Environmental Innovation and Societal Transitions 47 (2023) 100724

Contents lists available at ScienceDirect

Environmental Innovation and Societal Transitions

journal homepage: www.elsevier.com/locate/eist

# (Re)framing technology: The evolution from biogas to biomethane in Austria

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ARTICLE INFO

*Keywords:*
Socio-technical transitions
Frames and framing
Technological expectations
Narrative analysis
Q method
Energy policy

ABSTRACT

Socio-technical niches are often presented as key drivers for transitioning established production and consumption systems to more sustainable configurations. In previous research, the important roles of collectively shared expectations in shaping the development and nurturing of such niches has been emphasised. At the same time, this research has shown that niches are often associated with fluctuating expectations, typically showing patterns of hype and disappointment. In this study, we analyse how such hype and disappointment patterns interact with framing dynamics by combining the concept of technological frames with the sociology of expectations and the multi-level perspective. By using the shift in understanding that has occurred from a 'biogas' to a 'biomethane' frame in the Austrian anaerobic digestion (AD) niche as an example, we shed light on niche-internal framing struggles, illustrate the normative character of technological frames, and relate the emergence of dominant frames to hype cycle and transition dynamics.

## 1. Introduction

Mounting environmental problems such as climate change, biodiversity loss, or chemical pollution are putting increasing pressure on the Earth system (Bradshaw et al. 2021; Steffen et al. 2015; Rockström et al. 2009). Against this background, it is not surprising that calls for a comprehensive transformation to sustainability are growing (Grin et al. 2010; Olsson et al. 2014; Scoones et al. 2015; Patterson et al. 2017; Fazey et al. 2018; Linnér and Wibeck, 2020). While the notion of transformation is conceptualised in different ways (Fisher et al. 2022; Scoones et al. 2020; Feola, 2015), one group of scholars has referred to fundamental reconfigurations of the socio-technical systems that underlie the provision of our societal needs, such as energy provision, mobility, or housing (Köhler et al. 2019; Geels, 2019; Loorbach et al. 2017). Typically described as transitions, such reconfigurations are expected to be driven by emerging socio-technical niches, which combine innovative technological solutions with novel institutional structures and social practices (Markard et al. 2012; Schot and Geels, 2007; Geels, 2002; Geels 2004).

As shown in the growing body of literature on the sociology of expectations (e.g. Hoppmann et al., 2020; Budde and Konrad, 2019; Borup et al. 2006), the development and nurturing of niches strongly depend on collectively shared expectations. If shared by a large enough number of people, these expectations play key roles in creating legitimacy, mobilising resources, and managing uncertainty (Kester et al. 2020; Bakker et al. 2011; Berkhout, 2006). Moreover, expectations have important guiding functions (Truffer et al. 2008; Van Lente, 2012). In the latter context, expectations can change significantly over time due to learning processes associated with

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https://doi.org/10.1016/j.eist.2023.100724
Received 27 October 2022; Received in revised form 14 March 2023; Accepted 20 March 2023
Available online 4 April 2023

ongoing activities in the niche (Geels and Raven, 2006). This is particularly relevant in the sustainability context, which requires actors to continuously reflect on ongoing developments and, if necessary, adapt their hitherto-shared expectations (Schot and Geels, 2008).

Previous research on technological hype cycles has shed important light on the temporal evolution of expectations associated with emerging niches. Hype cycles are periods of rapid and strong increases in technological expectations which are followed by (often equally strongly) periods of falling expectations and disillusionment (Dedehayir and Steinert, 2016; Fenn and Raskino, 2008). A range of studies have documented such hype and disappointment dynamics as part of efforts to develop and implement sustainable innovations, including alternative fuels (Melton et al. 2016; Alkemade and Suurs, 2012; Berti and Levidow, 2014), stationary fuels cells (Ruef and Markard, 2010; Konrad et al. 2012; Bakker and Budde, 2012), solar PV (Kriechbaum et al. 2018), and biogas (Geels and Raven, 2006; Verbong et al. 2008). These studies suggest that fluctuating expectations are inherent characteristics of niche development. At the same time, they show that the specific shape of expectation dynamics is influenced by a range of factors, including not only economic and technical performances, but also the policy environment (Melton et al. 2016), strategic action and power struggles (Bakker and Budde, 2012), and the alignment with wider institutional settings (Budde and Konrad, 2019).

Several scholars have dealt specifically with the period after a hype and tried to identify factors that influence the capacity of technological fields to counteract disappointment (Van Lente et al., 2013; Ruef and Markard, 2010; Konrad et al. 2012). This work highlights the importance of external legitimacy and the question of how innovation activities are 'framed' around broader societal issues and goals. For instance, Ruef and Markard (2010) suggested that actors in the Swiss innovation system of stationary fuel cells were able to continue their innovation activities despite a general disappointment in the field, because fuel cells were still framed positively in terms of their potential societal contributions (e.g. maintaining competitiveness, preventing pollution, securing the energy supply). Markard et al. (2016) also demonstrated the consequences of negative framings by illustrating how biogas technology entered a strong legitimacy crisis in Germany due to environmental and ethical concerns about the growing use of energy crops.

The linkages between expectation dynamics and framing processes have also been emphasised in more recent studies (Hoppmann et al. 2020; Lempiälä et al. 2019; Kriechbaum et al. 2021). These linkages, however, have not yet been analysed in connection with efforts to counteract severe disappointment, which typically force actors in the technological field to fundamentally redefine pre-existing understandings of the technology (Van Lente et al. 2013; Kaplan and Tripsas, 2008). Moreover, equating the notion of framing with processes that align innovation activities with wider societal issues, which is common practice in studies on emerging socio-technical niches (e.g. Lempiälä et al. 2019; Rosenbloom et al. 2016; Smith and Raven, 2012), only partially reflects the already-existing concept of technological frames (Kaplan and Tripsas, 2008; Orlikowski and Gash, 1994; Bijker et al. 1987). Most notably, it neglects interpretations of the nature of the technology itself.

In this study, we contribute to filling this lacuna by using biogas technology in Austria as our empirical case. In many European countries, biogas technology has received a strong amount of attention over the last 20 years (Scarlat et al. 2018). But as indicated above, the deployment of the technology has been also characterised by setbacks (Verbong et al. 2008; Fevolden and Klitkou, 2017; Markard et al. 2016), and Austria is a good example of a country that experienced particularly high levels disappointment (Brudermann et al. 2015; Stürmer, 2017). Furthermore, the term "biogas" already refers to a specific understanding in the niche of anaerobic digestion (AD) technology (Lazarevic and Valve, 2020). This is illustrated by the fact that a new niche variant is gaining increasing attention in Austria and in other European countries: biomethane (Anca-Couce et al. 2021; Brémond et al. 2021). The resulting shift in the understanding of the technology's nature and purpose presents an interesting case for analysing the framing dynamics associated with severe disappointment and led us to develop the following research questions:

How did the hype cycle associated with the niche of anaerobic digestion (AD) technology in Austria evolve over time and how did this evolution interrelate with collectively shared understandings of the technology?

To answer these questions, we applied a multi-method research strategy that included semi-structured interviews, a media analysis, and the application of the Q-method. While the interviews as well as the media analysis were used to gain insight into the historical development of the AD niche, applying the Q-method allowed us to examine in detail the (competing) narratives associated with emerging expectations about biomethane. Before the methodological approach is described in detail in Section 3, the theoretical background of the study is presented in the subsequent section.

## 2. Theory

### 2.1. Technological frames

Introduced as one of the key concepts in the seminal book "The social construction of technological systems" (Bijker et al. 1987), technological frames were initially referred to as 'the ways in which relevant social groups attribute various meanings to an artefact' (p. 102). This definition was based on Kuhn's understanding of a "paradigm" (Kuhn, 1962) and depicted frames as dominant problem-solving concepts and techniques that encompass not only theories and knowledge, but also practices, procedures, and networks (Bijker, 1987), or simply 'all elements that influence the interactions within relevant social groups and lead to the attribution of meanings to technical artifacts' (Bijker, 1995: 123).

Based on the sociological work on frames (Goffman, 1974; Weick, 1993) and Wittgenstein's concept of family resemblances (Wittgenstein, 1953), Orlikowski and Gash (1994) proposed a narrower definition. Studying how actors in organisations make sense of technology, they defined technological frames as a set of shared assumptions, expectations, and knowledge that is used to understand technology. In our study, we apply this definition but go beyond individual organisations (Kaplan and Tripsas, 2008). Specifically, we conceptualise technological frames as intersubjectively shared *meaning structures* that co-emerge with socio-technical niches and allow the associated actor groups to interpret the nature and purpose of the respective niche technology. "Associated" actor groups include a broad range of actors, such as firms, researchers, users, government actors, professional associations, unions, social pressure groups, and the public media. Treated as a whole, these actor groups constitute networks that are similar to organisational fields (DiMaggio and Powell, 1983; Geels, 2020); this renders our understanding of technological frames similar to the understanding of field frames (Cornelissen and Werner, 2014; Kaplan and Tripsas, 2008).[1]

It is important to note that technological frames are not used merely to interpret technology in a narrow sense (Sovacool and Axsen, 2018). As highlighted already by Orlikowski and Gash (1994: 178), they also enable actors applying them to gain a shared understanding about 'specific conditions, applications, and consequences of that technology in particular contexts'. This implies that technological frames are also associated with normative interpretations, which we expect to be manifested through technological narratives and connected storylines (Bomberg, 2017; Lovell, 2008). While the precise relationship between frames and narratives has been conceptualised in different ways (e.g., Dijk, 2011; Crow and Taylor, 2016), narratives can be generally understood as stories that 'facilitate the normative leap from *is* to *ought*' (Rein and Schön, 1993: 148) and are 'focused more on emotion than cognition' (Olsen, 2014: 252). We understand a technological narrative as a coherent set of storylines that is used to establish the normative basis of a technology and co-emerge together with cognitive interpretations.

