



Non-economic barriers to large-scale market uptake of fuel cell based micro-CHP technology

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Non-economic barriers to large-scale market uptake of fuel cell based micro-CHP technology

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EXECUTIVE SUMMARY

The large-scale market introduction of fuel cell (FC) based micro combined heat and power (micro-CHP) systems in residential application faces a broad range of challenges, including non-economic barriers, which require special attention. This report identifies the non-economic barriers in terms of product perception by consumers or installers, supply chain limitations, policy and political environment and the performance of the system in operation, and proposes actions to address them to facilitate the market uptake of FC micro-CHPs.

Complementing the right market conditions, awareness among end-users and supply chain, as well industry's further efforts to speed up the industrialisation of FC micro-CHP production, a coherent, steady and predictable policy framework, is key to recognise and incentivise investments by the European heating sector in advanced products and new business models contributing to a more efficient, reliable and cleaner energy system¹.

The comprehensive review of the policy and political context², conducted as part of the ene.field project, concluded that the multiple consumer and energy system benefits of FC micro-CHP **are not adequately recognised and rewarded by most policy at the EU and national levels**.

In addition to high level recognition of fuel cell micro-CHP at both EU and national levels, **removing barriers** and fully **accounting for the consumer and system level benefits in building codes, energy labelling and other secondary policy** instruments is key to ensure that the right drivers are in place, once the mass market commercialisation stage has been reached. Promoting innovative business models to accompany the roll out of FC micro-CHP will also help consumers derive further benefits from the technology.

A **lack of a common framework of European standards** is seen as a great hindrance to market uptake. Manufacturers points to a need for updating, improvements or revisions for a large amount of the current standards³. Issues include **lack of consistency between different standards** dealing with similar topics and **standards that refer to too general co-generation systems** fitting poorly with the reality of FC micro-CHP technology. The **sheer amount of standards** that are in some way relevant to FC micro-CHP installation makes it hard for the manufacturers to keep an overview.

From a supply chain point of view the main challenges for the FC micro-CHP technology is significant **increase of production volume, simplification of maintenance and part replacement** procedures and **reduction of system complexity** and the cost of components. In the same thread, **cost reduction** is necessary for market introduction of the technology⁴. Here the main can be grouped into three main areas of work: **increase in volume, system simplification and development of collaborative strategies** between key players.

¹ From the forthcoming ene.field report: **Fuel Cell micro-CHP in the Context of EU Energy Transition: Policy Analysis and Recommendations**. Will be available on <http://enfield.eu/category/news/reports/> in September 2017

² See above note

³ [Position Paper on Regulations, Codes and Standards](#), ene.field, 2014. An update of this report is due August 2017

⁴ [European Supply Chain Analysis Report](#), ene.field, 2014. An update of this report is due August 2017

From the more technical point of view of **field installation**, the largest problem identified is the sheer **time** some installations take⁵. Here **component standardisation** may be a way of decreasing the required installation time. Additionally, while **training of installers** has progressed tremendously in active markets such as Germany, a lack of such training may be a barrier for market entry **in smaller dormant markets**.

Lastly, while **customers** participating in the ene.field project were found to be **overwhelmingly positive** to the FC micro-CHP technology, two main areas where **improvements** would be desirable were identified: **running costs and ease of use of the technology**⁶. This latter point was most notable when asked about satisfaction with heating and hot water and therefore it should be noted that issues with the backup boiler or heating circuit might just as well have caused this.

⁵ See section **3. Consumer and installation barriers** in present report

⁶ See section **3. Consumer and installation barriers** in present report

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1. INTRODUCTION

1.1 Aim of this work

The aim of this report is to review current non-economic barriers to mass uptake of the fuel cell (FC) micro combined heat and power (micro-CHP) technology. The report considers technical, consumer and political barriers. It is based on data from the ene.field trial programme and draws on the knowledge and expertise of the ene.field project partners.

Based on analysis performed the authors and partners of the ene.field project seek to, deliver clear recommendations for actions to address these non-economic barriers at national and European level.

The market barriers discussed in this paper relate to the installer, consumer, product performance, supply chain, regulations codes and standards, and political barriers.

Analysis of consumer and installer barriers was done by the Energy Savings Trust (Aled Stephens and Andrew King), input on regulation codes and standards was delivered by Polito (Massimo Santarelli and Davide Drago) and politics analysis was supplied by COGEN Europe (Alexandra Tudoroiu-Lakavičė). This report also includes performance analysis by Gas- und Wärme-Institut Essen (GWI) and Gastechnologisches Institut (DBI) (Mustafa Flayyih and Frank Erler respectively) and input on supply chain barriers by Element Energy (Edward Boyd, Lisa Ruf and Ian Walker).

This report was curated, and partly written, by the Technical University of Denmark (Carsten Brorson Prag, Jonathan Hallinder and Eva Ravn Nielsen).

1.2 About the ene.field project

This report is a part of Europe's largest demonstration project for fuel-cell-based micro-CHP (micro combined heat and power) systems, ene.field (*European-wide field trials for residential fuel cell micro-CHP*, grant no. 303462). The aim of the project is to demonstrate small stationary fuel cell systems for residential and commercial applications. The project will deploy up to 1000 micro-CHP units in 12 EU member states. This is a step change in the volume of fuel cell micro-CHP deployment in Europe and an important step to push the technology towards commercialization. The project involves 27 partners. Besides the manufacturers of the FC systems, several research institutes as well as utilities are also involved as partners in the project.

<p>The ene.field project has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) for the Fuel Cells and Hydrogen Joint Technology (FCH-JU) under grant agreement N° 303462.</p>
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2. TECHNICAL PERFORMANCE BARRIERS

2.1 Data collection and analysis

This section is based on technical performance data collected during the ene.field project field trials. The results presented here are thus based on data from units in field operation, supplying an end-user with heat and power.

The data collected falls into three categories: standard monitoring, detailed monitoring and issues encountered.

All installed units in the ene.field project were subject to standard monitoring. Here monthly data regarding gas consumption, heat production, electricity production, operation hours and on/off cycles is collected. 10% of the installed units were further equipped with detailed monitoring capabilities. Here data regarding electricity and heat production and consumption, electricity import and export, indoor and outdoor temperature, and more was collected every 15 minutes. Issues encountered were reported by manufacturers and installers during installation and operation.

All installed units were identified by an anonymous unit-ID, consisting of three letters, identifying the manufacturer and four random numbers.

All monitoring data from the individual units was transmitted to GWI (Gas- und Wärme-Institut Essen) and DBI (Gastechnologisches Institut). Here the data was collected and anonymised in a cleanroom process before being distributed to other partners in the project for analysis. The manufacturer of a given systems were entitled to the un-anonymised data for said system. In the clean room process, the data was agglomerated by technology type (SOFC and PEM) and normalised.

Analysis requiring un-agglomerated data was carried out by DBI and DWI and subsequently anonymised.

2.2 Operation and Failures encountered

Operation

Availability of installed units

Part of the monitoring of the FC micro-CHP units deployed in the ene.field project was an investigation of their availability to the end-users. The system availability was calculated based on information regarding system off time in connection with issues encountered as well as maximum possible availability (total hours in operation period minus seasonal shutdown). The result is shown below for SOFC and PEM units deployed and in operation in 2015 and 2016. The results are shown for each half-year interval from start 2015 to end 2016. The half's are named H1 to H4 respectively.

Figure 1 shows the availability of SOFC units in percent and Figure 2 shows the availability as cumulative hours available. It is seen that all availability is above 98% with a maximum of 100%. While there is a decrease in availability from H2 to H3 and H4 there is a simultaneous almost doubling of the number of operation hours.

