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ORIGINAL ARTICLE

Regulating gene editing in agriculture and food in the European Union: Disentangling expectations and path dependencies

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Abstract

This study investigates how proponents and critics of gene editing in agriculture and food (GEAF) employ expectations—discourses with future-oriented impacts—as they compete to secure desired futures and mobilise social processes and resources towards their goal of influencing GEAF (re)regulation and agro-food systems within the EU. We draw on 27 semi-structured interviews and 53 Euractiv media articles to identify and analyse GEAF proponents' and critics' responses to the 2018 European Court of Justice regulatory decision that GEAF will be regulated as genetically modified organisms. Despite similar themes of environmental sustainability, food security and winners and losers in agricultural innovation systems, proponents' and critics' discourses reflect divergent expectations of GEAF. We argue that both groups link their expectations with concerns about path dependencies in technological innovations and agro-food systems, which serve to influence emerging political, public and elite perspectives on GEAF. Although to some extent performative, these concerns offer important insights that should be

problematised and engaged within GEAF governance spaces. This study is conceptually framed by the socio-technical futures, path dependency and political economy of food and agriculture literature.

KEYWORDS
agricultural biotechnologies, European Union, expectations, gene editing, governance

INTRODUCTION

Technological change and agricultural restructuring have been longstanding areas of inquiry within rural sociological literature (Busch et al., 1989; Rotz et al., 2019). New genetic engineering techniques, such as gene editing techniques in general and the Clustered Regularly Interspaced Short Palendromic Repeats-Cas9 (CRISPR-Cas9) system in particular, are nascent biotechnologies praised for their potential to solve myriad agronomic, food security and environmental sustainability challenges (Abdallah et al., 2015; Georges & Ray, 2017). Scientists have even argued that gene editing advances will usher in a revolution in plant breeding (Doudna, 2015; Kumlehn et al., 2018).

Despite the high expectations in media (Dahlstrom et al., 2022) and scientific communications about gene editing in agriculture and food (GEAF), its role, if any, in future EU agro-food systems remains uncertain due in part to tensions around GEAF regulations. As Strand et al. (2018, p. 1849) highlight, 'Most, if not all large-scale policy issues in modern societies are entangled into the governance of science and technology'. In July 2018, the European Court of Justice (ECJ) ruled that gene editing techniques are—from a legal perspective—creating genetically modified organisms (GMOs) and must be regulated as such. The EU's Directive 2001/18/EC, referred from here on as the GMO Directive, requires entities seeking to commercialise GMO crops to complete strict risk assessment processes and monitoring requirements.

The ruling is significant because GMOs have a complex and controversial history within the EU, which explains why very few GMO crops are cultivated or eaten by EU consumers. A key tension involves diverging opinions on appropriate scientific risk assessment and management processes due to concerns that GMOs may cause harm to human health or the environment (Bonny, 2003; Bruce, 2017). In addition to scientific risk concerns, myriad social dimensions complicate the GMO controversy further. Scholars and critical non-governmental organizations (NGO) have focused much attention on agro-food structural issues, linking GMO seeds, patents and research with the growth, concentration and power of agro-chemical corporations over global agro-food systems (Brandl & Glenna, 2017; Clapp & Fuchs, 2009; Glenna et al., 2015a; Kinchy, 2012; Pechlaner & Otero, 2008). Other concerns surround consumers' right to information about their food, as well as farmers' rights and protections regarding GMO and non-GMO crop coexistence (Areal et al., 2011; Devos et al., 2009; Frewer et al. 2004; Herrero et al., 2017; Levidow & Boschert, 2008; Seifert, 2009). Additional GMO tensions are situated at the nexus of values, ethics and ideologies (see Brooks, 2005; Bruce, 2016; Bruce, 2017; Herrero et al., 2016).

As new forms of biotechnology follow in the footsteps of GMOs, gene editing's role in the future of EU agriculture and food is a contentious topic as well (Macnaghten & Habets, 2020). The trajectory and impacts of GEAF will likely be influenced by key social actors and networks, as well

as by the interactions among them (Jørgensen et al., 2009; Parayil, 2003). However, an important consideration is that all future impacts discussed by proponents and critics of GEAF are ultimately speculative, uncertain and contingent. Proponents of GEAF are taking actions to avoid repeating the intractable GMO controversy and to persuade the EU Commission to enact what they deem as more favourable regulations for GEAF (Macnaghten & Habets, 2020). In contrast, many critics of GMOs are also critical of GEAF and have voiced support for the 2018 ECJ ruling because they view strict risk assessments and oversight as necessary for any new biotechnological innovations in agriculture (Friends of the Earth, 2021).

Our research is situated within the GEAF (re)regulation conflict. We draw on empirical data from Euractiv media publications and semi-structured interviews with EU stakeholders to illustrate how GEAF expectations—references to future-oriented impacts—are employed to influence GEAF regulations. We argue that GEAF proponents and critics aim to influence political, public and elite perspectives on GEAF regulations through competing and contested expectations suggesting how GEAF may or may not distribute social, economic, agronomic and environmental benefits and consequences. Our analysis demonstrates how GEAF expectations are intertwined with concerns about path dependencies and lock-in situations within agricultural systems. Although expectations serve to persuade, they should not be dismissed as mere rhetoric. The varied expectations highlight complex potential barriers to developing more socially, environmentally and economically sustainable agro-food systems. As such, examinations of expectations can serve to inform more robust and inclusive debates on GEAF regulations and agro-food systems in general (Beumer & Edelenbosch, 2019).

This research is important for several reasons. It builds upon existing social science scholarship on biotech controversies by establishing timely baseline data of social actors' expectations connected to GEAF *before* it is widely commercialised anywhere. It also fills a gap in sociological research as scholars have called for greater engagement with the future as a social object (Beckert & Suckert, 2021; Selin, 2008) and answers calls for science and technology studies on governance for, and by, expectations (Konrad & Alvial Palavincino 2017). Much of the GMO literature has focused on understanding the present state of GMO attitudes and beliefs, potentially overlooking the critical role the future plays in creating, alleviating and exacerbating tensions within biotech controversies and sustainability efforts. Finally, while sociological studies of agriculture and path dependencies tend to explain why agro-food systems, practices and particular technologies dominate, this study takes a novel approach to understand how path dependency *discourses* are performed to influence and inform governance.

The article begins by briefly contextualising the regulatory conflict surrounding agricultural biotechnologies in the EU. We then present literature informing our conceptual framework on socio-technical futures, expectations and path dependencies in agriculture. Next, we describe our methods and data collection, followed by the results, analysis and discussion interrogating the expectations and path dependency lock-in/out scenarios advanced by proponents and critics of GEAF.

STUDY CONTEXT: REGULATING GMOS AND GENE-EDITED CROPS IN THE EU

The EU social and political agro-food landscapes have essentially rejected and resisted the introduction of GMO foods and crops. In June 1999, a *de facto* moratorium paused the evaluation of new GMO crop applications in the EU in partial response to the rapid developments in genetic

modification techniques during the 1990s and the simultaneous public debate surrounding the risks and safety of GMOs to human health and the environment (Nuffield, 2003). In October 2001, the GMO Directive was enacted, creating a strict authorisation system for GMOs within the EU (Macnaghten & Habets, 2020). Additional directives were subsequently passed to clarify peripheral concerns, such as establishing labelling and traceability standards and allowing individual member states to fully opt out of GMO cultivation.

Despite additional regulations and efforts to promote acceptance of GMO foods and crops by diverse publics, and coexistence among organic, non-GMO/conventional and GMO production, GMO opposition in the EU has been widespread, led in part by a consumer and environmental activist social movement (Helliwell et al., 2019; Herrero et al., 2017). Surveys continue to suggest broad, but uneven, opposition and scepticism among EU publics towards GMO foods (Bonny, 2003; Gaskell et al., 2000; Gaskell et al., 2011; Vlontzos & Duquenne, 2016). As of November 2020, 18 EU member states had legally opted out of GMO cultivation. Only two GMO crops, corn and potato, have been approved for cultivation since the GMO Directive was enacted in 2001 (Baulcombe, 2014). At the same time, GMO cultivation globally has proliferated. By 2019, 29 countries planted 190 million hectares of GMOs (ISAAA, 2019), yet only Spain and Portugal cultivated any GMO crops within the EU (Rostoks et al., 2019). Paradoxically, despite limited cultivation, the EU imports large quantities of GMO cereals and legumes to feed livestock (Tagliabue, 2017).

