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Constructing legitimacy for technologies developed in response to environmental regulation: the case of ammonia emission-reducing technology for the Flemish intensive livestock industry

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Abstract
This study is focused on unsustainable agri-food systems, especially intensive livestock farming and its resulting environmental harms. Specifically we focus on the development of technologies that seek to mitigate these environmental harms. These technologies are generally developed as incremental innovations in response to government regulation. Critics of these technological solutions allege that these developments legitimate unsustainable food production systems and are incapable of supporting agri-food systems transformation. At the same time, technology developers and other actors seek to present these technologies as the legitimate solution to agri-environmental harms. Our study seeks to explore the perceptions and constructions of legitimacy for technologies that are developed to reduce ammonia emissions in intensive livestock farming in Flanders (Belgium). We use a qualitative case study, employing semi-structured interviews and workshops, with technology developers of ammonia-emission reducing technologies and stakeholders in the intensive livestock farming industry in Flanders. What our study shows is that technologies developed to reduce emissions are dependent on regulative legitimacy. The normative and cognitive legitimacy of these technologies is lacking, both due to ties to the intensive livestock industry and due to uncertainty over the performance of these technologies. With the delegitimation of intensive livestock farming, the legitimacy of these technologies is also under threat. In response, technology developers are looking to (re-)construct this legitimacy through knowledge claims over the performance of their technologies. We show several ways for other actors to deal with this, centred on either re-legitimising technologies to maintain the status quo, or to contest these knowledge claims and use them to disrupt path dependencies.

Keywords Legitimacy · Hegemonies · Emissions · Agri-environment · Technology · Socio-technical regime

Abbreviations

AEA Ammonia-Emissie-Arm (list of ammonia-emission-poor barn systems)
PAS Programmatische Aanpak Stikstof (list of programmatic approach nitrogen)
SME Small and medium-sized enterprises

Introduction

It is commonly known that agriculture, and especially intensive livestock farming, causes a number of environmental harms. These harms include emissions to the air (of ammonia, odour, greenhouse gasses, and particulate matter), as well as the contamination of watersheds with nitrogen, phosphorus, organic matter and faecal microbes (Melse et al. 2009; Tullo et al. 2019).

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Agri-environmental policies have been drafted in response to these environmental harms. In Europe, international protocols and directives alongside national (and regional) regulation are employed in order to meet environmental targets (Cullen et al. 2021; Melse et al. 2009). These policies range from voluntary agri-environmental schemes to mandatory practices that farmers need to comply with. Similar variety exists in how policies address environmental impact, whether through environmental permits, by seeking to change farmer behaviour and farm practices, or by ensuring compliance to minimal environmental standards (Burton and Schwarz 2013; Cullen et al. 2021).

Novel technologies that address and reduce agri-environmental impacts often play a key role in agri-environmental policies. As other authors have pointed out, these technologies generally address agri-environmental impacts without fundamentally altering the agricultural system (Barnes 2016; Firbank 2020). For this reason, several authors have taken to calling these technologies techno-fixes (Mooney 2018; Wojtynia et al. 2021). Governments have a key role in directing the development of these technologies, by setting out the problem–solution space in agri-environmental regulation (Borrás and Edler 2020; Conti et al. 2021; Wojtynia et al. 2021). Other authors have shown that existing socio-technical configurations lend legitimacy to such technological solutions (or techno-fixes) for environmental problems (Montenegro de Wit and Iles 2016; Vanloqueren and Baret 2009).

A major element in legitimising these technological solutions is what (and whose) knowledge is considered legitimate (Montenegro de Wit and Iles 2016). The direction of knowledge production, and the knowledge claims that become accepted, lend legitimacy to certain technologies over others (Vanloqueren and Baret 2009; Wesselink et al. 2013).

As a concept, legitimacy can be understood as the fit of entities (in this case technologies) with existing institutional environments, with existing technologies, regulations, cultures, and knowledges (Binz et al. 2016; Bork et al. 2015; Dehler-Holland et al. 2022; Geels and Verhees 2011; Markard et al. 2016). In technology studies, legitimacy has generally been used to explore how novel technologies become part of existing institutional environments. However, as other have pointed out, it is equally important to understand how existing socio-technical regimes remain legitimate (Frank and Schanz 2022; Geels 2014).

As de Boon et al. (2022) highlight, legitimacy is key in transitioning to sustainable agri-food systems. Unsustainable agri-food systems legitimate technologies that solve agri-environmental impacts, where the connection of these technologies to the socio-technical regime makes it easier to construct technology legitimacy (Mooney 2018). At the same time, these technologies lend legitimacy to unsustainable agri-food systems (Mooney 2018; Wolf and Wood 1997).

In our research, we use these two concepts (legitimacy and knowledge) to understand how technologies become seen as the main solution to agri-environmental issues. In order to study this, we focus on technologies that are developed to reduce ammonia emissions from livestock farms in Flanders (Belgium). These technologies are part of current agri-environmental regulation and are used in order to reduce the emissions of ammonia to the environment. We study the legitimation process of emission-reducing technologies through semi-structured interviews and workshops with technology developers and other stakeholders in the intensive livestock farming industry.

The focus of this research is how regime actors in the intensive livestock industry seek to construct legitimacy for technologies that reduce agri-environmental impacts. This provides a deeper understanding on the stability of existing regimes, and opens up opportunities for disruption of the existing regime. In this, we do however not focus on macro-political forces that keep the regime intact, but on the interactions between actors within the socio-technical regime, and how they employ knowledge claims, construct legitimacy and through this seek to make their technologies the legitimate solution to agri-environmental impacts.

This leads us to a two-fold research question: How is the legitimacy of technologies developed in response to agri-environmental regulation perceived and constructed, and how are knowledge claims involved in the construction of this legitimacy?

This research question allows us to explore both how the legitimacy of these technologies is perceived by other actors and how technology developers construct this legitimacy. We explore this research question throughout our paper, where we first set out the theory behind technology legitimacy and connect this to debates around knowledge and knowledge claims. Following this we set out the case and the methods used to study this topic, which is focused on technology developers who develop ammonia emission-reducing technologies. We use the findings to describe and analyse the case, followed by a discussion and conclusion.

Theoretical framework

To develop the theoretical framework we use legitimacy studies and connect this to the literature on knowledge conflicts and knowledge claims. To recall, we aim to improve the understanding of how technology developers use knowledge claims to construct legitimacy for their technologies. We first engage with the concept of legitimacy, which describes how entities become considered legitimate, something that is essential to the success of an innovation (Bork et al. 2015; Geels and Verhees 2011). In the latter part of this framework we set out the literature on knowledge claims and how this is tied to constructions of technology legitimacy.

Technology legitimacy

Legitimacy as a concept fits within an institutional lens on innovations and technologies. Innovations start out lacking legitimacy, where technology developers have to make these innovations seem legitimate to other actors. Legitimacy can then be conceptualised as the fit of an entity within larger institutional frames and systems, or as Suchman (1995, p. 574) defines it: "a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions."