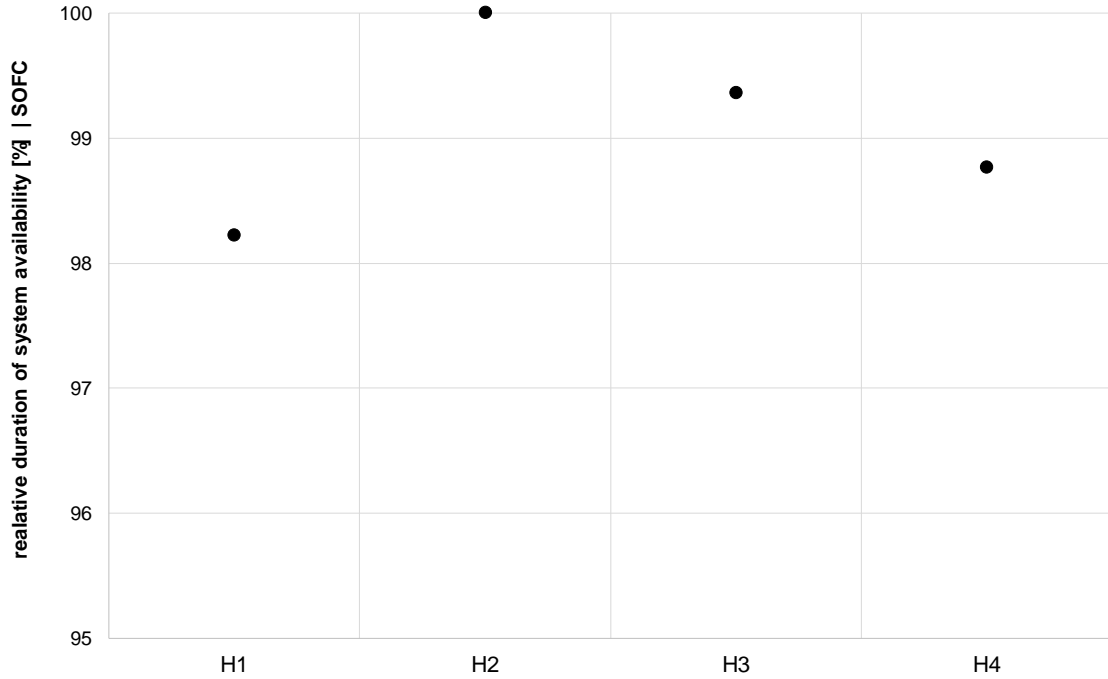


Figure 1: Availability of deployed SOFC micro-CHP units presented as percentage of maximum possible hours in operation. H1 to H4 refers to first half of 2015 to second half of 2016 respectively.

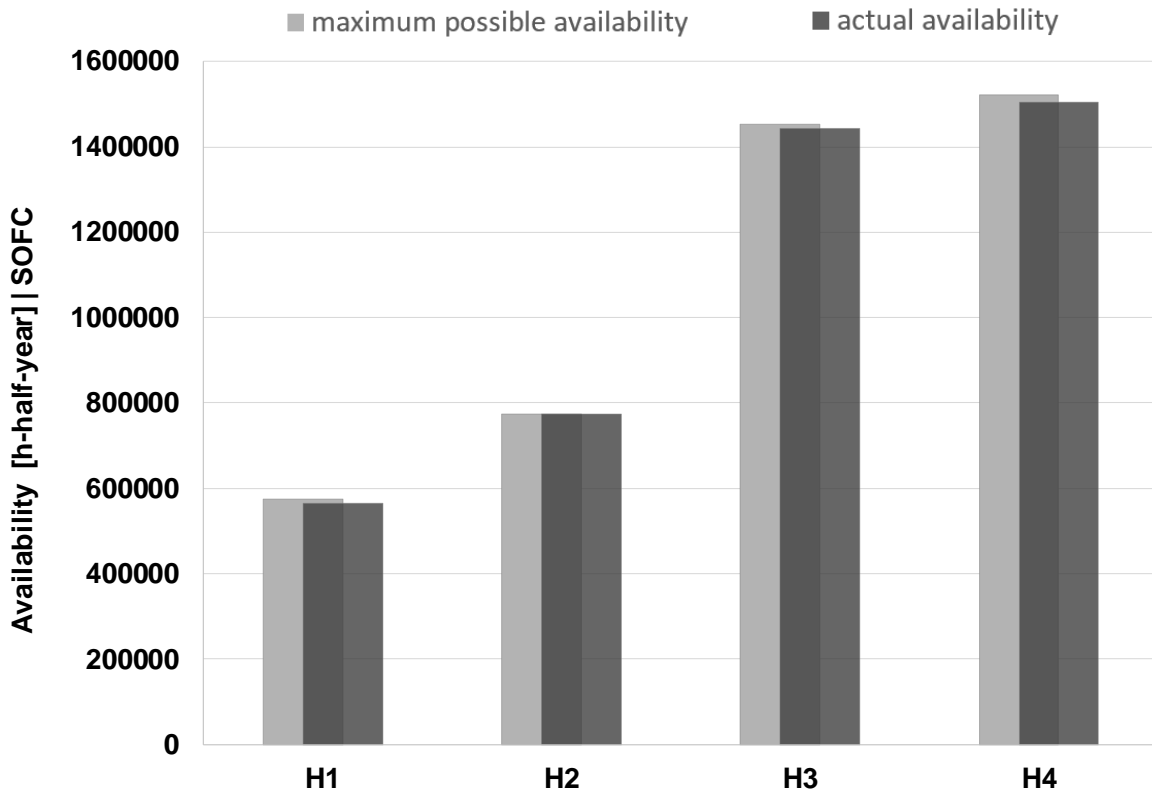


Figure 2: Availability of deployed SOFC micro-CHP units presented as cumulative hours available for all units. Maximum possible hours in operation are shown for reference. H1 to H4 refers to first half of 2015 to second half of 2016 respectively.

Figure 3 shows the availability of PEM units in percent and Figure 4 shows the availability as cumulative hours available. It is seen that all availability for 2015 is around 95% while availability for 2016 is above 99% and with more than double the amount of operation hours. This progression is very encouraging as it shows clear improvements with time.

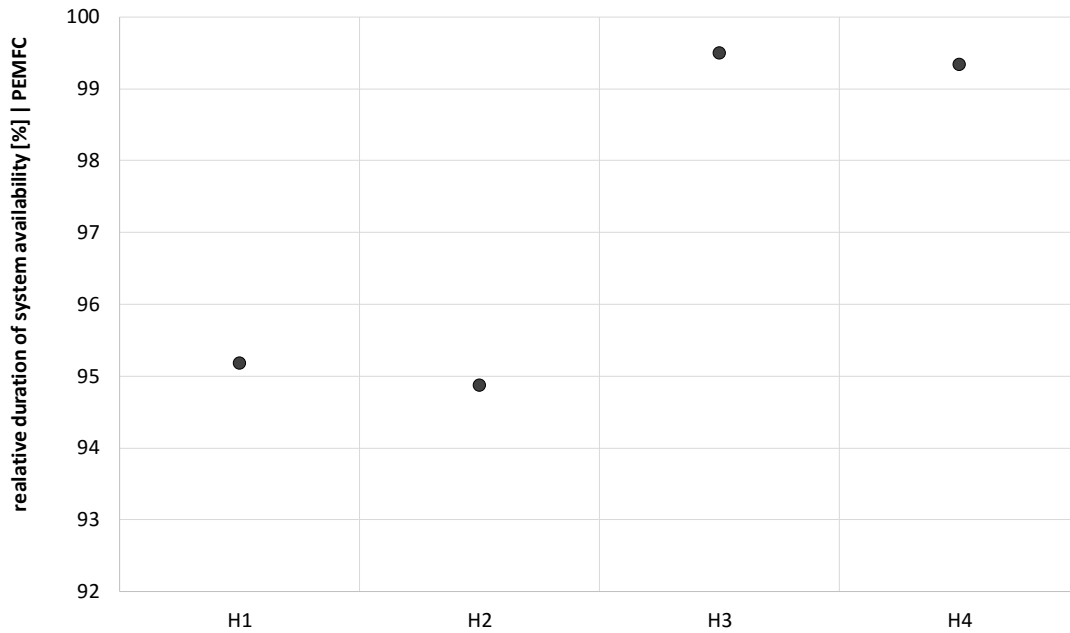


Figure 3: Availability of deployed PEM micro-CHP units presented as percentage of maximum possible hours in operation. H1 to H4 refers to first half of 2015 to second half of 2016 respectively.