### 2.2. Framing and technological trajectories

Innovation scholars widely acknowledge that framing processes play crucial roles in shaping technological trajectories (Cornelissen and Werner, 2014; Davidson, 2006; Bijker, 1995). In particular, the emergence and impact of competing frames in technological fields and the associated impacts on the innovation process have been studied extensively (e.g. Ibsen, 2009; Leonardi, 2011). Already in 1987, Bijker et al. illustrated how actors' understandings of the early versions of the first synthetic plastic differed and how this "interpretative flexibility" delayed the development of the material that finally become known as Bakelite. The existence of competing interpretations of technology has been primarily associated with early development stages, where high levels of uncertainties take place and which are characterised by the varying objectives, knowledge, and interests of involved actors (Van de Ven and Garud, 1993; Anderson and Tushman, 1990). Conversely, maturing innovation trajectories are expected to be linked with a process of alignment and stabilisation, which results in a situation of "closure" (i.e. a situation where one frame asserts itself and becomes dominant) (Bijker, 1995).

Along these lines, Kaplan and Tripsas (2008) compared the evolution of technological frames to the four phases of a technological life cycle (Anderson and Tushman, 1990). The first phase, the *era of ferment*, is characterised by large frame variation due to the prior affiliations and idiosyncratic interpretations and understandings of involved actors. In the second phase, the field experiences a convergence into a unified frame, which is manifested by the emergence of a *dominant design*. According to the authors, this convergence arises from the increasing numbers of interactions among diverse actors and is shaped by the strategic actions of actors who purposefully try to push their own frame. In the next phase, the *era of incremental change*, the dominant frame solidifies and becomes more firmly embedded in the wider socio-technical environment. The final phase of *technological discontinuity* is characterised by the emergence of a new frame, which develops outside of the existing one.

In the widely cited multi-level perspective (MLP) (Geels 2004; Geels et al. 2007), the gradual alignment and stabilisation of technological frames is acknowledged as well. Building on insights from the strategic niche management literature (Schot and Geels, 2007), the MLP suggests that (radically) new technologies are developed in niches where they co-emerge together with new actor networks and user practices. The maturation of such socio-technical niches, in turn, is expected to correlate with the increasing "structuration" of the initially unstable and diverse niche-internal rules, such as expectations, problem agendas, and search heuristics (Geels, 2019). As described in the work of Kaplan and Tripsas (2008), the increase in the number of interactions among actors is highlighted as the main driver of this process. Specifically, the alignment and stabilisation seem to occur due to the formation of social networks and a continuous learning process that is driven by the interplay between the (initially vague) cognitive rules at the field level and local practices at the micro level (Schot and Geels, 2008; Geels and Raven, 2006).

In addition, MLP research suggests that framing processes also play crucial roles in creating legitimacy in the wider socio-technical context (Hess, 2019; Geels, 2010). According to the MLP, emerging niches may eventually break into and transform established socio-technical systems, resulting in far-reaching socio-technical change. Such "transitions" are expected to be characterised by conflicts and tensions, because the emerging niches typically differ radically from the established and highly stable norms, beliefs, and expectations that underlie existing socio-technical systems (the so-called regime) (Geels 2002; Geels and Schot, 2007). Furthermore, niches often present a threat to incumbents, since they tend to challenge existing power structures (Geels et al. 2016; Lee and Hess, 2019). The arising conflicts and tensions, in turn, typically manifest in the form of framing struggles, where actors try to influence innovation pathways by sharing narratives that favour particular courses of action (Rosenbloom, 2018; Smith et al. 2014; Geels and Verhees, 2011).

A key strategy employed during such framing struggles is to create storylines that link the emerging niche technology with issue and problem frames associated with the wider socio-technical context (Smith and Raven, 2012). Lee and Hess (2019), for instance,

[1] Our broad understanding of associated actor groups is also similar to Bijker's (1995: 123) definition of these groups, which refers to "relevant social groups". However, unlike Bijker, we refrain from *conflating* meaning structures with all elements that influence the attribution of meaning, since this not only leads to conceptual fuzziness but also raises ontological concerns (Sorrell, 2018). At the same time, we acknowledge that technological frames – in much the same way than institutional structures (Scott, 2014) – need to be inscribed in actual practices and material artefacts in order to persist.

mapped the framing struggles that took place between incumbents of the U.S. electricity sector and the distributed solar energy industry. Their analysis shows how both sides used environmental and economic frames (e.g. related to climate change and consumer costs, respectively) to legitimise their positions. Using the example of solar electricity in Ontario, Rosenbloom et al. (2016) offered a detailed account of the process by which actors with different capacities, interests, and resources made claims about the characteristics of the solar niche (content) and linked these with developments in the established energy system as well as the broader socio-technical landscape (context). In addition, these authors emphasised the dynamic nature of framing struggles (and associated narratives) by highlighting the fact that the actors continuously adapted their discursive strategies to respond to competing storylines as well as to content- and context-related developments (see also Rosenbloom 2018).

### 2.3. Framing and hype cycles

Hypes can be expected to be strongly and closely connected to the previously described frame alignment and stabilisation dynamics. Understood as waves of strongly rising expectations associated with emerging technological fields, hypes provide directionality and guide innovation activities through agenda setting (Van Lente, 2012; Konrad, 2006). Furthermore, expectations shared during hypes are used as points of reference that allow actors to mobilise resources and convince other actors to join the bandwagon (Fujimura, 1988). Through the increasing involvement of actors and resources, these expectations gradually grow into requirements, guidelines, and specifications (Van Lente et al., 2013). As such, hypes are performative in the sense that their specific, inherent ideas structure innovation activities and eventually shape the emerging technological trajectories (Borup et al. 2006). When interpreted from the life-cycle perspective developed by Kaplan and Tripsas (2008), we can see that technological hypes contribute to the structuration process necessary to move beyond the era of ferment.

While expectations and promises shared during such hypes shape how innovation processes materialise, they ‘hardly ever materialize precisely as foreseen’ (Van Lente et al. 2013: 1616). In fact, technological hypes are typically followed by periods of disappointment, which are characterised by falling expectations and decreasing attention levels. According to Fenn and Raskino (2008), such hype cycles naturally accompany the introduction of new technologies due to the enthusiasm of humans for novel ideas and their tendency to overestimate the true value of innovations in the short term (cf. Gartner hype cycle). In the literature on the sociology of expectations, however, scholars suggest that a range of additional aspects shape the formation of technological expectations, such as the strategic behaviour of actors (Bakker et al. 2011, 2012) and power struggles (Bakker and Budde, 2012). Furthermore, supporters of the sociology of expectations are critical of the assumption that technologies have a single ‘true’ value. Instead, they take a constructivist stance by emphasising the performativity of expectations and the existence of self-fulfilling prophecies (Van Lente, 2012).[2] Finally, while the Gartner hype cycle suggests that a hype eventually ends in a phase of “enlightenment”, where the associated technology is fully mature and widely adopted, the sociology of expectations highlights the fact that innovation fields may also experience multiple hypes, fail to fully counteract disappointment, or disappear completely (Borup et al. 2006; Van Lente et al. 2013).

Technological hype cycles have also been linked to the legitimacy struggles associated with socio-technical transitions. While the (de-)legitimising nature of expectations has been widely acknowledged in papers on the sociology of expectations (e.g. Berkhout 2006; Van Lente, 2012), the emergence of hype cycles was directly related to the wider socio-technical change processes described in the MLP framework in more recent work. In this work, Kriechbaum et al. (2021) interpreted hypes as ‘manifestations of the discursive struggles that are associated with periods in which niche technologies challenge and compete with the existing socio-technical system’. In their study on “networks of expectations”, Budde and Konrad (2019) argued that the three levels of the MLP (niche, regime, and landscape levels) can be used both to classify technological expectations and to explain their dynamics over time: At the niche level, alternative expectations (associated with new technologies) develop and eventually compete with expectations shared in the established socio-technical system (regime level). Because the latter are typically highly stable, their change requires additional pressure from subordinate expectations at the landscape level (e.g. societal expectations about mitigating climate change).