This means that technologies need an integration with existing institutions and a broader societal embedding for them to become considered legitimate (Geels and Verhees 2011). This can be made concrete by separating legitimacy into different pillars of technology legitimacy (Binz et al. 2016; Suchman 1995). Which pillars are identified, or used to define legitimacy, differs per author. Generally, these tend to coalesce around pragmatic, regulative, normative (or moral), and cultural-cognitive legitimacy, based on the definitions of legitimacy by W. R. Scott (1995) and Suchman (1995). We define the pillars in Table 1, displaying the aspects of legitimacy within these pillars. Important to note is that few authors apply all pillars of legitimacy and that understandings of the different pillars of legitimacy diverge between different authors. Following this, in our article we will focus on regulative, normative and cognitive legitimacy.

A large body of literature on legitimacy has focused on processes of legitimation and de-legitimation, especially considering the sustainable transformation of the energy sector, although several recent articles have also addressed legitimacy in agricultural transitions (de Boon et al. 2022). This provides ties to a more politicised view on legitimacy, where incumbent actors seek to preserve the legitimacy of the existing socio-technical regime while new entrants and new industries are seeking to disrupt the regime and build legitimacy for themselves (Geels 2014; Haas 2020; Novalia et al. 2021). This is an antagonistic view on legitimacy, where legitimacy is gained at the expense of other actors. Through this lens, the struggle for legitimacy is often also a struggle between incumbent actors and new entrants (e.g. developers of new technologies).

This fits with a process-relational view of legitimacy, where we understand legitimacy as constructed by a network of actors. This sees legitimacy as being in flux, in a constant process of legitimation and de-legitimation (Binz et al. 2016; Geels and Verhees 2011; Suddaby et al. 2017). Legitimacy is not a static property but is rather formed as an element of an active and continuous process, where actors can take from a number of strategies in order to increase or reduce the legitimacy of certain technologies (Geels and Verhees 2011; Jansma et al. 2020; Suchman 1995).

Multiple authors have identified various strategies that actors can take in gaining legitimacy. For our analysis, we classify these strategies into three overarching categories, which are (1) conforming to institutions, (2) selecting among environments for the most favourable one, and (3) manipulating or lobbying institutions. This understanding follows common categorisations of legitimation strategies (Van Oers et al. 2018). All three strategies connect to a systemic view of technology acceptance, where legitimacy is constructed within larger socio-technical configurations (Binz et al. 2016; Markard et al. 2016). Practically, technology developers can conform to institutions by making their technology fit with the three aspects of legitimacy that we described in Table 1. They also have the option to find a specific environment or 'niche' where their innovation is considered legitimate, or otherwise try to change existing institutions. In changing institutions, technology developers can lobby for changes to regulation, reframe their technologies or seek to change the perception of their innovations. We summarize these strategies in Table 2, where we also provide some examples of agricultural technologies in terms of the three strategies of legitimation.

Table 1 Aspects of legitimacy

Legitimacy pillar	Motivation	Essential element	Specific to our study
Cultural-Cognitive	Taken-for-granted understanding of technology	The technology operates according to expectations people have of the technology	It is clear which technologies reduce emissions and what reductions these technologies can achieve
Normative	Moral obligations in a given place and culture	The technology fits with existing norms and values in society	Emission-reducing technologies fit with existing norms and values, both in society and among farmers
Regulatory	Existing rules and laws	The technology functions in accordance with government standards and regulations	The technology fits (or is made to fit) with existing agri-environmental regulation and policies

Table 2 Strategies of legitimation

Strategies for legitimation	Examples in agriculture
Conform to institutions	Early-stage biogas plants that fit with farm infrastructures, farming procedures and environmental regulation (Markard et al. 2016)
Select among institutions	Selecting favourable markets or geographic locations (i.e. close to cities for farms that sell directly to consumers) (Van Oers et al. 2018)
Manipulate or lobby institutions	Lobbying governments to change regulation on insect feed (Marberg et al. 2017) or GMO crops (Jansma et al. 2020). Change the public perception of GMO crops (normative & cognitive legitimacy) (Jansma et al. 2020)

This also informs the first set of specific empirical questions in our research, focused on perceptions and constructions of legitimacy. These questions are:

> How are normative, cognitive and regulative legitimacy of technologies developed to reduce ammonia emissions perceived by stakeholders in the intensive livestock industry in Flanders?
>
> What strategies do technology developers employ to construct normative, cognitive and regulative legitimacy for technologies developed to reduce ammonia emissions?

In manipulating and lobbying institutions, knowledge is key. This can be read throughout many of the articles on legitimacy, although relatively few authors make this explicit. Particularly relevant are accounts of how knowledge production and the direction of research can lend legitimacy to some technologies over others (Cashore 2002; Jain and Ahlstrom 2021; Montenegro de Wit and Iles 2016). In understanding this central role of knowledge in legitimacy processes, we move to the literature on knowledge and knowledge claims.

Knowledge claims for legitimacy

Knowledge conflict and the use of knowledge claims are a vital aspect in the construction of legitimacy (Jain and Ahlstrom 2021). Knowledge claims refer to the use of reports and studies in order to prove a new technology to the public and to institutional actors, where different actors set claims over the right kind of epistemology and make claims over what data should be valid in proving the technology (Bergek et al. 2008; Binz et al. 2016; Jain and Ahlstrom 2021).

This connects to the literature on how knowledge is used in governance (Buuren 2009; Lee 2012; Leino and Peltomaa 2012). This is particularly relevant for agri-environmental governance, where uncertainties exist around agri-environmental impacts and where scientific knowledge cannot provide all the answers (Bruce 2013; Thorsøe et al. 2017).

Knowledge claims can be used to both construct or to weaken the legitimacy of technologies (Bergek et al. 2008; Geels and Verhees 2011). This can be recognised when reports are constructed that discuss the potential performance of new technologies, based on expert and scientific knowledge, as Bergek et al. (2008) show. Scientific forms of knowledge, used to develop these reports, already have a certain legitimacy that can be employed in the legitimation of technologies (Bergek et al. 2008; Kraft and Wolf 2018).

Equally, competing knowledge claims can be developed because different actors, including the private industry, societal groups and various experts, can produce and legitimise knowledge claims in order to influence other actors and policy processes (Bergek et al. 2008; Edelenbos 2004). This is a political process, where different actors use knowledge claims to further their interests. These competing claims can be at the level of debating the performance of a new technology, but can also be at a larger scale, as is shown by the use of knowledge on climate change in order to disrupt the fossil-fuel based industry (Ruebottom 2013).

In response to these developments and conflicts over knowledge, authors have generally called for co-production of knowledge, where actors develop knowledge together (Edelenbos et al. 2011; Schut et al. 2014). Equally, in response to conflicts over what knowledge should be used, authors have called for joint fact-finding and collaborative policy processes (Edelenbos 2004). These inclusive and multi-actor processes seek to solve conflicts over knowledge by involving involving local actors, private industries and societal organisations alongside scientists and policy-makers in order to build consensus on how knowledge should be used (Schut et al. 2014).

