Identifying business opportunities for green innovations: A quantitative foundation for accelerated micro-fuel cell diffusion in residential buildings

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Identifying business opportunities for green innovations: A quantitative foundation for accelerated micro-fuel cell diffusion in residential buildings

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ABSTRACT

Combined heat and power (CHP) production in buildings is one of the mitigation options available for achieving a considerable decrease in GHG emissions. Micro-CHP (mCHP) fuel cells are capable of cogenerating electricity and heat very efficiently on a decentralised basis. Although they offer clear environmental benefits and have the potential to create a systemic change in energy provision, the diffusion of mCHP fuel cells is rather slow. There are numerous potential drivers for the successful diffusion of fuel cell cogeneration units, but key economic actors are often unaware of them. This paper presents the results of a comprehensive analysis of barriers, drivers and business opportunities surrounding micro-CHP fuel-cell units (up to 5 kWel) in the German building market. Business opportunities have been identified based not only on quantitative data for drivers and barriers, but also on discussions with relevant stakeholders such as housing associations, which are key institutional demand-side actors. These business opportunities include fuel cell contracting as well as the development of a large lighthouse project to demonstrate the climate-neutral, efficient use of fuel cells in the residential building sector. The next step could involve the examination and development of more detailed options and business models. The approach and methods used in the survey may be applied on a larger scale and in other sectors.

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1. Introduction

According to the IPCC (2014) report, buildings accounted for 32% of the total global final energy use in 2010. By 2050, the global energy use of buildings is expected to double or triple in some scenarios[1] (IPCC, 2014 p. 711). Improvements to the energy efficiency of buildings are therefore crucial to achieve ambitious climate goals. Combined heat and power (CHP) production in buildings is one of the mitigation options available for achieving a decrease in GHG emissions. Micro-CHP (mCHP) fuel cells are capable of cogenerating electricity and heat very efficiently on a decentralised basis. Although they offer clear environmental benefits and have the potential to create a systemic change in energy provision, the diffusion of mCHP fuel cells is rather slow. There are numerous potential drivers for the successful diffusion of fuel cell cogeneration units, but key economic actors are often unaware of them.

CHP plants in Germany produced a total of 98 TWh of electricity in 2014, which was equivalent to 16.6% of the net electricity produced in Germany that year (Gores et al., 2015). The share of heat from CHP accounted for about 20% of the total heat market (below 300 °C). In total, cogeneration plants in Germany enabled the avoidance of 56 million tons of CO_2 in 2013 compared to the situation with the uncoupled generation of heat and power (Wünsch, 2015). Klotz et al. (2014) have identified a microeconomic CHP potential of 170 TWh_{el} at the business level and a macroeconomic potential of 240 TWhel at the national level in Germany. Together,

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[1] The report uses several models in each of two scenarios (baseline and mitigation). In both scenarios, the three integrated models POLES AMPERE, GCAM 3.0, TIAM-WORLD 2012.2 are those that exhibit a strong increase in annual global final energy demand in the building sector (IPCC, 2014 p. 710–711).

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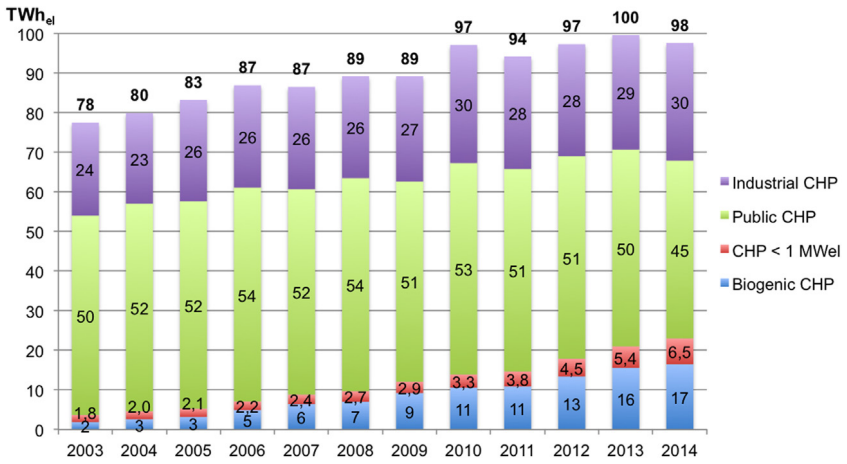

Fig. 1. Development of CHP by sector in Germany between 2003 and 2014.
Source: Own illustration, data by Gores et al. (2015, p. 9).

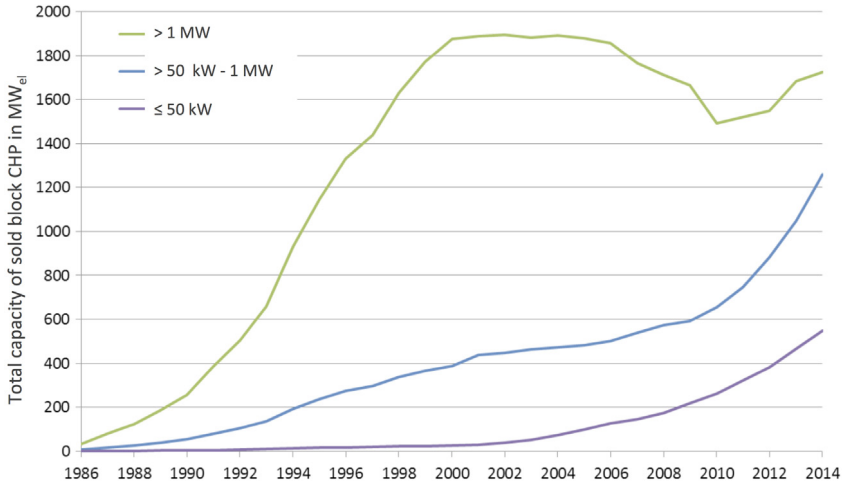

Fig. 2. Development of cumulated fossil block CHP installations in Germany between 1986 and 2014.
Source: Gores et al. (2015), own translation.

the public sector (45 TWh) and industry (30 TWh) produce 77% of Germany's CHP electricity. As Figs. 1 and 2 show, however, biogenic and small-scale CHP plants (<1 MWel) exhibited the strongest growth rates in the period from 2005 to 2014. In industry, on the other hand, CHP increased only slightly and remained more or less constant in the public sector.

At the European level, the energy policy framework for CHP is mainly provided by the Energy Efficiency Directive (EED) 2012/27/EU and the earlier CHP Directive 2004/8/EC. To enable investments to be made in cogeneration plants in a liberalised power market with overcapacity, the Cogeneration Act (Kraft-Wärme-Kopplungs-Gesetz, or KWKG for short) was passed in Germany in March 2002. This Act provides for the financial support of power from CHP involving a feed-in tariff system featuring a surcharge; it also obliges network operators to accept electricity that has been fed into the grid. The Act has been revised several times, most recently in January 2016. In this most recent revision, the German Government abandoned its previous relative development goal of a 25% share of electricity from cogeneration (defined in the KWKG 2009) in favour of an absolute goal of 110 TWh$_{el}$ for the year 2020. In relation to Germany's net electricity production of 589 TWh in 2014, this figure corresponded to less than 19%. In addition, the previous general obligation of network operators to accept and pay for electricity from CHP has been gradually replaced by compulsory self-consumption or, alternatively, direct marketing for plants larger than 50 kW$_{el}$. The payment to small CHP systems below 50 kW$_{el}$ fell from 5.41 ct per kWh$_{el}$ to 4.0 ct per kWh$_{el}$ in the case of self-consumption and supplying a third party, and increased to 8.0 ct per kWh$_{el}$ in the case of feeding in power to the public network.