### 2.4. Disappointment and reframing: relating hype cycles to framing and transition dynamics

Summarising the information provided above, we can conclude that the technological trajectory described by the Gartner hype cycle (hype-disappointment-wide adoption) coincides with both the life cycle perspective of frame evolution and the transition dynamics described by the MLP (Figs. 1, 1a-1b). Along this trajectory, the hype allows the niche to move beyond the era of ferment and coincides with the emergence of a collective frame, which is associated with a dominant design, facilitating regulative structures, and stable actor networks. Associated with stabilised rules and supported by favourable landscape developments, the emerging niche competes with and challenges the existing regime. The subsequent disappointment requires frame adjustments, but it does not force actors to fundamentally change their understanding of the technology’s nature and purpose. Eventually the frame solidifies, and the new technology establishes itself in the socio-technical system; this phase is accompanied by the wide diffusion of the technology and the transformation of the regime.

As indicated in the previous section, however, technological trajectories do not necessarily follow such an ideal-typical pattern. For instance, a hype may contribute to the alignment of innovation activities without resulting in a stabilised frame. The emerging field of graphene technology provides a good example in this context. While this field experienced a strong hype in the previous decade (Lee

[2] At the same time, the role of materiality in shaping and constraining these dynamics is acknowledged (Hoppmann et al. 2020).

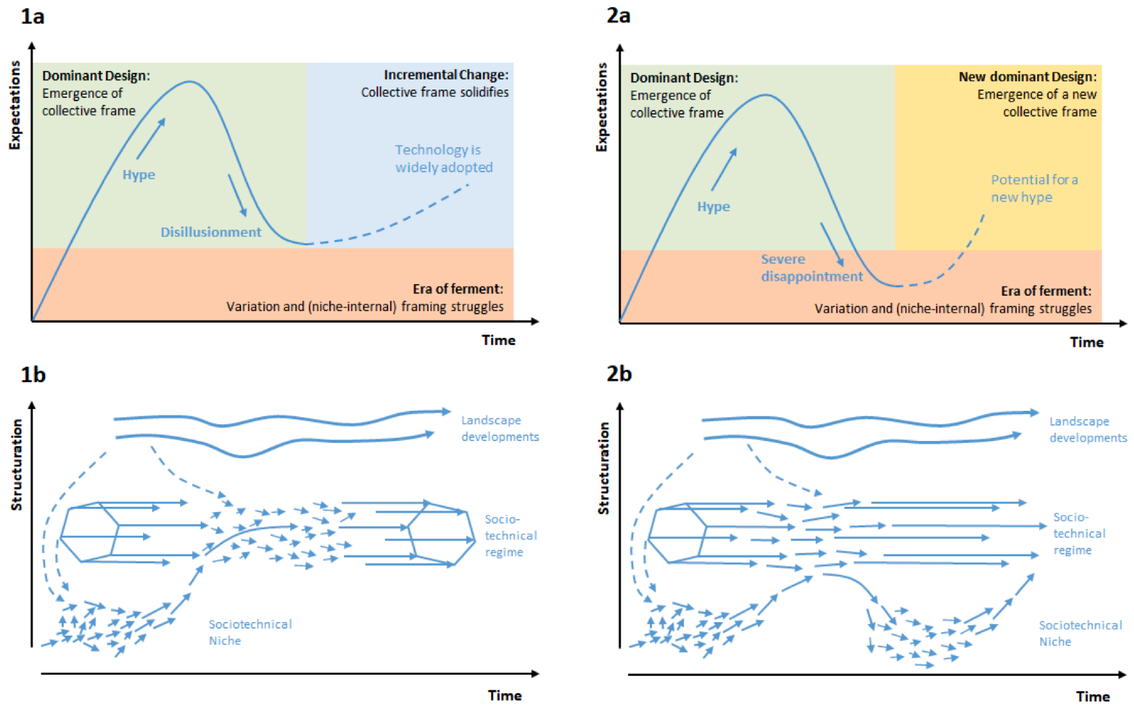


**Fig. 1.** Relationship between hypes, frame evolution, and transition processes in an ideal-typical case (1a, 1b) and in a situation of heavy disappointment (2a, 2b). Adapted from Fenn and Raskino (2008); Geels (2002).

et al. 2022; Alvial-Palavicino and Konrad, 2019), it is still characterised by a variety of search directions in terms of potential application areas (Zhong et al. 2017) and production techniques (Backes et al. 2020). In this case, multiple hypes might be needed before convergence on a collective frame and stabilisation. In other cases, a hype might stabilise an already existing field frame, as was the case with grid-connected solar PV in Germany (Kriechbaum et al. 2018).

With looking at the evolution of the AD niche in Austria, the empirical focus of this paper is directed along yet another trajectory: a case where the hype contributes to the emergence of a collective frame but is followed by such high levels of disappointment that the established understanding about the technology's nature and purpose falls apart and the field 'returns' to the era of ferment. While in such a situation, innovation activities may disappear completely, they may also continue and lead to the formation of a new hype – and with it the emergence of a new collective frame (Figs. 1, 2a-2b). As Kaplan and Tripsas (2008:793) put it, 'Certain understandings of a technology may lead to greater support for a particular direction, but if the realities of the technology do not ultimately play out in the way anticipated, then that incongruity will force actors to shift away from the original technological frame to a new understanding of what the technology is and what performance criteria should be applied'.[3]

## 3. Methodology

To study the expectation dynamics and underlying framing processes associated with the Austrian AD niche, a multi-method strategy was applied. In a first step, we carried out a narrative analysis to reconstruct the evolution of the AD niche. A narrative analysis links historical events and actions by configuring them into a story (Abbott, 1990; Van de Ven, 2007). The overall objective is to develop causal reconstructions that explain the investigated social phenomenon (i.e. expectations and framings associated with the developments of the Austrian AD niche) by revealing the processes by which it is created (Mayntz, 2004; Geels 2022).

Multiple data sources were used to reveal the 'uniqueness of the individual case (…) and provide an understanding of its idiosyncrasy and particular complexity' (Polkinghorne, 1995: 15). First, 30 interviews were carried out with representatives of the industry, governments, and academia (see Table 1). All interview partners, who were recruited by performing snowball sampling and screening relevant websites (e.g. of associated ministries or the industry association), were responsible for relevant policies or strategies and/or had a privileged access to information about the technological field due to their long-lasting engagement (e.g. as a

[3] While the question of whether 'realities of the technology play out the way anticipated' is itself subject to collective interpretations, these interpretations are still inferences based on and constrained by actual or 'real' developments (e.g., resource availabilities, price developments, material properties). In addition, collective interpretations are real as well (i.e. they act as a causal force that shape how actors behave).

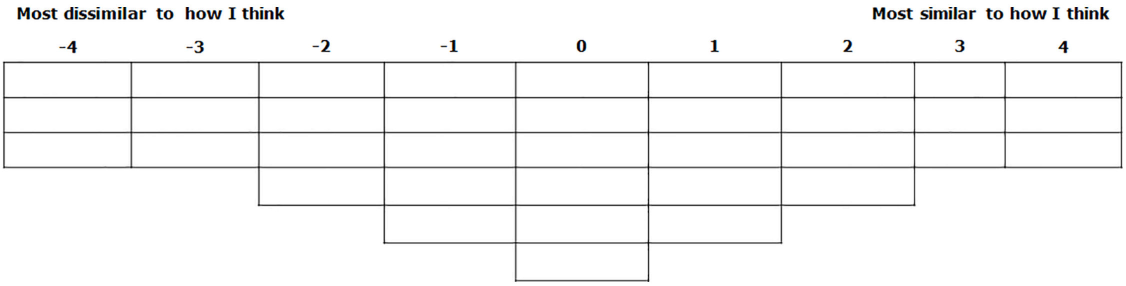


**Fig. 2.** Bell-shaped distribution according to which participants ranked the statements.

**Table 1**
List of interview partners with acronyms.

| Acronym | Organisation/Role | Acronym | Organisation/Role |
|---|---|---|---|
| Ind1 | Representative from the Austrian Biogas Association | Oprt1 | Operator of a small plant |
| Ind2 | Representative from the Austrian Biogas Association | Oprt2 | Micro plant operator |
| Ind3 | Expert at the Austrian Biogas Association | Oprt3 | Operator of a biogas plant <400kW |
| Ind4 | Plant manufacturer and pioneer | Oprt4 | Operator of a biogas plant <400kW |
| Ind5 | Manager at the Austrian Renewable Energy Association | Oprt5 | Operator of a biogas plant <400kW |
| Ind6 | Founder of a pioneering company & plant operator | Oprt6 | Operator of a biogas plant >400kW |
| Ind7 | Representative from the Association of Gas- and District Heating Supply Companies | Oprt7 | Operator of a biogas plant >400kW |
| Off1 | Manager at OEMAG, the Austrian processing and administration centre for ren. electricity | Oprt8 | Operator of a biogas plant >400kW |
| Off2 | Manager at E-Control, a government regulator for electricity and natural gas markets | Oprt9 | Operator of a biogas plant >400kW |
| Off3 | Energy expert at the Economic Chamber | Oprt10 | Operator of a biogas plant >400kW |
| Off4 | Energy expert at the Chamber of Agriculture | Oprt11 | Operator of a biogas plant >400kW |
| Off5 | Energy expert at the Chamber of Labour | Oprt12 | Plant operator and award winner |
| Off6 | Official at the Ministry of Sustainability and Tourism with biogas focus | Cons1 | Energy consultant with focus on biogas |
| Off7 | Official at the Ministry of Sustainability and Tourism with focus on strategic energy policy | Acad1 | Engineering professor with a focus on biogas |
| Off8 | Official at the Federal Department for Energy Technology and Climate Protection | Acad2 | Engineering professor with a focus on biogas |

member of the industry association, an official, or a plant operator). The interviews were conducted between March and September 2020, took on average 50 minutes each, and were structured around three main themes[4]: (i) previous developments of the technological field, (ii) current situation, and (iii) prospects. The interviews were transcribed and analysed using the software MAXQDA.