In July 2018, the ECJ ruled that based upon their interpretation of the GMO Directive, all organisms created through gene editing techniques are considered GMOs, and gene editing techniques are not included as exempted methods because they do not have a long safety record (Gelinsky & Hilbeck, 2018). The GMO Directive regulates based on the process of creating the plant rather than the characteristics of the final plant product. All gene-edited plants, regardless of the nature or complexity of genomic changes, are required to go through the same stringent regulatory authorisation processes as GMOs. Currently, most GEAF contain changes to their own DNA. These gene-edited organisms differ from what are commonly considered GMOs because GMOs typically contain a gene transferred in from another species, making them transgenic (FDA, 2022).

Nevertheless, GEAF regulatory oversight in the EU is not settled. Proponents have achieved some momentum in creating a path for enacting new GEAF regulations in the future. In April 2021, an EU Commission report was released on the legal status and social, environmental, economic, scientific and ethical dimensions of new genomic techniques, including gene editing methods and other technologies that have been developed since the GMO Directive was adopted in 2001 (European Commission, 2021). The study concludes that the current GMO legislation may not be appropriate for overseeing the rapid scientific developments of new genomic techniques (European Commission, 2021), suggesting new governance mechanisms for GEAF are needed in the coming years.

CONCEPTUAL BACKGROUND

Socio-technical futures and expectations

As a rapidly developing field of science and technology innovations, GEAF warrants sociological investigations into how social actors—many of whom represent powerful and influential institutional, corporate and expert organisations—attempt to secure desired futures (Brown et al., 2000) and mobilise social processes and resources towards their goals (Borup et al., 2006).

To illustrate the significance of the future in EU GEAF regulatory oversight discourses, we draw on the socio-technical futures literature, with a specific focus on the sociology of expectations.

Marris and Calvert (2019, p. 36; see also Brown 2003) explain why references speculating about the future matter: 'they have real effects in the present because actions in the present *are made legitimate through promises about the future* (emphasis added)'. Science and technology studies scholars emphasise that socio-technical futures are *performative* (Brown et al., 2000; van Lente, 1993), serving as a tool for social and political life by acting as resources for envisioning and realising technological development trajectories (Jasanoff & Kim, 2009; Lempiälä et al., 2019). Social actors draw on collective messages about the future as reference points to influence decision-making and co-ordination (Konrad et al., 2016), which Beckert (2016) argues is a critical social dynamic within capitalist economic systems, especially under conditions of uncertainty. The power of socio-technical futures lies in their ability to focus attention, guide actions, attract scientific allies, garner investments and legitimate government decisions pertaining to innovations (Borup et al., 2006; Brown et al., 2000; Konrad et al., 2016; Marris & Calvert, 2019; Michael, 2000; Selin, 2008).

Socio-technical expectations hold persuasive power because they are rarely neutral and may be overly optimistic or pessimistic about a technology's potential applications, impacts and adoption (Geels & Smit, 2000). Positive expectations are optimistic and often interpreted as promises, the assumed benefits that are dependent upon additional actions to bring them to fruition (Borup et al., 2006; van Lente & Bakker, 2010). Conversely, negative expectations can be understood as concerns and cautions about potential harms and risks resulting directly or indirectly from a technology's development, application, or diffusion (Konrad et al., 2016; te Kulve et al., 2013). Nevertheless, speculations about technologies and the future are rooted in uncertainty (Michael, 2000; van Lente, 1993). Eventual impacts stemming from technologies are contingent upon collective processes shaped by history, culture and power relations (Beckert, 2016).

Sociological studies often examine the dynamics of persuasion techniques and messaging but overlook important temporal factors (Beckert, 2016). For example, a study by Siebert et al. (2022) analyses the strategic framing of GEAF in Germany leading up to the ECJ ruling. Several of these frames also appear in the 2021 EU Commission report concluding that the GMO Directive is not fit for regulating new genomic techniques such as gene editing. While Siebert et al. (2022) do not examine the temporal significance of the frames, several are clearly futured in nature. Proponents of maintaining the current strict GEAF regulatory framework (defined as *critics* in our study) employed a Pandora's Box frame, which emphasised the unknown risks associated with GEAF, suggesting that environmental or other harms may potentially result in the future.

The sociology of expectations has been applied to the sense-making social processes around emerging science and technologies such as hybrid potatoes (Beumer & Edelenbosch, 2019), hydrogen technologies (Bakker et al., 2011), in vitro meat (Chiles, 2013), artificial intelligence (Vicsek, 2021), nanotechnologies (te Kulve et al., 2013), synthetic biology (Marris & Calvert, 2019) and lab-on-a-chip technology (van Merkerk & Robinson, 2006), among other topics. Multiple futures concepts appear in science and technology studies on the governance of innovation dynamics. These concepts include knowledge objects including expectations, promises, imaginaries, foresight, visions and scenarios (Konrad & Boehle, 2019). For this article, we employ the concept of *expectations*, which are 'statements about future conditions or developments' (Konrad et al., 2016 p. 465).

Recent studies illustrate how socio-technical futures are employed as powerful tools to influence governance perspectives and oversight of GEAF and GMOs. For instance, Yamaguchi (2020) argues that Japanese support for gene editing research and development was advanced through

collective frameworks based on epistemic nationalism. In the US, Bain et al. (2020) conclude that GEAF proponents are employing socio-technical imaginaries to influence GEAF regulatory decisions. Proponents' imaginaries suggest GEAF will usher in a new Green Revolution and enhance global food security, as well as 'democratize' the agricultural biotechnology innovation pipeline (Bain et al., 2020, p. 274). Jansen and Gupta's (2009) study interrogates how GMO proponents use visions of the future paired with morality claims to influence GMO governance debates. Proponents describe a threatening future where agricultural production stagnates, increasing hunger, poverty and inequalities. This dire future could be averted if swift actions were taken to reduce regulatory barriers to GMO development and commercialisation, allowing smallholder farmers in the Global South to capitalise on GMOs to improve wellbeing and food security (Jansen & Gupta, 2009).

Agriculture, path dependencies and lock-in/out

The meaning of path dependency as a theory and concept varies (Hanger-Kopp et al., 2022). In the context of agriculture, it is often used to explain processes and situations, sometimes called pathways or trajectories, where particular technologies, production systems and/or practices dominate and resist change (Arthur, 1989; Stone & Flachs, 2018). Lock-in occurs when multiple reinforcements—such as capital, institutional support, favourable regulations, education and training programs and social norms—coalesce to encourage one pathway and lock out others, exerting influence on innovation and systems trajectories (McGuire, 2008). Locked-in pathways are often viewed as sub-optimal and maladaptive, causing socioeconomic or environmental harms (Arthur, 1989; Berkhout, 2002; Konrad, 2006; Stone & Flachs, 2018; Vanloqueren & Baret, 2009). Meanwhile, alternative pathways and options are rejected or deemed unfeasible even though they may be superior in some ways (McGuire, 2008). *Path dependency* provides a useful analytical lens for making sense of GEAF expectations because it accounts for how complex social, institutional and technological forces shape and reinforce agricultural systems and structures through processes and relations.

The literature on GMOs, agricultural systems and path dependency underscores how systems, institutions and processes can align across scales to embed or disrupt agro-food system pathways and practices. For example, Stone and Flachs (2018) demonstrate how in Telangana, India, powerful external actors intentionally introduced GMO cotton to undermine existing cotton production practices grounded in local knowledge, institutions and economics. The disruption rendered farmers dependent on herbicides and GMO crops moving forward. Similarly, Iles and Montenegro de Wit (2015) argue that the developers of GMO crops created a US agricultural system whereby GMOs are so entrenched that many farmers, legislators, researchers and agro-food companies dismiss the viability of other agro-food pathways, such as agroecological systems. To understand how this GMO path dependency materialised requires relational and scale analyses to see how processes merge: 'scientific research and corporate plans develop the technology, regulators approve it, food companies require its use through contracts…farmers are forced to adopt GM crops… consumers are conditions to expect GMOs in their food…' (Iles and Montenegro de Wit, 2015, p. 488).

Other recent studies investigate path dependencies to understand how and why agricultural systems are recalcitrant to adopting environmentally sustainable practices. Rønningen et al. (2021) and Burton and Farstad (2020) examine Norwegian dairy and beef farming to understand barriers to climate change mitigation and greenhouse gas emission (GHG) reduction efforts. Rønningen

et al. (2021) conclude that several factors contribute to lock-in dynamics that reinforce current maladaptive practices, including policies, farmland access, culture and technology investments. Similarly, Burton and Farstad (2020) determine that both structural and sociocultural factors deter farmers from adopting GHG mitigative practices. Cultural factors include spousal, parenting and recreational norms, which encourage the adoption of time-saving technologies. In the US, Spangler et al. (2022) conclude that climate, land use norms and farm inputs are key factors predicting crop diversification, but the influence of those variables differed across regions, demonstrating the importance of spatial scale when examining path dependencies.