In addition to passing the CHP Act, the Federal Ministry for the Environment also started subsidising small CHP plants with an electric capacity of less than 20 kW in April 2012. New CHP plants are eligible for a state grant, which depends on the system's electric power. The basic grant is €1900 for very small CHP plants with an electric power capacity of 1 kW — typically installed in detached houses and two-family homes. The basic grant for additional kilowatts is increased by €300 for plants between 2 and 4 kW$_{el}$, €100 for plants between 5 and 10 kW$_{el}$, and €10 for plants between 11 and 20 kW$_{el}$ (see Fig. 3). In other words, larger plants with an electric capacity of less than 20 kW are eligible for a grant of up to €3500. Since the funding directive was revised on 1 January 2015, mini-CHPs benefit from two additional bonus payments: a "Power Efficiency Bonus" is granted to plants with a minimum electric efficiency of more than 31 to 35% and a "Heat Efficiency Bonus" is designated for plants equipped with condensing boiler technology (see Fig. 3). Hence, the maximum funding available is between €3515 for a 1 kW$_{el}$ plant and €6,475 for a 20 kW$_{el}$ plant.

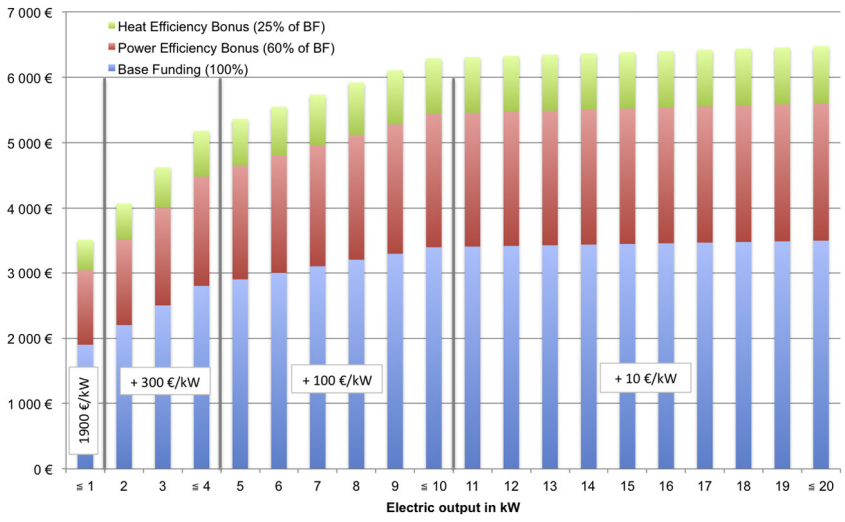

Fig. 3. Three components of funding for mini-CHP plants $\leqslant 20\ kW_{el}$.
Source: Own illustration, data from BAFA 2014.

In August 2016, the German Government put in place an additional funding programme exclusively for stationary small-scale fuel cells between 0.25 kW_{el} and 5 kW_{el}. These micro-CHP plants in new or refurbished residential buildings are eligible for a grant of up to €28,200 or 40% of the total investment costs, depending on the size of the plant. Several initiatives and networks such as the "IBZ — Initiative Brennstoffzelle" (www.ibz-info.de) at the national level and the "Fuel Cell and Hydrogen Network NRW" (www.fuelcell-nrw.de) at the federal state level have become well established in Germany. In addition, actors have demonstrated the technical feasibility of fuel cells in a domestic setting in practical tests such as the Callux Project (http://enefield.eu/related-projects/callux-project).

The fuel cell market appears to be in transition, somewhere between the pilot phase and market diffusion. One of the main market barriers is the high investment costs involved compared to standard heating systems such as boilers. A number of funding schemes (see above) seek to redress this lack of uptake, and yet it appears that other aspects are instrumental to the successful rollout of fuel cells. Against this background, this paper presents the results of a comprehensive analysis of barriers, drivers and business opportunities surrounding micro-CHP fuel cell units (up to 5 kW_{el}) in the German building market. The overall aim is to provide quantitative data on drivers and barriers and to explore specific business opportunities with housing associations – key institutional demand-side actors – in mind. The methods applied during the survey and its findings are presented in this article. The results are then discussed and conclusions drawn.

2. Methods

In order to identify barriers, drivers and business opportunities surrounding micro-CHP fuel cell units (up to 5 kW_{el}) in the German building market, three key steps were taken: (i) a literature review, (ii) a survey, and (iii) a workshop. Quantitative and participatory aspects were included at every stage.

2.1. Literature review

The first step of the study was to undertake a literature review. We conducted a desk-based research of key studies on market drivers and barriers for the successful market diffusion of mCHP fuel cell units. The key phrases included in the screening were not only "fuel cells", but also the broader market of "combined heat and power generation", "energy/heating technology", and "eco innovation in buildings" in Germany and other European countries. The drivers and barriers identified in the key sources analysed (Großet al., 2015; Nitsch, 2015; Prüggler et al., 2009; Haas et al., 2010; Pehnt and Traube, 2004; Schüwer and Venjakob, 2007; Bradke et al., 2009; Woldt et al., 2007; Krewitt et al., 2004, 2006; Brown et al., 2006; Droste-Franke et al., 2009; Voss et al., 2006; Marth and Breitschopf, 2011; Karger and Bongartz, 2008; Lewis, 2014; Kaestle et al., 2015) were clustered using five thematic areas: economic and financial factors; technological factors; ecological factors; socio-cultural factors; and the regulatory and policy framework (based on O'Brien et al., 2011).

2.2. Survey

The second step of the study involved an online survey. The key challenges encountered during the development of the survey were the following three issues (i) the need to address a wide range of stakeholders from the demand and supply side who, it is assumed, have very differing previous knowledge and interest in the topic, (ii) the difficulty in developing questions that not only enable drivers and barriers to be quantified beyond the number or share of answers but that also provide valuable qualitative responses concerning business opportunities, and (iii) the difficulty in developing a survey that takes no longer than 20 min to complete.

For these reasons, survey development involved a method analysis of existing questionnaires with regard to aspects such as the stakeholders addressed, the extent and content, the clustering of topics, and the types of question used (Michelsen and Madlener, 2013; O'Brien et al., 2011; Nitsch, 2015; Schüwer and Venjakob, 2007; GfK, 2015).

Since the aim of the analysis was to be able to distinguish between responses from different stakeholder groups, at least the demand and supply side of the fuel cell market, we drew up a list of relevant stakeholder groups from the literature in cooperation with our project partners. The list we produced contained 11 stakeholder groups, which we then classified by their market perspective (see Table 1).

We then selected key drivers and barriers from the literature review, and applied clustering following O'Brien et al. (2011). However, we adapted the clusters by combining the technological and ecological factors and by separating the regulatory and policy

Table 1
Stakeholder groups of the survey classified by market perspective (demand and supply).

Demand-side acteurs	Supply-side acteurs
Tenant	Manufacturer
House owner	Retailer
House owner community	Public utility and energy supplier
Housing sector	Installer or craftsman
Property developer	Business association
Municipality	

framework into two topics. The five sub-topics implemented in the survey relating to drivers and barriers are (i) costs, (ii) technology and ecology, (iii) socio-cultural aspects, (iv) regulatory aspects, and (v) structural aspects. In addition, we subdivided the sub-topics into one question on drivers and barriers each, and compiled a set of usually four promoting and inhibiting factors. As a result, a list of 18 drivers and 20 barriers was selected, plus the field "other", which respondents were invited to complete, and an open question field headed "comments".

