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Agency and structure in a sociotechnical transition: Hydrogen fuel cells, conjunctural knowledge and structuration in Europe

Abstract

Despite each level of the multilevel perspective of sociotechnical transitions reflecting a different degree of structuration, structuration perspectives have been little used to help explain sociotechnical change and stasis. Here we show how 'strong structuration' can be used to theorise the role of agency in sociotechnical systems in a way that brings together psychological and sociological perspectives. Strong structuration gives weight not only to actors' practices, but also to their experiences. Practices and structures are viewed as mutually influencing, as in Giddens' original conception, but the role of situated, subjective experience is also explicitly acknowledged. Applying this perspective, we show how individual attitudes and beliefs in relation to a niche energy technology are influenced by experience of national economic and innovation policy environments, with in turn implications for expectations of action by self and others. The overall aim is to illustrate a framework that connects individual psychology to practice, with implications for sociotechnical structure. For this purpose we draw on case study data of European R&D stakeholder opinion of stationary hydrogen fuel cell applications for heat and power, focusing particularly on the contrasting situations of the UK, Germany and Spain.

1 Introduction

Residential-scale, fuel cell-based, combined heat and power (CHP) units are among the micro-level options for generating lower carbon heat and electricity, particularly where the energy vector is produced using renewable energy. Home fuel cells should have no harmful emissions at the point of use and have reached a commercialisation stage in several countries (e.g. Japan, South Korea and the United States) (Ammermann et al., 2015). Although the technology is expected to remain comparatively expensive in the short and medium term, in the long term, home fuel cells are perceived in some quarters as having mass-market potential – though only if costs can be reduced (ibid). Key among the ways to reduce those costs is production scale-up, but this will require increased demand, which will in turn requires public policy support in terms of, for example, subsidy to reduce the cost of the initial investment (ibid). As for other low carbon energy technologies, where governments make a sustained, public commitment, so does the willingness of other actors to commit increase. In this respect, action follows from shared positive expectations about the prospects for the technology and hence positive prospects for those making some form of investment in that technology. Defining

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expectations as beliefs about the future, we can say that beliefs, including attitudinal beliefs (beliefs that inform attitudes), both individual and collective, are important to sociotechnical processes. Yet whereas beliefs, attitudes and knowledge are viewed as important influences on behaviour from psychological perspectives (e.g. Fishbein and Ajzen, 1975), to date there has been little use of such accounts in the sociotechnical, sustainability transitions literature, partly for reasons that we discuss below. Here we are interested in not only describing and illustrating the interconnected role of attitudes, beliefs and knowledge in sociotechnical transitions, specifically sustainability-related transitions, but in framework-level, theoretical synthesis of psychological and sociological analyses. In principle there is the opportunity to bring together psychological accounts of individual-level processes with sociological accounts of practice-structure relationships, to give an account that connects actor psychology to sociotechnical change while drawing on the strengths of two perspectives.

Accounts of behaviour or agency that seek to retain ontological consistency with the most well-known contemporary model of sociotechnical change in the sustainability transitions literature - the multi-level perspective (Geels, 2002) – need to use a sociological perspective, in the sense of deploying terms relating to inter-individual (social) processes and structures. One of the most influential and debated of such accounts is structuration theory (Giddens 1984), which also underpins the multi-level perspective (MLP). To briefly rehearse, the MLP, three levels of interacting phenomena are posited (the niche, regime and the landscape), representing three different degrees of structuration (Geels and Schot, 2007; Grin et al., 2010: 44-47). To some extent one could say ‘different degrees of institutionalisation’, but structuration refers more specifically to practices and their role in the maintenance and reproduction of social structures (Giddens, 1984). Geels’ and Schot’s (2007) argument is that activities in the niche have less stabilized practices than in the regime. Niches are the protected spaces where entrepreneurs and innovators are active, where sociotechnical novelties arise and are nurtured (e.g. where new energy technologies receive various forms of subsidy); the regime is the mainstream, pre-existing system of more strongly embedded and institutionalised technologies and practices, with which niche innovations need to compete or supplement; and longer term, slower-changing background phenomena such as social values and culture, are conceptually allocated to the landscape level. The MLP framework is a heuristic intended to aid thinking about sociotechnical processes, draws on innovation studies, evolutionary economics and science and technology studies perspectives and invites supplementary accounts of process details (Geels, 2011).

Although (perhaps surprisingly) structuration per se has been given rather little attention in the transitions literature (Fuenfschilling and Truffer, 2014), as said, more widely it is a highly influential account of the ways in which social structures are created and maintained. Structuration focuses primarily on the role of agents or actors in these processes, in relation to their practices (Giddens, 1984). At the same time, Giddens' approach has been critiqued for an unsophisticated description of agents' *situated* motivations, reflexive monitoring and knowledgeability, through which they navigate other agents and institutionalised practices (Stones, 2005; Frie, 2011; Coad et al, 2015). That is, although Giddens (1984) gave a pivotal role to agents, he was not concerned with addressing their psychology in any depth: processes and constructs posited as operating within individuals, such as attitudes, beliefs and degree of knowledge, were given considerably less theoretical and empirical attention. Similarly, although cognitive aspects of regimes, including shared beliefs, are recognised as an important set of components of the regime (Geels, 2002), again there is little related use of individual-level (or even organisational-level) psychological literature in the sociotechnical, sustainability transitions literature.

While theoretical integration of psychological and sociological accounts is not possible and indeed contentious (Shove, 2010), it is possible to juxtapose such accounts within over-arching frameworks. Examples include the energy cultures framework (Stephenson, 2010) and the ISM (Individual, Social and Material) framework of behaviour change (Southerton et al, 2011). For the same purpose, but seeking tighter theoretical integration, here we use a particular extension of Giddens structuration approach – 'strong structuration' (Stones, 2005) – which is designed to include actor psychology in a four-fold account of how actors change structures. We show how actor perceptions of a particular technology (home fuel cells for heat and power) are conditioned by their own experience and situations – organisational, regional and national – and how these perceptions have implications for both their own actions and for the actions of others. We also highlight the extent to which actor views are focused on the anticipated actions of other actors and the way in which this mutual assessment and observation forms a significant part of what Stones (2005) characterises as 'conjunctural' knowledge. In this context, conjunctural knowledge is knowledge of the specific causes and trends present and operating in the moment, as perceived by the individual concerned and can here considered synonymous with situated knowledge in the sense of being experientially-conditioned¹.

¹ The term 'conjuncture' and its derivatives originate in the political science philosophy of Marx and others (e.g. Gramsci). A conjuncture is thus the coming-together of several pre-existing trends at a specific point in time, giving rise to a new situation in a way that is not pre-determined, but the origins of which can nonetheless be

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We suggest that strong structuration (Stones, 2005) is well-suited to the role of connecting psychological and sociotechnical accounts, through its broad scope, that extends from individual experience to system- or structure-level processes².

Stones' (2005) perspective is thus a four-element framework developed from Giddens' structuration theory; it is summarised in Figure 1 in relation to the MLP and is explained further in section 2.1. The value of the perspective when thinking about socio-technical transitions processes is that it both draws attention to the importance of individual agents' viewpoints and provides a theoretical connection of these to transitions processes. An important feature of the approach is its allowance for methodological bracketing (ibid), which in turn allows for use of multiple methods, epistemologies and indeed ontologies, as a phenomenon is studied in complementary ways in order to gain a fuller account. This clearly raises many issues relating to paradigmatic commensurability, but here we follow Feyerabend (1962), taking the view that the extent of commensurability between theories (and hence implicitly methods and disciplinary perspectives) is ultimately a matter of interpretation, leaving much to be gained from a multi-paradigmatic research approach (e.g. Hassard, 1993; Turnbull, 2002), particularly where one is working within a multi-level framing of interacting processes (such as the MLP) that benefit from different forms and levels of analysis.