In turn, these co-productive approaches have been critiqued for not being able to deal with existing power imbalances (Aarts and Leeuwis 2010; Purcell 2009; D. Scott 2021). The main critique is that these approaches provide a way for powerful actors to provide a veneer of legitimacy for their decisions. The co-productive approach is employed to provide legitimacy by having different actors involved, but the status quo is maintained as powerful actors dominate the co-productive process (Purcell 2009; D. Scott 2021). Approaches that contest power relations and hegemonies have been proposed in response (Mouffe 2007; D. Scott 2021). These approaches might also offer a way to disrupt the socio-technical regime by disrupting current institutional structures and by contesting the ideas that help maintain these institutions (Frank and Schanz 2022; Geels and Verhees 2011).

This informs our second set of empirical research questions, focused on knowledge conflict and knowledge claims:

> What knowledge claims are used in constructing legitimacy for ammonia-emission reducing technologies?
>
> How are knowledge claims used to construct legitimacy for ammonia-emission reducing technologies?
>
> What is the link between knowledge claims used to construct legitimacy and the current socio-technical regime of intensive livestock farming?

We will study this social construction of legitimacy using a qualitative case study, involving stakeholders connected to the intensive livestock farming industry and technology developers who develop ammonia-emission reducing technologies. We set out how we developed and analysed this case study in the methods section below.

Methods

To address the research question, we study technologies that are developed for the intensive livestock farming industry in Flanders, specifically for pig and dairy farms. The focus of this case study are the technologies that are developed to reduce ammonia emissions, one of the environmental harms produced by intensive livestock farming. In this section, we illustrate the case and then describe the methods used to analyse the case.

Case study background

Similar to other places, livestock farms in Flanders (the northern part of Belgium) are increasing in scale while decreasing in number (Departement Landbouw and Visserij 2019a, b). In general, livestock farming in Flanders follows an intensive model, where livestock populations are disconnected from available land, creating a dependency on imported feed and the export of manure.

The typical livestock farm in Flanders is specialised, raising a single type of livestock. The average number of livestock per farm remains relatively low (at around 1500 pigs or 59 dairy cows respectively) (Departement Landbouw and Visserij 2019a, b). A second characteristic that typifies the Flemish livestock industry is the proximity of farms to natural areas and nature reserves, as well as to (sub-) urban populations. This is particularly striking in Flanders because of high spatial fragmentation combined with high population densities (488 inh./km^2) (Poelmans and Van Rompaey 2009). This brings intensive livestock farming in conflict with other societal actors and necessitates interventions to reduce environmental impacts (of odour, particulate matter, and ammonia).

Flanders, as a region in Belgium, has legislative powers over agriculture and sets its agricultural policies following European regulation. Ammonia emissions are one of the driving elements in regulation for livestock farming in Flanders and are addressed through successive EU protocols and directives (Melse et al. 2009; Tullo et al. 2019). Technologies are seen as the main solution in order to reduce emissions in both international and Flemish policies. This can be recognised in lists that set out government-approved technologies for reducing emissions (Jacobsen et al. 2019; Kros et al. 2013; Van der Heyden et al. 2015).

Two lists in Flanders set out the technologies that are approved for reducing ammonia emissions. The first list, the AEA-list (freely translated to: list of ammonia-emission-poor barn systems) was developed in 2004 and slowly expanded over the years with several additional technologies. This list sets out a range of technologies that apply to pig and poultry farming. Later, a second list, the PAS-list (programmatic-approach-nitrogen) was developed that applies to all livestock animals and contains a wider range of interventions that farmers can use to reduce ammonia emissions. These lists set out which technologies farmers can use to reduce emissions, the level of emission reduction that these technologies can achieve, and lastly, how these technologies should be used by farmers.

The lists are tied to the environmental permits of intensive livestock farms. When permits are renewed, farmers are generally obliged to install a technology from the government-approved lists. The government develops the lists in consultation with scientists. The role of scientists is to determine whether a technology reduces emissions and the reduction percentage that can be achieved.

Technologies that have a place on either of the two lists are developed by a range of companies and have diverse mechanisms for reducing emissions of ammonia on livestock farms. This starts with feed technologies that improve nutrient uptake and that reduce the amount of ammonia that can be formed in manure (Bruce, 2013; Melse et al. 2009). A second set of technologies are focused on preventing the formation of ammonia in manure. A third option is to prevent the emission of ammonia to the outside air, either by trapping manure gasses or by using air scrubbers to filter the outgoing air in the livestock shed (Van der Heyden et al. 2015).

Technology developers who develop these technologies are often specialized in the agricultural sector and work for small to medium-sized enterprises (SMEs). Feed technologies are an exception, where technology developers mainly

Table 3 Overview of participants

Type of data gathering	
Semi-structured interviews	15 Interviews 8 Technology developers (5 SMEs, 3 Multinational) 2 Respondents from agricultural unions 2 Researchers 1 Respondent from a research farm 1 Innovation advisor 1 Policy advisor
Workshops	21 Additional stakeholders 8 Researchers, studying ammonia emissions 5 Advisors on agri-environmental permits 5 Respondents from research farms 1 Respondent from an agricultural union 1 Technology developer 1 Farmer

work for larger multinational companies. Both groups of companies were included in this research, alongside other stakeholders (researchers, agricultural unions, permit-bureaus, and government advisors). To develop the case and to study the research question we opted for a qualitative case study following the methods described below.

Data collection and analysis

To study our case, we used a purposive sampling strategy combined with snowball sampling to select respondents for this research. We opted for this approach because there are a limited number of technology developers active in the field of ammonia emissions in Flanders and several key respondents were already known to the researcher. As a group, technology developers were male, ages between 30 and 60, working for both SMEs and multinational companies. The respondents were selected by the companies developing these technologies, leading to interviews with engineers developing these technologies, owners of SMEs, and managers of innovation processes at feed companies. Companies involved in the research were (1) barn construction companies (SMEs) that develop floor systems to reduce emissions, (2) companies that develop air scrubbers (SMEs) and (3) feed companies (multinationals) developing low-protein feeds and feed additives.

Additionally, a diverse group of stakeholders were interviewed on how they perceived the legitimacy of emission-reducing technologies. This group of stakeholders was balanced in gender, roughly varying in age from 25 to 50 and consisted of researchers, agricultural unions, permit-bureaus, and advisors. All participants of this research have ties to the intensive livestock sector in Flanders. Technology developers and stakeholders generally know of each other through existing organisations and collaborations. These relations vary, and are generally one-on-one, where some technology developers work together on the development of a new technology or where a technology developer has contacts with researchers or advisors.