In addition to the topic of drivers and barriers, we also included open questions on options and suggestions, resulting in a draft questionnaire. We undertook a participatory review of the draft questionnaire with our project partners, conducting interviews in which the methods and content of the survey (sending of draft by email, telephone interviews) were discussed.

The feedback on the draft provided by our project partners was very encouraging with regard to the approach and content. One of the key comments mentioned the fact that the survey started with questions on CHP drivers and barriers, meaning that respondents needed a high level of knowledge to answer some of the questions. It was also suggested to change the order of the drivers and barriers to prevent demand-side respondents with little previous knowledge from dropping out of the survey. As a result, we developed opening questions that addressed attitudes to energy saving measures, previous knowledge and interest in the topic of fuel cells. The final survey is composed of three parts: Part A: Introductory questions and stakeholder classification; Part B: Drivers and barriers; and Part C: Options and suggestions. The Fuel Cell Survey questionnaire lists questions, instructions and answers. The survey was originally conducted in German. Appendix A presents an English translation of the German questionnaire.

Finally, we prepared and pretested the final questionnaire using the online survey tool SoSci Survey (www.sosciesurvey.de). The invitation to complete the survey was distributed by the project partners via their relevant communication channels. The survey was available online for a period of six weeks (from 26 Oct to 4 Dec 2015).

2.3. Workshop

The third step of the study involved delivering a workshop. The aim of the workshop was to validate the results of the survey with regard to the key drivers and barriers, and to identify potential business opportunities. The workshop covered two main phases.

Phase 1: The main drivers and barriers identified in the survey were presented and discussed. Participants were then asked to prioritise from their perspective. To this end, they were asked to allocate a total of ten points to any of the options, highlighting what they considered to be the most important aspects and what they identified as the most important drivers and barriers.

Phase 2: The "brainstorming" creativity technique was used to generate potential business opportunities. After a number of ideas were put forward by individual participants, they then presented their ideas to the group as a basis for further discussion. Finally, the project members were asked to prioritise the most promising suggestions.

Seven project members, representing both the supply and the demand side as well as the research perspective, participated in the workshop.

3. Outcome of the survey

The results of survey are presented in this section. First, respondents are characterised and a brief overview of the responses to the introductory questions is presented as well as a classification of the stakeholders. The results for both the drivers and barriers and the suggested options and proposals are then presented.

3.1. Characterisation of respondents

A total of 126 participants completed the survey. Fig. 4 shows the response rates of all respondents by questionnaire topic. Respondents took an average of around 12 min to complete the questionnaire.

3.2. Results of the introductory questions

The results of the survey reveal that 63% and 32% of respondents considered energy saving in the housing sector to be important or significantly important, respectively.[2] With regard to the energy saving measures they supported,[3] around half of the participants supported measures relating to their personal behaviour, statement of costs and the modernisation of heating installations. Around 60% of respondents supported measures that provide information and consultancy on energy savings as well as the "Energy Performance Certificate for Buildings". When it comes to the implementation of those measures — i.e. the respondent has implemented the measure or been affected by it — the proportion is generally lower than the percentage of measures supported. This was the case with the following measures: modernisation of heating systems (42%), information and consultancy on energy savings (37%), and "Energy Performance Certificate for Buildings" (15%). Implementation of the following two measures was higher than the support of the same measures: measures addressing one's own behaviour (67%) and the measure statement of energy costs (63%). 11% supported other measures and 7% have implemented other measures (e.g. building insulation, fuel cell micro-CHP, optimisation of current heating system, daily overview of energy consumption).

Willingness to pay[4] : Respondents stated that the costs induced by modernising a heating system need to be reduced (34%) or that the costs should not change (28%). Thus, two-thirds of respondents were against an increase in costs. In comparison, 22% of respondents were in favour of a slight increase of no more than 10%, whereas 4% had nothing against an increase of more than 10%.

Knowledge and interest in the topic of fuel cells[5] : Almost all respondents stated that they had already heard of fuel cells and

[2] Question E004: "How important is the topic of energy saving to you in your personal life?".

[3] Question E005: "Which of the following energy saving measures (power, heat) do you support? Which measures have you already taken/been affected by?".

[4] Question E008: "The modernisation of heating installations is associated with costs that can increase the rent and reduce energy bills. How do you think costs should develop following modernisation (sum of increased rent and reduced energy bills)?".

[5] Questions E001: "The purchase and use of modern heating systems is one option to save energy. Have you already heard about fuel cell units in residential buildings that combine the generation of heat and electricity?"; Question E002: "How do you assess your previous knowledge of fuel cell units in residential buildings that combine the generation of heat and electricity?"; Question E003: "How do you assess your interest in fuel cell units in residential buildings that combine the generation of heat and electricity?".

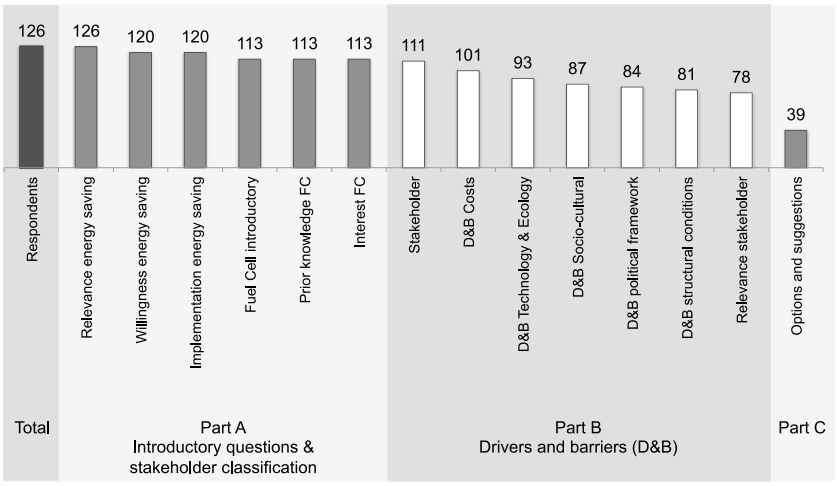

Fig. 4. Response statistics showing the number of answers in each topic.

their application in residential buildings. 58% were aware of the topic from the media, 35% dealt with the topic for professional reasons, 25% have already seen a fuel cell onsite, and 4% stated that they encountered fuel cells in their daily lives. Only 3% had never heard of fuel cells and their application in residential buildings before. Respondents' previous knowledge and interest in fuel cells as a means of producing electricity and heat in residential buildings were predominantly moderate to high (40% moderate and 33% high previous knowledge, 24% moderate and 56% high interest). 16% appeared to have little previous knowledge and 10% had little interest in the topic. 5% had no previous knowledge of fuel cells, and 1% were not at all interested in the topic.

3.3. Results of classification into stakeholder groups

Fig. 5 shows the classification results. A total of 111 respondents answered this question, 99 of which classified themselves into one of the 11 predefined stakeholder groups. Based on the stakeholder classification by market perspective (see Table 1), the results show that 70% of respondents belonged to the demand side and 19% to the supply side. The majority of respondents were house owners (about 61%, $n = 99$). Few responses were given in stakeholder groups (such as retailers and property developers). No responses were given by municipalities.