In terms of further definitions, socio-technical systems are understood as 'the linkages between elements necessary to fulfil societal functions (e.g. transport, communication, nutrition)' (Geels, 2004: 900). Such elements consist of resources such as technologies, artefacts, knowledge, capital, labour, cultural meaning, etc. Agency plays a pivotal role in socio-technical processes and is acknowledged as such in research agendas on socio-technical transitions (STRN, 2010). While agents themselves are viewed as critical in the socio-technical transitions literature (e.g. Genus and Coles, 2008; Geels, 2011; Pesch, 2014; Rauschmayer et al, 2015) and their structuring practices as likewise (Geels and Schot, 2007), there has been little work explicitly emphasising the sequence of connections between agents'

observed post-hoc. For political actors, understanding the nature of any given conjuncture is important for successful intervention (Brill, 2012). It is not difficult to see the relevance of this to the overall project of sustainability transitions, particularly in terms of understanding how sociotechnical systems inter-relate with political processes.

² We use the terms system and structure loosely, to denote sociotechnical regularities of a 'demi-reg' nature, i.e. regularities that are 'sometimes but not always' (Fleetwood, 2016): "Demi-regs are event regularities, but not deterministic or stochastic, event regularities" (ibid: 60). This represents a particular view of the nature of social life, or, more simply, of people. It follows that people are sometimes, but not always, predictable. Agency is defined broadly, as: "the human capacity for reflective action and choice" (Frie, 2011: 341).

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locally situated perceptions of their contexts – their lived experience (e.g. Shotter, 2005) of technologies - and of sociotechnical processes. The application of a strong structuration perspective builds on the limited sub-literature on the structuration of sociotechnical systems to date (Fuenfschilling and Truffer, 2014) (Hermwille 2016), but more explicitly connects the micro-level of individual experience to the structuration processes relevant to sociotechnical change and stasis at the niche, regime and landscape levels.

In terms of the structure of the paper, we first provide an overview of strong structuration, outlining the approach, its rationale and its relevance to understanding sociotechnical transitions processes, for which purpose we refer to Geels' (2002) multilevel perspective. We then refer to the case study with which we illustrate the value of a strong structuration approach, as a way of connecting the situated experiences and hence perceptions of agents to the broader structures in which they operate. We draw from illustrative opinions elicited in interviews with European R&D actors on hydrogen fuel cell (HFC) systems, focusing here on HFCs for the provision of heat and/or electric power in stationary contexts. We aim to illustrate a way of conceptually connecting the psychological, sociological and technical aspects of system change, in recognition of their connectedness in practice and also in recognition of the role of structures. In so doing, we discuss the relevance of the approach for the MLP model of sociotechnical change.

2 Theory

2.1 Strong structuration and conjunctural knowledge

From a structuration perspective, social structures exist and function through agents' actions, which assign specific roles and meanings to those structures (Grin et al., 2010: 233). Giddens' theory of *agency-structure as practice* (1984) constitutes a seminal insight into the relationship between agency and structure, specifically via three elements: signification, relating to discourse; legitimation, relating to values, norms and standards; and domination, relating to control over resources. Yet the relatively abstract nature of structuration theory has been critiqued for neglecting situated detail, particularly actor psychology (such as motivations, attitudes, beliefs and knowledge) and their contexts (including organisational positions and roles) (Stones, 2005).

Accordingly, the 'strong structuration' framework was developed to explicitly account for agents' internal worlds as a neglected element of organisational and wider structural change (Stones, 2005).

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Extending Giddens' theory, strong structuration posits four elements: *external structures* that condition the actions of agents; *internal, psychological structures* within agents; an assumption of *active, intentional agency*; and *outcomes* that are internal and/or external to the agent (Stones, 2005; Schwandt et al, 2012; Fjellstedt, 2015). With the MLP providing a conceptualisation of the external structures of interest here, Figure 1 depicts Stones' (2005) strong structuration approach in relation to the basic levels of the MLP and to sociotechnical sustainability transitions features and processes more generally. In fact Stones' approach (2005) is briefly acknowledged by Geels and Schot (2010) as a structuration approach of relevance for the analysis of motivations, perceptions, aims and interests of actors in local projects and niches, but to our knowledge has not been pursued for this purpose.

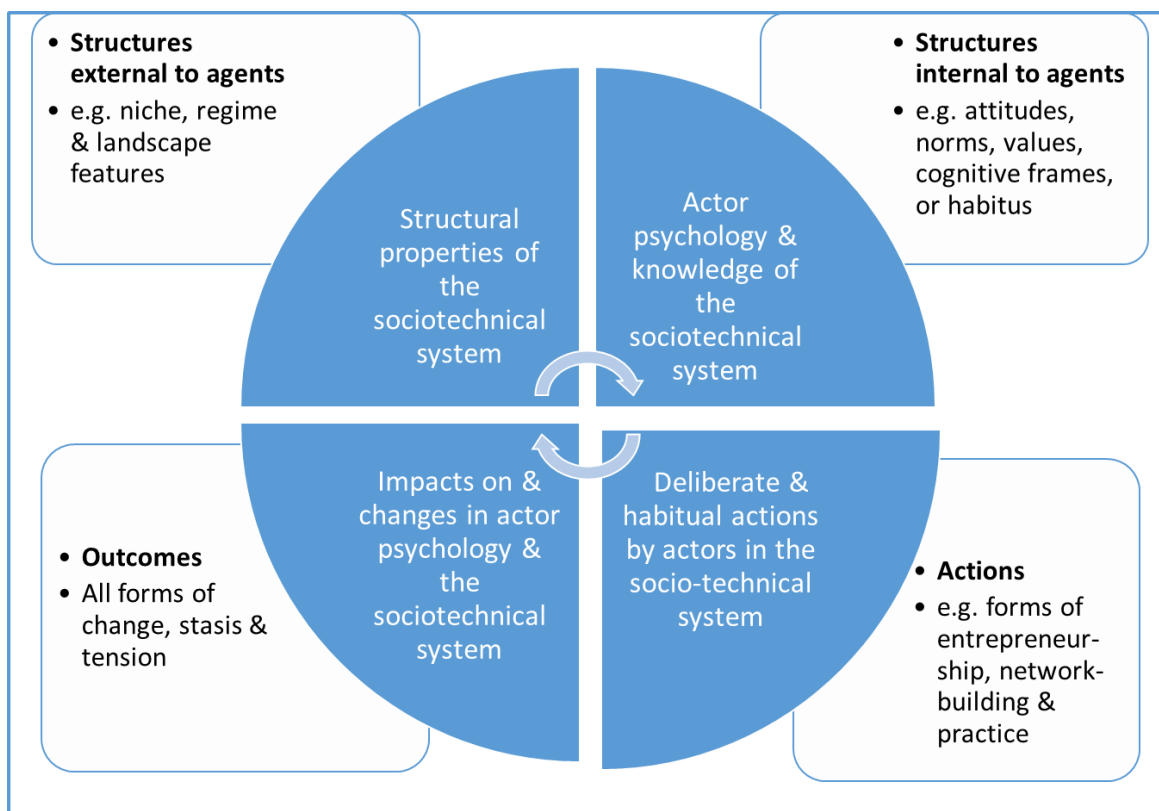


Figure 1: Application of the strong structuration framework (Stones, 2005) to elements of socio-technical change

Note: methodological bracketing supports the use of different types of analysis (i.e. different methodologies and different disciplinary perspectives) in each quadrant, in a sequence of closely related studies that are designed

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to reveal the connections between individual and structure-level processes in more detail than can be achieved with a mono-disciplinary approach.

Stones (2005) elaborates the four elements as follows: *external structures* are understood as separate from the agent and set boundary conditions; in a socio-technical context they include laws, regulations, formal and informal institutions, policies and organisations. *Internal structures* are divided into two classes: those that are *general-dispositional* (including habitus, norms, values³, attitudes, worldview etc, depending on one's analytic frame) and those that are *conjunctural*, relating to agents' knowledge and understanding of their immediate and wider context. While these two classes are analytically distinct, in practice they may overlap. *Actions* (active agency) relate to processes of thoughtful, sometimes strategic action: in this context, active agency would include all forms of entrepreneurship, lobbying, coalition-building, resistance and 'mindful deviation' (Garud and Karnøe, 2001) in general. *Outcomes* are any consequence of the foregoing for the agents and their structural context, here including all forms of socio-technical pathway and the tensions that these comprise.