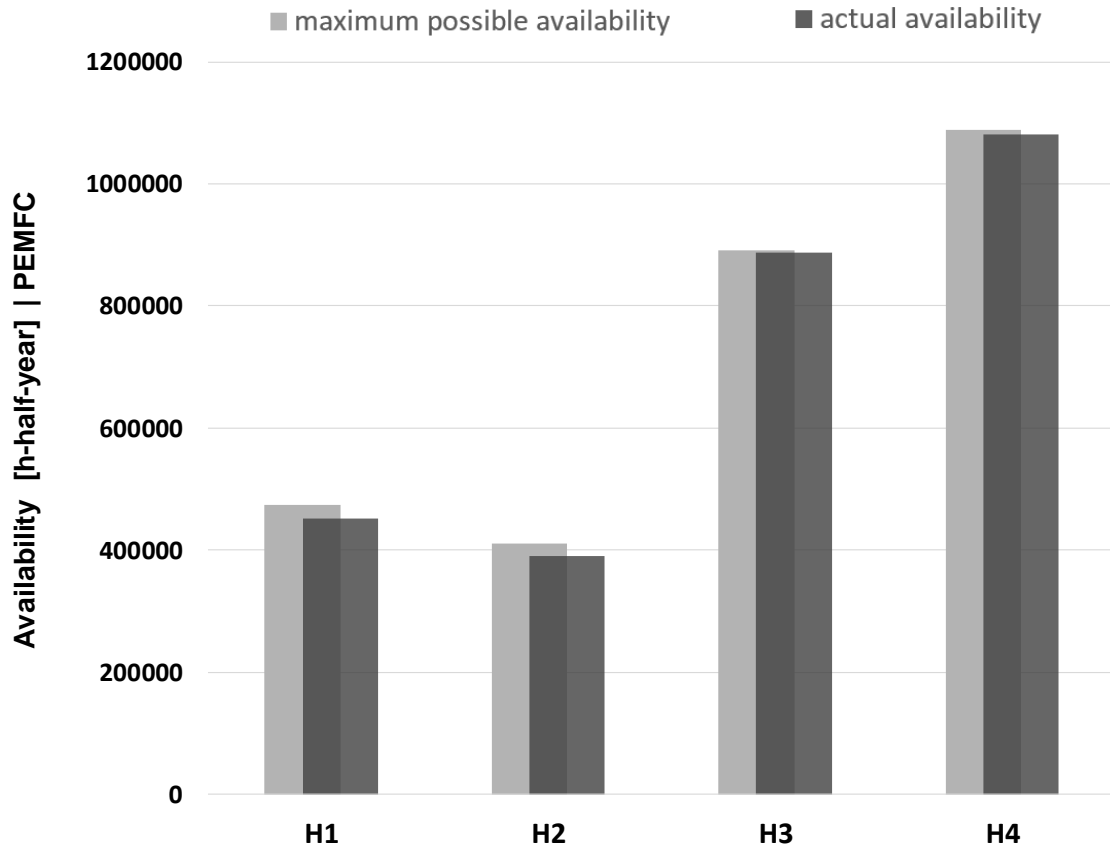


Figure 4: Availability of deployed PEM micro-CHP units presented as cumulative hours available for all units. Maximum possible hours in operation are shown for reference. H1 to H4 referrers to first half of 2015 to second half of 2016 respectively.

The above SOFC and PEM results show that the technology is well on its way to a very high availability. In previous projects, such as Callux and SOFT-PACT, availability has been reported between 90% and 96%. For upcoming actions, such as the PACE project⁷, goals of up to 99% availability has been set. The results from ene.field clearly shows that this is feasible.

Failures encountered

Analysis of Issue Categories

To qualify observed non-availability of the installed units in the ene.field project the events that caused a deployed unit to be off-line were categorised, sorted and reported.

An issue was defined as an event which reduced the availability of the fuel cell. This included faults causing a shut down (e.g. critical faults like too high temperature) as well as downtime due to service. A period during normal operation in which the unit was turned off is not counted as an issue. This could be the case if there is no thermal demand. A service activity during this regular off-time is also counted as an issue. Events were sorted into the following categories:

⁷ www.pace-energy.eu, website available from early September 2017

- 1 stack
- 2 reformer
- 3 stack / reformer⁸
- 4 inverter
- 5 balance of plant
- 6 service
- 7 back-up
- 8 periphery
- 9 other

A detailed description of the categories can be found in Annex 1.

The relative distribution of issues encountered for SOFC and PEM FC is presented in Figure 5 and Figure 6.

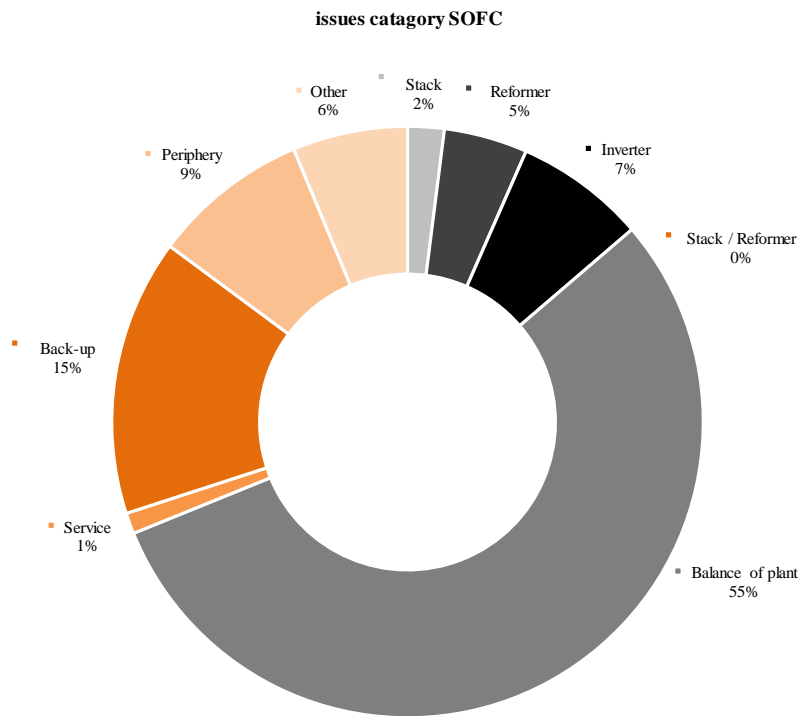


Figure 5: Distribution of issues encountered to the 9 issue categories for SOFC

⁸ For some units it is not possible to distinguish between issues in the stack and the reformer. To solve this problem a combined category “stack / reformer” has been used in these special cases.

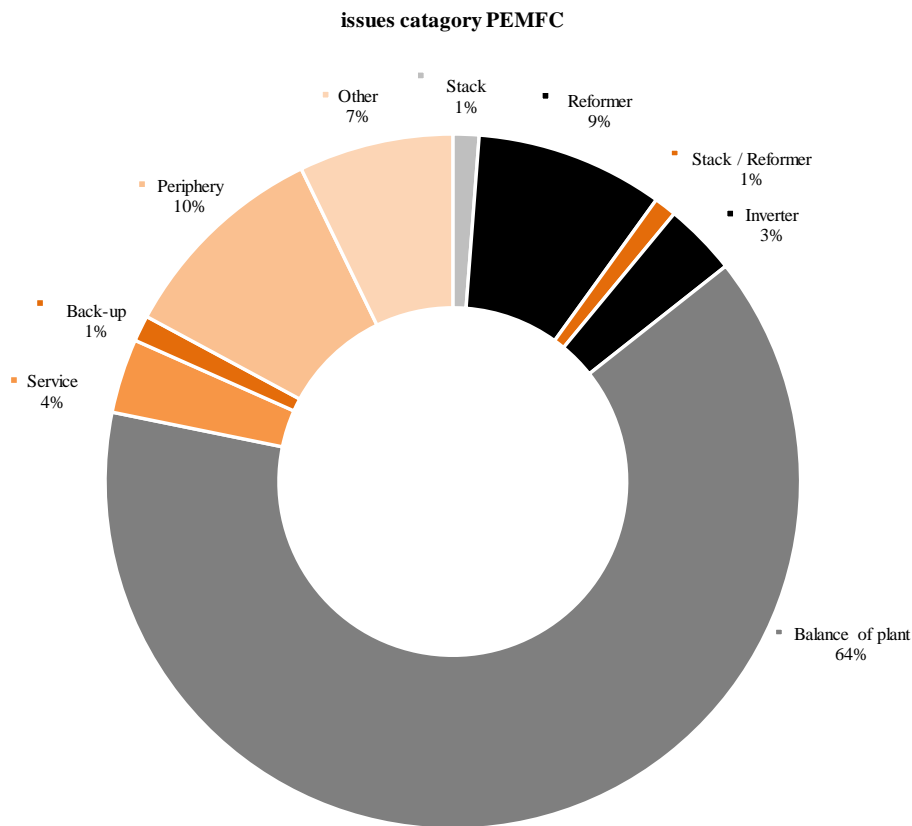


Figure 6: Distribution of issues encountered to the 9 issues categories for PEM FC

In the above Figures, we see very similar results for SOFC and PEM units installed in the ene.field project.

Of the total failures encountered only 1%-2% of them relates to the central stack component. This is in line with the robustness reported by stack manufacturers and shows the core technology of the systems is reliable in real life installations.

The most failure prone part of the installation, with 55% and 64% for SOFC and PEM installations respectively, is the balance of plant of the fuel cell system. This is components, such as gas valves, which are used for competing technologies as well as for fuel cell system installations. This indicates that components exclusive to the fuel cell technology are not contributing with nearly as many availability constraining issues as more common components. This point can also be illustrated by including failures due to back-up systems (peak demand boiler and electricity grid connection) and periphery related failures (e.g. heating circuit failures). Doing this shows that 79% and 80% of failures, for PEM and SOFC installations respectively, are not related to the fuel cell and its core components. It should however be noted that for both technologies the reformer and inverter are responsible for 12% of the issues encountered.

