISPR-Cas9 based gene editing of plants and livestock would, despite the novel technological approach, constitute a "doomed technology" in the German context.

Both researchers had a critical stance toward the role of researchers in prior debates about genetic technologies in Germany. Notably, one of the researchers often remarked that scientists should have taken a more active role, not only in discussing technical risks and technical safety, but also in addressing the social and political aspects of genetic technologies, e.g., by actively working to not only make technologies available for international agricultural conglomerates, but also develop use cases for smaller farmers or maybe even exclusively realigning their research agendas with the needs of smaller farmers.

The FORTiGe project was born out of the desire to learn whether, if such an approach was taken with CRISPR-Cas9, it could create new opportunities for genetic technologies in agriculture in Bavaria. The scientists thus reached out to local breeding organizations and like-minded researchers to form a transdisciplinary consortium. They decided the project would only address targets deemed important by local farmers and breeders, which led to the shared decision to focus exclusively on editing targets that improved animal health and not, for example, yields. For these specific targets, the researchers wanted to explore if editing was possible, i.e., if a disease resistance could be conveyed through genetic edits, and if it was possible without off-target effects or other negative impacts on the animals' health and well-being. The researchers also reached out to social scientists in STS (the authors of this paper) and legal scholars to join the consortium. The core idea of the project was to explore the technical, social, and legal feasibility of using CRISPR-Cas9 for livestock gene editing in Bavaria alongside and in conversation with each other.

The representatives of local breeding organizations were both highly interested in and skeptical of the project from the start. They knew that they themselves and many of the members of their associations were motivated to learn more about if and how novel genetic technologies could improve breeding outcomes. They were already using genetic analysis to select animals for breeding, and the prospect of utilizing gene editing to improve certain traits, particularly to reduce vulnerabilities to infectious diseases and hereditary defects—some of which had occurred due to the limitations of conventional breeding methods—was highly attractive to them.

It is important to note that while these stakeholders had a very practical background in agriculture, such as coming from farming families or having training in practical agronomy, many had also studied at the university and were familiar with the advances of agricultural science. Similarly, and possibly contrary to public perception, many livestock farmers are regularly in contact with genetic technologies, for example, because of the genetic analysis of their livestock. Working with CRISPR-Cas9 thus represented, for many, rather an extension of their engagement with genetic technologies than a *de novo* introduction.

However, despite their practical interest in the technology, representatives of breeding associations were, from the start, skeptical if there would ultimately be a place for livestock gene editing in Bavaria. This skepticism was rooted not so much in questions concerning a possible interest in their own breeding and farming community, but rather in the configurations of the wider policy field that shape their range of action. While we will analyze these constraints in more detail below, at the point of the project application, these concerns were simplistically framed as a problem of "public acceptance" of these new technologies—a problem that should be addressed by the social scientists on board (who, of course, immediately reframed the issue from one of unidirectional acceptance toward one of contestations over values, interests, and power structures).

Including social scientists in the project was part of the life scientists' credibility work within and beyond the consortium: having researchers on board who would engage the public and examine their perspectives on livestock gene editing was important for the agricultural stakeholders to agree to participate in the project and it was also regarded favorably by the funding agency. Similarly, both agricultural stakeholders and funders deemed it essential to have a legal scholar on board who would assess the legal feasibility of gene editing applications in a dynamic landscape of national and European legal regulations. Overall, by combining these different aspects in one project, the life scientists successfully promised to possibly develop a form of "thick legitimacy" (de Wit and Iles, 2016) for livestock gene editing in Bavaria by performing a number of "credibility tests" (de Wit and Iles, 2016) with regard to the scientific, social, and legal dimensions of using gene editing in Bavarian livestock agriculture. This argumentation convinced the funder, and they ultimately supported the project, despite the arguably controversial character of the project topic—after all, the two senior researchers in the project were not the only ones in the research and the policy community who considered that gene editing might be a "doomed technology" in the German context.

## RESEARCH RESULTS AND RECEPTION OF RESULTS IN THE CONSORTIUM

After nearly three years of research, the consortium had gathered a range of results. Markedly, life scientists had successfully identified a range of targets to decrease specific disease vulnerabilities in cows, pigs, and chickens and had effectively conducted proof-of-concept experiments. While for some researchers some questions still remained open, for example concerning off-target-effects for some specific targets, overall, the group was confident that, if it were legally possible, they could start working with breeding organizations to cultivate genetically edited livestock in the near future. Legal analysis focused primarily on commenting on and offering alternative visions to the recent European Court of Justice verdict which ruled that organisms which have been edited with CRISPR-Cas9 GMOs must be regulated under the common European GMO law. Our social science analysis offered two sets of insights, which we presented to the consortium at an RRI-themed workshop in year three. These insights have been and will be published elsewhere (Müller et al., 2021; Clare et al., forthcoming; Feiler et al., forthcoming) and are summarized below in in order to set the stage for the subsequent discussion with the consortium members.