As a theoretical perspective, strong structuration has most commonly been applied to understanding the connections between individual action and organizational processes and outcomes (e.g. Schwandt et al, 2012). However Greenhalgh and Stones (2010) also discuss the relevance of strong structuration for socio-technical contexts at an intra-organisational level, focusing on new healthcare technology, where a key issue is its role in influencing micro-social structures or 'position-practices' within a hospital. Fjellstedt (2015) takes a similar case, analysing resistance to change. Yet there is no reason to limit the analytic boundary to which a strong structuration framework may be applied. In the context of the MLP, this is particularly so, given that the latter is, as said, explicitly premised on three different levels of sociotechnical structuration. Figure 2 describes the relationships of agency, practice and sociotechnical structure at a general level, whereby agents are influenced by their subjective experience, habitus and individual interpretations of events; these influence practices that reproduce, maintain or (less commonly) change structures.

³ It should be noted that dominant values, in so far as they are slow-changing, can be conceptually located at the 'landscape' level; however their expression is through individuals and their organising practices at the regime level.

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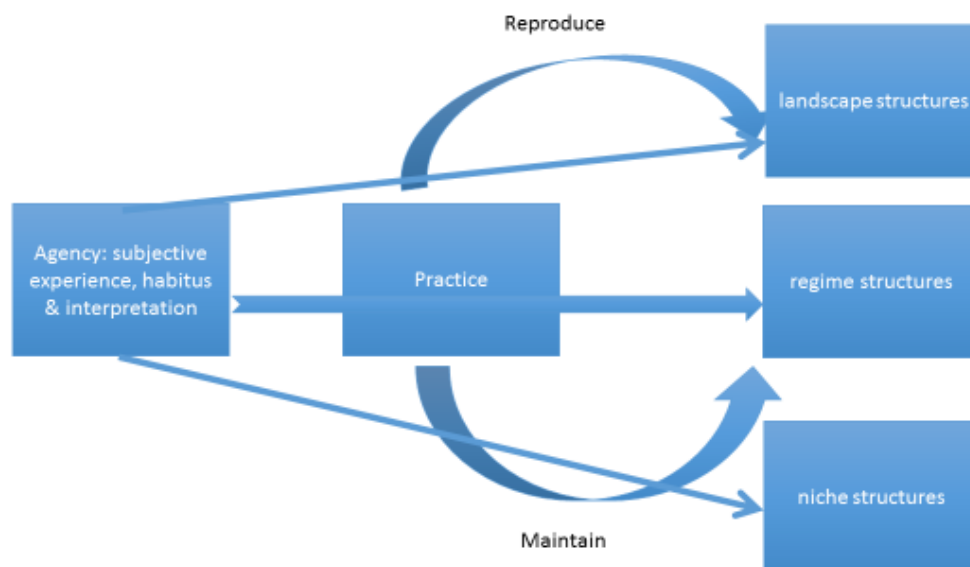


Figure 2 The relationships of agency, practice and sociotechnical structure

There are further, more specific reasons for extending Giddens' original (1984) conception of structuration to include additional processes. As Coad et al (2015) observe, whereas Giddens' (1984) theory of structuration characterises structure and agency as mutually constitutive and hence inseparable elements, Stones (2005) and others have argued that this has theoretical disadvantages, particularly the 'fallacy of central conflation': the tendency to see structure as so closely intertwined with every aspect of practice that 'the constituent components cannot be examined separately ... In the absence of any degree of autonomy, it becomes impossible to examine their interplay' (Archer, 1988, pp. 77, 80, in Coad et al, 2015).

For these reasons, it has been argued that understanding the interrelationships between structure and agency requires an analytical dualism, while also affirming the insights of practice theorists that practices connects agency and structure, reproducing and maintaining the latter (Archer 1995, Stones 2005, Coad et al 2015). Moreover, Giddens' assumption about active, reflexive agents is consistent with the proposition within strong structuration that agents can act to choose between alternative structures (Kilfoyle and Richardson, 2011; Coad et al, 2015). Jack and Kholeif (2007) describe Stones' emphasis on actors' subjective experience and interpretation of the world, as well as their practice, in recreating and/or changing social structures:

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“... structure and action are not contemplated in abstract but observed in concrete situations, through the why, where and what of everyday occurrence, and through understanding the dispositions and practices of agents.” (Jack and Kholeif, 2007: 211).

In Figure 1, this subjective experience is located in the top right quadrant. In summary, Stones’ (2005) framework, despite an extended and arguably cogent rationale, consists essentially of a conceptual frame that supports the formal juxtaposition and connection of differing types of analysis. Yet this has significant implications for the analysis of social – and here sociotechnical – phenomena, through the enabling of a much fuller analysis and the inclusion – if useful – of analytic approaches that have differing ontologies. In the next sections, we first describe how we elicited and coded stakeholder perceptions of hydrogen fuel cells for stationary applications (heat and electric power). Identifying relevant attitudes, beliefs and experience-based knowledge, we use these to illustrate the value of Stones’ (2005) framework.

3 Case study

3.1 Method

The views summarised below are taken from a total of 145 semi-structured interviews of stakeholders involved in hydrogen and its mobile and stationary applications in five EU countries: France, Germany, Spain, Slovenia and United Kingdom. For reasons of limited space, here we present data on only the UK, Germany and Spain. The majority of interviewees work in a private company or in publicly funded research organisations; others are from government organizations and some from other non-profit organizations. Interviewees were recruited from large directories drawn together by the Hyacinth project⁴ partners with the intention of gaining a spread of opinion across the hydrogen and hydrogen fuel cell R&D community. The percentage split of interviewee numbers (n=145) by country location was: Spain 27%, Germany 23% and UK 16%, with France and Slovenia (not presented here) constituting 26% and 8% respectively. Table 1 gives the affiliations of interviewees from the countries considered here. Illustrative quotations are numbered to assist subsequent referencing and broad rather than specific interviewee affiliations are given, to avoid identification. Interviews were undertaken in the spring of 2016 in person and by telephone, on condition of anonymity. Summary transcripts were produced that retained original quotations of interest, also translated to English. These were then

⁴ <http://hyacinthproject.eu/project/>

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coded with MaxQda qualitative data analysis software, with themes condensed to a level that allowed graphical representation, given the large number of interviewees.

Table 1 Interviewee organisational affiliation by country (n)

Affiliation	ES	DE	UK
Local government	7	0	4
Public company	2	4	1
University or state research organisation	7	15	1
Multisector partnership	1	0	7
Government Ministry or agency	8	2	4
Commercial	8	16	4
Other non-profit organization	1	2	3
Total	34	39	24

The coding approach used is both quantitative and qualitative (e.g. Budd, 1967; Weber, 1990; Short et al, 2009). Most of the analytic frame and hence codes were pre-determined (i.e. a form of priori coding - Stemler, 2001), as the question themes followed the themes of a quantitative stakeholder survey that is not reported on here. Nonetheless the analytic design also allowed for open coding – i.e. for new codes arising from the data to be added (Saldana, 2011). Numerical incidence is used as an indicator of relative salience and hence thematic prominence, helping to synthesise the large number of interviews.