3. CONSUMER AND INSTALLATION BARRIERS

3.1 Summary

187 respondents to the pre-installation survey reported the types of properties and demographics in which FC micro-CHP systems would be installed. 75% of the properties where FC micro-CHP systems were installed were generally quite modern (post 1970s), large detached or semi-detached houses, with gas heating systems. End-users had relatively high household incomes and consisted primarily of a mixture of working, studying and home-workers. The remaining 25% were non-residential properties which included schools and office buildings.

153 installers of FC micro-CHP systems reported that the systems were generally easy to install. Installation times were investigated excluding the installations with detailed monitoring equipment. All installation took at least 2 days, with most installations taking 4-6 days. Estimates of man hours for each installation varied, with most installers reporting installation times of around 24-32 man hours, and around 64-72 man hours. As installations require multiple visits to the installation site by a handful of professionals before, during and after installation these numbers are more reasonable than they may appear at first glance, especially when compared to a standard gas boiler requiring 2 day of installation. Installation times are also likely to decrease significantly as installers became more familiar with the installation of FC micro-CHP systems.

Of all the components of a FC micro-CHP system installation, the fuel cell units were considered to be slightly more difficult to install than other components, however they were still considered to be easy to install. On average the fuel cell unit took around a quarter of the total installation time.

Of the 49 end-users that completed the post-installation survey, the end-users were satisfied with the information they received on their systems. 45 of the 49 end-users felt that they understood their system at least well enough to use it.

End-users were generally very satisfied with all the aspects of their FC micro-CHP systems that were included in the survey. Considering all responses to the satisfaction questions, overall average satisfaction was very good (a score of 3.9 out of 5). Satisfaction with comfort and warmth, space heating, hot water production, and environmental performance scored higher than the average 3.9 out of 5 while satisfaction with running costs, ease of use/controllability scored slightly lower than average.

End-users were generally more satisfied with their FC micro-CHP system than their previous heating system, and the systems generally exceeded the expectations that end-users had reported in the pre-installation survey.

Although around half of the FC micro-CHP systems had 1 or more failure in the first year of operation, the proportion of time that the systems were available was very high (over 95%). Rate of failure had a minimal impact on perceived reliability or overall user satisfaction with their FC micro-CHP system.

3.2 Introduction

The following analysis provides information from the pre-installation, installer and post-installation surveys conducted during the Ene.field fuel cell (FC) micro-CHP trial. The results of these surveys have been analysed to gain an understanding of the attitudes of consumers toward the FC and barriers to installation.

3.3 Data collection and analysis

Three surveys were conducted to collect information about end-user and installer expectations and experience with the FC micro-CHP systems. This work was carried out to investigate property types, user demographics, perceptions and behaviours of end-users and installers in order to locate barriers to market uptake of the technology.

Pre-installation survey

The first end-user survey polled the end-user on their household, current method of heating, demographic, and expectations of the FC. This questionnaire was distributed to the end-user prior to FC installation.

Installer survey

The installer survey polled the installer about technical details of FC micro-CHP system and the heating system that was being replaced, ease of various aspects of the FC micro-CHP installation and time taken to carry out the installation. This was completed by the installers shortly after installation.

Post-installation survey

The second end-user survey was distributed one year after FC micro-CHP system installation and polled the end-user on their satisfaction with various aspects of the FC micro-CHP system, their understanding of the system as well as electricity generation, economics and perceived performance of the system. Household data was also verified in this questionnaire.

Table 1: Number of respondents to each survey

Survey name	Respondents
Pre-installation	187
Installer	153
Post-installation	49

Performance monitoring

All installed units were subject to standard monitoring. Here monthly data regarding gas use, heat production, electricity production, operation hours and on/off cycles is collected.

In the Ene.field trial, 10% of the FC micro-CHP units were equipped with detailed monitoring capabilities. Here data regarding electricity and heat production and consumption, electricity import and export, inside and outside temperature, and more was collected every 15 minutes. Issues encountered were reported by manufacturers and installers during installation and operation.

All questionnaires were distributed using the anonymous unit-ID and collected and stored using the online tool Questback. All data was delivered to GWI and subjected to a clean room process before being made available for use in analysis. The clean room process stripped the data of the anonymous unit-ID, and thus manufacturer identification, country and postal code in order to protect the identity of the end-user. The remaining datasets were made available to EST and DTU for analysis.

A number of correlated responses from the pre-installation and post-installation surveys were provided by GWI to allow a comparison of the important variables (for example change in satisfaction between the previous heating system and the FC micro-CHP system).

The following sections draw on the data from the questionnaires in an attempt to identify the perceived barriers to market uptake from consumers and installers.

3.4 Properties and demographics

In this section, we describe the property types and demographics of the end-users that were surveyed in the pre-installation survey.

Properties

To gain an understanding of the type of properties that would have their existing heating systems replaced with FC micro-CHP systems, the survey questioned end-users about property type, size and age.

The property types were mostly residential (75%) with some non-residential properties (25%). The majority of the residential properties consisted of detached and semi-detached houses; these properties generally have a higher heat demand than smaller properties such as flats or terraced properties. Most of the residential properties had a floor area of around 200 m², this represents a relatively large house size.

Table 2: Property types

Property type	Proportion of properties
Detached	43%
Non-residential	25%
Semi-detached	17%
Terraced	7%
Flat	5%
Other	4%

Most properties in the sample were constructed between 1976 and 2000. The properties are generally quite modern properties, with 81% of the properties having been constructed after 1950. Newer

properties are more likely to have been built to be more energy efficient than older properties (e.g. higher levels of insulation).

Although the energy efficiency ratings of properties were asked for in the pre-installation survey, this has not been included in the analysis due to a low number of responses to this question.

Table 3: Property ages

Age	Proportion of properties
Pre 1900	4%
1901-1925	6%
1926-1950	9%
1951-1975	21%
1976-2000	34%
2001+	26%

Heating System

To gain an understanding of the existing heating systems that would be replaced with FC micro-CHP systems, the surveys asked end-users about the heating fuel they used and the age of their heating system. End-users were also asked to what temperature they tended to heat their homes.

The vast majority of heating systems are gas (69%). Mains gas is a relatively low carbon and generally inexpensive fuel.

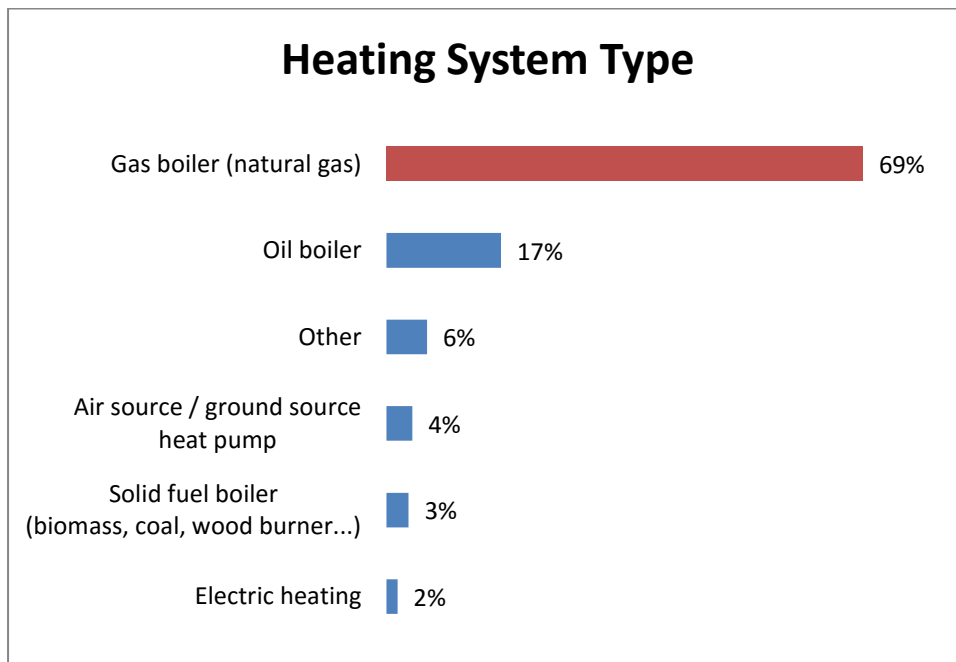


Figure 7: Heating system types

Although over a quarter (27%) of systems were relatively modern (newer than 7 years) the majority were older, with around half the systems (48%) being installed before the year 2000, and therefore being over 16 years old. Older heating systems are generally less efficient especially since these older systems are likely to include non-condensing boilers.