Second, we accessed the archives of all Austrian national newspapers by using the online data base WISO and searched for those articles that were published about the technological field in the years between 2000-2021 (for the detailed search strategy and a list of the included newspapers, see Supplement A). In total, our final sample of articles included 672 articles. We screened the articles and grouped them according to whether they were about (i) 'traditional' biogas technology (biogas with on-site power generator) or (ii) biomethane (purified biogas with same properties than natural gas). Using again MAXQDA, all expectation statements were coded and categorised according to their sentiment (positive, neutral, or negative) and their associated level: specific, general, and frame levels (for the detailed coding strategy, see Supplement B). Subsequently, we created an Excel data base that structured all statements according to year, level, and sentiment. This allowed us to plot the number of positive and negative statements per year and thereby depict expectation dynamics over time. In addition, we plotted the media attention over time (i.e. number of articles per year). Finally, we triangulated both media and interview data with additional data sources, including legal and policy documents, relevant publications, statistical and market information, as well as press releases.

To identify the emerging narratives associated with biomethane, we applied the Q-method (Shinebourne, 2009)[5]. The mixed-method approach, which was first used in early psychological research (Stephenson, 1953), has increased in popularity over the last two decades inter alia in the field of sustainability research (Webler et al. 2009; Barry and Proops, 1999; Cotton, 2015). It allows scholars to explore intersubjectively shared perspectives on complex and socially contested issues by applying an "inverted" factor analysis of (pre-selected) statements that have been sorted by stakeholders according to their level of agreement (Watts and Stenner, 2005). A Q-study consists of three main steps: First, all statements that exist about the studied issue are mapped (the concourse); second, stakeholders are asked to sort these statements according to their degree of agreement; and, third, the factor analysis is then used to analyse the resulting sorts and identify commonly shared narratives.

[4] Depending on the role and knowledge of the interview partner, one or two of these themes were prioritised. The last two themes were mainly used for the Q-study (see below).

[5] In other words, we combined the above-described "narrative analysis" with an "analysis of narratives" (Polkinghorne, 1995).

**Table 2**
Participants of the Q study.

| Segment | Participant's role |
|---|---|
| 'Traditional' biogas industry | Expert at the Austrian Biogas Association |
| | Operator of a biomethane plant |
| | Operator of a biogas plant |
| | Representative from the Austrian Biogas Association |
| Gas industry | Representative from the Association of Gas- and District Heating Supply Companies |
| | Manager at the ÖVGW Austrian Association for Gas and Water |
| | Expert at the ÖVGW Austrian Association for Gas and Water |
| Energy sector more broadly | Manager at a regional energy supplier |
| | Manager at the Austrian Association of Energy Companies |
| | Energy policy expert at the Federation of Austrian Industries |
| | Manager at the Austrian Renewable Energy Association |
| Energy policy | Manager at E-Control, a government regulator of electricity and natural gas markets |
| | Energy expert at the Austrian Chamber of Agriculture* |
| | Energy policy expert from the federal government (Conservative Party) |
| | Energy policy expert from the federal government (Green Party) |
| Research | Engineer at a research organisation with a focus on biotechnology |
| | Professor in the field of environmental biotechnology |
| | Engineer head of research unit at an applied research institute for bioenergy |
| | Managing director of an applied research institute for renewable energy technologies |
| | Social sciences professor in the field of sustainable energy technologies |
| NGO | Spokesperson for climate and energy at a leading environmental NGO |

* Identical with interview partner Off4 (see Table 1).

The concourse (i.e. all ideas and statements about biomethane) was obtained from the interviews as well as the collected newspaper articles. Regarding the latter, we focussed on the years 2018–2021, which was the period when the attention paid to biomethane started to increase. In addition, we also analysed forum entries of selected articles (i.e. those that were associated with particularly intense discussions). The resulting sample, which consisted of 156 statements, was then classified according to five inductively derived categories (application area, policies, economic aspects, environment, social aspects) and shortened to 36 statements which best represented the different ideas and positions within these categories. While some statements were cited directly from the source material, others were revised to be more concise and direct, taking care to maintain the original meaning of the concept (Webler et al. 2009).

Twenty-one participants were then recruited and asked to rank the statements according to their degree of agreement using a scale between -4 (was most dissimilar from how they thought) and +4 (was most similar to how they thought). As is the common practice in a Q-study, the participants were asked to rank the statements along a bell-shaped distribution (Fig. 2); this helped them to differentiate among their priorities and revealed their preferences (Webler et al. 2009). The participants carried out these rankings autonomously between May and August 2021 by using the online tool Q-Sortware. The sample of participants was chosen based on how well they represented the relevant actor groups in the technological field and included researchers, industry representatives, NGO members, policymakers, and plant operators (see Table 2).

Using the software program PQMethod 2.35, we subsequently carried out the factor analysis of the completed sorts (principal component analysis combined with varimax rotation). This allowed us to identify commonly shared narratives about biomethane (i.e. specific configurations of statements that were similar among several participants). The final set of narratives were selected according to their Eigenvalues ($> 1$) and manual interpretation was performed, considering the principles of simplicity, clarity, distinctiveness, and stability (Webler et al. 2009).

## 4. From biogas to biomethane

In the first part of this section, the historical evolution of the Austrian anaerobic digestion (AD) niche is described; we reconstruct the hype cycle dynamics and illustrate how these dynamics relate to (i) the emergence (and breakdown) of the biogas frame and its associated *energy farmer* narrative, (ii) wider landscape developments such as changes in agricultural prices or increasing decarbonisation efforts, and (iii) a 'framing shift' towards biomethane. In the second part, the results of our Q study are presented, specifically showing that the emerging biomethane frame has been subject to three competing narratives. In the third part, the Q study results are synthesised with the findings of the historical analysis.

### 4.1. The historical evolution of the AD niche

The development of the Austrian AD niche can be divided into six phases, each of which are associated with distinct sector developments, expectations, and framings:

- 1990s-2001: The pre-hype phase and increasing amounts of attention from the agricultural industry
- 2002-2004: The biogas hype and the consolidation of the energy farmer narrative

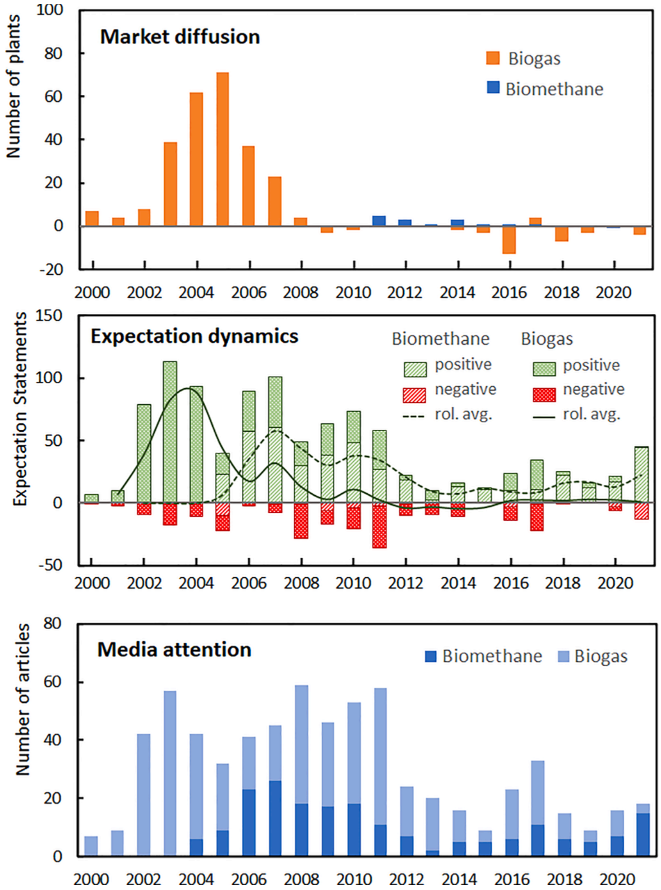


**Fig. 3.** Identified media attention (in all national newspapers), associated expectation dynamics, and market diffusion. Expectation dynamics and media attention are based on an analysis of articles in the following newspapers: *Kurier, Oberösterreichische Nachrichten, Wiener Zeitung, Der Standard, Kronen Zeitung, Die Presse,* and *Salzburger Nachrichten*. Sources for market diffusion: Stürmer (2017), AGCS – Austrian Gas Clearing and Settlement AG (2021), E-Control (2021).