Participants of our research were interviewed using semi-structured interview guides (provided in Online Resource 1). We used specific interview guides for the technology developers (asking about the development of the technology) and for the other stakeholders (asking about their views on emissions, the technologies and technology development). Interviews lasted 30 to 90 min. Additionally, we held two workshops with a diverse group of stakeholders. These workshops were part of a larger research project about the future of agriculture and ammonia emissions. The structure of these workshops is presented in Online Resource 2. The workshops were focused on the role of technology in ammonia emission reduction and allowed the participants to interact and discuss both the role of technology, the development of these technologies and how they saw the future of technologies in ammonia emission reduction.

In total 15 people were interviewed and 21 additional stakeholders were involved in the workshops (for a total of 36 participants). Most of the respondents that were interviewed also took part in the workshops. An overview of the respondents is provided in Table 3 below. Audio recordings from the workshops and the interviews were transcribed using a clean verbatim style in NVIVO 12. Transcription and data analysis was done in the native language (Dutch). Quotes used in the article are translated from Dutch by the first author.

In data analysis our goal was to strive for consistency between the data and the results, rather than working towards a single objectivist account (Creswell 2007, p. 203). Our position is that knowledge is socially constructed, that multiple interpretations are possible and that interpretations are always temporal, located and open to re-interpretation (Creswell 2007, p. 203; Merriam 2009, p. 222). The goal of our analysis is to provide an account that is consistent between data and the results, where different methods can be used in order to show the validity of these results. In our research we sought to provide this validity both through a thick description of the data and by data triangulation (by involving both a diversity of stakeholders alongside the technology developers and by using workshops so respondents could interact and respond to each other's statements) (Creswell 2007, pp. 207–209).

The interpretation of the data followed principles outlined by Creswell (2007, pp. 150–155) and Merriam (2009, pp. 182–186, 203–206), starting with a broad categorisation of the data and working towards a more fine-grained analysis.

We started analysis during data collection by broadly categorising the incoming data using inductive coding (Skjott Linneberg and Korsgaard 2019). Following Creswell (2007, p. 152) we linked these codes to text segments, focused on 'lean coding' to end up with a limited first set of codes (25 codes in this case) which were aggregated in 4 broader categories, as shown in Online Resource 3. After discussing key themes that emerged through this categorisation, we decided to approach the data with a technology legitimacy lens, linked to issues around knowledge and knowledge claims, as presented in the theoretical framework. Based on this framework, a new set of codes was developed for deductive coding. This set of codes is also provided in Online Resource 3, including references to where codes originated in the literature. We used this categorisation in order to describe and interpret the case. Combining the inductive and deductive steps of coding allowed us to remain open to the reality of our respondents while still connecting this to existing theory and academic debates.

Findings

We structure our findings in three parts. In the first section we discuss how emission-reducing technologies are perceived (both by the stakeholders involved in this research and in wider society). In the second part of the results we discuss how regulative legitimacy is the main focus for technology developers and how this affects technology development. Lastly, we discuss how technology developers seek to construct regulative legitimacy through knowledge claims.

Perceptions of legitimacy

As we showed in the theoretical framework, there are several types of legitimacy: normative, cognitive and regulative legitimacy. We show how stakeholders perceive the emission-reducing technologies through these three types of legitimacy, starting with normative legitimacy and then discussing cognitive and regulative legitimacy in turn. At the end of the section, we use Table 4 to summarise our findings.

An interesting finding on perceived legitimacy is that the group of stakeholders were themselves generally supportive of the intensive livestock industry. Stakeholders emphasised in both the workshops and the interviews that technologies were essential to ammonia emission reduction. Technical innovations were seen as the main answer to ammonia emissions, as the quote below also shows. Two advisors discuss (AD1 & AD2):

> "AD1: Well, we need better policy, but we also should have research that helps us towards new innovations and insights [in emissions].
> AD2: Hm, for new technologies
> AD1: Yes, that is what we do hope for."

This is linked to the view that if technology is not sufficient, the only other option is to reduce the amount of animals in intensive livestock farming, completely changing current systems of livestock farming. During the second workshop, several of the respondents (two advisors (AD1, AD2), a researcher (R1) and a farmer F1) discussed this. This was after they were asked to sketch out a negative scenario for ammonia emission reduction:

> "AD1: The most negative scenario is that a reduction of livestock is the only way to reduce emissions. […] That technology is insufficient.
> R1: Or if it is unaffordable
> AD2: Or not suitable to farmers
> F1: If it is not economical, if your energy bill increases
> AD1: Yes, that it's cheaper to reduce animals rather than to invest in technologies [to reduce emissions]"

These two discussions show the view on emission-reducing technologies by stakeholders. They see it as the only real solution to ammonia emissions. Within this group, of stakeholders connected to intensive livestock farming, these technologies are seen as the legitimate (and only) solution to ammonia emission reductions.

There are concerns however, both among stakeholders and technology developers. They feel threatened by recent developments, both in broader society and in government, where they feel that the view on intensive livestock farming and emission-reducing technologies has shifted. The legitimacy is under threat from outside, as an advisor explains during the second workshop:

> "Well, you can have a technological innovation for farms that makes them even more industrial. But that might still not make those farms justified. Well, maybe that's not the right word, but if they are not accepted [in society], then you also have a problem right?"

Related to this topic, at the first workshop a discussion took place between a technology developer (TD) and an advisor (AD) where they highlight the difficulties in addressing societal concerns on livestock farming:

> "TD: I also want to return to animal welfare. And I ask you how that impacts ammonia emissions? […]
> AD: Well, there is no clear answer to that, is there?
> TD: Well for sure it will get worse [i.e. more emissions]. We have measurements showing it.
> AD: Well, that is the difficulty right? Similar to organic farming and emissions. The more space and animal welfare you give, the worse your [ammonia] emissions become. But you have to find the middle ground somehow."

Table 4 Discussions on the legitimacy of emission-reducing technologies

Form of legitimacy	As shown in the results
Cognitive	Centres on the uncertainty around emissions. Due to the variability of emissions it is difficult to provide an exact number for the emission reduction that a technology can achieve
Normative	Perceived risks in normative legitimacy because of societal perceptions of intensive agriculture, sustainable farming, and animal welfare. Technologies fit intensive farming practices and can increase resource use
Regulative	A key issue because government approval and environmental permits are essential to technology adoption. Technology developers seek to claim government approval and focus on constructing this form of legitimacy

These developments are seen as a threat to the legitimacy of emission-reducing technologies. It is a broader process of delegitimation of intensive livestock farming and emission-reducing technologies. Normative legitimacy is under threat, as these technologies are tied to intensive livestock farming industries that have come under scrutiny. Equally, the trade-offs between forms of sustainability is a risk and make it difficult to keep the technologies seen as legitimate. This is recognized by the technology developers, as one of them describes below in relation to air scrubbers (a technology he himself did not develop):

> "Well, I note that those things use a lot of water, a lot of energy, and electricity. And well, with water, we have had three years of dry summers. Water should be used for drinking and not for an air scrubber. That is not a sustainable solution. You don't improve animal welfare, don't improve the conditions in the shed, it's only good for some forest and the neighbours but other than that nobody has a use for it. [for the emission reduction, and the air scrubbers]"