In addition to thematic coding, we have selected quotations to illustrate the value of the strong structuration framework. In particular, we select quotations that highlight connections between interviewees' opinions, organisational affiliations and roles; their national policy and economic contexts; their reflexive awareness of other actors and the possible, future actions of those actors; and the implications of all of this knowledge for the progress of HFCs. Taken together, this knowledge is a key *resource* in Giddens' terms and (as referred to above) includes knowledge of *rules*

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and anticipated rules at all levels (individual, organisational, governmental and beyond). However, whereas Giddens' approach to structuration is abstract – his aim was to articulate a universally-applicable theoretical approach (Stones, 2005) – strong structuration seeks to understand the relationship between agency and structure as mediated by the individual's *lived experience* (Aldous, 2014). Our premise is that this lived experience also has implications for sociotechnical dynamics and that some of these implications and connections can – at least in part - be identified via interview questioning.

3.2 Policy and practice contexts

The development and installation of hydrogen fuel cell stationary applications for power and heat are in part driven by the European Directive 2012/27/EU on energy efficiency and by the Renewable Energy Directive 2009/28/EC. Both directives are relevant to HFCs because the technology can use renewable fuel feedstock and tend to be more efficient than combustion systems (though the broader system efficiency of HFCs is contested). The Directive on energy efficiency establishes a common framework of measures for the promotion of energy efficiency within the EU in order to ensure the achievement of a 20 % headline target on energy efficiency improvement by 2020. The Directive provides indicative national energy efficiency targets (these targets can be based on primary or final energy consumption, primary or final energy savings, or energy intensity) for 2020 and paves the way for further energy efficiency improvements beyond that date. The renewable energy directive requires that 20% of the energy consumed within the European Union is renewable, when averaged across the EU.

Of the five European countries in which we interviewed stakeholders (France, Germany, Slovenia, Spain, UK), although there is HFC-related innovation activity in all, often funded or co-funded by the European Union, only Germany has a dedicated national hydrogen implementation plan. Launched in 2006 with an expected lifetime of 10 years but extended to 2026, the “Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie – NIP” (National Hydrogen and Fuel Cells Innovation Program) is a public-private partnership across several ministries and regions, with an initial, planned budget of €700m from each of government and industry (€1.4bn total). NOW GmbH (National Organisation Hydrogen and Fuel Cell Technology) was created to manage this and is responsible for the coordination and management of the NIP and the “Nationaler Entwicklungsplan Elektromobilität – NEP” (National Electromobility Development Plan), launched in 2009. As implied by

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the latter, the programme as a whole includes HFCs for all types of applications: stationary for heat and power, vehicular mobility and portable applications such as laptops, mobile phones and small generators for e.g. mobile homes, temporary or emergency purposes.

For reasons of brevity, here we quantitatively indicate the spread of interviewee opinion on stationary applications only, and also only from countries with contrasting degrees of national policy support relating to HFCs – Germany, Spain and the UK. In none of these countries do HFCs yet register in national energy supply statistics for residential consumers, but such consumers are nonetheless intended as a target market for small-medium size HFCs by manufacturers. Currently in the UK, Germany and Spain, electric power for households is almost universally supplied by national networks, although heat is supplied on an increasingly diverse basis, with more diversity in Germany than in the UK. The UK domestic heat context is still one of largely natural gas-based, individualised heating provision: as of 2015, only c.10% of households had no boiler of their own (DCLG, 2017). Until relatively recently, the UK had a strong commitment to encouraging renewable energy provision, including for heat, but the policy direction is currently less clear. In 2013, the UK issued the equivalent of a national heat strategy *The Future of Heating: Meeting the challenge* (DECC, 2013), which makes 42 references to hydrogen and which viewed domestic and industrial demand and supply in relation to one another, i.e. in systems terms, with a view to making use of waste heat. Only a few years later, the consultative 2016 *Heat in Buildings* (DBEIS, 2016) has a much narrower scope, refers to district heating once and hydrogen not at all, and focuses largely on domestic boiler design. The UK is now viewed by the EU as falling behind on renewables targets and is less than half way towards meeting its target of supplying 12% of heat from renewable sources (REA, 2017).

By contrast, Germany has, and is implementing, a 2014 National Action Plan on Energy Efficiency (NAPE) that focuses not only on the energy-efficient upgrade of buildings but also on the use of buildings and urban spaces. As a result, for example, Germany has greatly expanded its district heating share of household heating, despite oil and gas-fired boilers being the typical system in single and two-family as well as multi-family dwellings (Federal Ministry for Economic Affairs and Energy, 2015a). The result is that as of 2014, while a natural gas boiler was installed in almost one in two newly built homes in Germany (49.8%), 21.5% of new homes relied on district heating, bringing this to a total of 13.5% of all homes (Federal Ministry for Economic Affairs and Energy, 2015b).

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The policy situation for renewables as a whole in both the UK and in Germany is significantly better than in Spain, which Alonso et al. (2016) colourfully describe as ‘losing the roadmap’. By 2012, Spain was a major European player in wind power, solar thermal electricity and photovoltaics, but since then, all subsidies for renewable energy have been eliminated and this has had a severed impact on the sector (ibid). Interestingly for the present argument concerning the role of locally situated perceptions, Alonso et al (2016) emphasise that ‘the marked differences in development of RE across the Spanish regions strongly reflects the different territorial, economic and administrative circumstances in each region’, including ‘the nature of the implementation process in each region and the different types of relationships that have been developed between the stakeholders involved in the process’ (ibid: 681).

4 Results

The results are partly structured in terms of four main descriptive themes – perceived strengths, weaknesses, expectations and recommendations relating to HFCs for stationary applications. Figures 3-5 show national differences in terms of normalised percentages indicating the frequency with which particular themes are referred to, specifically in relation to the stationary use of HFCs⁵. The purpose in presenting quotations is to illustrate the importance of situated experience as an influence on the actors’ perspectives: this perspective both constitutes and reflects part of their conjunctural or situated knowledge. The contributions of the strong structuration perspective here are to emphasise: (a) the importance of subjective, situated knowledge in shaping individual expectations (future-oriented beliefs) about technologies and sociotechnical systems; and (b) that individual, subjective experience has implications for action, albeit often indirectly, such that strong structuration can offer a characterisation of the connections between individual agency, practice or action and sociotechnical change or stasis. We discuss this and the results in section 5, including with reference to the MLP.

Quotations are drawn from three countries and from different sectors for contrast, but the selection of specific individuals is not significant in itself – all of the interviewees have their own personal experience, with their own exposure to particular policy, organisational, professional and epistemic community contexts that come together to inform their own, particular ‘conjunctural knowledge’.

⁵ The normalisation adjusts for there being differing numbers of interviewees per country: there were 34 interviewees in Germany, 39 interviewees in Spain and 24 interviewees in the UK.

For this reason we do not balance equal numbers of interviewees from sectors or countries. Rather the aim is to illustrate the above and at the same time to provide some insight into the range of European opinion on hydrogen and HFCs for heat and power. Behind each of the Figures below lies this subjective experience.

In terms of perceived strengths, interviewees strongly emphasised the utility of HFCs for uninterrupted and / or portable power as a key strength (see Figure 3). To a lesser extent, reliability and efficiency (e.g. relative to battery stacks), as well as anticipation of positive societal perceptions and environmental advantages to HFCs (particularly no emission of local air pollutants and compatibility with renewable fuels) were also emphasized, with German respondents being dominant in those categories.