Table 4: Heating system age

Heating System Age	Proportion of heating systems
Before 1970	1%
1971-1980	3%
1981-1990	14%
1991-2000	31%
2001-2010	25%
2010 +	27%

Responses on room temperatures from the post-installation survey indicate that although the majority of respondents (67%) report that they tend to heat their homes to between 18°C to 21°C. However, the remaining respondents (33%) heat their homes to between 22°C to 24°C; this is generally understood to be heating to a higher temperature than is required and will require more energy to maintain the high temperature.

Demographics

To understand the demographics of the occupants of the properties, the surveys asked questions about the ages and working status of the occupants and asked for total household incomes.

The majority (62%) of the occupants were 18 to 59 years old, with small proportions of children and retired people. 41% of the are working full or part time, and around a third (35%) are representative of demographics that are likely to be in the property during the daytime, these are likely to use more energy than the people who are away during the day. Almost three quarters of the households (71%) have a household income of over €61,000 Euros.

Table 5: Occupant ages

Age	Proportion of people
Children under 11 years	14%
Children 11-17 years	11%
Adults 18-59 years	62%
Adults 60 years +	13%

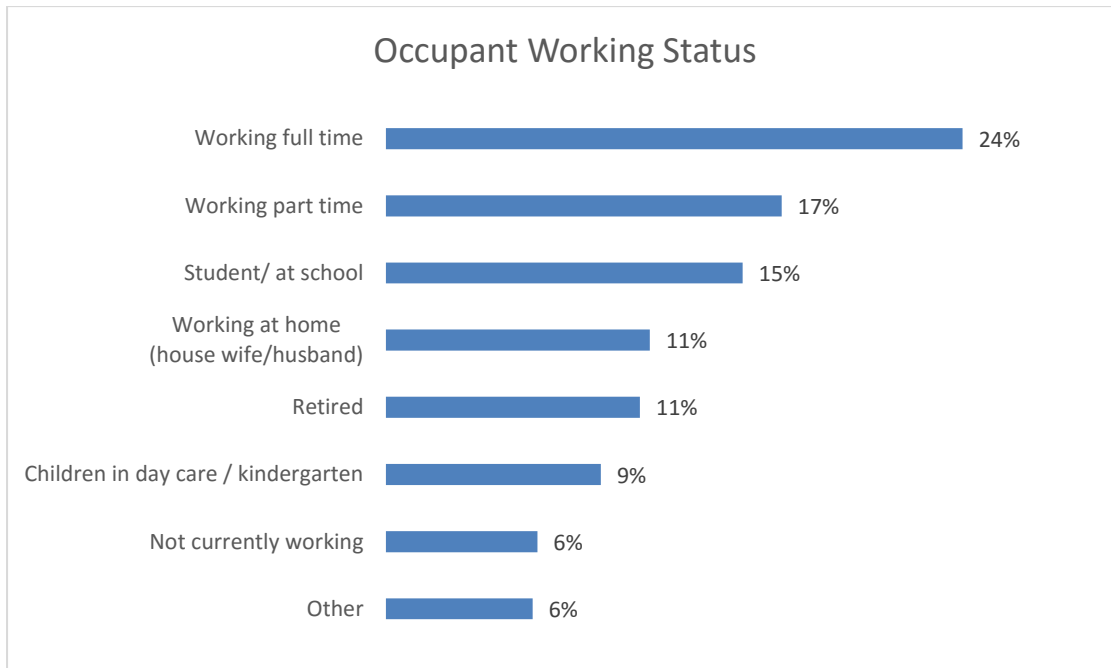


Figure 8: Occupant working status

Table 6: Household incomes

Income range	Proportion of properties
Up to €30,000	3%
€31,000-€60,000	26%
€61,000-€90,000	31%
€91,000-€120,000	14%
€121,000-€150,000	12%
€151,000-€180,000	3%
Over €180,000	12%

3.5 Installation

Details of the FC micro-CHP systems installed and the experience of the installers were recorded in the installer survey and are described in this section. Where applicable the results are split by system type, Solid Oxide Fuel Cell (SOFC) or Proton Exchange Membrane (PEM), and whether detailed monitoring was included in the installed or not.

Date of installation and type of system

The majority of installed FC micro-CHP systems that were reported in the survey were SOFC (61%) with 34% being PEM systems, consisting of a mixture of low and high temperature PEM systems.

The investigated systems were installed from the second half of 2013 onwards with an increase in installations in 2014, and a further increase in 2015 and 2016.

38% of the FC micro-CHP systems that were reported in the installer survey had detailed monitoring equipment installed.

The FC micro-CHP systems replaced natural gas heating systems in 85% of cases (131 systems), with 8% replacing oil, and the remaining systems replacing electric and solid fuel heating systems.

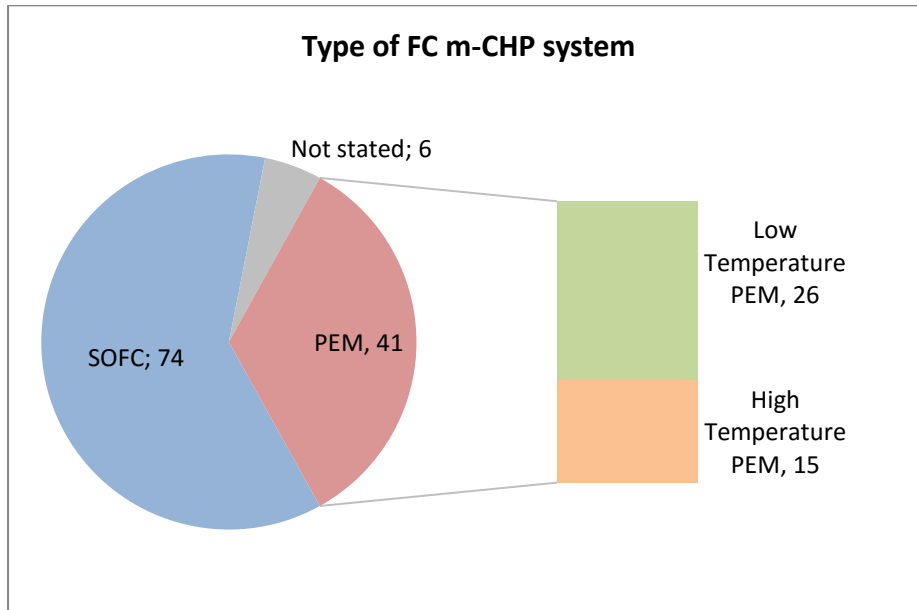


Figure 9: FC micro-CHP system types

Table 7: Year of installation

Year	Number of systems installed
2013	6
2014	33
2015	47
2016	45

Table 8: Detailed monitoring

Detailed monitoring	Number of systems
Yes	57
No	93

Ease of installation

Installers were asked to rate the ease of installing both the FC micro-CHP systems and the other individual components using a scoring system from 0 – “Not difficult” to 5 – “Very Difficult”.

The overall finding was that FC micro-CHP systems were not difficult to install. Overall installers rated SOFC micro-CHP systems to be slightly easier to install than PEM systems, however the number of PEM systems without detailed monitoring was low (16 systems) so the result may not be significant.

Table 9: Ease of installation – type of Fuel Cell

System type	Overall score	No of systems
PEMFC	1.3	16
SOFC	1.1	74
All systems	1.1	93

Scores for individual components varied, however no components were considered to be difficult to install. The components that were considered easiest to install were the standard connections that are found on other common heating systems (e.g. gas, water and back-up system). The components that were considered to be less easy to install are the less common connections that are specific to FC micro-CHP systems (e.g. fuel cell, electrical connection and other components). This could be because the installers are not as familiar with these components.

Table 10: Ease of installation - components

Component	Average Score
Gas connection	0.6
Back-up system	0.6
Water connection	0.6
Electrical connection	1.1
Data communication	1.1
Other components	1.2
Fuel cell unit	1.3

Installation time

Installers were asked to report on the amount of time it took to install the FC micro-CHP system and what proportion of that time was spent specifically installing the Fuel Cell unit.

FC micro-CHP systems with detailed monitoring took much longer than those without the extra monitoring equipment. Because of this extra time an overall analysis of the installation times is not likely to represent the commercial reality going forward. Therefore this analysis only considers the installations that did not include detailed monitoring to provide a better understanding of how installation times would be in real world situations where detailed monitoring equipment is not included.