The quote above touches on normative legitimacy, but with ties to cognitive legitimacy. Normative, as the respondents seek to articulate what should be a good and sustainable technology. Cognitive, as this is an argument over what emission-reducing technologies are, and what they do, especially when it concerns the impact on forests and neighbours (who would stand to benefit from reduced emissions). These contestations show doubt over what the technology

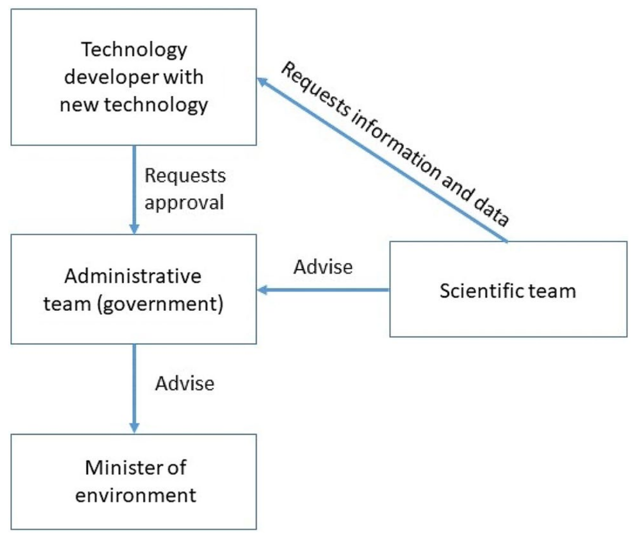

Fig. 2 schematic overview of the approval process of emission-reducing technologies (Vlaamse Landmaatschappij 2021)

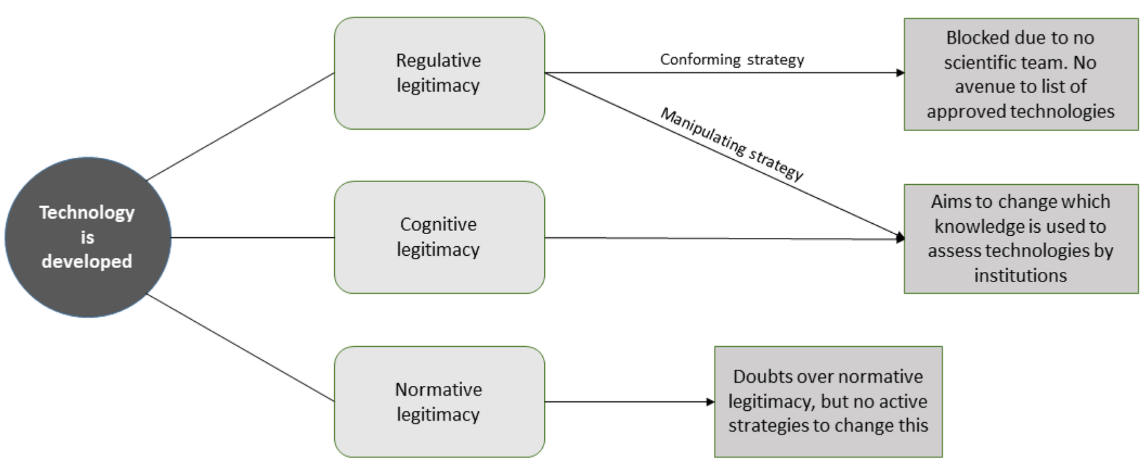

Fig. 1 Strategies utilised to construct legitimacy for emission-reducing technologies

is and does, linking perceptions of cognitive and normative legitimacy.

Summarising the perceptions on legitimacy, respondents in this research are worried that emission-reducing technologies are becoming delegitimised. There are threats to legitimacy, even though they themselves see these technologies as the main solution. Despite these threats, technology developers did not see these developments as a key issue but were more concerned with regulative legitimacy. The reason for this concern was given by a respondent working at a research farm, who described the reality of how these technologies are adopted on farms:

> "A farmer wants to farm, and the whole thing about emissions is a necessary evil, so to speak. So they do it because they have to, and because they need it for a permit. But well, I would not say that they care whether it works or not, as long as the government accepts it."

The response from technology developers is relatively straightforward. As long as ammonia emissions are an issue, and as long as intensive livestock farming exists, their technologies are the solution for governments seeking to reduce emissions. Adoption of the technology is a pragmatic choice of farmers, as they adopt these technologies not because they are seen as normatively or cognitively legitimate, but rather because it is the only way to gain an environmental permit from the government. Such 'forced technology use' is intimately linked to regulative legitimacy, as environmental permits and government regulation necessitate the use of these technologies. Regulatory frameworks become the main driver for technology developers in constructing legitimacy for their technologies, something we further explore in the next section. An overview of the findings on how legitimacy is perceived is also provided in Table 4.

Constructing regulative legitimacy

We start our discussion of regulative legitimacy with a short quote from an advisor, who describes what is needed in order to sell an innovation for emission reduction:

> "Here in Flanders, if you want to implement something or sell something [to reduce ammonia emissions], well you will need to get it on the PAS-list. And then you have to show reports of measurements and a whole number of things to prove it"

Government approval (and the connected regulative legitimacy) is essential. Our data shows that technology developers can take from two approaches in the construction of regulative legitimacy, which we have illustrated in Fig. 1 below. A first, seemingly simple option, which we will describe here, is to conform to regulation and to get a technology on the list of approved technologies. This has happened in the past, but is no longer possible for reasons we outline below. A second option, which we will discuss in the last part of the results, is a manipulating, or lobbying strategy where the role of knowledge claims becomes important. We first discuss the conforming strategy.

Most technology developers interviewed for this research had technologies on the government-approved list and had thus at some point used a conforming strategy in order to construct regulative legitimacy. One technology developer describes how this process worked:

> "Yes, we were worried that we had to do a full report where we measured emissions for a full year, and we were worried because of the cost of it all. And what if you get a disappointing result [i.e. a low reduction of emissions]? But luckily we could also get it approved with a model, based on literature and studies, with documentation from other partners that were involved in this project"

This quote highlights one of the paths (using a simulation model) for approval to the list. This approval process, as highlighted in Fig. 2, depends on a government team and a scientific team who determine how effective a new technology is in reducing emissions, and whether a technology is effective at all. The scientific team uses expert judgements based on existing knowledge and literature, as well as simulation models. If this is insufficient, they can also request additional measurements on the performance of a new technology. Following this, the scientific team advises the administrative team on whether to approve the technologies, who in turn advise the minister of the environment to approve the technology to the list. However, as one technology developer will describe below, this approval process is no longer functional:

> Very recently I contacted them because I wanted to discuss the possibility of adding some new technologies to the list. But apparently, that is no longer possible because there is no scientific team anymore. […] So they [the government] ask us to develop new technologies, but at the same time it's not actually possible [to have them approved].