We first presented results from the focus groups with members of the Bavarian public (Clare et al., forthcoming). In the focus group, we had presented the participants with different scenarios of using gene editing in agricultural and biomedical contexts and, markedly, with scenarios that hat connect both contexts. For example, we discussed scenarios where genetically editing chickens could prevent the spread of the bird flu among chickens and thus eliminate the culling of thousands of chickens in Germany every year, as well as the spread of the bird flu from chickens to humans. While participants generally found this possibility interesting, most of them ultimately argued against it, as they considered bird flu outbreaks as the result of factory farming and its overcrowded housing conditions. Even when focus group moderators mentioned that the bird flu was also a significant problem for organic farmers with outdoor chicken flocks since the bird flu often spreads from wild to domestic birds, their assessment did not change. Overall and across various scenarios, laypeople tended to assess gene editing as a technology that was only needed because of extensive factory farming.[3] Many argued that instead of such a superficial technological fix, what was really needed was a fundamental change in agricultural production toward more sustainable, small-scale agriculture and better living conditions for animals. The notion that this type of agriculture could also benefit from gene editing technology received little attention from focus group participants.

[3]These results correspond to similar findings by Middelveld and Macnaghten (2021) based on focus group discussions with Dutch publics.

Next, we presented results from our interviews with small to medium-scale farmers in Bavaria (Müller et al., 2021; Feiler et al., forthcoming). In these interviews, we discussed similar application scenarios with farmers as were discussed with laypeople in the focus groups. Interestingly, assessments diverged significantly. A majority of farmers in the interview sample (11 out of 18) had a very positive stance toward gene editing. They saw the technology as a possibility to reduce threats to their livelihoods, such as disease outbreaks, and to counteract hereditary defects that have accumulated in livestock populations due to the limitations of traditional breeding techniques, while at the same time offering a tool to improve animal welfare and possibly the environmental footprint of their businesses. Many did not see a significant difference between traditional and molecular breeding techniques and welcomed the more directed character of the latter. However, while they were fairly enthusiastic about the technology as such, they also conceived of themselves as highly vulnerable to public opinion. Only if consumers evaluated the technology positively, farmers argued, would it be possible for them to employ gene editing.

After we presented these results to the consortium at the workshop and conducted a brief general questions and answers session, we split the consortium members into three smaller inter- and transdisciplinary groups of 5–7 people to discuss what these results meant for them in terms of possible futures for gene editing in livestock agriculture in Bavaria and what a responsible approach to further developing this technology might look like. After these 30-min breakout groups, we all reconvened, discussed the results of the breakout groups, and any remaining topics. It was in this section, and particularly through the responses and accounts of the agricultural stakeholders, that tensions between the mission of the project and the dynamics in the wider field of agricultural policy became visible. The debate about these tensions ultimately served to deconstruct the term "public acceptance" that had so far often characterized the narratives and concerns of agricultural stakeholders' and scientists alike. In what follows, we recount and analyze these crucial accounts by the agricultural stakeholders during the workshop.

The agricultural stakeholders responded to and discussed primarily two aspects of the results: firstly, that the public operated with a clear distinction between factory farming on the one hand, which the public viewed highly negative and which they argued should not be supported further by the introduction of new technological fixes such as gene editing; and, on the other hand, the public imagination of sustainable and organic farming, which was often imagined as a return to traditional farming methods and connected to idyllic countryside scenes with small, local farms and free-ranging animals in laypersons' accounts. Secondly, agricultural stakeholders focused their discussion on the generally positive assessment of gene editing by small- and medium-scale farmers and why they might see gene editing technologies as an important opportunity to address their everyday challenges. By focusing on these two aspects and their connections in the breakout groups and final discussion, agricultural stakeholders performed an important analysis of how both of these positions might have been generated and co-produced by the discourses and actions of the wider agricultural policy field in Bavaria and beyond, i.e., on national and European levels.