Two responses that had unrealistically high installation times were discounted from the analysis. It may be that the installation time that was reported for these installations included time when the installation was in progress but not being actively worked on. It is unknown whether some of the other installation times reported by installers were also reported in this way.

Man hours required for installation

The following graph shows the man hours required to install the FC micro-CHP systems.

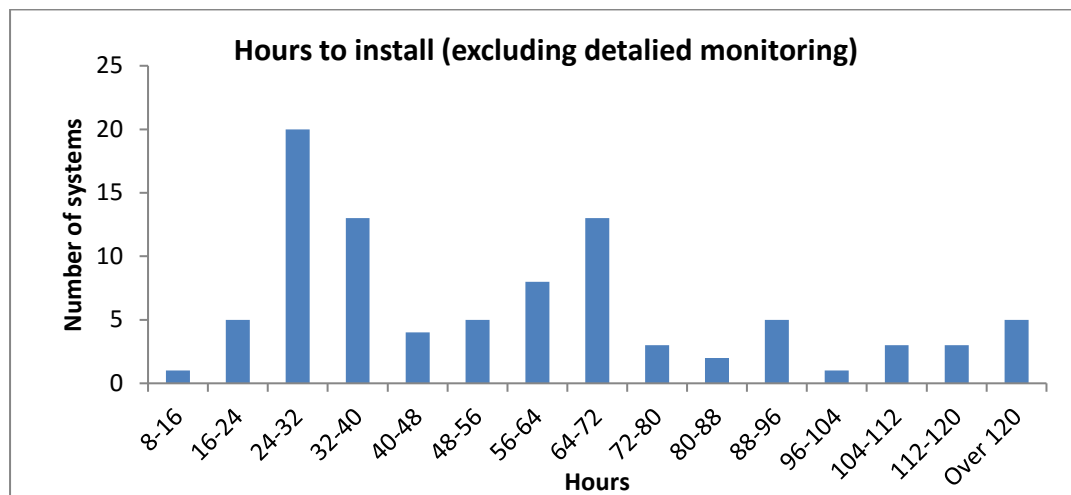


Figure 10: Hours to install

A wide range of man-hours was reported as being required for installation. For many installers these were the first FC micro-CHP systems that they had installed. It is expected that installation times will decrease significantly, as installers gain more familiarity with the installation of FC micro-CHP systems. The median number of hours to install was 24 hours, however because a number of installations took significantly longer, the average installation time was 58 hours. Over a third (36%) of installations took between 24 and 36 hours to complete. Almost half (48%) of installations were completed within 48 hours, and 81% of installations were completed within 80 hours.

Days required for installation

The following graph shows the number of days that it took to install the FC micro-CHP systems. Installers were asked to include time taken by all the companies involved in the installation process.

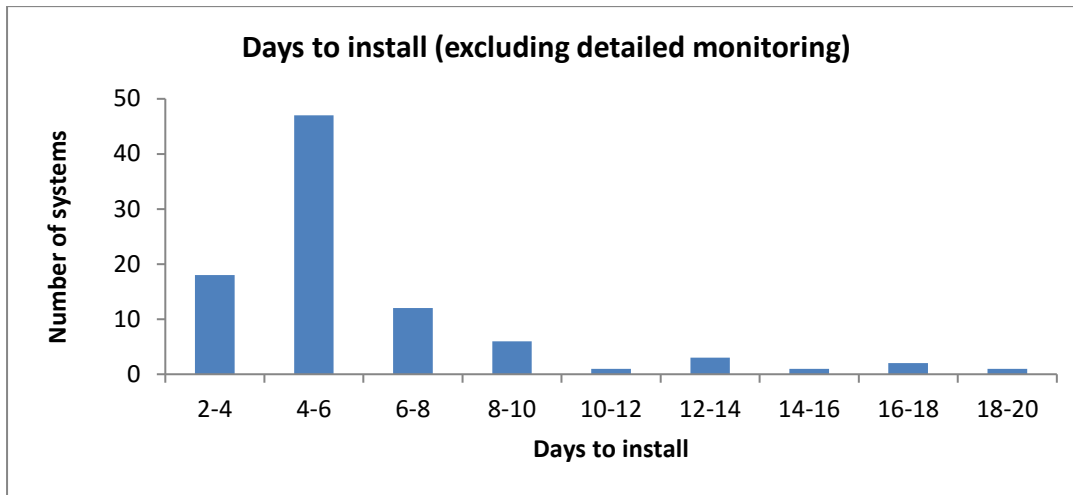


Figure 11: Days to install

The most common installation time was 5 days, with 71% of installations having been completed within 5 days. 80% of installations were completed in 8 days or less. There were no installations reported that took less than 2 days to complete. This is however expected, as a standard gas boiler requires a cumulative 2 day of installation.

Although there were relatively long installation times reported by installers, installations were reported to be relatively easy to perform. It could be that the installation process can be labour intensive, but not technically challenging. Experience from the ene.field project show that multiple professionals are required to visit the site before, during and after the physical installation. This being a combination of a plumber, the installer and an electrician both during site inspection, installation, approval of installation and commissioning. Taking into account that the questionnaire shows that no more than around a quarter of the installation time (26.5%) is taken up by the installation of the physical unit it is clear that the overall installation time will go down as site selection, connection and commissioning of the unit becomes more of a routine for the involved professionals.

3.6 Performance

The following section describes end-user understanding of their FC micro-CHP system and their satisfaction with it. The analysis investigates the post-installation survey results. For a number of the questions in this section a scale of 0 to 5 is used with 0 being the lowest score, and 5 being the highest.

Understanding

When asked about the quality of information that was provided by their installers, and their understanding of the information, end-users generally responded that they were provided sufficient information about how the FC micro-CHP system operates and that they had a good understanding of the information. Most end-users gave both criteria a score of 4 out of 5 (very good), with an average score of 3.7 for both criteria.

Figure 12 shows the scores given by end-users for the information provided by installers and their operation of the system. The percentages represent the proportion of scores that was received for each question. It should be noted that no end-users gave a score of 0 to any of the questions.

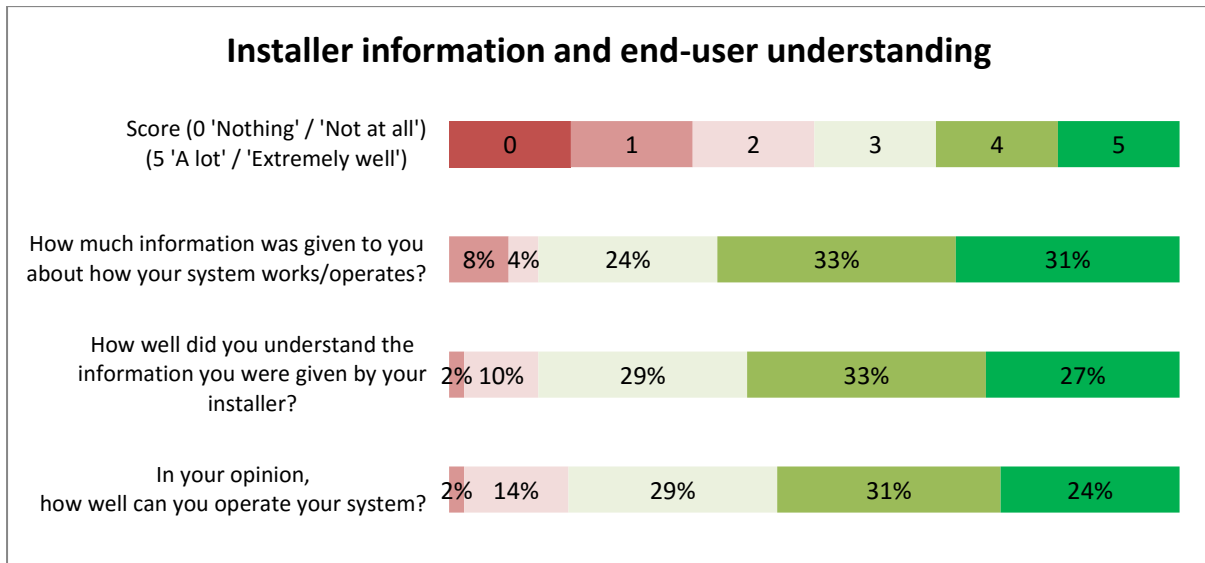


Figure 12: Installer information and end-user understanding

When asked about the quality of information that was provided by their installers, and their understanding of the information, end-users generally responded that they were provided sufficient information about how the FC micro-CHP system operates and that they had a good understanding of the information. Most end-users gave both criteria a score of 4 out of 5 (very good), with an average score of 3.7 for both criteria.