As technology developers indicate, the scientific team has been disbanded. This makes it impossible to follow a conforming strategy. A lack of information on the underlying reasons for disbanding the scientific team caused frustration among the technology developers as it makes the conforming strategy impossible. One developer indicates below:

> "But nowadays that doesn't work. There is no scientific team, there is no… Well, as if you enter the court and there is no judge, that is the current situation. And that's been for two years, right? So… yeah. As long as there is no stability, as long as there is no workable framework? […] We first need that, and only then can we go back to innovating. But for now, you can't do anything."

As the quote above indicates, this has impacted the development of new technologies. Most technology developers were holding back on developing new technologies. They also changed their approach to constructing regulative legitimacy, where they changed from a conforming approach to a more combative manipulative (or lobbying) approach, as indicated by one technology developer when discussing what action he was taking now that the conforming strategy was no longer feasible:

> Well, I have nothing against them [against the scientists who used to be involved in approving technologies], but I will start to take action. […] I am also in contact with politicians

The manipulating strategy for constructing regulative legitimacy contrasts with the conforming strategy. In the conforming strategy, there was an avenue for the knowledge of technology developers to be used in constructing regulative legitimacy, by developing a dossier and handing this over to the government. In a manipulating strategy, knowledge is used in a more confrontational way, and claims over knowledge structure the strategy. It is this strategy that forms the next part of this article: the knowledge claims of technology developers and how they mobilise these in constructing regulative legitimacy.

Knowledge claims in constructing legitimacy

We now turn to how technology developers seek to manipulate institutions to construct regulative legitimacy. We do this by analysing how knowledge claims are used in the construction of cognitive and regulative legitimacy. As we showed at the start of the results, there is tension about the cognitive legitimacy of emission-reducing technologies. This tension is connected to the construction of regulative legitimacy, where lists of technologies show the performance of each technology. As the quote below shows, technology developers dispute this listed performance and doubt the knowledge behind the formation of the government-approved list.

> And every technology is classified at 25% reduction. You must have noticed that in the list, for all those systems, all floor systems have the same classification of 25% reduction. And I have my doubts about that

An essential element of the manipulating strategy is that scientific knowledge on ammonia emissions is somewhat uncertain. At the same time, the administrative and scientific team (see Fig. 2) use average and predetermined values for approving technologies for ammonia emission reduction. This creates a tension between understandings of the scientific knowledge. Researchers themselves do not always fully agree with how government departments use their knowledge in order to approve the technologies. This tension is best shown by a conversation between a policy advisor (PA) and a researcher (R) at one of the workshops.

> "PA: Yes, that is the issue of scientific research, which has partially caused that for regulation we are now calculating it [ammonia emissions] to the letter.
> R: No, that is an interpretation of scientific research, an interpretation of the data. We provide data with the caveat: "well, it's not accurate to the dot". But they do use it like that. That is frustrating."

This comment highlights broader issues around environmental knowledge and the use of this knowledge. Important to take into account is the complexity of accurately measuring the performance of technologies that reduce livestock emissions, something that the researcher alludes to in the quote above. Emissions can show high variability between different farms, between different livestock sheds, and also between different breeds of livestock. Equally, emissions vary with the weather, with wind and temperature changes impacting emissions. This has been balanced with average values in the past, upon which government regulation is based. However, due to the variable nature of emissions, the accuracy of these average values and their use in approving technologies can be called into question by technology developers.

This is especially relevant because the emission reduction that a technology can reach is essential to the construction of regulative legitimacy for new technologies. As one of the respondents from a feed company describes:

> "Because of regulation you have to take measures that reduce emissions with 50%, and that is very difficult to reach with feed. And the effect is that as far I know, no pig farmers are seeking to reduce emissions through feed management. There are known techniques to do so, but nobody uses them. […] And to a large extent it all depends on regulation. If they tighten the regulation further, well then you have no choice but to reduce emissions through air scrubbers. "

This shows the value of emission-reduction percentages that are assigned to technologies. A higher reduction percentage (as listed on the government-approved list) will mean that more farmers will use the technology. Conversely, feed technologies were not being used to reduce emissions, as the listed reductions in emissions were not sufficient. Technology developers make knowledge claims about the performance of their emission-reducing technologies in order to construct this regulative legitimacy.

The arguments of technology developers are informed by their own knowledge. The knowledge production of technology developers generally involves experimental set-ups on farms, experiments at research farms and universities, as well as literature studies and the modelling of emissions. Elements of this knowledge production were also essential in the conforming strategy as described above, when technology developers had to collect this information to prove their technology to the scientific team (Fig. 2). One of the developers describes their knowledge by discussing an experiment they did together with a university:

> "We also noticed when we worked together with [a university]. So we had three set-ups, two with our test and one as a control. […] And we saw that we had 30 kilos of emissions from the control and the two tests had emissions of 6 and 11 [kilos]. Identical departments. So I asked the researchers, "how is that possible, they should be identical right?" And they said it was probably some other effects. So I told them, "well that's fun for your research right?" If you have an outside effect of factor two."

While describing how technology developers produce knowledge, this quote also shows some of the disillusionment of technology developers in scientific forms of knowledge production. This forms a basis for contesting the emission values as they are accepted by the government, as another innovator does in the following quote:

> "And in emissions, so emissions in agriculture, especially in intensive livestock farming, there are no secrets for us. It is clear as day. We know perfectly well what leaves the barn and we know perfectly well how much a chick, a sow, or a cow, how much ammonia they produce. We know what it is like in practice. And based on those values […], we have had to deviate from the values as they are assumed by the government."

Disagreeing with the knowledge as it is accepted by the government, technology developers seek to contest the government's use of knowledge and wish to have their knowledge taken into account as well. What knowledge is used is essential both to understand the performance of their technology (cognitive legitimacy) but also for governments to approve technologies (regulative legitimacy). Technology developers are however so far unsuccessful in having their knowledge recognised by the government.

In turn, technology developers seek to manipulate institutions, to change the procedures that are in place to approve technologies. Technology developers were focused on getting procedures in place that can take into account the variability of emissions, something that they have experienced in developing their technologies. This is illustrated by one of the technology developers who describes how he is seeking to change this:

> "Because what I do not understand, and what I would like to ask those people, also the politicians, because I also concern myself with politicians: how can you say, 'we do not approve the current measuring protocol' if you have no alternative? […] I find that much less scientific than approving a technology based on measurements, even if you can debate the findings, but it's the best we have".

This formed the main push of this lobby, where technology developers had approached politicians and scientists to convince them of changing the procedures for approving technologies. This lobby has not been successful so far. It remains to be seen whether technology developers will be successful in convincing the government to include their knowledge alongside the scientific knowledge in making decisions and in approving technologies. Recent news articles also indicate that several technology developers are now seeking publicity for their need to have new government procedures in place (Vilt VZW 2022a, 2022b).