3.4. Results concerning drivers and barriers

Respondents assessed the current and future relevance of 18 drivers and 20 barriers. The results of the assessment are based on respondents' answers. The most important drivers and barriers identified are listed in Tables 2 and 3. These were identified by calculating average values from the answers from a range of 1 (low relevance) to 5 (high relevance). The most important drivers and barriers were defined as having an average value of 4.0 or more. In addition, current relevance was evaluated separately for the supply and the demand side. Trend relevance is shown by average values of all respondents from a range of −1 (decreasing relevance) to +1 (increasing relevance). Table 2 shows the 12 drivers identified; Table 3 shows the 12 barriers that were assessed as being highly relevant at present (excluding "other").

Among the five sub-topics, the clusters "Costs", "Socio-cultural aspects" and "Structural conditions" scored the most point when it came to current relevant drivers and barriers. However, none of the five sub-topics appeared to be more important than the others. The relevance assessment of supply- and demand-side stakeholders appeared to be quite similar, except in the following cases: supply-side stakeholders assessed three aspects higher than demand-side stakeholders: the drivers and barriers' relevance of "socio-cultural aspects" in general, the cost-related barrier "government grants", and the policy barrier "lack of planning security (dynamic law)". Demand-side stakeholders found some of the structural conditions to be more relevant ("High potential for fuel cells in existing buildings", "High administrative effort and bureaucracy", "Increasing demand of home energy systems with a low capacity").

Ten of the twelve important drivers identified are expected to gain in importance in the future and two are expected to retain their level of current relevance. Eleven of the twelve barriers identified are expected to continue to be highly relevant in the future, and one barrier is expected to gain in importance.

3.5. Suggested measures

One key topic of the survey was to generate individual suggestions and options based on open questions.[6] A total of 39 participants provided at least one statement regarding suggestions (need for action). Half of these respondents were house owners. A total of 76 suggestions and 78 options were mentioned. However, some of the suggestions also address options. Both suggestions and options could be assigned to several sub-topics relating to drivers and barriers. For this reason, Fig. 6 shows an evaluation of the suggestions and options clustered into the five different sub-topics of drivers and barriers (own classification, double counting). Most suggestions can be assigned to socio-cultural aspects (35), policy framework (34) or costs (34). A total of 17 more suggestions were made relating to technical & ecological aspects; one proposal addressed structural aspects. Two suggestions could not be assigned to any of the aspects. Appendix B contains the detailed suggestions and options.

4. Discussion

The results of the survey were discussed at the workshop to validate the results and to identify ideas for business opportunities.

Validation of results: The main barriers and drivers identified in the survey served as the fundamental information for determining key barriers and key drivers at the workshop. Although the limited

[6] Question 0002: "Where do you think there is urgent need for action? Which options would you suggest for addressing them (e.g. service provision, new business models)?".

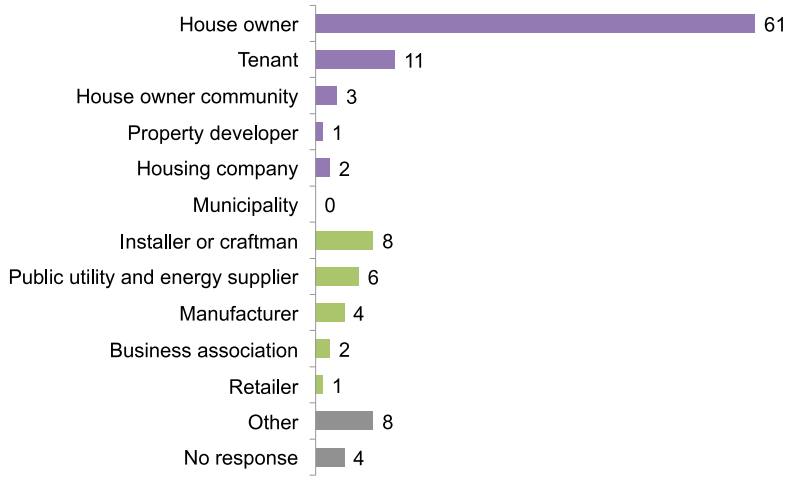

Fig. 5. Number of respondents by stakeholder group and market perspective (own classification); total responses ($n = 111$); purple bars show demand-side respondents ($n = 78$); green bars show supply-side respondents ($n = 21$); grey bars show other respondents and no response ($n = 12$).

Table 2
Drivers for the market diffusion of micro fuel cells: stakeholders' view of relevance and trends (as average values over survey respondents, $n = 81$–101).

Drivers	Relevance all stakeholders 1 (low) to 5 (high)	Trend all stakeholders −1 (decreasing) to +1 (increasing)	Relevance supply side 1 (low) to 5 (high)	Relevance demand side 1 (low) to 5 (high)	Trend all stakeholders
Thematic cluster "Costs"					
Savings of energy costs for consumer	4.1	+1.0	3.9	4.1	↑
Rising energy costs	4.1	+0.8	4.2	4.1	↑
Cumulative costs are comparable with other heating systems	4.0	+0.6	3.8	4.0	↑
Government grants	3.9	+0.2	4.2	3.9	→
Other	4.6	+1.0	4.7	4.6	↑
Thematic cluster "Technology & Ecology"					
Own power generation	4.3	+0.8	4.3	4.4	↑
High electrical conversion efficiency	4.2	+0.8	4.2	4.2	↑
Lower emissions due to energy savings and high efficiency	3.9	+0.8	3.6	3.9	↑
Other	3.8	+1.0	4.3	3.0	↑
Usage of existing heating systems possible	3.8	+0.2	3.7	3.8	→
Thematic cluster "Socio-cultural aspects"					
Awareness as technology for own power generation	4.2	+0.8	4.4	4.2	↑
Trust in advantages of the new technologies	4.0	+0.6	4.4	4.0	↑
Awareness as eco-friendly technology	4.0	+0.8	4.3	3.9	↑
Trust in government-aided technology	3.5	0	4.1	3.2	→
Other	4.0	−1.0	4.0	n.r.	↓
Thematic cluster "Policy framework"					
Laws promote profitability of fuel cells	4.0	+0.4	3.9	4.0	→
Laws positively promote demand	3.8	+0.4	3.5	3.9	→
The Cogeneration Act promotes this technology	3.7	+0.4	3.6	3.7	→
Other	3.0	n.r.	3.0	n.r.	→
Thematic cluster "Structural conditions"					
High potential for fuel cells in existing buildings	4.2	+0.8	3.9	4.3	↑
Branch's interest in market launch	4.1	+0.8	4.1	4.0	↑
Existing infrastructure	4.0	+0.2	4.1	4.0	→
Other	3.5	+1.0	n.r.	3.5	↑

Legend: the direction of the arrow indicates the trend for drivers based on the mean trend factor: upward arrow = factor higher than 0.4; sideways arrow = factor between +0.4 and −0.4; downward arrow = factor lower than −0.4. The colour of the arrows indicates the driver's relevance based on the average relevance factor: dark arrow = factor of 4 or more; light colour = factor less than 4. n.r. stands for no response.

Table 3
Barriers for the market diffusion of micro fuel cells: stakeholders' view of relevance and trends (as average values over survey respondents, $n = 81$–101).