These and other studies offer insights into path dependencies and how to possibly predict or divert fixed pathways. Collectively, they explain the importance of considering complex relations and processes across scales. Such insights can be used to inform efforts to affect change. Unlike the aforementioned path dependency studies, our study is interested in how social actors draw on path dependency references as part of messaging to influence GEAF regulations.

METHODS

To explore social actors' expectations linked to the 2018 ECJ decision to regulate GEAF as GMOs, we conducted qualitative research to examine GEAF expectations discourses and the references to path dependencies within them. We utilised Euractiv online media publications and interviews with GEAF proponents, critics and other key stakeholders. Multiple data sources increased both the quantity of sources and the richness of the data (Ritchie et al., 2014). It is important to note that GEAF proponents were over-represented in both datasets.

We analysed news stories, opinion pieces and interviews published in English on Euractiv.com, an online news media source covering EU policy and political topics. A notable strength of sampling from Euractiv is that in addition to its own journalism, it is a network that incorporates news from independent media companies across Europe, and it contained paid promotional content such as opinion pieces crafted by both proponents and critics of GEAF. The spatial scope of Euractiv publications was important for identifying EU macro-level collective expectations rather than meso- or micro-level expectations circulating within specific social or agricultural region contexts, such as individual EU member states.

All Euractiv articles were published between the ECJ's ruling on 25 July 2018 and 29 February 2020 when our study began. To identify articles, we used search terms including *new plant breeding techniques, genome editing, gene editing, CRISPR, GMO 2.0* and *new GMO*. The search terms identified 102 articles. Only articles that referenced GEAF and the ECJ's 2018 or the GMO Directive were included in the final sample, which contained 53 articles for our analysis.

Our second data source consisted of 27 semi-structured, in-depth interviews conducted between June and July 2019. Most interviews took place in person in The Netherlands, Belgium and Germany, and one interview was conducted online via Zoom video technology. The interviews were part of a larger study examining how proponents and critics of GEAF are organising and communicating to shape governance and public opinions on GEAF. Interview participants hailed from member state government agencies, agricultural seed and chemical companies, farmer organisations, alternative agriculture organisations and companies, policy advisory organisations and food industry companies. We identified participants through online public information using the Google search criteria *European court decision new breeding techniques gene editing*. Some participants were selected because their names or entities were listed on websites about gene editing conferences in the EU. Others were identified because their names or entities appeared online in

posted position papers and letters responding to the ECJ decision. Several participants and entities were mentioned in online news. Once interviews began, we obtained additional participants through snowball sampling (Ritchie et al., 2014). The goal was to capture a broad scope of perspectives on the ECJ decision, but more proponents of GEAF accepted our interview requests as compared to critics.

NVivo qualitative research software was used to manage and code our interview transcriptions and Euractiv publications. Through analysis, we identified two general groups concerned with GEAF regulations in the EU: proponents and critics. Proponents support changing GEAF regulations so that GEAF are not regulated within the current GMO Directive and subsequent regulatory structures, and critics support regulating GEAF within the GMO Directive definition of GMO processes.

We do not suggest that each group holds exclusively homogeneous views on GEAF expectations or concerns about path dependency situations; some nuances were present in the data among both proponents and critics. However, the sociology of expectations emphasises the *performativity* of group expectations whereby social actors seek to exert influence. The Euractiv articles reflect proponents' and critics' public performance of collective expectations through strategic messaging to support desired GEAF regulations. Like most popular media, Euractiv articles were short and likely limited by word counts. On the other hand, the interviews could be interpreted as semi-private since only the participants and researchers were present, allowing participants the opportunity to explain nuanced views that might not otherwise be shared publicly. As such, the proponent and critic groups should not be taken as ideologically *pro* or *anti*-GEAF and biotechnology.

Following Konrad et al. (2016, p. 465), we conceptualised expectations as 'statements about future conditions or developments', which we interpreted as future-oriented references about potential impacts. Both direct and implied expectations were coded. This included references to environmental, economic, scientific, agronomic, social and agro-food systemic impacts. Using an iterative process of coding by hand, we identified each group's collective GEAF expectation themes. Finally, using a deductive approach to analysing the themes, we identified how the social actors' expectations are justified through concerns linked to path dependencies and lock-in/out.

Results: Competing and contrasting expectations embedded in path-dependent futures

Both proponents and critics employ expectations—future-oriented references about potential impacts—as they attempt to influence GEAF regulations in the EU. The messages contain similar and interrelated themes, including (1) environmental sustainability and food security and (2) agricultural innovation winners and losers. In addition, proponents employ a unique theme: (3) the risks associated with *not* using GEAF due to regulatory hurdles. Despite the similar themes, proponents' and critics' GEAF expectations are situated within diverging and contrasting messages about the causes of agro-food problems and the role GEAF may play in particular agro-food pathways.

Proponents' expectations position GEAF innovation as a means to disrupt and prevent agro-food system path dependencies in the future, thus challenging the currently locked-in system where multinational agro-chemical corporations hold immense power and control over agricultural production. In that future, both public researchers and private small and medium enterprises (SMEs) will use GEAF technology to provide much-needed solutions to agronomic production

challenges and other social and environmental issues intertwined with agro-food systems. Proponents link positive expectations to agricultural futures with fewer regulatory barriers to GEAF innovation. Addressing these challenges is possible because GEAF is situated within an open research and innovation system, unlike the current system. To proponents, GEAF will bring benefits for EU consumers, farmers, the environment, agribusinesses and the science and technology sectors, both public and private, as well as farmers and societies in the Global South. Proponents juxtapose GEAF benefits claims with futures describing significant harms and missed opportunities if GEAF remains regulated as a GMO under the GMO Directive. Their major concern is a future in which GEAF is locked out of EU agro-food systems (Table 1).

Conversely, when critics consider possible futures if GEAF innovations proliferate and are no longer regulated as GMOs, their expectations often link to what they consider to be the negative current pathway dominated by large-scale, industrialised agricultural systems of food production and the concentrated power of multinational agriculture and chemical corporations. To many critics, GEAF will further lock in the industrialised agriculture model, thus exacerbating the inequalities and harms caused by that system. They foresee GEAF contributing towards the current path dependency situation with limited powerful actors and a biotechnology-based agr o -food future. Critics often note the complex relational aspects and history of multinational agrochemical corporations, technological innovations and dominant industrial agricultural systems. An alternative agriculture organisation representative explains:

> [GEAF] is just tweaking of a big systemic problem… We think the foundation needs to be changed. And the foundation should not be intensive monocultures, but a diversified agriculture that is not necessarily export oriented. A system that's much less oriented for feed for animals, etc. (Int 02).

To many critics, that agricultural future should be locally oriented, sustainability-focused and rooted in agroecological principles. They do not expect that future to materialise if GEAF enters the EU agro-food system and the current pathway to buttress industrial agriculture with power concentrated among a small group of companies continues (Table 2).

Environmental sustainability and food security

A key claim by proponents is that GEAF innovations will be crucial for realising a future EU and world with environmentally sustainable agricultural systems and climate change resilient agricultural production. They claim GEAF will reduce the use of harmful inputs, such as fertilisers and pesticides, and divert agricultural systems away from paths locked into intensive input applications. They rationalise that without these inputs—or with reduced quantities—soil, water and air will be cleaner, resulting in benefits to both the environment and human health. Some proponents claim that breeders will use GEAF to *increase* crop biodiversity through more diversity in crop traits. An agricultural association representative explains:

> The main argument in favour is using [GEAF] to create varieties which can be used for more sustainable agriculture, so reducing pesticide and fertilizer input. In view of climate change… there are challenges for agriculture and there need to be solutions (Int 05).

TABLE 1 Proponents' gene editing in agriculture and food (GEAF) expectations according to regulation scenarios.