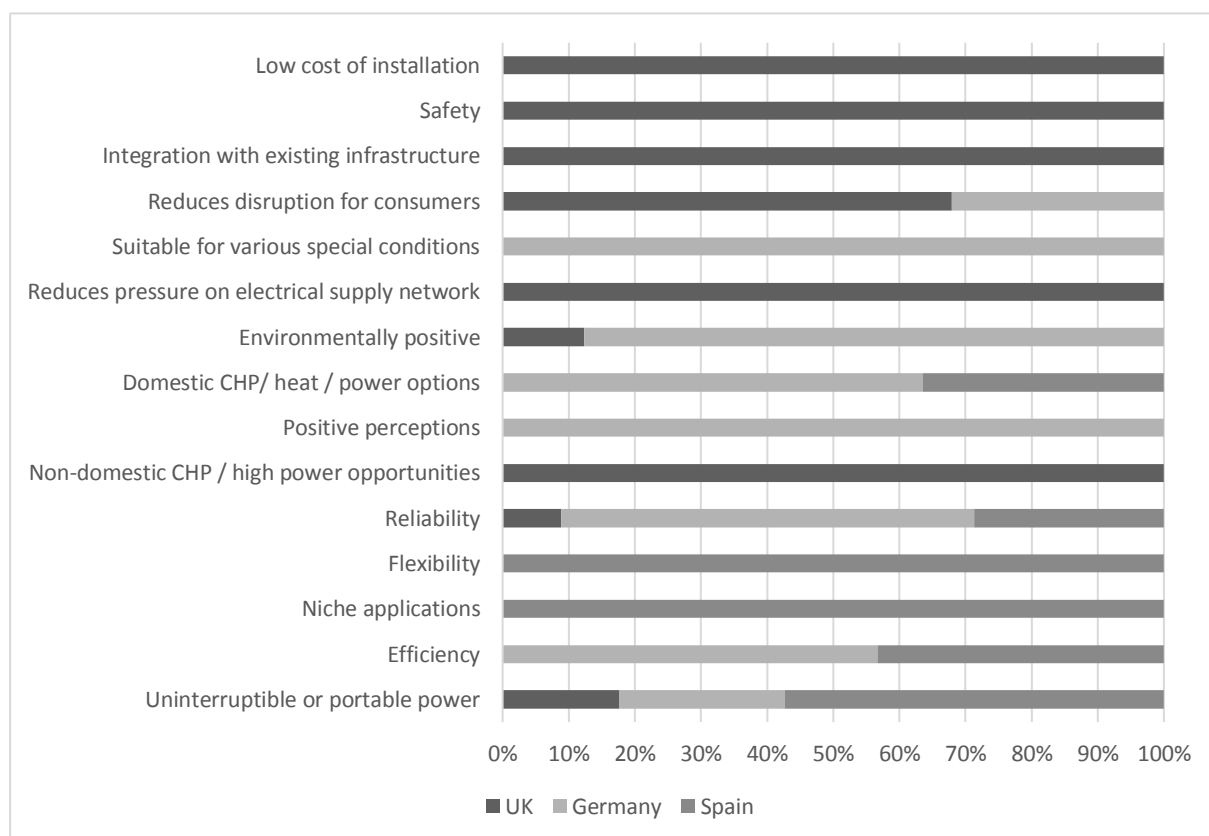


Figure 3 Nationally differing perceptions of the strengths of HFC stationary applications

UK government ministry actor

The potential for limited disruption of existing systems of heat provision is highlighted by an interviewee in a relevant UK ministry, whose role leads him to prioritise the minimisation of physical and hence political disturbance in connection with the public at large. He thus emphasises the way in which hydrogen can be added to the existing gas grid with relative ease, acting as an alternative to piped district heat networks and requiring only, or at least primarily, modifications to existing equipment within homes (new or modified boilers for water heating and gas hobs for cooking):

"If you compare that with hydrogen you are talking about someone coming in one day and changing the boiler for new boiler in much the same space, operates in much the same way as the previous one did... In terms of disruption that is hugely more attractive and a much easier sell than trying to convince people to take heat pumps." [1]

"Now if we are talking about heat networks the disruption there comes in terms of years of roads being dug up as heat networks to install and there is quite a concern about how practical that is going to be in London ... " [2]

This actor's role has included the commissioning of studies that support decision-making on the decarbonisation of both the UK electricity and gas grids. Over the three years that he has been working on this, his experience is that the role of hydrogen decarbonisation of the gas grid has been taken increasingly seriously by his organisational colleagues.

"I think what we've seen of the last 3 years is a move from total scepticism to an expectance that is an option that we need to look seriously at. " [3]

He views micro-combined heat and power units (CHP) that include a small reformer to separate hydrogen from natural gas, fed to fuel cells, as an option, but that this is likely to be less economically attractive to domestic users than the direct injection of hydrogen to the gas grid, followed by combustion for heat in modified boilers and gas hobs. In this regard his experience with UK politics and in particular past and assumed future public opinion lean him towards technology options that are as substitutional as possible, with minimal change and cost for individual citizen-consumers.

His embeddedness in a particular political system also inform his views on policy options for increasing hydrogen supply for injection to the gas grid, and presents him with a dilemma. He sees two main options: one, a "command and control economy from government turnaround and saying this is how it shall be. That is not typical of the UK". However the second option is also problematic:

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“A roll out plan that links with the distribution network operators together over time to make that happen...is very difficult to see how you make that happen without a strong steer from government.” [4]

Currently, the degree of government intervention required seems implausible to him, given prevailing beliefs in UK central government about the proper roles of commercial and public actors. He also refers to the UK having special circumstances as regards use of gas for heating:

“The biggest market for gas boiler in the world is the UK, followed by Korea and Italy. Most of Europe doesn’t have a huge gas network and so it doesn’t make sense for a European directive that says we are going to switch everyone to hydrogen.” [5]

In this way the UK case illustrates the role of cultural, political and technical specifics as acting on and perceived by the individual; also with particular implications for action and potential action by government. This perspective on the drivers of system change or stasis is intentionally different from one focused on political interests or institutional path dependence alone: it allows for both, but explicitly recognises that the beliefs, attitudes and knowledge of the actors involved in such interests and path dependencies are antecedent to action and inaction. Moreover this perspective emphasises the importance of the experience and views of *individuals* within organisations. This may seem a minor or even semantic point, but without individual perception, decision and action in accounts of system change and stasis, such accounts risk being unduly deterministic. Moreover, once individual level processes are acknowledged as important, this opens the way for the inclusion of corresponding accounts, both psychological and sociological, of the mutual relationships between individuals and collective forms of organisation and how processes at both levels influence sociotechnical structure. These accounts may relate to phenomena that include issues such as identity, learning, motivation, decision-making, affective and communicative influences, interpersonal factors, cognitive biases and all the variety of psychological processes. Within a strong structuration framework, this is not to the exclusion of collective-level processes, but as a supplement.

Spanish academic

A Spanish interviewee provides insights from his own contexts (conjunctures); we present his comments here to include comments on the hydrogen supply that HFCs require: the interviewee comments presented subsequently refer more to the stationary use phase of hydrogen. This interviewee is a Spanish academic with long experience with hydrogen and fuel cell research, who has

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recently been working on the production and storage of hydrogen via electrolysis with surplus electricity from a wind turbine array. The project is sponsored by the private company who owns the turbines, who are responding to regulated limits on their transmission of electricity to the grid at times of peak supply and low demand, looking for other options for use of some the renewable power they generate. He says that the companies he is working with are experimenting with power to gas for strategic, learning reasons, but his academic role also leans him towards a tempered view of the current state of power to gas technology for power grid balancing:

“It is not a mature technology, from a technical or commercial point of view. Regarding the connection with renewable energy sources there are fundamental deficiencies caused by the dynamics of the system, in terms electrolyzers, and with respect to the durability of equipment working under a variable load...With regard to the commercial aspects, the scaling factors are not conducive to think that it is an economically competitive technology against other competitive technologies.” [6]

He continues:

“Another problem is that there is no legislation. We had an experience in 2008 with a wind power company. We wanted to install a demonstration facility and we collided with the legislative barrier. You go to the corresponding council and the council looks away. The city council, the regional department or the ministry do not even know where to fit a project of these characteristics, because there is no legislative basis about these technologies ... it happens in all the applications of hydrogen. Try to convince the municipal administration or the municipal technical services to install a hydrogen refueling station in the center of a city. Very difficult.” [7]

Despite this, he still views hydrogen generation and storage as preferable to other options such as compressed air, in situations where the storage is large scale and where the comparison is with e.g. compressed air storage in underground caverns, which are only available in particular locations. In short, his experience leads him to favour renewable power to gas in principle but also to view it as having technical and economic problems in the short term at least.