Barriers	Relevance all stakeholders 1 (low) to 5 (high)	Trend all stakeholders −1 (decreasing) to +1 (increasing)	Relevance supply side 1 (low) to 5 (high)	Relevance demand side 1 (low) to 5 (high)	Trend all stakeholders
Thematic cluster "Costs"					
Higher acquisition costs compared to modern alternatives	4.2	−0.2	4.3	4.2	→
High maintenance costs	4.2	−0.2	4.2	4.2	→
Government grants	4.1	−0.2	4.5	4.0	→
Insecurities of energy price developments	3.7	+0.4	3.4	3.8	⇨
Other	4.3	−0.2	4.7	4.0	→
Thematic cluster "Technology & Ecology"					
Decreasing energy efficiency of fuel cells over time	4.0	0	3.9	4.0	→
Integration of the fuel cell system into existing heating systems	3.7	−0.2	3.2	3.9	⇨
Usage of conventional fuels	3.6	+0.2	2.6	3.6	⇨
Wrong conditions on site	3.6	−0.2	3.8	3.5	⇨
Other	4.2	+0.6	4.0	4.3	→
Thematic cluster "Socio-cultural aspects"					
Knowledge gap and lack of skills	4.5	0	4.6	4.5	→
Little trust in new technologies	4.2	−0.2	4.3	4.2	→
Lack of awareness	4.0	−0.4	4.5	3.9	→
Negative opinion of energy suppliers	3.8	−0.4	3.4	3.8	⇨
Other	5.0	+1.0	5.0	5.0	↑
Thematic cluster "Policy framework"					
Lack of secure planning (dynamic law)	4.3	+0.4	4.7	4.0	→
Many authorities to be contacted for grants	4.2	+0.2	4.4	4.1	→
Incentives of grants are too low	3.9	0	4.4	4.1	⇨
Disadvantage of contracting compared to existing energy supply	3.9	+0.2	4.2	3.8	⇨
Other	4.8	+0.4	5.0	4.5	→
Thematic cluster "Structural conditions"					
High administrative effort and bureaucracy	4.3	+0.4	3.6	4.2	→
Increasing demand of home energy systems with low capacity	4.0	+0.8	2.8	4.1	↑
High accounting effort for users	4.0	+0.4	3.9	4.0	→
Limited availability of financing models (contracting, leasing)	3.5	0	3.5	3.5	⇨
Other	5.0	+1.0	5.0	n.r.	↑

Legend: the direction of the arrow indicates the trend for drivers based on the mean trend factor: upward arrow = factor higher than 0.4; sideways arrow = factor between +0.4 and −0.4; downward arrow = factor lower than −0.4. The colour of the arrows indicates the driver's relevance based on the average relevance factor: dark arrow = factor of 4 or more; light colour = factor less than 4. n.r. stands for no response.

distribution per type of respondent meant a bias towards home owners, the barriers and drivers identified can be analysed based on the semi-quantitative results (see Tables 2 and 3). Nonetheless, the stakeholder groups covered and the related number of responses should be borne in mind when interpreting the results. With this knowledge, workshop participants were asked to prioritise the drivers and barriers identified in the survey. As a consequence, the seven project members who attended the workshop agreed on the following particularly relevant key barriers and key drivers.

Key barriers:

- High accounting effort for users (read out and record, taxes).
- High administrative effort and bureaucracy (e.g. application effort, funding schemes).
- Higher acquisition costs compared to modern alternatives.
- Knowledge gap and lack of skills (e.g. craftsmen and architects).

Key drivers:

- Governmental incentives via feed-in tariffs and subsidy of acquisition costs.
- Savings of energy costs for consumer.
- Option for electricity production for own consumption (desire for autarky).

Identification of business opportunities: The following business opportunities were identified using the "brainstorming" creativity method with subsequent discussion:

- Contracting (maintenance, billing to cut costs in conjunction with contracting, acquisition, running expenses).
- Energy self-sufficient building (use of cross-sectoral synergies with CO_2-neutral gas provision (wind gas or biogas) for fuel cells in residential buildings).
- Power-oriented mode of operation (as alternative to a heat-oriented mode of operation).
- Reliability of technology (reduce scepticism of potential clients, offer warranties).

Although the following aspects were classified as being less relevant, they were still awarded points:

- Offers for energy contracting (comprehensive energy services to execute energy efficiency measures based on fuel cells).
- Traditional distribution of fuel cells to end customers.

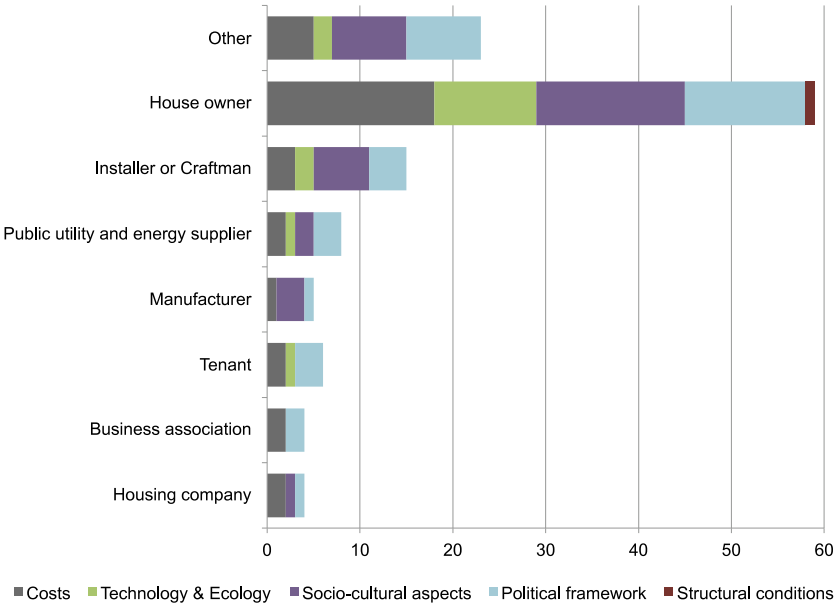

Fig. 6. Suggestions and options classified by driver, barrier and stakeholder (own classification, double counting).

- Take all stakeholders and market participants into account and share the burden equally.
- Reduction of administrative effort (effort has to be comparable to today's situation).
- Virtual power plant/load management (grid-compatible building, quarter).

However, other important topics were also brought up for debate. For example, workshop participants claimed that it is necessary to differentiate between active and passive users. "Active users" were described as actors who consciously seek to become self-sufficient, who are willing to pay more for technology, and who are interested in CHP. "Passive users" are not particularly interested in the topic or do not have the opportunity to change heating systems (e.g. tenant). As a result, it would be conceivable to design different models tailored to the specific requirements of different customer segments. In conclusion, active users who are interested in CHP may be willing to pay more for individualised contracting models. And for those who are less interested in energy production, models could be developed that are suitable for the mainstream market. Consequently, different customer segments could be captured one by one. To further promote fuel cells, workshop participants suggested promoting them as an innovative product that helps reduce CO_2 emissions. They also thought that there should be greater dialogue with institutions to promote the use of fuel cells. Another approach could be to place signs in the front garden of private homes publicising the fact that they use fuel cells. According to the survey results, however, this idea seems to be unacceptable from the customer perspective. The Federal Ministry for Economic Affairs and Energy (BMWi) claimed that training programmes that address supply-side stakeholders (e.g. architects, craftsmen) are crucial to the success of fuel cells as a new technology. In addition, the group of participants agreed that it would be useful in future research to use a system that is capable of analysing which mailing lists led individuals to take part in the survey.

5. Conclusion

The main focus of this study was to identify the key drivers and key barriers relating to the diffusion of micro fuel cells and to develop potential business opportunities. To achieve this, it was of utmost importance to collect data in a quantitative and participatory manner, which is why three methodological approaches were used: a literature review, an online survey and a workshop.

Quantitative data was indeed collected — 126 people completed the survey, enabling 12 main drivers and 12 main barriers to be identified. To validate these results, a workshop involving seven of the project members was conducted to further prioritise and nominate the most important key drivers and barriers. In addition, initial ideas for business opportunities were generated and discussed.