Satisfaction

End-users were asked about satisfaction with their FC micro-CHP system across a number of criteria. Questions included satisfaction with:

- Comfort and warmth
- Heating and hot water production
- Electricity generation
- Overall satisfaction

Considering all responses to the satisfaction questions, overall average satisfaction was very good (a score of 3.9 out of 5).

End-users were most satisfied by the comfort and warmth provided by the FC micro-CHP systems along with their space heating and hot water production. Perceived environmental performance also scored highly, both for heat and electricity production.

Although all criteria scored highly, the two criteria that scored lower than average, and are therefore most likely to be potential barriers to wider adoption of FC micro-CHP systems, were satisfaction with running costs and ease of use/controllability. However, due to the nature of the survey, it is unclear which aspects of these criteria end-users were considering when answering the question.

Other criteria which scored lower than average included satisfaction with the noise from the FC micro-CHP system and size of the FC micro-CHP system. Satisfaction with maintenance (cost, frequency and waiting times) scored slightly below the average, however this was still a high score indicating that end-users were broadly satisfied with the maintenance aspects of the FC micro-CHP systems.

Satisfaction with electricity production was generally not as high as satisfaction with room heating and hot water. This indicates that the end-users were more satisfied with the heating performance of the system than the electricity generating performance. Satisfaction is based on the end-user’s perception, rather than actual amounts of electricity generated by the FC micro-CHP systems.

The results are detailed in the figures below.