- 2005-2007: Biogas purification and rising expectations about biogas as a transport fuel
- 2008-2012: Rising substrate costs and disillusionment
- 2013-2017: Discursive 'break' and the break-up of the energy farmer narrative
- 2018-2021: Renewed expectations about biomethane

#### 4.1.1. *The pre-hype phase and increasing attention from the agricultural industry (up until 2001)*

In the 1990s, the AD niche was characterised by do-it-yourself plants that ran on on-site manure and biogenic waste; these were constructed by farmers and local engineers who took a trial-and-error approach (Dissemond et al. 1993). While many of these plants were connected to a standard combustion engine that generated electricity (and heat) for self-consumption purposes, experiments with feeding surplus electricity into the grid were also carried out (Stürmer, 2017). Furthermore, the 'biogas' produced by these AD plants was occasionally used directly for heating purposes (*ibid.*), and ideas about utilising the gas as a transport fuel were discussed (Fankhauser et al. 1985; Kaufmann, 1981). In addition, the increasing amount of knowledge about the performance of different feedstock materials led to discussions on using field crops such as maize as additional substrate materials (Amon et al. 2001).

After 2000, the vision of upscaling the production of biogas by using field crops gained an increasing amount of attention. At that time, Austria saw itself as a pioneer in the utilisation of renewable energy sources. Renewable energy was generally associated with environmental protection, energy independency, and domestic value creation. As one interview partner stated, '*(…) there was a clear consensus across the whole political spectrum that all renewable energy technologies must be supported*' (Off4). At the same time, the market prices for agricultural commodities were at historically low levels (Stürmer et al. 2021)[6]. Furthermore, some actors in the agricultural sector expressed fears that Austrian's EU membership (Austria entered the EU in 1995) would lead to increasing competition with

[6] See Figure A.2 in the Appendix for the price development of corn maize.

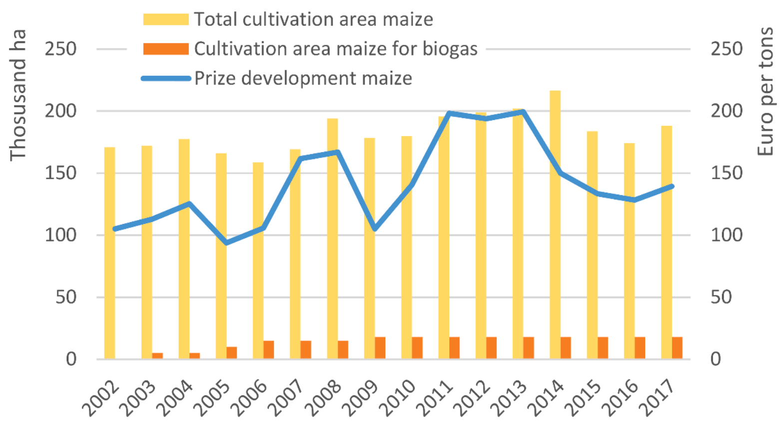


**Fig. 4.** Development of cultivation area and price of maize in Austria (graph created based on Agrarmarkt Austria (2019) and Ökosoziales Forum, 2015 data).

other member states (Ind3; Sinabell, 2004). Against this background, the prospective biogas sector was increasingly perceived as a promising market for farmers (Wirth et al., 2013).

#### 4.1.2. *The biogas hype and the consolidation of the energy farmer narrative (2002–2004)*

The *Green Electricity Act 2002* (BGBl. I No. 149/2002) consolidated the emerging *energy farmer* narrative. The act constituted the first national support regime for renewables in electricity generation and was implemented by a coalition government led by the liberal-conservative Austrian People's Party, which has traditionally strong ties to farmers. It contained highly attractive tariff structures for feeding electricity produced from biogas into the grid and provided strong incentives for utilising energy crops.[7] While the Green Electricity Act created financial incentives for farmers to invest in biogas plants, the Chamber of Agriculture played a key role in convincing farmers to make use of these incentives (Oprt4-6,9-10; Cons1; Off3). One of the interviewed plant operators remembered that '*Back then, the Chamber [of Agriculture] did not tire of taking every opportunity for emphasising how promising the technology would be (…) the message that we can earn good money with biogas was communicated at every event and in every newsletter*' *(Oprt5)*.

The high expectations associated with biogas quickly became widely shared by the broader public. As shown in Fig. 3, the media attention levels were increasing significantly, whereby the reporting was predominately positive. The articles reiterated the *energy farmer* narrative and emphasised the market potential and high profitability rates associated with the technology, as well as the possibility of producing 'green electricity'. Furthermore, planned or already built biogas plants were frequently showcased. Apart from a few exceptions, which related to unpleasant smells, these plants were portrayed in a highly positive light. Overall, a "gold-rush atmosphere" developed (Off2-3; Cons1), which led to a strong market uptake and thereby to a professionalisation of the market (Ind3-4), the development of unified technical standards (e.g. BMWA, 2003), and the emergence of a dominant design (i.e. the plants increased in size, maize silage was used as main substrate, and the generation of electricity was placed in the foreground).

#### 4.1.3. *Biogas purification and rising expectations about biogas as a transport fuel (2005–2007)*

Already in the previous phase, planners and plant constructors had increasing difficulties in coping with the strong demand, which resulted not only in delays but also in an unanticipated cost increase for the plants. Together with newly introduced (and more expensive) building regulations, this overheating led to the first slump in the industry (Off3,8; Cons1; Ind3-4). At the same time, the sector was associated with a technological breakthrough. In a pilot project which was implemented in 2005, biogas could be 'upgraded' to biomethane for the injection into the gas grid for the first time (Stürmer, 2017). This purified form of biogas had the same properties as natural gas, opening up new perspectives for the biogas sector, such as being able to inject biogas directly into the gas grid or utilise biogas in the transport sector. The latter option was the subject of strong interest from both policymakers and representatives of the oil industry.

The dynamics in the public discourse mirrored these opposing sectoral developments. While the amount of media attention paid to 'traditional' biogas technology diminished, the amount of reporting on purified biogas rose substantially. Most of this reporting was highly positive, and many expectations arose related to the utilisation of biogas in the transport sector (e.g. high expectations about the potential share of biogas in the transport sector, plans to create a filling station network, or the environmental benefits of switching to biogas vehicles). In addition to transport-related expectations, the level of optimism about replacing natural gas also was increasing (even though the opinions about its exact potential were divided). But except for a few pilot projects, such as those for the first biogas filling stations (Salzburg AG, 2007; TBB, 2007), the expectations shared during this period were rarely fulfilled. Instead, they were

[7] The tariffs for biogas ranged between 10.3 and 16.5 euro cents/kWh. As a comparison, the German EEG 2000 offered between 8.7 and 10.23 euro cents/kWh and reduced the tariff by 25% if only residuals were used.

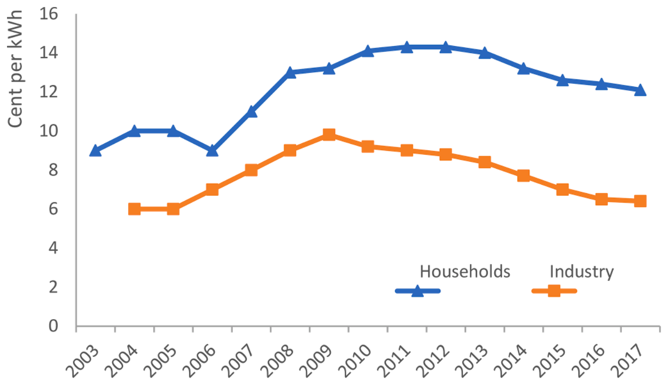


**Fig. 5.** Development of electricity prices (power and grid). Graph based on Statistics Austria (2019) data.

increasingly overshadowed by the emergence of a severe sector crisis.

#### *4.1.4. Rising substrate costs and disillusionment (2008–2011)*

While the profitability of the biogas plants had turned out to be lower than had been expected in the previous period, the (global) agricultural prices started to increase significantly in 2007 (Fig. 4). This led to a situation where the operation of many of the biogas plants was no longer economically viable. Against this background, the government, which consisted of a coalition of Social Democrats (leading party) and the Austrian People's Party at the time, agreed to make a temporal feedstock bonus payment (BGBl. II No. 212/2008). However, the negotiations for this government support were difficult (Ind1-5; Off36; Oprt4-8) and, while the support payment prevented plant operators from immediately filing bankruptcy, it also triggered intense framing struggles.

Spearheaded by the Chamber of Labour[8], an anti-biogas coalition emerged and criticised the aid as an indefensible "farmer support". Coalition leaders argued that biogas plants were too expensive, inefficient (e.g. citing that many of the plant operators did not use the heat arising during the generation process), and ethically unjustifiable. The latter was linked to the (global) fuel versus food debate that had been triggered by rising agricultural prices and was mainly associated with biofuel production.[9] The Chamber of Agriculture[10] and the newly founded Biogas Association, in turn, emphasised the positive effects of the plants on the domestic economy and the important role played by biogas in Austria's effort to achieve greater independence from the fossil industry.