Future research could involve examining and developing concrete business models for the business opportunities identified. Examples include fuel cell contracting and the development of a larger lighthouse project to demonstrate the climate-neutral, efficient use of fuel cells in the residential building sector. In addition, the approach and methods used to conduct the survey could be applied on a larger scale and in other sectors.

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Disclaimer

The opinions expressed in this paper by the authors are the personal opinions of the authors alone and do not necessarily represent the views of the organisations they work for. There are no conflicts of interest.

Appendix A. Survey questionnaire

The Fuel Cell Survey questionnaire lists questions, instructions and answers. The survey was originally conducted in German. The following questionnaire was translated by the authors.

Duration of survey: 26 Oct to 4 Dec 2015
Data set: 4 Dec 2015
Evaluation: 21 Jan 2016

Part A: Introductory questions and stakeholder classification
E0 Introductory questions

E004 Attitude towards energy saving measures

There are several opportunities to save energy in residential buildings (power and heat). How important is the topic of energy saving to you in your personal life?
Please choose one answer.

- ☐ very important
- ☐ important
- ☐ less important
- ☐ not important

E005 Energy saving measures

Which of the following energy saving measures (power, heat) do you support? Which measures have you already taken / been affected by?
Please select all applicable statements from the following list.

	I support this measure	I have implemented / been affected by this measure
Information and consulting on energy saving (e.g. internet, consumer centre)	☐	☐
Changing own behaviour (e.g. saving power or heat at home)	☐	☐
Statement of costs (e.g. annual overview of energy use and costs)	☐	☐
Energy Performance Certificate for Buildings (e.g. when finding accommodation or offering accommodation/housing as a landlord)	☐	☐
Modernisation of heating installation (e.g. in one's own house or by the landlord)	☐	☐
Other:	☐	☐

Comment: The field "Other" enables you to add your own aspects (open field) and to select from the two answer categories (I support this measure; I have implemented / been affected by this measure).

E008 Willingness to pay

The modernisation of heating installations is associated with costs that can increase the rent and reduce energy bills. How do you think costs should develop following modernisation (sum of increased rent and reduced energy bills)?
Please choose one answer.

- ☐ Costs may not change.
- ☐ Costs may increase slightly (no more than 10% in total).
- ☐ Costs may increase considerably (more than 10% in total).
- ☐ Costs may decline in total.
- ☐ Other:

Comment: The field "Other" enables you to add your own aspects (open field).

E001 Introductory question on fuel cells

The purchase and use of modern heating systems is one option to save energy. Have you already heard about fuel cell units in residential buildings that combine the generation of heat and electricity?
Please select all applicable statements from the following list.

- ☐ I have heard about fuel cell application in my professional life.
- ☐ I have heard about fuel cell application in my everyday life (e.g. retrofitting of own house, fuel cell heating system in my house, tenant of house with fuel cell)
- ☐ I have heard about fuel cell application in the media (e.g. TV, internet, print media)
- ☐ I have already seen fuel cell application on site (e.g. at a friend's or relative's house, information centre)
- ☐ I have not heard much about fuel cell application.
- ☐ Other:

Comment: The field "Other" enables you to add your own aspects (open field).

E002 Previous knowledge

How do you assess your previous knowledge of fuel cell units in residential buildings that combine the generation of heat and electricity?

Please choose one answer.

- ☐ no previous knowledge
- ☐ little previous knowledge
- ☐ moderate previous knowledge
- ☐ high previous knowledge
- ☐ no response

E003 Interest

How do you assess your interest in fuel cell units in residential buildings that combine the generation of heat and electricity?

Please choose one answer.

- ☐ no interest
- ☐ little interest
- ☐ moderate interest
- ☐ high interest
- ☐ no response

A0 Perspective

A001 Stakeholder groups

We would like to select answers from different stakeholder groups. Please select one stakeholder group that applies most to you, representing the perspective from which you answer the subsequent questions:

Please choose one answer.

- ☐ Tenant
- ☐ House owner
- ☐ House owner community
- ☐ Housing sector
- ☐ Property developer
- ☐ Municipality
- ☐ Manufacturer
- ☐ Retailer
- ☐ Public utility and energy supplier
- ☐ Installer or craftsman
- ☐ Business association
- ☐ Other:

Comment: The field "Other" enables you to add your own aspects (open field).

Part B: Drivers and barriers

K0 Costs

K001-K004 Promoting factors

The installation of fuel cell heating systems is related to several cost aspects, which may positively influence the broad market diffusion of this technology.

Please estimate the current relevance (from not relevant to highly relevant) and the future relevance (increasing or decreasing over the next five years) of the following aspects listed.

	Relevance today					Future relevance	
	no relevance	rather little relevance	moderate	rather high relevance	high relevance	increasing	decreasing
Savings of energy costs for consumer	☐	☐	☐	☐	☐	☐	☐
Cumulative costs are comparable with other heating systems	☐	☐	☐	☐	☐	☐	☐
Rising energy costs	☐	☐	☐	☐	☐	☐	☐
Government grants (e.g. investment scheme, electricity remuneration rate)	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment: The field "Other" enables you to add your own aspects (open field).

K005-K008 Inhibiting factors

The installation of fuel cell heating systems is related to several cost aspects, which may negatively influence the broad market diffusion of this technology.

Please estimate the current relevance (from not relevant to highly relevant) and the future relevance (increasing or decreasing over the next five years) of the following aspects listed.

	Relevance today					Future relevance	
	no relevance	rather little relevance	moderate	rather high relevance	high relevance	increasing	decreasing
Insecurities of energy price developments (electricity, natural gas)	☐	☐	☐	☐	☐	☐	☐
Higher acquisition costs compared to modern alternatives	☐	☐	☐	☐	☐	☐	☐
High maintenance costs (e.g. costs for changing fuel cell stack)	☐	☐	☐	☐	☐	☐	☐
Government grants (e.g. ending funding schemes, limitation of funding duration)	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment: The field "Other" enables you to add your own aspects (open field).

T0 Technology & Ecology

T001-T004 Promoting factors

The installation of fuel cell heating systems is related to several technological and ecological aspects, which may positively influence the broad market diffusion of this technology.

Please estimate the current relevance (from not relevant to highly relevant) and the future relevance (increasing or decreasing over the next five years) of the following aspects listed.

	Relevance today					Future relevance	
	no relevance	rather little relevance	moderate	rather high relevance	high relevance	increasing	decreasing
Own power generation	☐	☐	☐	☐	☐	☐	☐
Lower emissions due to energy savings and high efficiency (e.g. dust, greenhouse gases)	☐	☐	☐	☐	☐	☐	☐
High electrical conversion efficiency	☐	☐	☐	☐	☐	☐	☐
Usage of existing heating systems possible	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment: The field "Other" enables you to add your own aspects (open field).

T005-T008 Inhibiting factors

The installation of fuel cell heating systems is related to several technological and ecological aspects, which may negatively influence the broad market diffusion of this technology.
Please estimate the current relevance (from not relevant to highly relevant) and the future relevance (increasing or decreasing over the next five years) of the following aspects listed.

	Relevance today					Future relevance	
	no relevance	rather little relevance	moderate	rather high relevance	high relevance	increasing	decreasing
Wrong conditions on site (e.g. height of cellar, lack of natural gas connection)	☐	☐	☐	☐	☐	☐	☐
Decreasing conversion efficiency of fuel cells over time	☐	☐	☐	☐	☐	☐	☐
Usage of conventional fuels	☐	☐	☐	☐	☐	☐	☐
Integration of the fuel cell system into existing heating systems is more complex compared to conventional systems	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment: The field "Other" enables you to add your own aspects (open field).