Discussions about what knowledge is legitimate, and which forms of knowledge production should be considered by the government remain important. In constructing technology legitimacy, there is a claim for knowledge legitimacy. The knowledge of technology developers is currently not seen as legitimate and as it turns out this creates difficulties in constructing regulative legitimacy. In response, they seek avenues for constructing regulative legitimacy by contesting the legitimacy of the 'official' knowledge and comparing it to their forms of knowledge. This leads to technology developers lobbying for procedures that consider their knowledge.

Discussion

We return to the twofold research question posed at the end of the introduction. First, how is the legitimacy of technologies developed in response to agri-environmental regulation perceived and constructed? Second, what is the role of knowledge claims in the construction of this legitimacy? We studied this by taking the position of the technology developers themselves, but further studies could aim to bring in government actors and scientists as well.

Throughout this discussion, we will highlight the struggle for technology legitimacy, and how this links to a broader struggle on the legitimacy of intensive livestock farming. We also highlight the struggle for technology legitimacy as a potential space to disrupt path dependencies and to work towards novel co-productive approaches in technology development.

Perceptions of legitimacy

An interesting aspect of the legitimacy of emission-reducing technologies stems from the fact that technology developers and stakeholders were both connected (in some way) to intensive livestock farming. The data shows that respondents believed that technologies were the main solution to ammonia emission reduction. This can be linked to broader understandings of legitimacy, where the legitimacy of a technology ensures that it becomes seen as the only solution (Genus et al. 2021).

This is however only an element in a broader process. Respondents acknowledged a relative lack of normative and cognitive forms of legitimacy in broader society. Emission-reducing technologies are tied to the intensification of livestock farming at a time when livestock farming itself is suffering from a legitimacy crisis (Caffyn 2021; van Wessel, 2018). Respondents recognise a delegitimation of the technology in connection to this, as society and governments are putting pressure on the status quo of livestock farming. This further highlights how technology and the broader socio-technical regime are intertwined, where a delegitimation of the regime is putting pressure on the legitimacy of the technology (Markard et al. 2016). It also adds some nuance to how technologies tied to the dominant socio-technical regime become legitimate, as the processes in our research shows the continuous struggle to construct and preserve this legitimacy.

While this delegitimation is a concern to technology developers, they did not describe strategies to improve normative legitimacy, and they focused on cognitive legitimacy only to gain regulative legitimacy. As we described, the Flemish government, through regulation, sets limits to the expansion of livestock farms but does allow farmers to expand their farms when they adopt these emission-reducing technologies. This creates an environment where technology developers seek to construct technology legitimacy towards regulators rather than to broader society and to farmers, as farmers only adopt these technologies because they 'have to'. (Klerkx et al. 2006; Leeuwis 2003). As we described, adoption is driven by the achieved reduction of emissions rather than by other parameters. The government and scientific teams determine this reduction.

Technology developers thus seek to claim this legitimacy from the government, where they employ two main strategies. These are a conforming strategy, where technology developers conform to existing institutions, and a manipulating strategy, recognised through the knowledge claims made by technology developers. These strategies can be recognised in other legitimacy studies, where authors describe that strategies generally either fall into conforming, selecting, or manipulating strategies towards existing institutions (Binz et al. 2016; Markard et al. 2016; Van Oers et al. 2018). We did not find a selecting strategy in this research but will discuss the conforming and manipulating strategy in the next sections. We follow this with a discussion of other potential strategies in (de-)legitimation of emission-reducing technologies.

Conforming to institutions for legitimacy

To choose a conforming strategy is to construct legitimacy by aligning with the broader intensive livestock farming sector. As other authors have described, these technologies are legitimated by the current farming system and also legitimate this type of farming (Wolf and Wood 1997). This links to an analysis of how legitimacy is part of hegemonic structures, where legitimacy and power are co-constitutive (Mouffe 2007). Existing institutional structures, at the government level and through the intensive livestock industry benefitted technology developers, whose technologies in turn provided legitimacy to the intensive livestock industry (Markard et al. 2016).

The role of the government is interesting in this respect, as the legitimacy of emission-reducing technologies has been supported by government policies and regulation. The importance of government regulation for technologies addressing agri-environmental impacts can be recognised in the broader literature (Borrás and Edler 2020; Klerkx and Begemann 2020; Wojtynia et al. 2021). The government forms an element in the broader power structure that supports the need for emission-reducing technologies. In a conforming strategy, technology developers seek to align, and conform to these institutions in order to construct legitimacy for new technologies.

However, the government processes for approving emission-reducing technologies have stalled, as is illustrated by the lack of a scientific team and the disruption of the conforming strategy. The effect of this development is striking, and shows vulnerability of the current socio-technical regime, where technology development has halted after the conforming strategy was disrupted. This creates perspective to strategies that seek to disrupt path dependencies, as it shows the sometimes limited effort needed to disrupt existing technological developments (Conti et al. 2021).

The lack of new technology development is however also due to a lack of other forms of legitimacy. Normative and cognitive legitimacy were not a major concern to technology developers, but this also means that there is no adoption of their technologies in the absence of regulative legitimacy. This has implications for the promotion and induction of technological change by governments, and for technologies that promise to reduce environmental impacts. Techno-fixes that are developed purely to comply with regulation are only adopted when regulation also ensures this adoption.

The solution for technology developers in this situation is to (re-)construct legitimacy for their technologies. As we saw in the results, they are using a lobbying strategy in order to construct legitimacy. In the next part of the discussion, we will discuss this strategy and highlight several other strategies that can be employed by various actors in the (de-) legitimation of emission-reducing technologies.

(De-)constructing technology legitimacy

In our research, we see that in absence of regulative legitimacy, technology developers are mainly focused on constructing technology legitimacy through knowledge conflict and knowledge claims. The main goal of these strategies is focused on re-instating government procedures for approving technologies which would make the conforming strategy possible once again. A second goal of this strategy is to have their technologies classified with a higher performance than they currently have. This highlights the strategies that actors utilise in legitimation processes and links these processes to the broader literature on knowledge conflicts (Leino and Peltomaa, 2012; Markard et al. 2016).

These strategies can be linked to the discussions in the previous section. Technology developers are longing back for the time when the socio-technical regime enabled a conforming strategy and provided their technologies legitimacy. Their strategies are so far unsuccessful, leading us to propose several other solutions to the construction of legitimacy for emission-reducing technologies. This ranges from methods to construct legitimacy to more transformative approaches that can de-legitimise these technologies and help disrupt the current socio-technical regime.

Other authors have proposed knowledge co-production in dealing with knowledge claims (Edelenbos et al. 2011; Wesselink et al. 2013). Knowledge co-production is helpful in dealing with the uncertain nature of knowledge in environmental governance, as it allows for the various parties who make knowledge claims to come together and build consensus (Edelenbos et al. 2011; Lee 2012; Thorsøe et al. 2017). A range of authors have described how these approaches may be used to legitimise both governance decisions and innovations to broader society (Eshuis and Stuiver 2005; Leino and Peltomaa 2012; Runhaar 2017; Singh et al. 2021; Thorsøe et al. 2017).