Expectations themes	If GEAF remains regulated as a genetically modified organism (GMO)	If GEAF is not regulated as a GMO
Environmentally sustainable and climate change resilient agriculture	Negative impacts for humans and environment • Without GEAF, cannot reduce inputs and farm more sustainably • Crops and farmers negatively impacted because plant breeding is slow	Benefits for humans and environment • Reduce chemical inputs • Improve soil, water and air • Increase biodiversity • Climate change adaptation and mitigation possible
Food security for growing global population	Barrier to necessary gains to feed a growing global population • Hunger and malnutrition	*Tool in the toolbox* for more efficient agricultural systems • Grow more food on less land • Improve rural livelihoods in Europe and Global South • Increase yields and improve nutrition
Agronomic innovations and solutions	Multinational agro-chemical corporations control GEAF innovations and development	small and medium enterprises, multinationals and public researchers compete and contribute • Open innovation system • Improve varieties faster than traditional breeding
EU consumers	Denied desirable food characteristics	More desirable food characteristics in markets • Better taste • More nutritious • Improved shelf-life • Removed allergens Indirect benefits, such as cheaper food
Economic and innovation impacts	EU plant breeders and scientists cannot use GEAF • Exodus to countries with fewer regulations • US, China and other countries dominate global agro-food trade • Scientific progress happens elsewhere • EU farmers denied access to solutions	EU competitive in global food trade and GEAF innovations • Science and technology independence

TABLE 2 Critics' GEAF expectations according to regulation scenarios.

Expectations themes	If GEAF remains regulated as a GMO	If GEAF is not regulated as a GMO
Environmental and climate impacts of industrial agriculture systems	Changes to large-scale industrial agriculture systems may be possible (implied)	Continuation of current systemic harms • More soil degradation, chemical and nutrient applications, and contributions to climate change
GEAF and food security issues (earlier GMO promises did not materialise)	Resistance against multinational corporations' global agro-food power and control • Benefits to Global North and South through local solutions	Power and control remain concentrated among a few multinationals • Similar to GMOs, most benefits accrued by businesses and producers in the Global North • Enhanced agro-food socio-economic inequalities in the Global South • GEAF intellectual property and patents further entrench power of multinational agro-chemical corporations
Agronomic innovations and solutions	Agroecological, natural, integrated, local and socially responsive solutions may spread (implied) Possibilities to increase biodiversity	Reinforce existing corporate dominance of industrial agriculture systems • Increase farmer dependency • More herbicide-resistant varieties • Decrease biodiversity

Proponents' expectations include descriptions of how GEAF is one of several approaches and technologies that can help address the need to increase global food production for food security purposes. GEAF is often presented metaphorically as a critical *tool in the toolbox* of solutions to farm more efficiently. These expectations counter critics' concerns about path dependency and lock-ins that are socially inequitable. By suggesting that multiple 'tools' will be needed for agriculture innovations, it implies that diverse farming systems and various technologies and innovations will be utilised to feed the world's most food-insecure nations. A farmer association representative explained: 'Of course, farmers in the world have to farm… more efficiently because the world population grows and we need to feed the people' (Int 18). Another common claim is that GEAF will enable farmers to produce more food on less land, which may be beneficial for environmental and biodiversity conservation. According to proponents, GEAF's diverse benefits will help improve the livelihoods of farmers and societies in Europe and in the Global South.

However, critics expect that rather than supporting sustainable production systems, GEAF crops will further entrench the pathway of the existing industrial agricultural system model and farm-level production practices that cause environmental harms, such as soil degradation, intensive chemical and fertiliser applications and greenhouse gas contributions to climate change. As Greenpeace's Marco Contiero argues, 'The obsession with simplified technological fixes for complex problems is a distraction from systemic change we must achieve, which is arguably more of a serious concern than the potential consequences that these technologies might have of changing the genome of living organisms' (Euractiv 44). Contiero's point also highlights that critics are

concerned about more issues than just the possible scientific risks of GMOs to human health and the environment.

Both proponents and critics express scepticism towards the credibility of the other group's expectations by suggesting that the opposing views are performative, seeking to garner political, economic and social support for particular interest groups. Proponents argue that civil society organisations and organics organisations are critical of GEAF because they want to protect their own economic interests, while critics suggest that proponents are capitalising on current social concerns around sustainability to gain support for purported agricultural biotechnology solutions through GEAF. This awareness supports critics' scepticism towards whether proponents' GEAF promises will materialise. Critics' expectations often draw on the history and impact of GMOs, as well as the past failed promises from agribusinesses and scientists supporting GMOs, when describing GEAF impacts on future agro-food pathways. For example, critics cite how early GMO advocates predicted social, environmental and economic benefits for both the Global North and smallholder farmers in the Global South, which largely did not materialise (Macnaghten & Habets, 2020). French MEP Benoît Biteau contends, 'These new GMOs are not a solution to climate change nor to food sovereignty; they have never delivered their promises' (Euractiv 45). A university researcher elaborates further: 'Today people are more worried about climate change, and I think that is why the proponents are more focused on climate change. That is where the fears are' (Int 22).

Agronomic Innovation: Winners and losers

Proponents claim that removing GEAF regulatory barriers will foster a more inclusive and open agricultural biotechnology innovation regime in the future, contributing to the rapid development of improved crop varieties while also disrupting the existing locked-in path of concentrated corporate dominance in the global agro-food system. Within this future regime, public scientists and SMEs can be at the forefront of GEAF developments. They argue that the GMO Directive's costly and excessive risk assessments make it very challenging for smaller farmers and companies to use the technology. A representative from an agricultural organisation contends, 'if you want to regulate gene-editing…like GMOs here in Europe, you are giving them on a silver platter to [multinational corporations] because only they have the capabilities to work under complex regulations… [strict regulations make it] more difficult for small companies to deal with' (Int 24). References to inclusive GEAF innovation regimes are coupled with descriptions in which gene editing techniques quickly and efficiently create solutions to pressing agronomic challenges, such as drought tolerance, as opposed to what is perceived as the slow process of traditional plant breeding.

Contrary to proponents' optimistic expectations that reduced GEAF regulations will bring about a more inclusive and open GEAF innovation regime, critics contest the claim that SMEs and public researchers will be able to compete and innovate alongside multinational agro-chemical corporations. An alternative agriculture organisation representative explains, 'GMO and gene editing go against everything we stand for, so agroecology, farmers rights to choose what they want to produce, protecting small scale farmers against corporate control and the concentration of power in the hands of few multinationals…' (Int 17). To critics, GEAF will become another element of the current pathway whereby multinational agro-chemical corporations own and control the technologies, patents, seeds, artificial fertilisers and pesticidal chemicals already locked into industrial agricultural systems. Critics predict GEAF would further increase EU farmer and

rural community dependence on corporations, reducing farmer choice, power and ownership of seeds.

Critics reject claims that GEAF will be necessary for addressing agricultural production challenges, arguing that solutions to agricultural problems, such as plant pests, drought and climate change adaptation and mitigation, already come from traditional breeding, organic production and integrated farming approaches. When an organic producer was asked if GEAF might be acceptable within organic farming, he replies,

> If I see the whole package and I say "What are the benefits, costs, and risks for introducing [GEAF] into organic agriculture?" Then I think "Why should we do that when we have other methods to solve these problems?" (Int 02).

Critics desire future agricultural systems with a greater focus on agroecological, local and holistic approaches to agronomic and food production challenges as opposed to biotechnological fixes. They are concerned that their desired agricultural system will be locked out and pushed to the margins by GEAF proliferation and industrial agricultural systems. They emphasise the need for resilient farming systems where integrated solutions consider the wider ecological and social relations of food systems. Such a system, they claim, will increase plant biodiversity, while the existing industrialised agricultural system decreases biodiversity due in part to the focus on monocrop production practices. An alternative agriculture representative sums,

> [You can't] impose a variety from the top to solve a problem that is inherently local. Even if climate change is global, its impacts are inherently local, so you need a local solution, which typically comes from biodiversity. Not with one variety that is genetically improved (Int 02).

The risk of not using GEAF: Lock out

Unique to proponents' expectations is an explicit emphasis on future risks and harms for plant breeders, farmers, consumers and the environment that could result if GEAF remains regulated as GMOs. These concerning futures are often situated within the global agro-food system. Such expectations highlight negative impacts on EU economies, trade and technological innovation fields as compared to global agro-food powers. Proponents stress that existing regulations will hinder the innovation and economic competitiveness of EU plant breeders, forcing an exodus in which plant breeding companies and scientists leave the EU to establish operations in countries with reduced regulations. They describe a future in which the EU agricultural sector is 'left behind' (Euractiv 11) and locked out while other countries, such as the US and China, benefit from GEAF progress and trade. Additionally, proponents speculate these missed opportunities will impact EU farmers especially hard because they will be denied solutions to agricultural production challenges.