S0 Socio-cultural aspects

S001-S004 Promoting factors

The installation of fuel cell heating systems is related to several socio-cultural aspects, which may positively influence the broad market diffusion of this technology.
Please estimate the current relevance (from not relevant to highly relevant) and the future relevance (increasing or decreasing over the next five years) of the following aspects listed.

	Relevance today					Future relevance	
	no relevance	rather little relevance	moderate	rather high relevance	high relevance	increasing	decreasing
Awareness as an eco-friendly technology	☐	☐	☐	☐	☐	☐	☐
Awareness as a technology for own power generation	☐	☐	☐	☐	☐	☐	☐
Trust in advantages of new technologies (e.g. promises by manufacturer and consulting agencies on achievable cost savings are met)	☐	☐	☐	☐	☐	☐	☐
Trust in government-aided technology	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment: The field "Other" enables you to add your own aspects (open field).

S005-S008 Inhibiting factors

The installation of fuel cell heating systems is related to several socio-cultural aspects, which may negatively influence the broad market diffusion of this technology.
Please estimate the current relevance (from not relevant to highly relevant) and the future relevance (increasing or decreasing over the next five years) of the following aspects listed.

	Relevance today					Future relevance	
	no relevance	rather little relevance	moderate	rather high relevance	high relevance	increasing	decreasing
Lack of awareness (e.g. house owners and decision-maker in general)	☐	☐	☐	☐	☐	☐	☐
Little trust in new technologies (e.g. stated expectations on efficiency and cost savings not met)	☐	☐	☐	☐	☐	☐	☐
Knowledge gap and lack of skills (e.g. craftsmen and architects)	☐	☐	☐	☐	☐	☐	☐
Negative opinion of energy suppliers	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment: The field "Other" enables you to add your own aspects (open field).

R0 Policy framework

R001-R004 Promoting factors

The installation of fuel cell heating systems is related to several political aspects, which may positively influence the broad market diffusion of this technology.
Please estimate the current relevance (from not relevant to highly relevant) and the future relevance (increasing or decreasing over the next five years) of the following aspects listed.

	Relevance today					Future relevance	
	no relevance	rather little relevance	moderate	rather high relevance	high relevance	increasing	decreasing
Laws promote profitability of fuel cells	☐	☐	☐	☐	☐	☐	☐
Laws positively promote demand	☐	☐	☐	☐	☐	☐	☐
The Cogeneration Act promotes this technology	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment: The field "Other" enables you to add your own aspects (open field).

R005-R008 Inhibiting factors

The installation of fuel cell heating systems is related to several political aspects, which may negatively influence the broad market diffusion of this technology.
Please estimate the current relevance (from not relevant to highly relevant) and the future relevance (increasing or decreasing over the next five years) of the following aspects listed.

	Relevance today					Future relevance	
	no relevance	rather little relevance	moderate	rather high relevance	high relevance	increasing	decreasing
Incentives of grants are too low (amount and duration too low or short)	☐	☐	☐	☐	☐	☐	☐
Many authorities need to be contacted for grants	☐	☐	☐	☐	☐	☐	☐
Disadvantage of contracting compared to existing energy supply	☐	☐	☐	☐	☐	☐	☐
Lack of planning security (dynamic law) (short duration of funding schemes)	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment: The field "Other" enables you to add your own aspects (open field).

Z0 Structural aspects

Z001-Z004 Promoting factors

The installation of fuel cell heating systems is related to several structural aspects, which may positively influence the broad market diffusion of this technology.
Please estimate the current relevance (from not relevant to highly relevant) and the future relevance (increasing or decreasing over the next five years) of the following aspects listed.

	Relevance today					Future relevance	
	no relevance	rather little relevance	medium	rather high relevance	high relevance	increasing	decreasing
Existing infrastructure (e.g. connection to natural gas network)	☐	☐	☐	☐	☐	☐	☐
High potential for fuel cells in existing buildings (modernisation of heating systems)	☐	☐	☐	☐	☐	☐	☐
Branch's interest in market launch	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment: The field "Other" enables you to add your own aspects (open field).

Z005-Z008 Inhibiting factors

The installation of fuel cell heating systems is related to several structural aspects, which may negatively influence the broad market diffusion of this technology.
Please estimate the current relevance (from not relevant to highly relevant) and the future relevance (increasing or decreasing over the next five years) of the following aspects listed.

	Relevance today					Future relevance	
	no relevance	rather little relevance	moderate	rather high relevance	high relevance	increasing	decreasing
Increasing demand of home energy systems with a low capacity (lower heating demand in retrofitted houses and new houses)	☐	☐	☐	☐	☐	☐	☐
High accounting effort for users (read out and record, taxes)	☐	☐	☐	☐	☐	☐	☐
Limited availability of financing models (contracting, leasing)	☐	☐	☐	☐	☐	☐	☐
High administrative effort and bureaucracy (e.g. application effort, funding schemes)	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment: The field "Other" enables you to add your own aspects (open field).

Part C: Suggestions and options

O002-O007 Suggestions and options

Question: Where do you think there is urgent need for action? Which options would you suggest for addressing them (e.g. service provision, new business models)?
Please briefly describe the urgent need for action from your point of view and your suggestions for addressing them.
[Open question]

Urgent need for action:

Options:

Appendix B. Suggestions and options identified in the survey

See Tables B.1–B.3.

Table B.1
Summary of suggestions and options for demand-side actors (own translation and classification, double counting, $n = 39$, numbers in brackets indicate the number of similar responses).