In terms of the theoretical frame, understanding the way in which the interviewee's and others' beliefs and attitudes are shaped by experience adds depth to the account of action in the niche and the prospects for the technology. This experience spans more than one sector: the interviewee is an

academic with a history of working with commercial partners, the current firm operating with the long term in mind; at the same time he has experience of being challenged and constrained by regulatory disinterest, unfamiliarity and perplexity in relation to hydrogen. His beliefs about the current state of power to gas technology – at least in the context in which he has been working – are conditioned by experience of specific technological and operational challenges. His role as an academic involved in a commercial collaboration, where the company needs a reliable assessment of market readiness, gives him a clear motivation for neutral and open assessment of the state of development of power to gas under fluctuating load conditions. Hence he is positive about the potential for power to compressed hydrogen gas as a method of renewable energy storage, but at the same time open about the challenges. His approach is consistent with his dual roles. His account also provides information on other actors' motivations (e.g. for organisational learning), attitudes and what looks like public sector denial in response to lack of knowledge and institutional incapacity.

Turning to the interviewee group as a whole and to the perceived weaknesses of the technology, interviewees overwhelmingly cited cost as the key problem of hydrogen for heat and power. The complexity of HFC systems, as well as limited awareness and support by regulators and governmental stakeholders, were frequently mentioned. These were followed by several perceived weaknesses at similar frequency of occurrence, including, for example, the perceived inefficiency of HFCs when considered on a full life cycle basis, including the sourcing of hydrogen. Perceived and 'actual' safety were also raised as problems by several interviewees (Figure 4). While there is not space here to detail all of the reasons underlying individuals' views, we would again argue that the experiences of those individuals are critical to their views and that those views will have some degree of influence on investment decisions, directly and indirectly. While this may seem self-evident, once individuals are seen as mediators of sociotechnical change and stasis – albeit via organisations and institutions, formal and informal – this implies that individual-level processes cannot be ignored if a full account is sought. It implies, moreover, that psychological and sociological accounts of individual human behaviour are relevant, alongside theories of organisational and institutional processes, including firm-level processes.

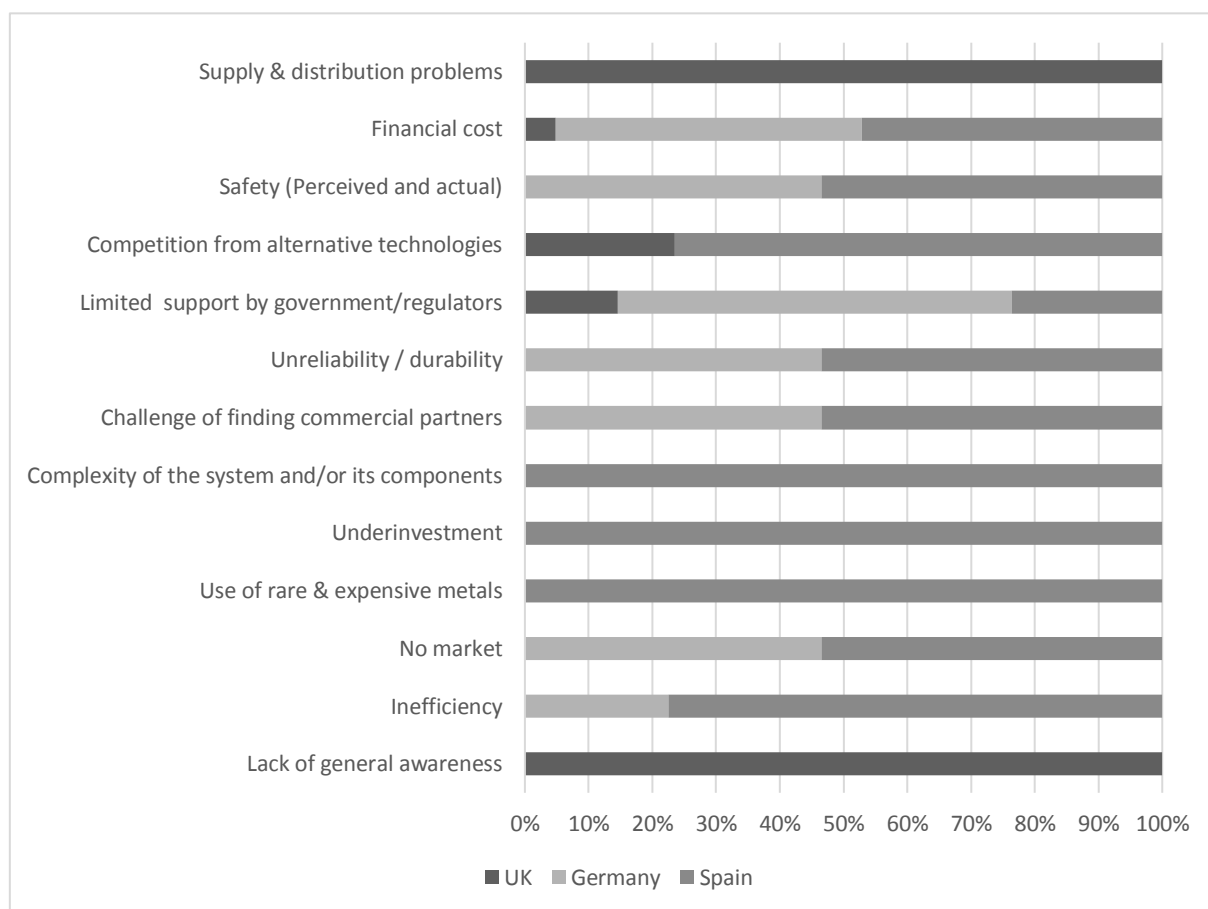


Figure 4 Nationally differing perceptions of the weaknesses of HFC stationary applications

Spanish actors (private sector)

Again drawing on personal experience, another Spanish interviewee highlights the implications of different levels of living space and power consumption internationally, while another comments on regulatory problems:

"I was in Yokohama at the hydrogen congress in 2005. At that moment, Honda, Mitsubishi and others were rehearsing fuel cells... electric cells of 1.5 kilowatts. In Japan houses are almost like the living room of a Spanish house... And imagine the situation in US, with a cell of 1.5kw you will just illuminate the porch. For this reason it is complicated, and now the tendency goes to a self-generation photovoltaic". [8]

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"And then there is the problem of handling the hydrogen. The current legislation is far from clear as to hydrogen, or at least it is not easy. This is also very important. If for installing a domestic fuel cell in your house you need to study 200 laws, you are going to get crazy." [9]

In both cases, the actors draw on and hold specific beliefs about the future and these inform their attitudes. From the perspective of attitude-belief models (Fishbein and Ajzen, 1975), changing those attitudinal beliefs will be a prerequisite for action and without such a change, belief in the value acting will be low (ibid). While the changes required will need to take place on several levels (institutional, technological and others), given we would contend that it is useful to be clear that attitudes and beliefs are involved and that these will need addressing.

Turning to the expectations for stationary applications, across the interviewee set, the tone was mixed: positive expectations were voiced as frequently as negative expectations. However only in Spain were expectations explicitly negative not only for the short but also for the medium term and also generally (Figure 4). UK interviewee expectations refer to hydrogen being used as a storage medium as key to the take-up of stationary applications. German interviewees referred to the expectation of niche uses first, with uninterruptible supply systems as one such niche; several interviewees viewed some form of market deployment as inevitable eventually.