To begin with, the agricultural stakeholders outlined what they perceived as the key pressures on farmers in Bavaria emanating from the current agricultural policy field: to either constantly grow bigger, increase the number of animals and production, or, to a lesser extent, to transition to organic farming, which might allow them to sell products at a somewhat higher price. These two options would be privileged both by the government's and retailers' current incentives—a bifurcation in policy field incentives as well as in farming practices that has been noted in other national contexts, too (see, e.g., Baur, 2020 for the US). In the Bavarian context, both options still often meant that farmers cannot support themselves through farming alone and must hold additional jobs since market prices for their products are too low. Importantly, agricultural stakeholders emphasized that both versions of farming—the farms that grow bigger and the organic farms—often do not fit the images that circulate in public discourses. Neither would the "bigger" farms in Bavaria, which are still small- to medium-scale farms in the context of international industrial agriculture, be equivalent to large-scale factory farms, its practices and images that circulate in public media. Nor would organic farming necessarily comply with the idyllic imagery that characterizes TV advertisements and packaging materials for organic products. None of these popular images would accurately represent the reality of farming in Bavaria. The agricultural stakeholders argued that this disconnect of image and reality would lead to skewed consumer perspectives on current practices and future possibilities in livestock agriculture and would limit opportunities for a constructive dialogue with the public.

In a second and related step, agricultural stakeholders then elaborated that they understood farmers' positive appraisal of gene editing both as a genuine interest in the technology and as an expression of the difficult socio-economic situation in which many farmers find themselves. This difficult situation would be caused by the policy field pressures outlined above, but also by an additional aspect of the agricultural policy field in Germany, which are increasingly stricter animal health and environmental protection regulations. While market prices for their products were low, farmers would still be expected to upgrade their facilities and practices to, for example, decrease the use of antibiotics and other medications or reduce the environmental footprint of their farms. A technology that promises disease resistance or other avenues to more sustainable farming would, under these circumstances, of course, become a beacon of hope for farmers.

Thirdly, agricultural stakeholders outlined that they considered themselves poorly represented by current agricultural spokespeople on the Bavarian and national levels, which made a difficult situation worse. Official organizations would mainly represent the interests of large-scale farmers and would fail to address the challenges of small- to medium-scale

farming. This would have motivated the recent emergence of protest movements in the agricultural community, such as *Land schafft Verbindung*[4] in Germany in 2019, a grass roots movement whose name can be roughly translated as "Soil Creates Connection[5]". This movement organized so-called farmers' strikes, during which farmers across Germany rode their tractors into cities and blocked traffic for hours to draw attention to their difficult socio-economic situation (ZDF heute, 2019). Following the motto "Let's talk with each other instead of about each other," *Land schafft Verbindung* aimed to initiate dialogue with the public and to dismantle prejudice against farmers and misconceptions about farming practices. One of the misconceptions they aimed to address was exactly the above-mentioned dichotomy of industrial vs. organic farming and the issue of farming practices that fall into neither category. Under the header of "Neither idyllic nor industrial: we show you the realities of primary agricultural production," the movement wanted to open up possibilities for the wider public to become familiar with contemporary agricultural practices beyond media reports and advertisements. However, the movement has since died down somewhat due to the COVID-19 crisis and has also splintered along contemporary political fault lines.

The agricultural stakeholders argued that the combination of the factors outlined above—the public misperception of farming practices, policy field pressures that encourage bifurcation into large industrial farms and possibly small-scale organic farms, and the associated socio-economic precarity of many farmers, and a perceived low level of political representation—would increase the perceived (and quite possibly factual) dependency on consumer opinion among farmers. It is within the context of this complex understanding of the Bavarian agricultural policy field that agricultural stakeholders situate the tensions between farmers' interest in gene editing technologies and the public rejection of these technologies. Lack of public acceptance for gene editing technologies then becomes part of a larger political, social, and economic dynamic, which has, from the perspective of agricultural stakeholders, led to a profound alienation between the farming community and the wider public, which affects farmers' abilities to adopt gene editing technologies but also affects their lives and livelihood in many other and often more substantial ways. It is unsurprising that at the end of the workshop, key considerations about how to move forward focused not necessarily exclusively or even primarily on the gene editing technologies. Rather, they focused on how the actors that were assembled at the workshop—life scientists, social scientists, legal scholars, and agricultural stakeholders—could help to facilitate a much-needed dialogue between agricultural practitioners and the public about the present practices and future possibilities of agriculture in Bavarian, of which one aspect could be the use of novel technologies such as gene editing with CRISPR-Cas9.

[4]landschafftverbindung.org

[5]"*Land*" in German is a multifaceted term: it can mean country, nation, land, ground, and many more related terms. In this translation we opted for soil to stress the agricultural connect of how the term is used here.