Area	Stakeholder group	Suggestions (need for action)	Options
Costs	House owners	Reduce costs, e.g. taxes, funding (7)	Political support (foster clean energy, CHP technology); commercialisation programme, massive state support, see photovoltaic technology, funding, increase power tariffs, implement variable power tariffs depending on demand (6)
		Reduce acquisition costs (5)	Simplify the tax system (e.g. resale of electricity to tenant, tax write-offs, tax refunds, network charges), tax-free domestic consumption (4)
		Reduce maintenance costs (2)	Mass production (economies of scale) (2)
		Reduce installation costs (1)	Political demand for industrial support (1)
		Costs of other heating technology (1)	Reduce maintenance costs (similar to current heating technology) (1)
			Reduce cost gap between fuel cells and other CHP technology/wood pellets, etc. by banning inefficient technologies (see Denmark) (1)
Technology & Ecology	House owners	Improve technology: increase reliability for users, storage of electricity, hydrogen-based efficiency (3)	Technology: increase service life (20 years or 100,000 operating hours equal to current technology) (1), modular design of the system (1)
		Ecology: foster renewable energy, life cycle analysis (3)	Ecology: use hydrogen instead of natural gas (energy sources), climate-neutral hydrogen production (2), foster hydrogen-based fuel cells (without reformer for natural gas) (1), consider grey energy (1)
Socio-cultural aspects	House owners	Increase public perception (6)	Address the public through the media and by running marketing campaigns (6)
		Increase positive information about the benefits of fuel cells and CHP, climate relevance (3)	Information campaign: public activities of manufacturers and product developers, new technologies and best available technology, funding schemes, benefits of fuel cells (energy and cost savings, greater independence of supply), particularly address municipalities (6)
		Reduce insecurity/increase trust in technology (2)	Visit model plants and open houses (2)
		Consulting in general and, e.g. for municipalities (1)	Introduce conceivable type series (1)
			Train planners and installers/staff (1)
			"All inclusive" offers, including consulting, planning, installation, operation and maintenance (1)
			Generous warranty and service policy (due to insecure reliability/service life/maintenance costs) (1)
Policy framework	House owners	Strengthen government funding (3)	Improve incentives for property developers and owners, specifications in development plans for eco-friendly heating installations (1)
		Broad market launch (2)	Abolish/simplify Renewable Energies Act levy (EEG-Umlage) on domestic consumption (2)
		Reduce bureaucracy (2)	Centrally disconnect CHP in case of high power supply (wind); during disconnection, domestic consumption should be free of charge (1)
		Modify Renewable Energies Act (2)	Design support/taxes in order to swarm connection of CHPs (replace expensive back-up power plants) (1)
		Improve regulation on domestic consumption (1)	Reduce bureaucracy: reduce administrative burden (especially taxes on selling power to tenants) (1), refund of energy tax, etc., need for simple accounting and administration (2)
		Support grid-friendly operation by state/ operator (1)	Improve funding/support of CHP (1)
			Ban inefficient technology, leading to the appreciation of efficient technology (see Denmark) and a reduction of the cost gap (1)
Structural aspects	House owners	Improving infrastructure design/management (2)	Design support/taxes in order to swarm connection of CHPs (replace expensive back-up power plants) (1)
			Centrally disconnect CHP in case of high power supply (wind) (1)
Costs	Housing sector	Cost reduction (1)	Amortisation within 5–7 years (1)
		Simplify accounting (1)	
Socio-cultural aspects	Housing sector		Train heating engineers (1)
Policy framework	Tenants	Financial support (3)	New support sector in the Combined Heat and Power Act (1)
		Define exergy as target (1)	Micro-CHP bonus based on exergy efficiency (1)
			Change Energy Saving Ordinance into Exergy Saving Ordinance (1)
Socio-cultural aspects	Tenants	Information (1)	Information on costs and cost savings (1)

Table B.2
Summary of suggestions and options for supply-side actors (own translation and classification, double counting, $n = 39$, numbers in brackets indicate the number of similar responses).

Area	Stakeholder group	Suggestions (need for action)	Options
Policy framework	Business associations	Technology rollout programme (1)	Evaluation and implementation of IZES recommendations by the Federal Ministry for Economic Affairs and Energy based on industry consultation (1)
		Combined Heat and Power Act for large stationary fuel cell unit (1)	Remuneration based on previous principle also for large stationary fuel cells independent of domestic consumption or feed-ins (1)
Technology & Ecology	Installers and craftsmen	Quality management (1) Availability (1) Ecology (1)	Functional reliability of new hardware (1) Availability of fuel cells (1) Modernisation of heating systems with proof of energy efficiency/emission reduction (1)
Socio-cultural aspects	Installers and craftsmen	Increase trust in technology (4)	Functional reliability of new hardware (1)
		Knowledge improvement/training (1)	Publish test; improve customer information on pros and cons (1)
		Information (2)	Honesty towards customers (missed energy saving/cost saving targets must be communicated (see VW affair) (1), avoid false promises and hidden costs in contracts (1) Train craftsmen in operation and marketing (1) Increase information (1)
Policy framework	Installers and craftsmen	Simplify Combined Heat and Power Act, Renewable Energies Act, tax laws (2) Obligatory installation of CHP (1) Regulate warranty (2)	Combine laws on renewable energy and CHP into Energy Production Act; remuneration based on exergy and credit (see CHP), no taxes on domestic consumption (1) E.g. tax free micro-CHP; power selling to tenant and operator should be handled in the same way (VAT-free additional rental services) (1) Ban inefficient technology (simple condensing/heating boilers); Modernisation of heating systems with proof of energy efficiency/emission reduction (1) Assumption of liability directly by manufacturer (craftsmen not liable for malfunction) (1), craftsmen should be released from liability in case of inaccurate forecasts and changing laws (taxes) (1)
Socio-cultural aspects	Manufacturers	Increase trust in technology (1)	Demonstration units at fairs/exhibitions (1)
		Knowledge improvement (2)	Implement new specific profession/training of electricians (2)
Policy framework	Manufacturers	Easy funding (1)	Promote simple and long-term investment; combine production-linked support; simple accounting (1)
Costs	Public utility and energy suppliers	Reduce costs (operation costs) (1)	–
Technology& Ecology	Public utility and energy suppliers	Improve availability (1)	Marketability of CHP (1)
Socio-cultural aspects	Public utility and energy suppliers	Simplification (1)	"All-round Carefree Package" (1)
Policy framework	Public utility and energy suppliers	Simplify application (1) Planning security (1)	Simplify application system (1) Increase planning security for demand-side stakeholders through long-term funding (including reduction of direct payments / "degression") (1)
		Laws (1)	electricity feed laws (1)

Table B.3
Summary of suggestions and options for other (non-value chain) actors (own translation and classification, double counting, $n = 39$, numbers in brackets indicate the number of similar responses).

Area	Stakeholder group	Suggestions (need for action)	Options
Costs	Consulting	State funding (2)	Broad market diffusion of fuel cell technology within the next five years and EU funding (1)
	Science	Reduce acquisition costs (1)	Simple funding schemes (see German "Abwrackprämie" [scrapping bonus], e.g. €10,000 for 20,000 units in 2017; leasing offers by manufacturer (1)
Technology & Ecology	Consulting	Technology: reliability/ durability (1)	Increase durability to longer than 5 to 10 years (1)
	Science	Ecology: life cycle wide analysis of risks and benefits (1)	Acknowledge critical aspects (fuel cells use natural gas, limited durability, complex and vulnerable technology, use of critical raw materials); assess life cycle wide risks and benefits (1)
Socio-cultural aspects	Consulting	Campaigns (3)	Campaign by manufacturers (TV, internet, schools), see German Association of the Insulation Industry GDI;

(*continued on next page*)

Table B.3 (*continued*)

Area	Stakeholder group	Suggestions (need for action)	Options
Science	Knowledge improvement (2)	Campaign, see CHP campaign of "Energieagentur NRW", joint campaign by the housing sector, manufacturer and public utility (3)	
		Trust — long-term policy framework (1)	Long-term funding and fair grants (without hidden time effort and additional payments) (1)
		Trust in technology and information (1)	Communication: Balance between marketing language and excessive discussion (1)
		Transparency on risks and benefits (life cycle) (1)	Acknowledge critical aspects (fuel cells use natural gas, limited durability, complex and vulnerable technology, use of critical raw materials); assess life cycle wide risks and benefits (1)
			Train and provide information independently from the manufacturer: planners, craftsmen, energy consultants, other actors (1)
Policy framework	Consulting	Long-term reliable framework (2)	Lobby for long-term funding and fair grants (without hidden time effort and additional payments) (1)
		Long-term funding and fair grant (1)	Long-term reliable framework (CHP, renewable energy), fuel cell-friendly laws (CHP) (1)
		Working group of key stakeholders (1)	Long-term stakeholder working group (policy, industry, science) to continuously improve policy framework and develop recommendations for application in housing sector and business (1)
			Binding agreement between European Commission and manufacturers on funding concept (decrease funding by increasing fuel cell units as selling prices decline); Germany should suggest this to the EU and establish partnerships with, e.g. Japan. (1)
			Strengthen market diffusion by energy providers: CHP electricity production by energy providers and own power generation should be treated equally (Renewable Energies Act levy) (1)

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