In the media, these framing struggles climaxed with the confrontational opinion pieces from the directors of the opposing chambers, which appeared in the liberal-conservative newspaper *Die Presse* (2008-05-27; 2008-05-17). While the direct confrontation soon vanished from the public discourse, media attention continued to focus on the plant operators' economic situation, which did not improve despite continuing bonus payments (BGBl. II No. 41/2010; BGBl. II No. 251/2011; BGBl. II No. 184/2012; BGBl. II No. 227/2012). The pessimism reached its peak in 2011, when the price of corn increased at an unprecedented rate (Fig. 4). For instance, in an article entitled "Biogas pioneers go bankrupt", a plant owner was cited as making the following statement, 'If nothing changes, the biogas industry is dead' (Kurier, 07-09-2011). At the same time, the media reporting on purified biogas, which was increasingly framed explicitly as biomethane, remained positive. Compared to the previous period, however, the focus was less significantly directed toward the transport sector, and an increasing emphasis was placed on the use of residual materials, rather than energy crops. Furthermore, the first steps towards institutionalising the biomethane frame were made by establishing a biomethane register and by providing a bonus for operators who produce electricity based on purified biogas (BGBl. I Nr. 75/2011).

#### *4.1.5. Discursive "break" and break-up of the energy farmer narrative (2012-2017)*

From 2012 and onwards, the media attention on biogas and biomethane diminished significantly. It became clear that positive expectations related to overcoming the sector crisis (which still existed in the previous period) would not materialise. Aside from the high substrate costs, the falling electricity prices (Fig. 5) additionally reduced the prospect that the operation of biogas plants would become viable any time soon. (This was especially problematic for those plants that reached the end of the 13-year feed in contract)[11]. While continuous financial support was provided for plant owners, the climate between the operators and regulators became increasingly difficult (Ind1-3; Oprt3-12). One of the interviewed biogas operators (Oprt4) remembered that '*It was really mortifying (…). At the beginning, we were treated as pioneers who were doing something really important, and then, suddenly, we became petitioners who needed to ask the government for help, year after year.*'

During this period, the *energy farmer* narrative finally fell apart. The idea of establishing an alternative market for agricultural

[8] The Chamber of Labour is a 'social partner' that represents workers and is strongly associated with the Social Democratic party. In Austria, social partners are influential and politically recognised interest groups that try to achieve a consensus and settle open conflicts of interests through negotiations.

[9] In fact, the area used for biogas accounted for less than 1.5% of total arable land (see Fig. 4).

[10] The Chamber of Agriculture is a 'social partner' that represents farmers and is strongly associated with the Austrian People's Party.

[11] The initial idea was that, after 13 years, the operation of the plants would be economically viable.

**Table 3**
Factor scores, which indicate how each statement was ranked (+4 to -4) within idealized Q-sorts. The idealized Q-sorts each represent a factor (or narrative).

| No. | Statement* | Factor** 1 | 2 | 3 |
|---|---|---|---|---|
| 1 | Investment support has established itself as an effective means for companies and should therefore also be applied in the context of biomethane. | 0 | -2 | 2 |
| 2 | The potential of green gas is limited, and its production is expensive. | -3 | 3 | -1 |
| 3 | Renewable feedstocks should continue to be used to produce biomethane in the future. | -2 | 1 | 3 |
| 4 | The use of renewable gases for residential heating would bar the way to the decarbonisation of the steel industry. | -4 | 4 | -2 |
| 5 | Especially in the decarbonisation of industry, biomethane will play an important role. | 0 | 2 | 0 |
| 6 | Maize should not be dispensed with for biomethane production due to its excellent properties in terms of energy density. | -2 | -2 | 1 |
| 7 | Biomethane creates local economic activity and jobs. | 1 | 1 | 4 |
| 8 | Biomethane should be promoted through technology-specific tendering with a market premium model. | 1 | 1 | 2 |
| 9 | In space heating and mobility, the ambitious decarbonisation plans cannot be achieved with green electricity alone. | 1 | -4 | 3 |
| 10 | The expansion of biomethane plants would further increase the pressure on nature. | -4 | 1 | -4 |
| 11 | In Austria, there is little risk that the use of energy crops for biomethane production will lead to competition with food and feed production. | -2 | -3 | -2 |
| 12 | In the future, biomethane plants should mainly be operated by energy suppliers; farmers should primarily act as raw material suppliers. | -1 | -1 | -4 |
| 13 | The gas industry lacks the expertise to operate biomethane plants. | -3 | 0 | 1 |
| 14 | Austria has the potential and technological knowhow to play a pioneering role in biomethane production. | 2 | -1 | 3 |
| 15 | To ensure a low-carbon energy supply, it will be important to use all available storage and conversion options. | 2 | 2 | 4 |
| 16 | Biomethane will not be able to meet the industry's demand for renewable gas, even if we can reduce gas demand and tap all available biogenic sources for production. | 0 | 4 | 2 |
| 17 | The conversion of manure into electrical or thermal energy makes sense from an energy policy point of view. | 2 | 0 | 4 |
| 18 | Biomethane will help make the energy transition affordable. | 3 | -3 | 0 |
| 19 | Biomethane should be promoted with a quota system (i.e., a mandatory share in the gas grid). | -1 | -2 | -2 |
| 20 | Without customers from the residential sector, the development of a biomethane market will not be possible. | 0 | -3 | -3 |
| 21 | The biomethane market has one central problem: fossil gas is cheaper. | -1 | 2 | 1 |
| 22 | Main crops such as maize should not be used in biomethane production for ethical reasons. | -1 | 1 | -4 |
| 23 | The technically exploitable potential of residues will never be sufficient to achieve the goals set by the gas industry (decarbonisation of gas supply for households). | -3 | 3 | -1 |
| 24 | Gas, especially green gas like biomethane, is needed as a bridging technology. | 2 | 0 | -1 |
| 25 | Biomethane is of very high value and should be used where it is most efficient. | 1 | 4 | 0 |
| 26 | Biomethane can be stored well and is therefore ideal for complementing pumped storage plants, which is needed in the electricity sector. | 4 | 2 | 1 |
| 27 | For the approximately one million Austrian households that currently heat with gas, a switch to green gas is possible without further investment. | 3 | -4 | 0 |
| 28 | Although small-scale plants are currently comparatively expensive, they should be promoted as well. | -1 | -1 | -1 |
| 29 | Biomethane as a fuel for heavy trucks is a good alternative to diesel and would thus be a significant step towards a low-carbon transport system. | 0 | 0 | 1 |
| 30 | In the future, biomethane should play a role everywhere, including in households. | 3 | -4 | -2 |
| 31 | The use of main crops such as maize should be avoided in biomethane production due to price fluctuations. | 0 | 0 | -3 |
| 32 | In future, biomethane should mainly be produced in large plants - small plants are too expensive. | 1 | -1 | -3 |
| 33 | Biomethane and other green gases are an important key for the energy transition. | 4 | 3 | 2 |
| 34 | To be able to manage the energy transition, the switch to green gas must be made as quickly as possible. | 4 | -2 | -1 |
| 35 | The larger the plants, the greater the logistical problems (substrate supply and removal of fermentation residues). | -2 | 0 | 0 |
| 36 | The "green gas" label is used for greenwashing. | -4 | -1 | 0 |

* Own translation from German statements.
** Each factor represents a narrative which is formed from a group of participants who sorted the statements in a similar way.

products by generating electricity from energy crops seemed to have become unfeasible in economic terms and problematic in normative terms. Plant operators began to experiment with residual materials and were already sharing their experiences in so-called 'operator meetings' when the commodity prices increased in 2007 (Oprt3-11; Ind4).[12] This trend of moving towards residual materials continued and manifested itself on the regulatory level, albeit with a significant time lag. It was only in 2017, when a maximum limit of 30% cereals and maize was specified in the Green Electricity Act (BGBl. I Nr. 108/2017). Furthermore, the promotion of new biogas plants was limited to small-scale facilities, which marked the end of the 'traditional' biogas frame. Those plants that reached the end of the 13-year contract received a successor tariff (BGBl. II Nr. 201/2017). However, this tariff was limited to three years and was only agreed upon after a long period of negotiations (Ind3-4; Oprt7,8,11).[13]

#### *4.1.6. Renewed expectations about biomethane (2018-2021)*

In the previous period, the biomethane frame was overshadowed by the breakdown of the traditional biogas frame, whereas in this period, positive expectations re-emerged both at the policy level and in the public discourse (Fig. 3). Against the background of national decarbonisation goals and a change in the government (the prior governments had been led by the Social Democratic Party, but

[12] See Fig. A1 in the Appendix for the development of the substrate composition.
[13] In 2019, the tariff was expanded at the latest end of the year 2022 (BGBl. I Nr. 97/2019).

the Austrian People's Party became the leading party again in 2018), biomethane became increasingly perceived as an integral part of the required energy transition (Ind3; Off4,6). Along these lines, the government's national climate and energy strategy published in 2018 suggested that a "significant share" of natural gas should be replaced by biomethane (BMNT and BVIT, 2019:17). At the same time, the strategy explicitly associated biomethane with the use of residual materials, substantiating the paradigm shift away from the use of energy crops.