## DISCUSSION AND CONCLUSIONS

We started this article by drawing attention to tensions between the orientations of science and technology policy and agricultural policy in Bavaria in the field of gene editing technology for livestock agriculture. While stakeholders in science and technology policy have identified gene editing in livestock agriculture as a worthwhile topic to support because it aligns well with Bavaria's strategy to position itself as an innovative high-tech state, the discourses and actions of state and non-state actors in the agricultural policy field limit the practical possibilities of implementing research results successfully in Bavarian agriculture. While conflicts between the goals and practices of different policy fields are, as such, not unusual, what we want to explore in this section is the question of what tensions between policy fields might mean for the possibility to conduct RRI type research with stakeholders from different fields "responsibly".

RRI type research usually aims to involve public stakeholders in research and innovation projects in order to incorporate their situated needs and concerns early in the development of novel bodies of knowledge and new technologies and create tangible benefits for the stakeholders (Stilgoe et al., 2013). In this sense, many RRI projects involve a certain amount of knowledge and/or technology co-creation between researchers and public stakeholders. In the case of our project, this particularly concerned the co-design of editing targets between life scientists and representatives of local breeding associations to meet the needs of small- and medium-scale farmers in Bavaria by focusing specifically on conveying resistances to certain common diseases in relevant livestock animals. Furthermore, social scientists were invited to become part of the project team not least to address the agricultural stakeholders' concerns about public opinion and "technology acceptance".

The project was, on many levels, a success. Targets were effectively identified, and proof-of-concept experiments were successfully performed. Some of the project researchers are certain that the results of the project could be implemented in Bavarian livestock breeding in just a few years. However, it is highly unlikely that this will happen—a fact that most agricultural stakeholders involved in the project were quite certain about before the project even started. The fact that they participated in and supported the project can be explained by their personal ties to the researchers with whom they previously worked with on less controversial topics (and in some cases trained and studied with) and through their genuine interest in the technology. However, what does such an odd constellation—to work toward the development of a technology that key members of the consortium believe will never be implemented in this national and regional context—mean for the social science researchers, who have been brought in to add a second "R", that is "responsible", to "research and innovation"? If responsibility means to understand and meet the needs of the public stakeholders who might be affected by a new technology, what might it mean in this specific context?

RRI research, and specifically co-creation activities, have recently been criticized for emphasizing technological solutions to societal problems to the detriment of social solutions (Müller et al., 2021; Timmermans and Blok, 2021). Social science

researchers have critically reflected upon what it means to be involved in such projects and have discussed if and how they could use their role to broaden the spectrum of problem definitions and solutions constructed in RRI projects (Conley and York, 2020; Rueß and Müller, forthcoming). We believe that a tentative answer to the question above concerning what responsible (social science) research in the context of our, and quite possibly many other projects, might mean is connected to this debate, though situated slightly differently. In the context of our project, the public stakeholders have many pressing problems. Their current (and quite possibly future) inability to use gene editing technology to improve their livestock is only a minor one in this context, and possibly more of an illustration of their difficult situation than an actual problem. They are thus unlikely to benefit from the project—while the researchers, including the social science researchers, have benefitted significantly in terms of research funding, publications, and reputation. The agricultural stakeholders might benefit in small ways by continuing to cultivate positive relationships with (life science) researchers, who are important collaboration partners for them regarding other technological needs (e.g., genetic sequencing). However, overall, the benefits are clearly skewed in favor of the research actors.

Other scholars, such as de Hoop et al. (2016), have drawn attention to these paradoxical situations that can arise in RRI projects, where even despite a degree of alignment between the scientific and public stakeholders' interests within the project, wider societal contexts and the roles these stakeholders hold in these contexts make it a virtual impossibility that public stakeholders will ultimately benefit from the project in any significant way. Drawing on their own field work on farmer-researcher collaborations in the biofuel sector in India, they argue convincingly that these wider constraints need to be taken into account and taken seriously as limitations for conducting RRI responsibly. For the agricultural sector, Rose and Chilvers (2018) have recently noted that, firstly, what RRI might look like in agricultural contexts is not yet well developed, and, secondly, that any RRI activity in this sector must take a systemic perspective on agriculture and its social and political dynamics in order to succeed. Yet, what if, as de Hoop et al. (2016) find in their case, an analysis of these systemic factors implies that it will be impossible to succeed, i.e., that it will be impossible to live up to the RRI expectation of creating significant benefit for public stakeholders? Should we then resort to a position of "innovating responsibly—or not at all" as de Hoop et al. (2016, p. 129) suggest?