Proponents also highlight how strict regulations could lock out consumers from GEAF benefits. They stress that GEAF will benefit the average consumer, unlike earlier GMOs that largely benefited producers. Proponents maintain that public dialogues and debates should focus on the consumer benefits so that consumers disassociate GEAF from GMOs and support reduced GEAF regulations, allowing these benefits to materialise. Cited examples include healthier and

tastier foods with reduced allergens and longer shelf life. In a Euractiv opinion article, medical pathologist Dr. Collin Berry explains,

> [Gene editing techniques] create mushrooms that don't brown, rice that is healthier for diabetics and oils with more omega 3 fatty acids. Potentially, they could remove the allergens from peanuts or make wheat safe for people with gluten intolerant Celiac's disease (Euractiv 8).

Proponents' expectations are also embedded with claims that strict GEAF regulations will result in negative consequences and harrowing scenarios for people and the environment. A report commissioned by CropLife International stresses,

> The continued unpredictable political environment will likely lead to further reductions in the availability of crop protection products and biotech seeds in the region, further hampering farmers' efforts to sustainably increase production (Euractiv 4).

To summarise, we find that both GEAF proponents and critics are circulating expectations connected to whether GEAF is regulated as a GMO within the strict guidelines of the GMO Directive. Future risks and benefits are situated within path dependency and lock-in/out scenarios. Proponents describe how a future with reduced GEAF regulations will bring diffuse benefits, suggesting GEAF innovations can help disrupt the current agro-food pathway where power and control are held by multinational agro-chemical corporations. However, without reduced regulations, harm will ensue because GEAF will be locked out, making social, environmental and economic benefits inaccessible. Conversely, critics are highly sceptical that such diverse benefits will materialise under reduced GEAF regulations and expect that GEAF would drive the EU further down what they perceive as the entrenched path of intensive, input-dependent and large-scale industrial agriculture systems. They foresee GEAF as likely another tool in socially, economically and environmentally harmful and inequitable agro-food systems. For critics' desired agroecological model of agriculture to expand, the current agricultural system, and relations within it, must change.

ANALYSIS AND DISCUSSION

GEAF proponents and critics are utilising expectations to shape understandings of the environmental, social, economic and political value of GEAF with the intent of realising certain agricultural, economic, technological and social goals and pathways. Both groups draw on the common themes of environmental sustainability, food security and agriculture innovation impacts on social groups. However, they hold fundamentally different visions of the role GEAF can, and should, play in achieving goals within those themes. These expectations matter because they are to some degree performative (Brown et al., 2000; van Lente, 1993) and promises about the future can serve as cultural and social resources to legitimise policy decisions and investments in technologies (Jasanoff & Kim, 2009; Konrad et al., 2016). After all, historical processes are non-linear, and the future that materialises is contingent and will be influenced by complex institutions, governance and economic systems, power dynamics and competing social actors.

By positioning GEAF as the antithesis to current path dependencies in agro-food systems and potentially beneficial for almost everyone in the EU, proponents have attempted to hide and deny

contestations and uncertainties (Beckert, 2016; Yanow, 2000) that were the key critical arguments in the earlier GMO debates and the current GEAF discussions. For example, proponents describe GEAF's future within an open science and innovation regime as opposed to another factor contributing to an agro-food pathway where large corporations benefit the most from GEAF and use it to bolster high-input industrial approaches to agriculture. Such messaging reflects deliberate attempts to pre-empt critics' concerns and garner political and social support for new GEAF regulations. This messaging of 'benefits for all' under reduced GEAF regulations is highly alluring, making the idea of GEAF lock-out seem unethical and unjust.

Critics' GEAF expectations are ultimately evaluations of interactions across levels, space and time. The history of GMOs largely shapes critics' beliefs that GEAF proponents' actual actions will be self-serving and profit-oriented rather than bringing diverse benefits. Although not explicitly stated, it is implied within critics' expectations that regulating GEAF as GMOs will help *lock-out* GEAF from EU agro-food systems, thus blocking what they view as one more potential barrier to the growth of agroecological models.

Addressing the grand challenges to sustainable agriculture will require additional considerations and actions beyond GEAF authorisation and risk assessment policies. This is perhaps the key to tensions within proponents' and critics' expectations and greater messages about path dependency and lock-in/out. These larger issues are about more than EU biotechnology regulations. Why would critics view proponents' GEAF expectations as legitimate, possible and credible? Why would they expect GEAF to help disrupt the power and control already deeply entrenched within EU and global agro-food systems? If GEAF is re-regulated under a less stringent authorisation and risk assessment system, additional policies and industry commitments are likely needed to ensure that an inclusive and open GEAF innovation regime can emerge and be sustained. As a young GEAF scientist suggested in an interview, new laws are needed to prevent even more corporate agro-food mergers and acquisitions (Int 21). Such legal changes could disrupt current agro-food pathways, possibly fostering more confidence that GEAF can contribute to more equitable and sustainable approaches to agriculture.

While critics' expectations represent an overall pessimism about potential impacts if GEAF proliferates in EU sciences and agriculture, that does not mean those voices are unanimously anti-GEAF. For instance, organic agriculture communities and consumer and environmental advocacy NGOs contain some diverging perspectives on the compatibility and acceptability of GEAF in agriculture systems (Helliwell et al., 2017). Within those communities, internal power imbalances are shaping which social actors' voices are heard and considered legitimate in discussions about GEAF and organics (Nawaz et al., 2020), which aligns with the performative aspect of expectations that ultimately appears as a bifurcated public debate despite the presence of nuanced positions within and between social actor groups.

A central tension among both groups' expectations is the idea that GEAF can coexist or contribute to agroecological models of production. Montenegro de Wit (2022) interrogates the 'complementarity narrative' whereby proponents argue CRISPR-Cas9 gene editing can complement agroecology values, principles and goals. Montenegro de Wit (2022) emphasises that a core assumption within this narrative is that technology is neutral, yet 'incentive structures for tech innovation are anything but neutral…the trope of neutrality unmoors biotechnology from path-dependent real-world circumstances…' (p. 738). Vanloqueren and Baret (2009) draw a similar conclusion, arguing that a genetic engineering technological research regime has fostered a lock-in condition that in turn constrains the development of agroecological agricultural research trajectories. The succession of corporate mergers and acquisitions among seed and agro-chemical companies since the 1990s was driven in part by company efforts to capitalise on genetically

engineering seeds to complement their existing agro-chemicals (Clapp, 2018). GMO developers and distributors were motivated by potential profit rather than a desire to reduce ecological impacts resulting from the existing systems. By pairing GMO commodity crops with agrochemicals, they encouraged and drove monocultural systems of agricultural production (Clapp, 2018). This is contrary to the idea of biodiversity, which is fundamental to agroecological systems. Critics' GEAF expectations often speak to such contradictions.

Proponents' expectations of GEAF and environmental sustainability benefits acknowledge how current large-scale agricultural pathways and practices are ecologically destructive, but they fall short of calling for systemic change by advocating for GEAF technological fixes. The widespread adoption of intensive, high-input monocultural agricultural practices over the last century has caused ecological harms such as increased carbon emissions; water pollution from pesticides and nutrients; biodiversity loss; soil erosion and degradation and weed and disease resistance, among other impacts (Liebman & Schulte, 2015; Reilly et al., 2021; Schütte et al., 2017; Silva et al., 2019). It can neither be assumed that EU farmers will adopt GEAF nor that they would incorporate gene-edited crops in a manner that reduces their farming operations' ecological footprints (Lassen & Sandøe, 2009).

Another area of contestation is in relation to GEAF's possible contributions to food security and improving farmer livelihoods, especially in the Global South. According to Glenna and Ransom (2021), the chances that the next generations of genetically engineered crops, which include GEAF, will deliver on their promises to farmers and publics in the Global North and South alike is dependent upon social institutional contexts. There is also a greater need for empirical research on GMO social and economic impacts despite proponents' claim that GMOs have been socially beneficial. The existing research contains many limitations and gaps, such as non-representative sampling of farmers, focusing too much on short-term benefits and overlooking community impacts (Catacora-Vargas et al., 2018; Glenna & Ransom, 2021). Many scholars argue that socioecological, institutional and cultural contexts should be considered before deciding to transfer agricultural technologies to less economically developed locations (Bain et al., 2018; Chataway, 2005; Glover et al. 2017). Failure to do so can result in unintended consequences and ultimately exacerbate social inequalities (Bain et al., 2018; Stone & Flachs, 2018). Similar to Luna's (2020) findings on GMO imaginary discourses in Burkina Faso, both GEAF proponents and critics make essentialised comments about rural communities and farmers. The difference is that critics call for considering local contexts.