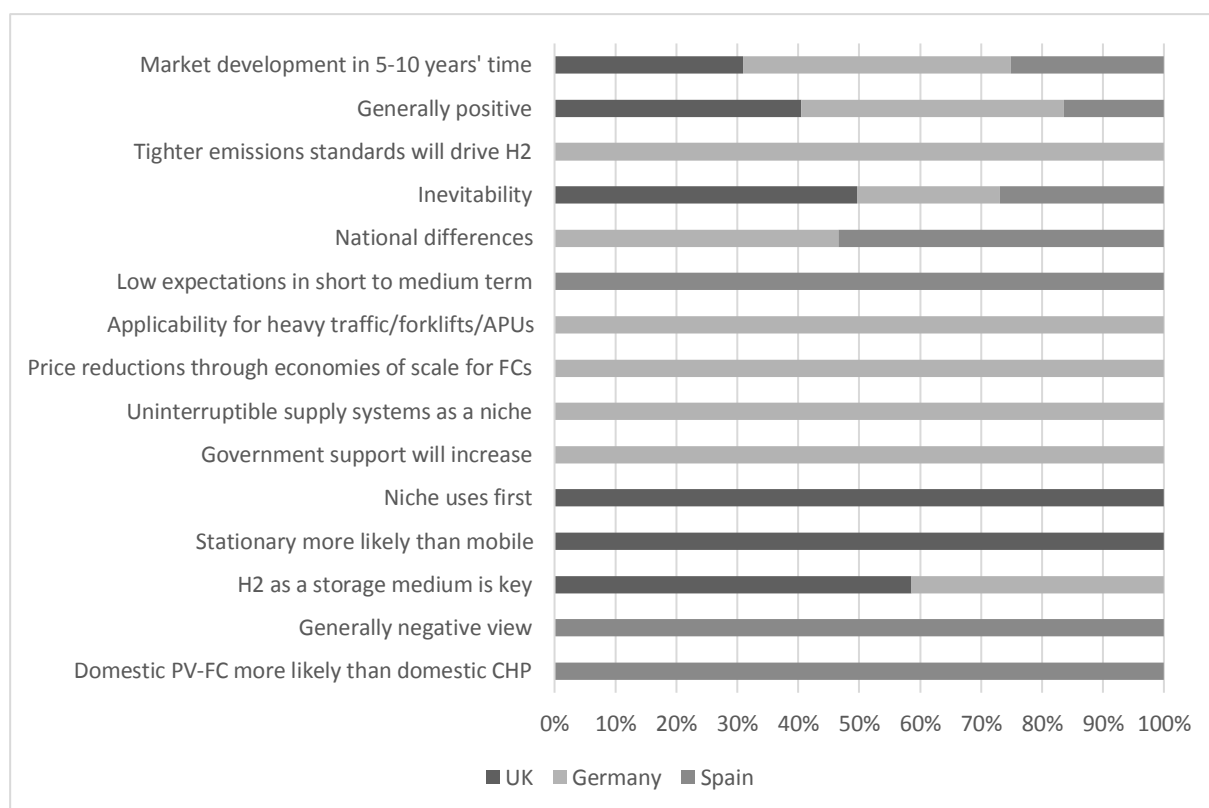


Figure 5 Nationally differing expectations for HFC stationary applications

German actors (university and government agency)

German interviewees, operating in the context of a substantial, national-level hydrogen innovation programme, had their eye on the long term:

"Currently, it is a 'dry period' as it will take some time for the market to develop. This is different from the situation in other countries, e.g. in Japan, where much more of these appliances are already installed and running. And the Japanese manufacturers are now also entering the German market so that this may have a negative impact on German manufacturers as they are more developed." *Germany, university research sector* [10]

„Of course, it’s a shame, as a young technology it is still expensive and has no market advantages. Things will arise. Overall, regarding the assessment of the technology – stationary applications – I believe, that it is a very important new component, which will capture relevant market shares sooner or later.” *Germany, government affiliation* [11]

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“We need a great leap forward. I question that we will manage this alone; a coordinated action is needed, by companies, investors, funding institutions and also customers, they should cooperate. Then we could succeed.” *Germany, private sector affiliation* [12]

What is perhaps most notable in the German interviews is that HFCs for stationary use are largely taken for granted as technically plausible: it is the market that is viewed as undeveloped. This, though, is expected to develop. In Figure 4 we see the German interviewees hold several specific expectations not mentioned by UK or Spanish interviewees: that both hydrogen and HFCs could be suitable for heavy vehicles, forklifts and auxiliary power units, with HFCs suitable for uninterruptible power; that price reductions will come from economies of scale for fuel cells; that Government support will increase. The attitudes and beliefs expressed were generally measured and cautiously positive, particularly for the longer term. Public-private collaboration was optimistically advocated⁶. Returning to our premise that understanding actor psychology provides a better understanding of structural processes, in this case we would suggest that the positive attitudinal and belief-level influences of the national innovation programme are (a) evident and (b) that these are at least pre-conditions for action, even if perhaps not sufficient conditions.

5 Discussion

5.1 General value of the framework

Stones' (2005) framework situates the practices, beliefs and experiences of agents as central to social interaction and hence structure, an approach that Greenhalgh and Stones (2010) extended to socio-technical contexts within organisations and that we are suggesting can be extended to larger sociotechnical scales. Clearly this requires a specification of the connections between the individual, the social and the sociotechnical. All agents are embedded in institutional contexts that influence behaviour, while also being subject to other actors' influence, both directly through action and indirectly through anticipation of that action. At the meso level, institutions and organisations also have particular logics (Fuenfschilling and Truffer, 2014). In principle, those logics can be changed, with impetus from disruptive, external pressures – understood by the MLP as coming from any of the three levels. However organisations tend to be path dependent and this shapes and is shaped by individuals within organisations, though unequally. Towards understanding such change, Stones' approach helps to link four elements: (i) agent psychology and conjunctural knowledge of their situation, (ii) the

⁶ cf. Quitzow (2015) on Germany unwittingly laying the ground for Chinese expansion into the photovoltaic production market.

external system and structures in which agents operate; (iii) agents' actions and practices that reproduce or challenge that structure or system; and (iv) outcomes, i.e. change or stasis in that system and/or in agents' experiences.

Transitions scholars (e.g. Geels and Raven, 2006) refer to a number of distinctions that can be made between global and local niches, in terms of the degree of concentration of network, geography or knowledge and that global niches are in part composed of multiple local projects. The HFC heat and power niche would seem to correspond well to this notion. Strong structuration adds to the account by inviting close attention to the perceptions of the actors involved, adding detail that is lost in structural accounts but at the same time seeking to show the connections to structural change. Hence through our examples we see in some detail the influence of the differing national economic and innovation policy contexts and also the professional experience of the actors (in sum, their conjunctural knowledge) on their attitudes and beliefs. We also see the attention paid by actors to activity in other countries and the influences of this activity on their attitudes. In this way, the actor-level effects of differing, State-level responses to climate-related landscape pressures are seen not just from the perspective of an outside observer, but also in the actors' own terms. Further questioning of the interviewees would reveal more detail on the connections to action or behaviour, but even from the examples given here, one gains some degree of understanding. Use of a strong structuration framework frames this formally, but one could then proceed further to examine other aspects of Giddens' (1984) conception, for example the degree to which the technology was achieving different forms of legitimation.

Most interviewees believe that HFC heat and power technologies will remain in their niche (or niches – discussed below) for the medium term at least. A key reason for this is intra-niche competition. In terms of mobility, electric vehicles are seen as strong competitors, though also as laying the necessary soft and hard infrastructure for HFCs as a subsequent and complementary technology. However in terms of meeting needs for heat and power, it is more difficult to see how HFCs would benefit from the installation of near-term, low carbon alternatives. Moreover several interviewees emphasised the value of hydrogen as methanated or blended with natural gas for use directly in familiar, combustion-based technologies. In this regard, concerns were raised about the environmental logic and losses of multiple conversion phases (e.g. wind power to compressed electrolytic hydrogen, to fuel cell conversion to power or heat). The environmental benefits of HFCs need to be determined in relation to the alternatives in particular contexts.

A further issue in this connection is the flexibility of hydrogen for crossing the regimes of heat, power and mobility, which in turn raises the question of how many regimes and niches are involved and the terms by which this may be indicated (e.g. network connections among individuals or organisations; or shared cognitive frames). Hydrogen also has strong potential and controversial connections with the fossil fuel sector, given its flexibility in terms of feedstock and that the competences for its safe handling lie principally in the fossil gas sector (from which some of the interviewees were drawn).