The renewed interest in biomethane was also strongly related to the gas industry, where the decarbonisation goals were being taken increasingly seriously. Along these lines, an executive member from the industry said (Ind7) '*[After the Paris Agreement] we have clearly recognised a tendency that natural gas will eventually pushed out from the market (…) so I am convinced that we are at the beginning of a fundamental transition process.*' In an effort to achieve the vision to maintain the usefulness of Austria's dense gas grid by replacing natural gas with renewable gas, the gas industry became a key actor in the emerging biomethane discourse (Ind7; Res1-2; Off7). It financed studies on the technology's potential (e.g. Lindorfer et al., 2017; Höher et al. 2019; Dißauer et al. 2019) and developed a 'greening the gas' strategy (www.gruenes-gas.at), which was incorporated into the above-mentioned climate and energy strategy and received frequent media coverage.

Compared to the biogas frame, however, the 'momentum' of the emerging biomethane frame has been much lower. The expectation from members of the gas industry that many operators of existing biogas plants would upgrade their systems and produce biomethane has not been fulfilled. Furthermore, media attention levels have been moderate and only rose significantly in 2021 (Fig. 3). At the same time, a new framing struggle arose when the projected potential of biomethane in replacing natural gas was called into question (e.g. Wehrle and Schmidt, 2021). In the media, this struggle appeared in confrontational opinion pieces in the liberal newspaper *Der Standard*, sent in by a leading executive of the gas industry and a former director of the Chamber of Agriculture (*Der Standard* 2021-02-04; 2021-02-08). While the Chamber of Agriculture had been the key proponent of the past biogas frame, the Chamber's former director now strongly criticised the gas industry for creating highly unrealistic expectations about biomethane. The fact that the topic of biomethane was largely omitted from the long-awaited Renewable Energy Expansion Act (BGBl. I Nr. 150/2021) shows that this framing struggle also affected the policy arena (where in 2020 the Green Party entered the government as a coalition partner of the Austrian People's Party).

### 4.2. Competing narratives about biomethane

In this section, we describe the previously mentioned framing struggles about biomethane in detail by discussing the three competing narratives that were identified in the Q-study (Table 3): the (i) *Greening the gas*, (ii) *Champagne of the energy transition*, and (iii) *Energy farmer 2.0* narratives (Factors 1-3, respectively). By juxtaposing these narratives, we see that the framing struggles about biomethane are not merely related to the feasibility of substituting natural gas through biomethane (14, 35), but to a range of additional aspects, including prospective application areas (4,30,2), the risk of increasing environmental pressures (10), the roles of energy crops (6, 22), the urgency of upscaling production (34), expected costs (27,2,18), as well as the ownership and size of prospective plants (13,32). The factor loadings of the participants and the distinguishing statements for each narrative are shown in Supplement C.

#### 4.2.1. "Greening the gas"

According to this narrative, biomethane is an energy carrier that will play a key role in the energy transition (33). It is emphasized that the switch to biomethane needs to be made as quickly as possible (34). The energy carrier will be used to provide heat, in particular in the residential sector (30,5). In addition, it will provide important balancing power in a renewable-based electricity system (26). A switch to biomethane in the residential sector is seen as possible without making massive investments (27). Biomethane is generally seen as a cost-efficient and sufficiently available renewable energy carrier (2,21,23) that will make the energy transition affordable (18). The narrative also emphasises the need to build large-scale plants (32), does not anticipate logistic problems to arise with such plants (35), and regards the gas industry as being in a good position and having sufficient knowledge to run these plants (13). Furthermore, it does not associate the future expansion of biomethane production with increasing environmental pressure (10). At the same time, the risk that distortions occur in the food and feed industry is acknowledged (11). Thus, the use of maize or other renewable feedstocks as substrate materials is not supported (6,3). Finally, the narrative views the gas industry's 'green gas' strategy as a genuine effort to decarbonise the industry (36).

#### 4.2.2. "Champagne of the energy transition"

Like the *Greening the gas* narrative, this narrative emphasises the important role biomethane will play in the energy transition (33). However, upscaling biomethane production is seen as less urgent (34), and serious doubts about the availability of usable residual materials are expressed (23). Generally, the quantitative potential of renewable gas is viewed as limited, and its use is associated with high costs (2, 21, 18). Accordingly, biomethane is considered as a highly valuable energy carrier that should be only used where it is most efficient and where no other decarbonisation alternatives exist (25); i.e this is, first and foremost, the industry and the electricity sector (long-term storage) (5, 15, 26). In the residential sector as well as in the mobility sector, biomethane will not be needed (29, 30), since the use of renewable electricity constitutes a better decarbonisation option (9). In fact, using biomethane in the residential sector would not only be expensive (27), but would block the path to decarbonising the industry (4). At the same time, it is emphasised that biomethane will not be able to meet the industry's demand for renewable gas, even if this demand were reduced and all available biogenic sources were used for biomethane production (16). Aware of a potential competition with feed and food production (11, 22), the use of maize is not supported (6), although the option of using renewable feedstocks is not categorically excluded (3). Finally, a

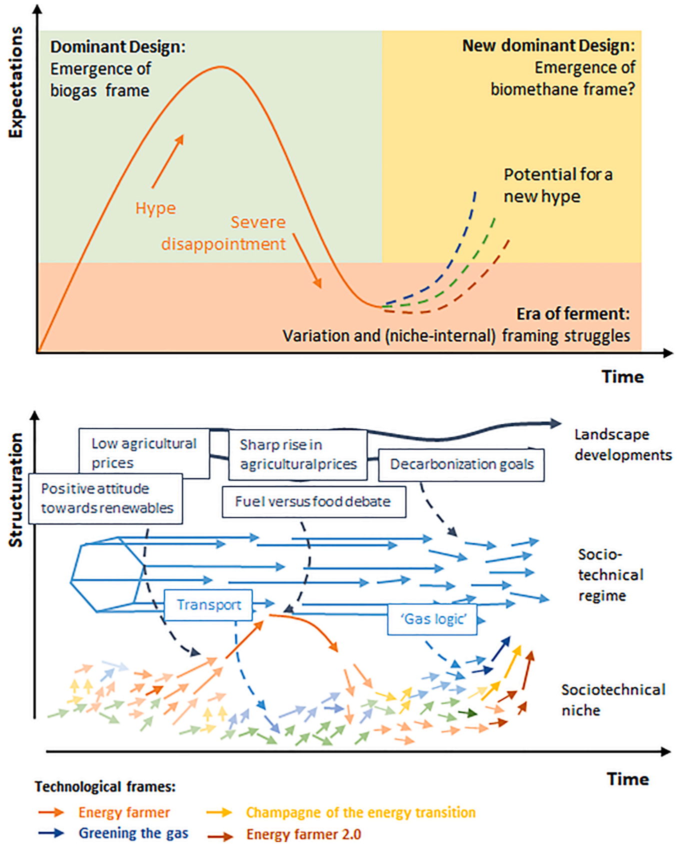


**Fig. 6.** Linkages among hype cycle, framing, and transitions dynamics. Adapted from Fenn and Raskino (2008) and Geels (2002).

comparatively strong awareness exists of the risk that upscaling biomethane production could increase the pressure on nature (10).

#### 4.2.3. *"Energy farmer 2.0"*

In this narrative, biomethane is strongly associated with the creation of jobs and local economic activity (7). It views Austria as being in a good position in terms of potential and technological expertise, allowing the country to play a pioneering role in biomethane production (14). Furthermore, the farmers are envisioned as the main operators of biomethane plants, rather than the energy companies (12, 13), and smaller plants are regarded as reasonable as well (32). Along these lines, and in contrast to the previous narratives, the use of renewable feedstocks as a substrate material is strongly supported (3), and the continuing use of maize is not clearly rejected (6). Although the risk of distortions in the food and feed industry are acknowledged (11), using main crops as a substrate for biomethane production is not seen as unethical per se (22). Furthermore, price fluctuations that might be associated with main crops are not seen as reasons to avoid their use (31). Supporting the use of manure is also seen as reasonable (17). A strong belief is expressed that ambitious decarbonisation plans in the heating and mobility sectors cannot be achieved by solely using renewable electricity (9), but scepticism is also observed related to the use of biomethane in the residential sector (30). As in the previous narrative, customers from the residential sector are not seen as necessary for kickstarting biomethane production (20). Still, the argument that using renewable gas in the residential sector would impede the decarbonisation of the industry is not supported (4).