While proponents in the EU and US are presenting GEAF as a democratic and open innovation technology that will be used by public and private researchers and firms of various sizes (Bain et al., 2020; Siebert et al., 2022), there are significant reasons to be sceptical about the likelihood of these expectations. For instance, in the US, multinational agro-chemical corporations are firmly invested in GEAF research and development internally as well as externally through public and private collaborations, giving them a structural advantage to reap economic benefits and determine GEAF crop research trajectories. For instance, Bayer Crop Sciences is arguably one of the most powerful seed and chemical corporations in the world. Bayer has formed agricultural research collaborations with gene editing start-up companies such as Pairwise and PivotBio, as well as contributing funds to universities that research GEAF. Corporate/start-up and even corporate/university collaborations could potentially limit the scope of research to serve corporate interests rather than create public goods (Glenna et al., 2015b), such as orphan crops that might benefit food-insecure nations the most. If the current corporate consolidation trends continue, GEAF innovation will likely encourage greater consolidation as large corporations absorb start-up companies.

Further, the intellectual property landscape of licensing and patenting for CRISPR-Cas9 gene editing technologies is not as open as suggested. The complex licensing landscape is especially challenging for start-ups and SMEs to navigate (Hönig et al., 2022), and they often do not have the same finances available for legal expertise as do large corporations. The foundational CRISPR-Cas9 licenses are only free to public and non-profit organisations for research purposes, limiting their ability to commercialise and distribute potential gene-edited plants. In addition, scientific advances have expanded the suite of CRISPR systems beyond the Cas9 enzyme, bringing gene editing technology patents to public and private entities who may not wish to license their technologies openly. Ultimately, intellectual property protections can restrict the diffusion of agricultural research and technologies, limiting possibilities to transform agricultural systems in socially, economically and environmentally sustainable manners (Glenna et al., 2015a).

Perhaps the greatest constraint to proponents' claims of an altruistic future where GEAF brings widespread benefits is the complex regulatory and normative economic structural forces of the neoliberal global agro-food system (McMichael, 2009). As such, GEAF and its potential benefits and harms must be considered within both local and global contexts. Since the 1980s, the global agro-food system has evolved and largely embraced trade liberalisation, neoregulations and stronger intellectual property rights (Pechlaner, 2010, 2020). Over time, structural factors such as public and private agro-food governance entities reinforced this pathway, making it difficult to introduce change (McGuire, 2008). Neoliberal capitalist logics of markets and quasi-markets privilege and reward systems that maximise returns on capital through intensification and commodification, which bolsters current large-scale agricultural systems (Goven & Pavone, 2014). There is no reason to believe that GEAF will be immune to capitalist market logics either. Also, modern commodity crop agriculture is largely dependent on costly inputs, such as proprietary seeds, pesticides and fertilisers, thus best suited for maximising profits within this industrial agriculture model. Because many structures, systems and processes buttress existing agro-food path dependencies, GEAF developments that are not aligned with those values and principles will face barriers.

CONCLUSION

Despite proponents' positive expectations for diverse GEAF benefits, it will require more than less stringent GEAF regulations at the EU level for such benefits to materialise. Governance, regulatory, institutional, sociocultural, scientific, economic and spatial-environmental factors can all potentially reinforce or disrupt agricultural and scientific innovation pathways and lock-in/out conditions. By considering these complex factors and critics' GEAF expectations, EU political decision-makers will be better prepared to establish various GEAF regulatory and institutional checks and balances to promote socially, environmentally and economically sustainable agro-food systems. This is not a simple task, despite proponents' expectations that GEAF can contribute substantially to all three sustainability legs without any negative impacts. Societies, groups, the environment and economies are influenced by a complex web of interactions. At the same time, considering path dependencies may sway decision-makers to avoid GEAF (re)regulation altogether, allowing for continued EU resistance to biotechnologies in agriculture. That by itself will not resolve issues and inequalities in EU agriculture, but it will block GEAF from potentially exacerbating unsustainable systems and practices. To foster inclusive and robust GEAF and agro-food governance, diverse perspectives from stakeholder groups, including EU publics, must be included or risk damaging the legitimacy of EU biotechnology oversight altogether (Lassen, 2018).

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CONFLICT OF INTEREST STATEMENT

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

DATA AVAILABILITY STATEMENT

The interview data that support the findings of this study are available from the corresponding author upon reasonable request. The Euractiv articles are publicly available online. Contact the corresponding author for a list of the article titles.

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REFERENCES

Abdallah, N.A., Prakash, C.S. & McHughen, A.G. (2015) Genome editing for crop improvement: challenges and opportunities. *GM Crops & Food*, 6(4), 183–205.

Areal, F.J., Riesgo, L. & Rodríguez-Cerezo, E. (2011) Attitudes of European farmers towards GM crop adoption. *Plant Biotechnology Journal*, 9(9), 945–957.

Arthur, W.B. (1989) Competing technologies, increasing returns, and lock-in by historical events. *The Economic Journal*, 99(394), 116–131.

Bain, C., Lindberg, S. & Selfa, T. (2020) Emerging sociotechnical imaginaries for gene edited crops for foods in the United States: implications for governance. *Agriculture and Human Values*, 37, 265–279.

Bain, C., Ransom, E. & Halimatusa'diyah, I. (2018) 'Weak winners' of Women's empowerment: the gendered effects of dairy livestock assets on time poverty in Uganda. *Journal of Rural Studies*, 61, 100–109.

Bakker, S., Van Lente, H. & Meeus, M. (2011) Arenas of expectations for hydrogen technologies. *Technological Forecasting and Social Change*, 78(1), 152–162.

Baulcombe, D., Dunwell, J., Jones, J., Pickett, J. & Puigdomenech, P. (2014) *GM science update*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/292174/cst-14-634a-gm-science-update.pdf [Acccessed 1st June 2022]

Beckert, J. (2016) *Imagined futures*. Cambridge, MA: Harvard University Press.

Beckert, J. & Suckert, L. (2021) The future as a social fact. The analysis of perceptions of the future in sociology. *Poetics*, 84, 101499.

Berkhout, F. (2002) Technological regimes, path dependency and the environment. *Global Environmental Change*, 12(1), 1–4.

Beumer, K. & Edelenbosch, R. (2019) Hybrid potato breeding: a framework for mapping contested socio-technical futures. *Futures*, 109, 227–239.

Bonny, S. (2003) Why are most Europeans opposed to GMOs? Factors explaining rejection in France and Europe. *Electronic Journal of Biotechnology*, 6(1), 50–71.

Borup, M., Brown, N., Konrad, K. & Van Lente, H. (2006) The sociology of expectations in science and technology. *Technology Analysis & Strategic Management*, 18(3-4), 285–298

Brandl, B. & Glenna, L.L. (2017) Intellectual property and agricultural science and innovation in Germany and the United States. *Science, Technology, & Human Values*, 42(4), 622–656.

Brooks, S. (2005) Biotechnology and the politics of truth: from the Green Revolution to an Evergreen Revolution. *Sociologia Ruralis*, 45(4), 360–379.

Brown, N. (2003) Hope against hype—accountability in biopasts, presents and futures. *Science & Technology Studies*, 16(2), 3–21.

Brown, N., Rappert, B. & Webster, A. (Eds.) (2000) *Contested futures: a sociology of prospective techno-science*. Aldershot: Ashgate Publishing.

Bruce, A. (2016) Frankenfish or fish to feed the world? Scientism and biotechnology regulatory policy. *Rural Sociology*, 82(4), 628–663.

Bruce, D. (2017) Genome editing: does it move the goalposts on the GM playing field? In: San-Epifanio, L.E. (Ed.) Towards a new regulatory framework for GM crops in the European Union *(online)*. Wageningen, The Netherlands: Wageningen Academic Publishers, pp. 123–129.

Burton, R.J.F. & Farstad, M. (2020) Cultural lock-in and mitigating greenhouse gas emissions: the case of dairy/beef farmers in Norway. *Sociologia Ruralis*, 60(1), 20–39.

Busch, L., Bonanno, A. & Lacy, W.B. (1989) Science, technology, and the restructuring of agriculture. *Sociologia Ruralis*, 29(2), 118–130.

Catacora-Vargas, G., Binimelis, R., Myhr, A.I. & Wynne, B. (2018) Socio-economic research on genetically modified crops: a study of the literature. *Agriculture and Human Values*, 35(2), 489–513.