Nonetheless, the most frequently expressed views of HFCs for stationary use are that they *simultaneously* have a variety of positive characteristics, can offer a variety of benefits relative to other technologies and are suitable for niche use in the near-term; that they are too expensive and have been too little supported for widespread use in the near-term; that they are likely to be used, or (for some) are even inevitable, in the long term; and that they require and deserve increased governmental, regulatory and public support. In this respect many of the views summarised in Figures 2-4 (though not all) are of what the sociology of technological expectations literature describes as techno-promissory (e.g. Berti and Levidow, 2014): they implicitly and explicitly embody the argument that were the conditions different (e.g. in this case a significant carbon tax), or when they are different, the benefits of HFCs for stationary use would or will be realised and that this justifies a change in those conditions. This form of argument is common among those involved in the development of new technologies: the latter require investment of private or public resources, cases must be made for this and positive beliefs about the future of a technology tend to help. The techno-promissory case, while necessary and ubiquitous, is not always successful and can be resisted by path dependent industries, leading to decades of hype cycles (Melton et al, 2016).

The quotations illustrate the value of not only better understanding the role of individual actor perceptions in sociotechnical (structural) processes, but of also taking into account the actor's experienced situation, which Stones (2005) refers to as conjunctural knowledge. This experience and knowledge both influences and is a part of on-going sociotechnical processes. In our examples, they shape and reflect the views of government actors and scientists in the public and private sector, which then influence or have the potential to influence further decision-makers to whom they are connected. Importantly, this knowledge and experience often includes other actors as an object. Hence 'the public' often feature as a key actor group to which characteristics are attributed in discussions of new

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technology acceptance and adoption, in our interviews, typically in a conflated consumer-citizen role. The UK government interviewee above prioritises and anticipates the reactions of the British public in relation to government and utility decision-makers, is risk averse and emphasises the value of 'drop-in' technologies. The Spanish interviewee anticipates the Spanish public's preferences and living circumstances, relative to the smaller occupational space of urban Japanese citizens. These types of attribution are made through 'lived' experience (the interviewee are part and parcel of these structures with their personal and professional identity) and they both induce and respond to a degree of path dependence. They drive technological substitution pathways rather than any more substantial reconfiguration.

5.2 National differences

The interviewees' differences reflect a range of longstanding, interconnected factors. UK perspectives (quotation 1, 2, 4) are shaped by experience of a relatively individualised heating system, limited State involvement in utility provision and limited co-ordinating functions and powers in local and regional government, relative to other parts of Europe. Germany has a tradition of co-operative federalism that supports regional co-operation and a relatively decentralised fiscal system that supports investment in local infrastructure: regions and municipalities levy a higher proportion of tax revenue than in the UK, relative to national government (EUI, 2009). While country comparisons are always complicated, the UK and German actors have different experiences of what is possible in terms of infrastructure provision. The UK actors 'know' that injection of hydrogen to the gas grid and modification of gas boilers and hobs is more feasible than either changing longstanding cultural inclinations or installing district heating.

The same could be said for the Spanish quotations on technical and economic limitations (quotation 6), the legal and regulatory complexities and lack of regulatory awareness experienced (quotation 7): interviewees' experiences are shaping their views of what is possible. Despite interviewees sometimes referring to single-instance anecdotes (e.g. quotation 8), rather than being unimportant, these cognitively represent for them (symbolise) a notable aspect of their experience and knowledge. In short, actors are using their conjunctural knowledge to understand other actors (regulators, government and publics) and aspects of their situation, as well as to inform their views on what is plausible and implausible as regards action. In this way, they reflect the existing sociotechnical structures in which they are located, reinforcing its path dependencies.

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The German examples, quotations 10-12, have a somewhat different tone. They explicitly and implicitly assume that HFC use for stationary applications *is* likely at some point in time, be these manufactured by German or Japanese firms, and this assumption is not premised on any imputed advantages that HFCs may have relative to other options. There is a confidence and assurance to the comments: in the long run, HFCs for stationary applications will happen. One can only speculate as to the origins of this confidence, but being part of a billion euro R&D programme focused on hydrogen cannot but help. Conversely, Spanish interviewees are operating in a context of withdrawn subsidies for renewable energy and the operating context for UK interviewees is somewhere in between. Expectations of what is considered plausible are conditioned, though not determined, accordingly.

The above account proposes that subjective, situated experience informs opinions or beliefs, some of which are heavily normative and many of which make assumptions about other actors, which influence practice and thence the creation, reproduction or change in structures and the institutions that support these. Fully evidencing such a process can be difficult: researchers do not always have access to the archival or in situ data required and the processes being studied may take place over considerable periods of time (Barley and Tolbert, 1997) – or may happen suddenly after a long lead period. Methodologically, reporting subjective experience also poses some degree of research challenge in terms of maintaining anonymity.

Nonetheless we know that expectations – beliefs about the future and what is possible - do play a role in realising technological futures. We know that there are many arenas and communities in which expectations relating to future technologies circulate and compete in more or less formal environments (Bakker, 2011). Such arenas include conferences, other scientific and technological meetings and discussion fora, but also in association with research programmes that further develop the technologies in question (ibid). We also know that at some point, those with positional authority can and do commit public and private sector resources that strengthen niche activities, bringing them into the 'regime'. In terms of the research process, it is possible to work in an embedded way within changing contexts, documenting processes (Barley and Tolbert, 1997) and with indicators of change, such as discourse; institutional and organisational design, objectives and practice; social interaction patterns; investment decisions and so on: in short, using the usual material of sociological analysis. So such analysis is possible, even if in practice research in real-time, rather than with an historical perspective, may capture only a part of the process.

6 Conclusions and research directions

We have made a case for a strong structuration perspective for the analysis of agency-structure dynamics, with the intention of providing a theoretical account of agency for the socio-technical transitions literature that builds on the MLP's premise of multiple levels of structuration in sociotechnical systems. Actors' beliefs, knowledge and experience are characterised as conjunctural knowledge, an individual-level component of structuration processes (Giddens, 1984). In terms of empirical illustration, we argue that R&D stakeholder beliefs of the prospects for hydrogen fuel cells for stationary applications are partly conditioned by their socio-economic and innovation policy context and that the beliefs in turn have consequences for sociotechnical processes. That is, there are mutually influencing relationships among the variables involved. Assertion of a mutual connection between the social and the technological is axiomatic in sociotechnical perspectives. Yet it is still uncommon to find an emphasis on the role of individual beliefs in the sociotechnical literature. Even where this does appear, in the form of expectations as future-oriented beliefs, it is usually in isolation from explicit consideration of social theory that seeks to understand how structures are created and reproduced.

Strong structuration draws attention to actors' conjunctural or situated knowledge as a potential influence on technological pathways. More generally, strong structuration supports the inclusion of psychological and subjective processes more centrally in accounts of niche-regime dynamics. This flexibility has the potential to embrace individualist psychological perspectives, where behaviour is seen as an outcome of individual-level factors (attitudes, norms, values, intentions, motivations, behaviours), without seeking to identify the role of exogenous factors; or where behaviour is viewed as practice embedded in primarily social or cultural processes, heavily influenced by material infrastructures or 'systems of provision', with individuals having concomitant 'careers of practice'. Here we have focused on sociotechnical beliefs, expectations and knowledge, but other possibilities for investigation include identity and roles in motivating and helping to structure change processes.

For analysing system-level processes, the sociotechnical transitions literature deploys the language of path dependency, path creation, logics, disruption, stabilisation, evolution, institutionalisation, emergence and so on. Yet all of these processes inevitably depend on agents as individuals and in collective forms, whose reflection, willingness and capacity to act are in part a function of their past and present situations. Understanding and characterising agent-level characteristics and processes, in

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relation to wider structural characteristics, is a precondition for influencing agent-level processes, even if one's perspective on the individual is as a deeply social creature, a reflection of society.

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