There is of course no "one size fits all" answer to this question. Moreover, it is in the nature of research that many systemic constraints that inhibit responsible research and innovation will only come to the fore during the research process and not beforehand. Yet, as responsiveness is one of the key characteristics of RRI, the question remains how researchers, and maybe particularly STS and other social scientists involved in RRI project, can respond to these situations as they emerge. We suggest two avenues, not as an exclusive enumeration of possibilities, but as a starting point for further debate.

Firstly, we suggest that one possibility to tip the scales slightly in the direction of creating public stakeholder benefit could be to largely abandon the original problem and solution framing of the RRI project (i.e., in our case, the focus on gene editing technology) and instead follow the public stakeholders' problem definition in order to conceive positive interventions. This might be more easily possible for the social scientists in a project than for natural scientists or engineers, whose livelihoods might be more closely tied to the original problem framing. In our case, this implied shifting the focus of our attention away from the future of gene editing in Bavaria toward the wider question of the relationship between farmers, the public, and the agricultural policy field. In this new framing, questions of technology might still play a role but they have moved away from the center. For STS scholars, this might mean that they have to go off script and leave familiar territory by moving questions of science and technology backstage, possibly even reaching out to scholars from other fields to complement their expertise as the focus of inquiry shifts. It might mean recognizing that we might not have as much to contribute to the life worlds of the public actors we intended to support and care for as we hoped. In our specific case, our contributions are certainly modest at best and remain limited to two activities. First, we reframed the problem in all project reports from a question of "technology acceptance" toward understanding attitudes regarding gene editing technology among farmers and the lay public as shaped in non-trivial ways by the current discourses and actions in the agricultural policy field in Bavaria, Germany, and Europe. We proposed that future research projects should focus on exploring relationships between agricultural communities and publics in Bavaria and examine co-existing and competing visions for the future of agriculture in Bavarian society. Through these actions, we aimed to decenter gene editing technology and instead to shift focus on key issues that concerned the public stakeholders in our project and which ultimately constituted the wider contexts of any use of genetic technology in Bavarian agriculture. As another activity, all project partners committed to organizing a public event and workshop on the topics of concern to the public stakeholders. All researchers further committed to using their networks and institutional reputation to widen the debate and access audiences beyond the circles usually accessible to the agricultural stakeholders.[6]

A second important way for social scientists to respond to situations in RRI projects, where benefits for public stakeholders remain limited, is to analyze and publish about these instances. As de Hoop et al. (2016) argue, there is, to date, "relatively little work on [R]RI's limitations and failures" (p. 112). Similarly, Rose and Chilvers (2018) argue, in reference to Macnaghten's work (Macnaghten, 2016), that "research needs to assess whether responsible innovation frameworks make a difference in practice" (p. 5). de Hoop et al. (2016) also remark that researchers often tend to report the outcomes of RRI projects in an overly positive way in order to ensure future funding. This can also hold true for social science researchers, who often, possibly even more than natural science or engineering researchers, depend on RRI funding sources.

[6]Due to the COVID-19 pandemic, this event has not yet taken place, as we consider it inadvisable to conduct the event online.

Yet, analyzing and sharing situated experiences of limitation is important for the further development of RRI practices and should, where possible, be encouraged. It is important to note that this is not synonymous with attributing wrongdoing to the stakeholders who were involved in the RRI process. In our case, the different stakeholders authentically engaged with each other and implemented RRI principles effectively—still, contextual factors, in this case the dynamics of the wider agricultural policy field, limit the possibilities for the public stakeholders to significantly benefit from the project's outcomes.

All of what we propose here are modest actions. However, they can still create benefits for public stakeholders in RRI projects, where this is otherwise unlikely, and inspire an RRI discourse that can face such limitations and situated constraints more openly. From personal conversations with other RRI practitioners and researchers, we are well aware that such situations are not uncommon, however, the whats and whys of these situations can differ significantly. Mapping the limitations of concurrent RRI practices and categorizing different types of constraints thus emerges as an important field of action for RRI researchers in order to improve future practices, acknowledge their limits within specific social, economic and political contexts, and ultimately assess if innovating responsibly is possible and what it might mean in these specific contexts.

## DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because they are confidential qualitative social science research data. We ensured participants in the informed consent forms that only project researchers would have access to the data. Requests to access the datasets should be directed to ruth.mueller@tum.de.

## ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

RM designed the study and wrote this article. All authors were involved in conducting the empirical research and analysis that contributed to this article. All authors contributed to the article and approved the submitted version.

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