Chataway, J. (2005) Introduction: is it possible to create pro-poor agriculture-related biotechnology? *Journal of International Development*, 17(5), 597–610.

Chiles, R.M. (2013) If they come, we will build it: in vitro meat and the discursive struggle over future expectations. *Agriculture and Human Values*, 30(4), 511–523.

Clapp, J. (2018) Mega-mergers on the menu: corporate concentration and the politics of sustainability in the global food system. *Global Environmental Politics*, 18(2), 12–33.

Clapp, J. & Fuchs, D. (Eds.) (2009) *Corporate power in global agrifood governance*. Cambridge, MA: MIT Press.

Dahlstrom, M.F., Wang, Z., Lindberg, S., Opfer, K., & Cummings, C.L. (2022) The media's taste for gene-edited food: comparing media portrayals within US and European regulatory environments. *Science, Technology, & Human Values*. [Preprint]. Available from https://doi.org/10.1177/01622439221108537 [Accessed 30 July 2022].

Devos, Y., Maeseele, P., Reheul, D., Van Speybroeck, L. & De Waele, D. (2009) Ethics in the societal debate on genetically modified organisms: a (re)quest for sense and sensibility. *Journal of Agricultural and Environmental Ethics*, 21(1), 29–61.

Doudna, J. (2015) Genome-editing revolution: my whirlwind year with CRISPR. *Nature*, 528(7583), 469–471.

European Commission. (2021) *Study on the status of new genomic techniques under Union Law and in light of the Court of Justice ruling in case C-528/16*. Available at: https://ec.europa.eu/food/system/files/2021-04/gmo_mod-bio_ngt_eu-study.pdf [Accessed 15th June 2021]

FDA (United States Food and Drug Administration). (2022) *Agricultural biotechnology*. Available at: https://www.fda.gov/food/consumers/agricultural-biotechnology [Accessed 16th January 2023]

Frewer, L., Lassen, J., Kettlitz, B., Scholderer, J., Beekman, V. & Berdal, K.G. (2004) Societal aspects of genetically modified foods. *Food and Chemical Toxicology*, 42(7), 1181–1193.

Friends of the Earth (2021) *Biased from the outset: the EU commission's "working document" on new GM techniques fails to uphold environmental and consumer protection standards*. Friends of the Earth and signatories. Available at https://gmwatch.org/files/Response-to-EU-Commission-on-gene-editing-deregulation-plans.pdf [Accessed 28th April 2022].

Gaskell, G., Allansdottir, A., Allum, N., Castro, P., Esmer, Y., Fischler, C., Jackson, J., Kronberger, N., Hampel, J., Mejlgaard, N., Quintanilha, A., Rammer, A., Revuelta, G., Stares, S., Torgersen, H. & Wager, W. (2011) The 2010 Eurobarometer on the life sciences. *Nature Biotechnology*, 29(2), 113–114.

Gaskell, G., Allum, N., Bauer, M., Durant, J., Allansdottir, A., Bonfadelli, H., Boy, D., de Cheveigné, S., Fjaestad, B., Gutteling, J.M., Hampel, J., Jelsøe, E., Jesuino, J.C., Kohring, M., Kronberger, N., Midden, C., Nielsen, T.H., Przestalski, A., Rusanen, T., Sakellaris, G., Torgersen, H., Twardowski, T. & Wagner, W. (2000) Biotechnology and the European public. *Nature Biotechnology*, 18(9), 935–938.

Geels, F.W., & Smit, W.A. (2000) Lessons from failed technology futures: potholes in the road to the future. In: Brown, N., Rappert, B. & Webster, A. (Eds.) *Contested futures: a sociology of prospective techno-science*. Aldershot: Ashgate Publishing, pp. 129–145.

Gelinsky, E. & Hilbeck, A. (2018) European Court of Justice ruling regarding new genetic engineering methods scientifically justified: a commentary on the biased reporting about the recent ruling. *Environmental Sciences Europe*, 30(1), 52.

Georges, F. & Ray, H. (2017) Genome editing of crops: a renewed opportunity for food security. *GM Crops & Food*, 8(1), 1–12.

Glenna, L.L. & Ransom, E. (2021) Impacts of GE crop technologies on farmers. In: James, H.S. Jr. (Ed.) *Human impact of agriculture*. Northampton, MA: Edward Elgar Publishing, pp. 86–113.

Glenna, L.L., Tooker, J., Welsh, J.R. & Ervin, D. (2015a) Intellectual property, scientific independence, and the efficacy and environmental impacts of genetically engineered crops. *Rural Sociology*, 80(2), 147–172.

Glenna, L., Shortall, S. & Brandl, B. (2015b) Neoliberalism, the university, public goods and agricultural innovation. *Sociologia Ruralis*, 55(4), 438–459.

Glover, D., Venot, J. & Maat, H. (2017) On the movement of agricultural technologies: packaging, unpacking and situated reconfiguration. In: Sumberg, J. (Ed.) *Agronomy for development: the politics of knowledge in agricultural research*., London, UK: Routledge, pp. 14–30.

Goven, J. & Pavone, V. (2014) The bioeconomy as political project: a Polanyian analysis. *Science, Technology, & Human Values*, 40(3), 302–337.

Hanger-Kopp, S., Thaler, T., Seebauer, S., Schinko, T. & Clar, C. (2022) Defining and operationalizing path dependency for the development and monitoring of adaptation pathways. *Global Environmental Change*, 72, 102425.

Helliwell, R., Hartley, S., Pearce, W. & O'Neill, L. (2017) Why are NGOs sceptical of genome editing? NGOs' opposition to agricultural biotechnologies is rooted in scepticism about the framing of problems and solutions, rather than just emotion and dogma. *EMBO Reports*, 18(12), 2090.

Helliwell, R., Hartley, S. & Pearce, W. (2019) NGO perspectives on the social and ethical dimensions of plant genome-editing. *Agriculture and Human Values*, 36(4), 779–791.

Herrero, A., Binimelis, R. & Wickson, F. (2017) Just existing is resisting: the everyday struggle against the expansion of GM crops in Spain. *Sociologia Ruralis*, 57(S1), 859–880.

Herrero, A., Wickson, F. & Binimelis, R. (2016) Seeing GMOs from a systems perspective: the need for comparative cartographies of agri/cultures for sustainability assessment. *Sustainability*, 7, 11321–11344.

Hönig, M., Köpf, A. & Ebner, C. (2022) *Challenges in licensing CRISPR gene editing*. Rentsch Partner. Available at: https://www.rentschpartner.ch/en/blog/blog-posts/1323-challenges-in-licensing-crispr-gene-editing [Accessed 1st November 2022]

Iles, A. & Montenegro de Wit, M. (2015) Sovereignty at what scale? An inquiry into multiple dimensions of food sovereignty. *Globalizations*, 12(4), 481–497.

ISAAA. (2019) *Global status of commercialized biotech/GM crops in 2019. International service for the acquisition of agri-biotech applications*, Brief 55. ISAAA, Ithaca, NY.

Jansen, K. & Gupta, A. (2009) Anticipating the future: 'biotechnology for the poor' as unrealized promise? *Futures*, 41(7), 436–445.

Jasanoff, S. & Kim, S.H. (2009) Containing the atom: sociotechnical imaginaries and nuclear power in the United States and South Korea. *Minerva*, 47(2), 119–146.

Jørgensen, M.S., Jørgensen, U. & Clausen, C. (2009) The social shaping approach to technology foresight. *Futures*, 41(2), 80–86.

Kinchy, A. (2012) *Seeds, science, and struggle*. Cambridge, MA: MIT Press.

Konrad, K. (2006) The social dynamics of expectations: the interaction of collective and actor-specific expectations on electronic commerce and interactive television. *Technology Analysis & Strategic Management*, 18(3–4), 429–444.

Konrad, K. & Alvial Palavicino, C. (2017) Evolving patterns of governance of, and by, expectations: the graphene hype wave. In: Bowman, D., Stokes, E. & Rip, A. (Eds.) *Embedding new technologies into society: a regulatory, ethical, & societal perspective*. Singapore: Pan Standford, pp. 187–217.

Konrad, K. & Böhle, K. (2019) Socio-technical futures and the governance of innovation processes—an introduction to the special issue. *Futures*, 109, 101–107.

Konrad, K., Van Lente, H., Groves, C. & Selin, C. (2016) Performing and governing the future in science and technology. In: Felt, U., Fouche, R., Miller, C. & Smith-Doerr, L. (Eds.) *Handbook of science and technology studies*. Cambridge, MA: MIT Press, pp. 465–493.