### 4.3. *Analysis*

By revealing the competing narratives associated with biomethane, the Q study results complement the findings of the historical analysis and deepen our insights into the discursive struggles associated with the emergence of the biomethane frame. In a nutshell, the evolution of the hype cycle in the Austrian AD niche and its associated linkages to framing and transition dynamics can be summarised as follows (see Fig. 6 for a graphical summary):

The strong hype which the niche experienced in the early 2000s correlated with the emergence and stabilisation of the biogas frame. This frame depicted AD technology as a technology for energy crop-based and grid-connected electricity production, and was associated with a narrative that emphasised the benefits of renewable energy and the economic advantages for farmers. Thus, the technology was aligned with important landscape developments, such as low agricultural prices and positive attitude towards renewables. But the simultaneous emergence of a dominant technological design – and first steps taken to establish this design in the existing energy system – was followed by severe disappointment: Changing landscape developments (i.e. rising agricultural prices, emerging fuel versus fuel debate) made the *energy farmer* narrative implausible and eventually led to the break-up of the biogas frame. In other words, the technological field was pushed back into the era of ferment (and onto the niche level). As the landscape changed further (in pursuit of the decarbonisation goals), a new frame emerged: the biomethane frame. However, the existence of three competing narratives (or the absence of "discursive" closure) impeded the formation of widely shared optimism and simultaneously hampered the stabilisation of this frame.

## 5. Discussion and Conclusion

In this study, we used the socio-technical niche of anaerobic digestion (AD) technology in Austria as an empirical example to analyse the nature and role of framing processes in the context of severe disappointment. We described how the dominant understanding of AD technology evolved from a biogas to a biomethane frame and illustrated how this evolution was interrelated with the pronounced hype cycle that the niche has experienced over the past two decades. Furthermore, we shed light on specific narratives associated with these frames and explained the relatively slow uptake of the biomethane frame by pointing out the existence of three competing narratives. Finally, our findings illustrate the linkages between dominant frames and alignments with wider landscape developments, emphasising the important roles of narratives in establishing these linkages.

While the identified developments reflect the stylised hype cycle trajectory derived in the theory section, they also provide insights that were not considered in our theoretical analysis. First, a process of closure does not necessarily mean that all subsequent search directions are in line with the dominant technological frame and their associated narratives. This observation coincides with that of Lazarevic and Valve (2020), who highlighted the persisting variety of different "niche configurations" that are found in the AD niche (and in niches in general). The emerging expectations about using biogas in the transport sector are a good example of this. While these expectations already reflect the logic of the biomethane frame, they appeared when the institutionalisation of the biogas frame was at its height (i.e. the frame became increasingly embedded in the energy regime). In fact, they emerged in the slipstream of the breakthrough of the biogas frame, indicating that the stabilisation of one niche configuration can positively impact the formation of alternative expectations in the niche. However, this mechanism worked in both directions, since the severe disappointment about biogas also led to the disappearance of transport expectations (as well as the associated, and still rather tentative, innovation activities).

Second, our analysis results stress the important roles of established (regime) actors in shaping discursive dynamics in the niche. This is most obvious in the case of the biomethane frame, where the gas industry became a key actor within the associated discourse coalition (Hajer, 1996). While the overall idea of establishing biomethane as a renewable gas was widely shared among the members of this coalition, the gas industry brought in its own ideas and expectations (e.g. a focus on the residential sector or highly optimistic expectations about resource availability), which eventually led to the emergence of a distinct technological narrative (*greening the gas*). This observation underlines that of Kaplan and Tripsas (2008), who emphasised that actors in emerging technological fields aim to create a collective technological understanding that favours their own interests. But it also adds to the rising transitions literature on the connections between framing and politics (Lee and Hess, 2019; Hess, 2018; Rosenbloom, 2018) as well as to the debates about the complex roles of incumbents during transitions (Smink et al. 2015; Wesseling et al. 2022; Berggren et al. 2015; Turnheim and Sovacool, 2020; Hansen and Steen, 2015).

Third, our findings highlight the evolutionary nature of technological frames. The emergence of the three competing narratives about biomethane could hardly be explained without referring to the preceding biogas hype cycle. While the *energy farmer 2.0* narrative can be understood as a relic from the biogas hype that has survived, the two other narratives were shaped by collective learning, i.e. the sense of disappointment regarding the use of energy crops (as both narratives are characterised by a strong emphasis on residuals). At the same time, however, the disregard of resource scarcity that has been associated with the *greening the gas* narrative shows remarkable parallels with the (failed) *energy farmer* narrative. This might be explained by the similar constellation of strategic interests held by the actors behind these narratives. Like members of the agricultural industry in the beginning of the 2000s, members of the gas industry believed that anaerobic digestion could be the solution to their deteriorating market prospects, and, in both cases, the prospect of resource scarcity challenged the plausibility of this belief.

From a policy perspective, these findings emphasise the importance of acknowledging the historical context of emerging niches when assessing and reacting to associated discursive dynamics. Reflecting on the historical evolution allows decision-makers to put existing frames into perspective and helps them to identify futile narratives. In the case of biomethane, this is all the more important given the current energy crisis and the ever-increasing attention paid to the potential roles of green gases in substituting natural gas.

Overall, our study supports the findings of previous studies on the roles of wider institutional settings in shaping the specific course of technological expectations (Budde and Konrad, 2019; Lempiälä et al. 2019; Geels and Verhees, 2011). By elucidating discursive processes and the associated framing struggles that occur in an emerging socio-technical niche, our study also complements the existing transition research on discursive dynamics, which has mainly addressed niche-regime struggles (Mylan et al. 2019; Rosenbloom et al. 2016; Smith and Raven, 2012) or struggles among different niches (Mutter and Rohracher, 2021; Magnusson et al. 2020; Lin and Sovacool, 2020). Finally, our study offers a conceptualisation of the linkages among emerging technological frames (and their associated narratives), hype cycles, and transition dynamics.

Our study has several limitations which offer interesting avenues for future research. First, while we have analysed a country in which the biomethane trajectory is still at a very early stage, other countries such as the UK, Denmark, or Sweden have already ramped up their biomethane production. Analysing the underlying framing dynamics in these countries would help identify country-specific differences and provide important insights into processes by which framing struggles have been overcome. Second, our focus on the

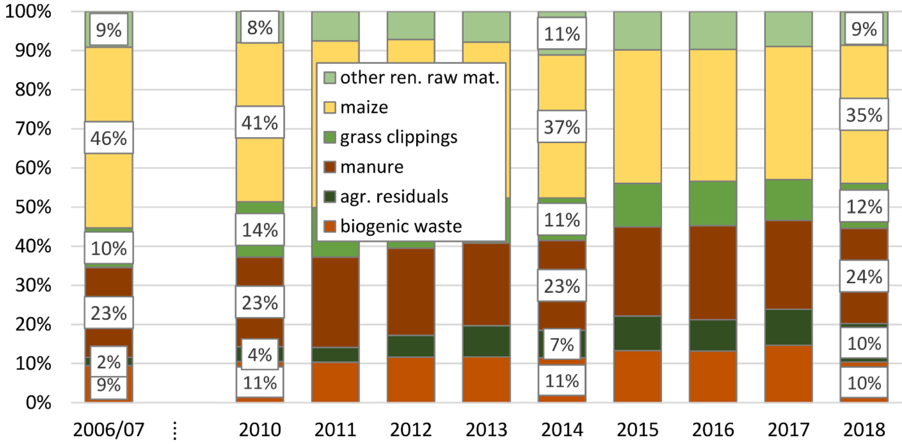


**Fig. A.1.** Development of substrate composition (mass ratio). Source: BMNT - Bundesministerium für Nachhaltigkeit und Tourismus (2019).

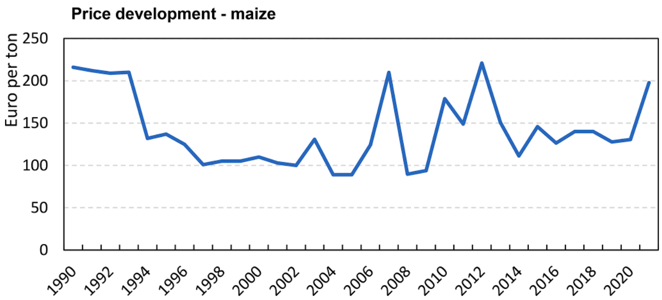


**Fig. A.2.** Historical development of the price of corn in Austria (annual average). Source: Statistics Austria.

evolution of a specific technological field questions the extent to which our findings can be extrapolated to other fields. Niches that are less dependent on government support, for instance, might be associated with different framing dynamics, as they are less vulnerable to a (perceived) incoherence between the established frame and developments in the wider socio-technical context (Konrad et al. 2012). Third, our analysis provides only limited insights into policymaking processes. Based on previous work on the relationship between hypes and policymaking (Melton et al. 2016: Budde and Konrad, 2019), it would be interesting to more carefully analyse how policymakers perceive and act upon hype cycle and associated framing dynamics.

## Declaration of Competing Interest

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 paper.

## Data availability

Data will be made available on request.

## Acknowledgments

The authors thank Günter Getzinger and two anonymous reviewers for their helpful comments and suggestions. Furthermore, they would like to thank Alexander Faustini, Elisa Heitzinger, Marina Linortner and Philipp Malle for their support in the data collection process. Michael Kriechbaum gratefully acknowledges funding by the Austrian Science Fund (FWF) (grant number P 35345) and the Styrian Government (IAS-STS Manfred Heindler grant).

## Appendix

See Figs. A.1-A.2.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.eist.2023.100724.

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