Generally, the goal of these approaches is to seek consensus between different knowledge claims and to work towards a shared truth. This process would help construct legitimacy for the claims of technology developers, as it acknowledges the legitimacy of their knowledge claims and allows them to seek consensus with researchers and government agencies over how to deal with these knowledge claims. The downside of this approach is however that it does not critically interrogate issues of power in the legitimation process and in knowledge conflicts. This is especially true for those actors seeking to disrupt existing regimes and work towards the sustainable transformation of agriculture. Following D. Scott (2021) and Mouffe (2007) we propose to use agonistic pluralism in order to (re-)politicise discussions on technology and innovation processes.

Agonistic pluralism tackles several weaknesses in typical co-productive approaches, taking an approach that highlights dissent over consensus and that stresses the role of power in dealing with knowledge claims. This perspective is especially relevant to our case, where a large group of actors are connected to intensive livestock farming. These actors see technologies as the solution to deal with the legitimacy crisis of intensive livestock farming, while there is a broader societal and political move away from intensive livestock farming. If co-productive approaches are too limited (not involving a plurality of voices), there is a strong risk that these approaches end up legitimising the status quo.

Agonistic pluralism seeks to highlight conflict between groups of actors, where conflicting power relations (and desired power relations) are essential. In relation to our research, that would mean highlighting the different knowledge claims. Rather than seeking consensus between the parties involved (technology developers, scientists and governments) it would keep these conflicts alive and involve additional actors who have a stake in the game. This broadening of actors can include both human actors who are impacted by emissions and the intensive livestock industry (e.g. rural people, farmers, nature conservationists) but on a more radical and disruptive path can also include non-human actors (e.g. nature reserves, non-human animals including both wildlife and livestock) (Szymanski et al. 2021; Tschersich and Kok 2022). These approaches are becoming more common in innovation studies, and fit with a broader call for multi-species justice in technology development (Tschersich and Kok 2022). This would tie conflicts over knowledge to broader political visions for the future, where knowledge claims are part of these politicised debates. This creates the struggle necessary to envision different agri-food systems and to break the legitimacy of current farming systems.

Limitations and further research

In our research, we were limited to the perspectives of technology developers and other stakeholders in the livestock farming sector. Despite several attempts, government agencies involved in approving the technologies did not wish to be involved in this research. Future studies on this topic could seek a broader perspective, including government actors and possibly other societal actors. Especially the formation of government-approved lists of technologies might form an interesting avenue for future research.

More research is needed to understand how these findings translate to other domains. Ammonia emissions are a core focus in Flemish agri-environmental policy, influencing the legitimation processes, as more actors are involved and the stakes are higher than for other agri-environmental domains. Whether similar dynamics play out in other, less contested domains remains to be seen. Further research might test whether this also plays out in issues such as eutrophication or water usage of agriculture, where technologies are promised to solve these issues so that we would not have to radically transform our food system (Kaspersen et al. 2016; Pérez-Blanco et al. 2020).

It might also be interesting to reflect upon this in relation to pesticides and pesticide approval, where similar knowledge conflicts in the face of regime destabilisation take place (Frank and Schanz 2022). Especially the ongoing battle over neonicotinoids is interesting in this aspect, where knowledge conflicts play a central role in whether these pesticides can be approved for use in the EU (Bozzini and Stokes 2018).

Further research is also needed on approaches that can deal with the legitimacy issue of ammonia-emission reducing technologies. We have described two possible approaches, but further research could identify additional ways to construct or deconstruct this legitimacy. Pathways for legitimacy that are less dependent on the government could be beneficial to technology developers. This could be a transfer of responsibility over approval to the industry, reducing the difficulties of gaining approval at the risk of regulatory capture (Saltelli et al. 2022).

Though this was not part of this research, increasingly venture capital in agriculture is also making sustainability claims (see e.g. Broad 2020; Clapp and Ruder 2020), discursively constructed through imaginaries to attract investment (Biltekoff and Guthman 2022; Fairbairn et al. 2022), and it would be interesting to further study whether these claims can serve to legitimise technologies such as the ones studied here. Whether this is desirable to farmers or for sustainability transitions in agriculture is doubtful, as other authors have earlier shown the major downsides of having venture capital involved in agri-environmental issues (Leach et al. 2012).

Conclusion

We started this article by asking how technologies that reduce agri-environmental impacts become seen as legitimate solutions to agri-environmental harms. We asked the question of how technology developers construct legitimacy for technologies that are developed to reduce agri-environmental impacts and sought to understand the role of knowledge claims in this process.

Our account adds some nuance to the belief that technologies developed to reduce agri-environmental impacts gain legitimacy just because they fit within the dominant socio-technical regime. It shows the struggles in constructing and preserving this legitimacy, especially when the dominant regime of intensive livestock farming is itself in a process of delegitimation. Technologies that address the environmental impact of intensive livestock farming are intimately tied to this type of farming, and depend on regulation and regulative legitimacy in order to be adopted and used. Normative and cognitive legitimacy for these technologies is lacking. What our account adds to previous work is to highlight the strategies that technology developers utilise to preserve and construct legitimacy in the face of this broader delegitimation.

In response to these threats to legitimacy, technology developers seek to find ways to retain and reconstruct regulative legitimacy. Conforming pathways to construct this regulative legitimacy are currently non-functional, and technology developers use knowledge claims to lobby other actors, especially government agencies and scientists, to construct legitimacy for their technologies. This highlights the importance of knowledge claims in the construction of legitimacy, and ties knowledge conflicts to the process of legitimation. While this has been shown in other fields than agriculture, our account shows some of the specific elements around agri-environmental issues that impact the link between knowledge conflicts and legitimacy processes. The uncertainty inherent to agri-environmental impacts enables developers in their knowledge claims.

There are several ways forward for policy makers and other actors involved in this process. It might be possible to legitimise technologies through a co-productive approach that would acknowledge the knowledge claims of technology developers. This can however be problematic as the focus on technology as a solution to reducing environmental harms may remain uncontested, leading to continuation of strong path dependencies and system lock-ins.

We see a more contested view on knowledge conflicts as fruitful. An agonistic pluralism lens on knowledge and legitimacy conflicts, which acknowledges the power relations and lock-ins in this field, would enable other actors to be involved and to contest the ideas and narratives underlying the need for ammonia-emission reducing technologies. This approach might conclude that other solutions to environmental harms are needed, such as reduction of livestock and a move to plant based protein, potentially impacting the intensive livestock farming sector as a whole (see e.g. Broad 2019). In turn, this will most likely lead to resistance from technology developers and other actors in the intensive livestock farming industry, making this approach more challenging than a co-productive one.

Either choice is a political one, to be made by societal actors, policy-makers and politicians. The intensive livestock farming sector is in transition and the technologies studied here are part of the transition. Whether they will have been a temporary fix during a transition away from intensive livestock farming, or a permanent feature in continued intensive livestock farming, depends on the choices that will be made.

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