Kumlehn, J., Pietralla, J., Hensel, G., Pacher, M. & Puchta, H. (2018) The CRISPR/Cas revolution continues: from efficient gene editing for crop breeding to plant synthetic biology. *Journal of Integrative Plant Biology*, 60(12), 1127–1153.

Lassen, J. (2018) Listened to, but not heard! The failure to represent the public in genetically modified food policies. *Public Understanding of Science*, 27(8), 923–936.

Lassen, J. & Sandøe, P. (2009) GM Plants, farmers and the public—a harmonious relation? *Sociologia Ruralis*, 49(3), 258–272.

Lempiälä, T., Apajalahti, E.-L., Haukkala, T. & Lovio, R. (2019) Socio-cultural framing during the emergence of a technological field: creating cultural resonance for solar technology. *Research Policy*, 48(9), 103830.

Liebman, M. & Schulte, L.A. (2015) Enhancing agroecosystem performance and resilience through increased diversification of landscapes and cropping systems. *Elementa: Science of the Anthropocene*, 3, 41.

Levidow, L. & Boschert, K. (2008) Coexistence or contradiction? GM crops versus alternative agricultures in Europe. *Geoforum*, 39(1), 174–190.

Luna, J.K. (2020) Peasant essentialism in GMO debates: Bt cotton in Burkina Faso. *Journal of Agrarian Change*, 20(4), 579–597.

Macnaghten, P. & Habets, M. (2020) Breaking the impasse: towards a forward-looking governance framework for gene editing with plants. *Plants, People, Planet*, 2(4), 353–365.

Marris, C. & Calvert, J. (2019) Science and technology studies in policy: the UK synthetic biology roadmap. *Science, Technology, & Human Values*, 45(1), 34–61.

McGuire, S.J. (2008) Path-dependency in plant breeding: challenges facing participatory reforms in the Ethiopian Sorghum Improvement Program. *Agricultural Systems*, 96(1), 139–149.

McMichael, P. (2009) A food regime genealogy. *The Journal of Peasant Studies*, 36(1), 139–169.

Michael, M. (2000) Futures of the present: from performativity to prehension. In: Brown, N., Rappert, B. & Webster, A. (Eds.) *Contested futures: a sociology of prospective techno-science*. Aldershot: Ashgate Publishing, pp. 21–39.

Montenegro de Wit, M. (2022) Can agroecology and CRISPR mix? The politics of complementarity and moving toward technology sovereignty. *Agriculture and Human Values*, 39(2), 733–755.

Nawaz, S., Klassen, S. & Lyon, A. (2020) Tensions at the boundary: rearticulating 'organic' plant breeding in the age of gene editing. *Elementa: Science of the Anthropocene*, 8, 34.

Nuffield Council on Bioethics. (2003) The use of genetically modified crops in developing countries: a follow-up discussion paper. Available at: https://www.nuffieldbioethics.org/wp-content/uploads/GM-Crops-Discussion-Paper-2003.pdf [Accessed 1st November 2019]

Parayil, G. (2003) Mapping technological trajectories of the Green Revolution and the Gene Revolution from modernization to globalization. *Research Policy*, 32(6), 971–990.

Pechlaner, G. (2010) The sociology of agriculture in transition: the political economy of agriculture after biotechnology. *The Canadian Journal of Sociology /Cahiers canadiens de sociologie*, 35(2), 243–269.

Pechlaner, G. (2020) Neoliberalization and alternative food movements: Vermont's 'right to know' GMO campaign. *Journal of Rural Studies*, 74, 76–85.

Pechlaner, G. & Otero, G. (2008) The third food regime: neoliberal globalism and agricultural biotechnology in North America. *Sociologia Ruralis*, 48(4), 351–371.

Reilly, K.H., Bennett, E.M., Adamowski, J.F. & Hickey, G.M. (2021) Reducing nutrient loading from agriculture to lake ecosystem—contributions of resilience principles. In: Baird, J. & Plummer, R. (Eds.) *Water resilience: management and governance in times of change*, Cham: Springer International Publishing, pp. 91–111.

Ritchie, J., Lewis, J., McNaughton Nicholls, C. & Ormston, R. (2014) *Qualitative research practice*. London: SAGE Publications.

Rønningen, K., Magnus Fuglestad, E., & Burton, R. (2021) Path dependencies in Norwegian dairy and beef farming communities: Implications for climate mitigation. *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography*, 75(2), 65–78. https://doi.org/10.1080/00291951.2020.1865443

Rostoks, N., Grantiņa-Ieviņa, L., Ieviņa, B., Evelone, V., Valciņa, O., & Aleksejeva, I. (2019) Genetically modified seeds and plant propagating material in Europe: potential routes of entrance and current status. *Heliyon*, 5(2), e01242.

Rotz, S., Duncan, E., Small, M., Botschner, J., Dara, R., Mosby, I., Reed, M. & Fraser, E.D.G. (2019) The politics of digital agricultural technologies: a preliminary review. *Sociologia Ruralis*, 59(2), 203–229.

Schütte, G., Eckerstorfer, M., Rastelli, V., Reichenbecher, W., Restrepo-Vassalli, S., Ruohonen-Lehto, M., Saucy, A.-G.W. & Mertens, M. (2017) Herbicide resistance and biodiversity: agronomic and environmental aspects of genetically modified herbicide-resistant plants. *Environmental Sciences Europe*, 29(1), 5.

Seifert, F. (2009) Consensual NIMBYs, contentious NIABYs: explaining contrasting forms of farmers GMO opposition in Austria and France. *Sociologia Ruralis*, 49(1), 20–40.

Selin, C. (2008) The sociology of the future: tracing stories of technology and time. *Sociology Compass*, 2(6), 1878–1895.

Siebert, R., Herzig, C. & Birringer, M. (2022) Strategic framing of genome editing in agriculture: an analysis of the debate in Germany in the run-up to the European Court of Justice ruling. *Agriculture and Human Values*, 39(2), 617–632.

Silva, V., Mol, H.G.J., Zomer, P., Tienstra, M., Ritsema, C.J. & Geissen, V. (2019) Pesticide residues in European agricultural soils—a hidden reality unfolded. *Science of The Total Environment*, 653, 1532–1545.

Spangler, K., Schumacher, B.L., Bean, B. & Burchfield, E.K. (2022) Path dependencies in US agriculture: regional factors of diversification. *Agriculture, Ecosystems & Environment*, 333, 107957.

Stone, G.D. & Flachs, A. (2018) The ox fall down: path-breaking and technology treadmills in Indian cotton agriculture. *The Journal of Peasant Studies*, 45(7), 1272–1296.

Strand, R., Saltelli, A., Giampietro, M., Rommetveit, K. & Funtowicz, S. (2018) New narratives for innovation. *Journal of Cleaner Production*, 197, 1849–1853.

Tagliabue, G. (2017) The EU legislation on "GMOs" between nonsense and protectionism: an ongoing Schumpeterian chain of public choices. *GM Crops & Food*, 8(1), 57–73.

te Kulve, H., Konrad, K., Alvial Palavicino, C. & Walhout, B. (2013) Context matters: promises and concerns regarding nanotechnologies for water and food applications. *NanoEthics*, 7(1), 17–27.

van Lente, H. (1993). Promising technology: the dynamics of expectations in technological developments. PhD thesis, University of Twente, Enschede.

van Lente, H. & Bakker, S. (2010) Competing expectations: the case of hydrogen storage technologies. *Technology Analysis and Strategic Management*, 22(6), 693–709.

van Merkerk, R.O. & Robinson, D.K.R. (2006) Characterizing the emergence of a technological field: expectations, agendas and networks in Lab-on-a-chip technologies. *Technology Analysis & Strategic Management*, 18(3–4), 411–428.

Vanloqueren, G. & Baret, P. V (2009) How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. *Research Policy*, 38(6), 971–983.

Vicsek, L. (2021) Artificial intelligence and the future of work—lessons from the sociology of expectations. *International Journal of Sociology and Social Policy*, 41(7/8), 842–861.

Vlontzos, G. & Duquenne, M.N. (2016) To eat or not to eat? The case of genetically modified (GM) food. *Nutrition & Food Science*, 46(5), 647–658.

Yamaguchi, T. (2020) Performativity of expectations: the emergence of plant gene editing technologies in Japan. *Elementa: Science of the Anthropocene*, 8(1), 036.

Yanow, D. (2000). *Conducting interpretive policy analysis*. Qualitative Research Methods, vol. 47. Thousand Oaks, CA: Sage University Paper Series.

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