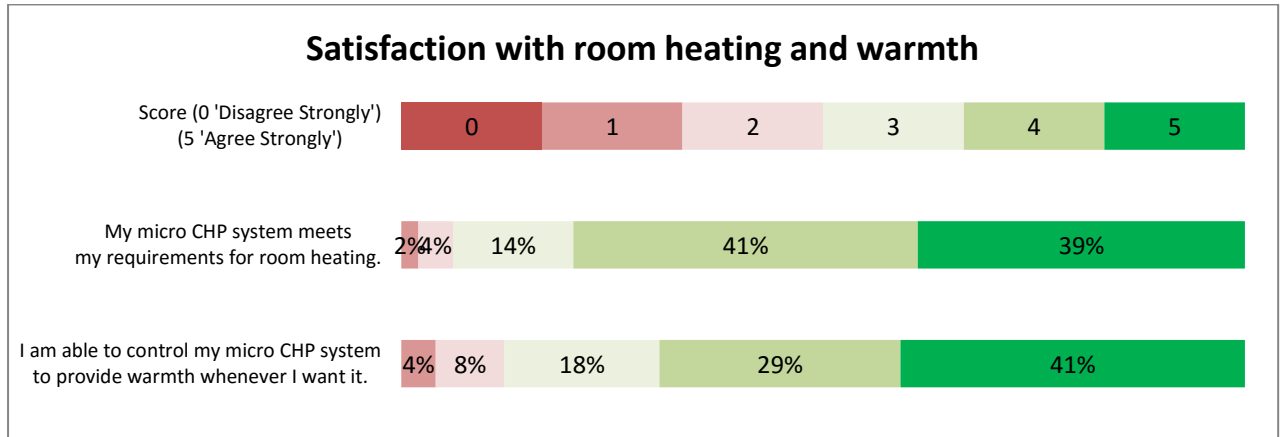


Figure 13: Satisfaction with room heating and warmth on demand

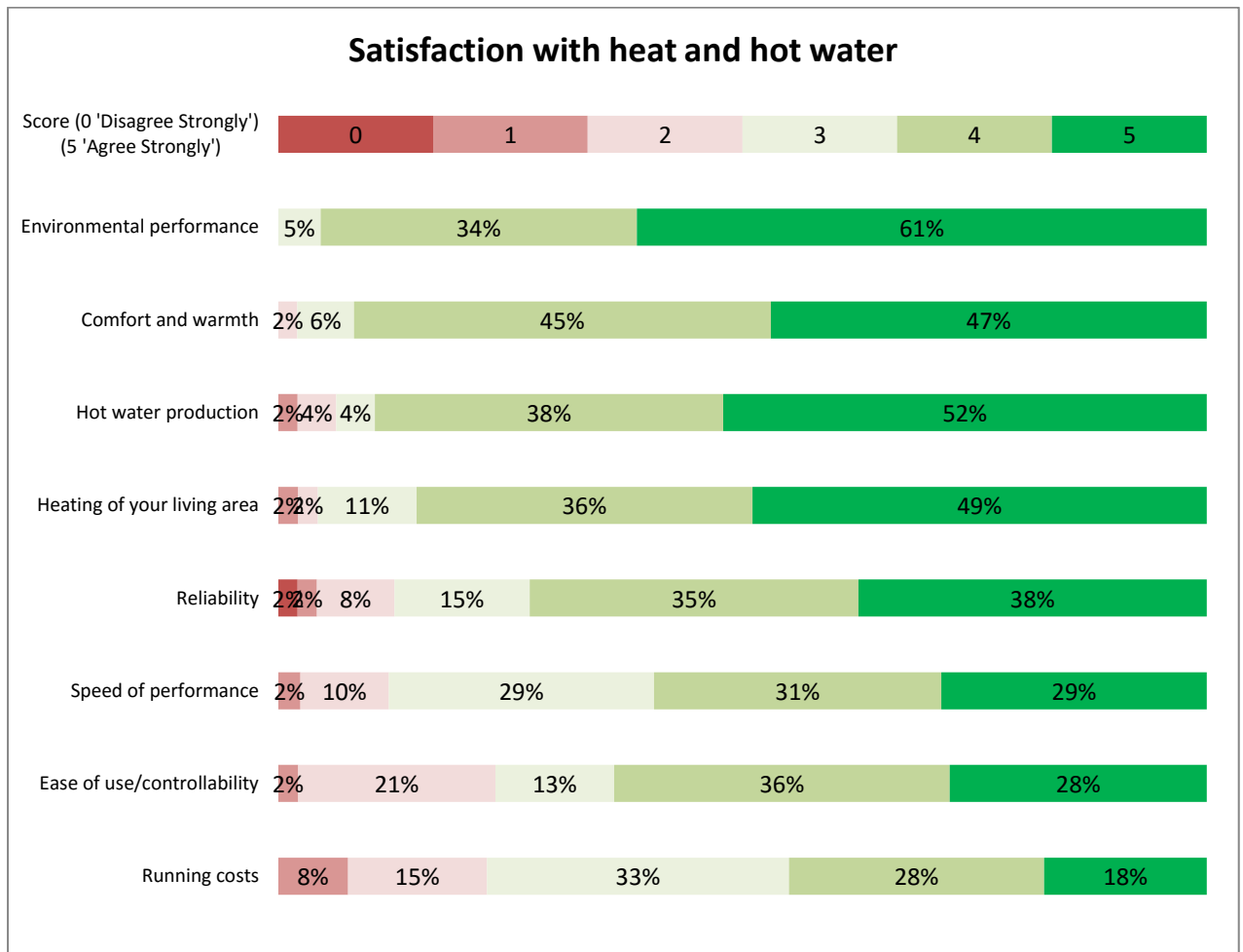


Figure 14: Satisfaction with Heating and hot water

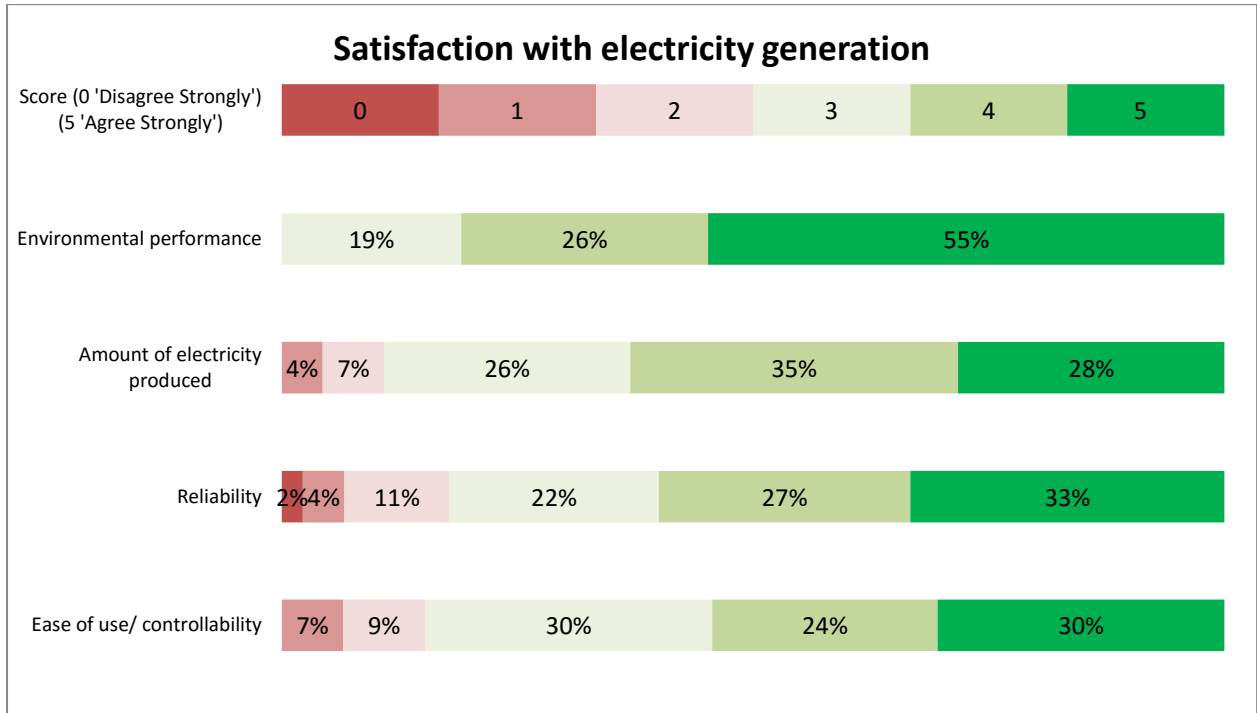


Figure 15: Satisfaction with aspects related to electricity production

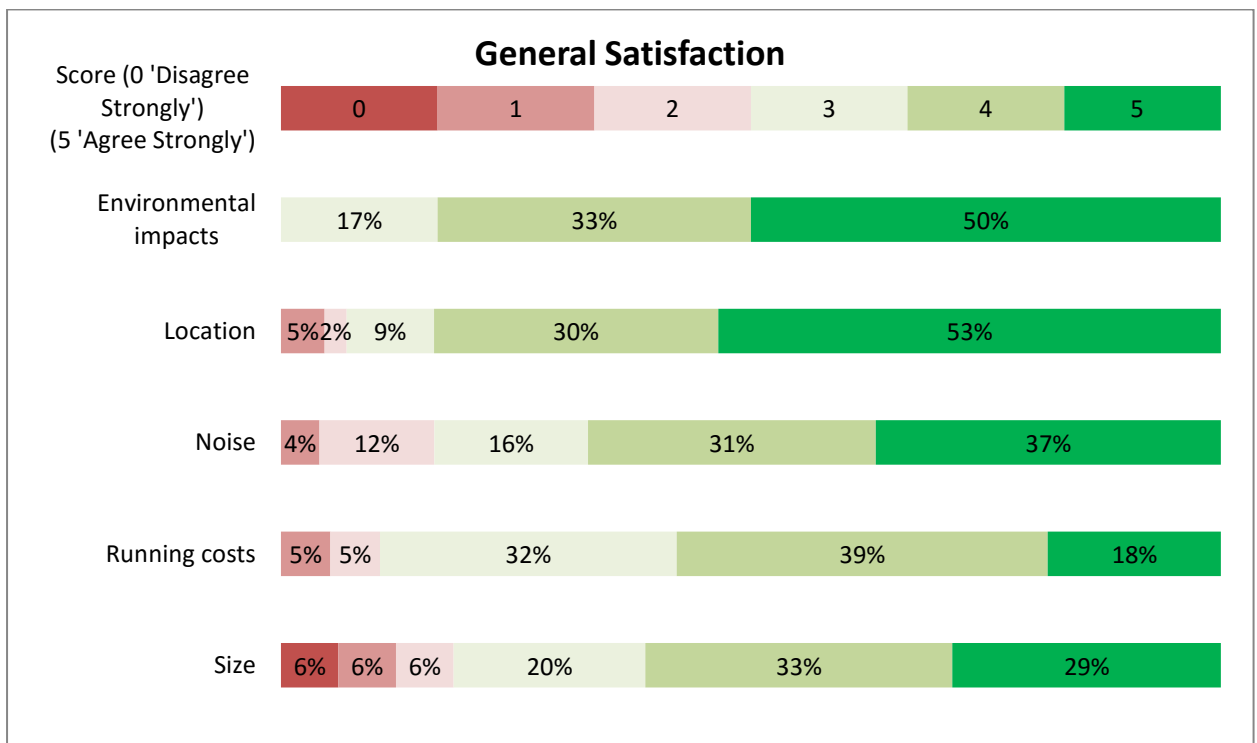


Figure 16: Overall satisfaction of the end-users

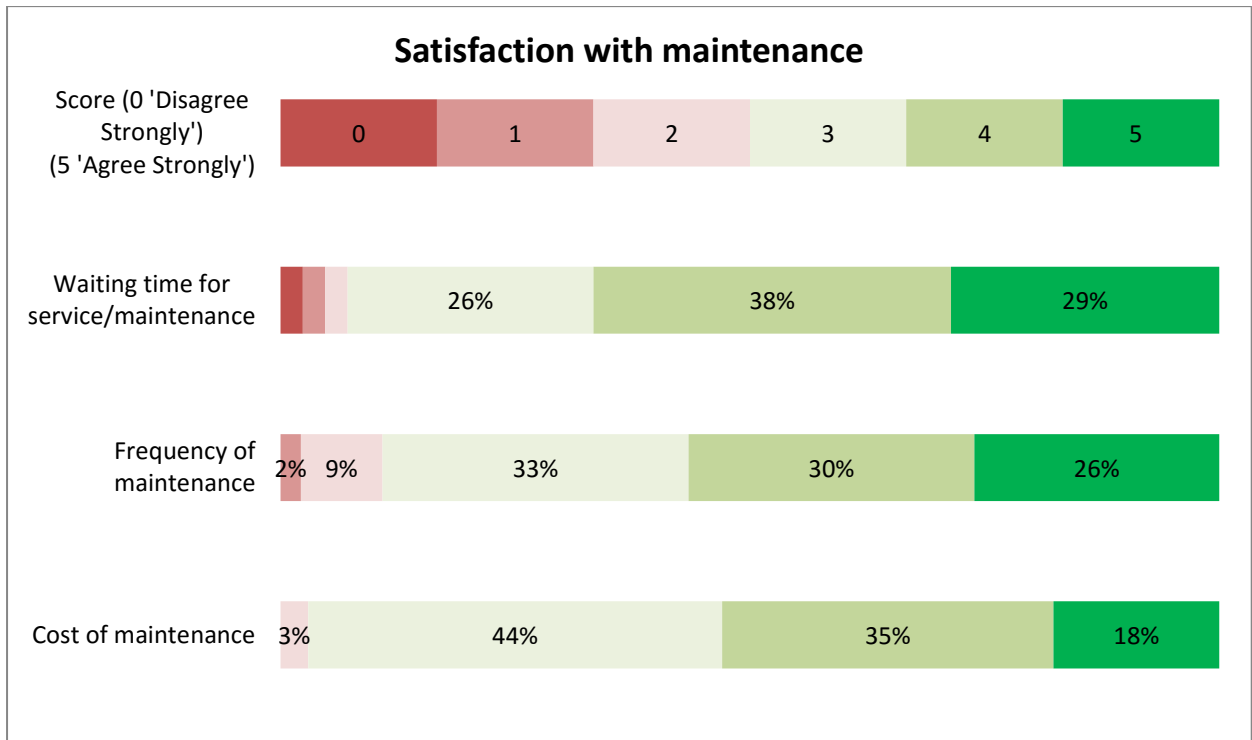


Figure 17: Satisfaction with aspects related to maintenance

3.7 Comparison with previous information

The following section utilises responses to the pre-installation and post-installation surveys to compare user satisfaction with their previous heating systems, and with their expectations of how their FC micro-CHP system would perform across a range of criteria.

Previous heating system type

Households in which the FC micro-CHP system replaced systems other than natural gas systems were most satisfied with their new system. In particular, end-users of oil, electric and solid fuel systems were most satisfied with the FC micro-CHP system being easier to control, cheaper to run, and more reliable.

Satisfaction with heating and ease of use

On average, people were slightly more satisfied with the room heating provided by their FC micro-CHP system than their previous system. Satisfaction increased for 25 end-users, and decreased for 15 end-users, this is shown in Figure 18.

Although there was no overall change in how end-users reported the FC micro-CHP systems ease of controllability compared to their old systems, satisfaction increased for 25 end-users and decreased for 18, this is shown in Figure 19. This indicates that additional considerations around reducing complexity around usage of the system would contribute to increase users' experience. This may however not be directly related to the FC system but a general trend in moving from older systems with simpler, but more coarse, controls to more advanced systems with the added complexity of finer control.

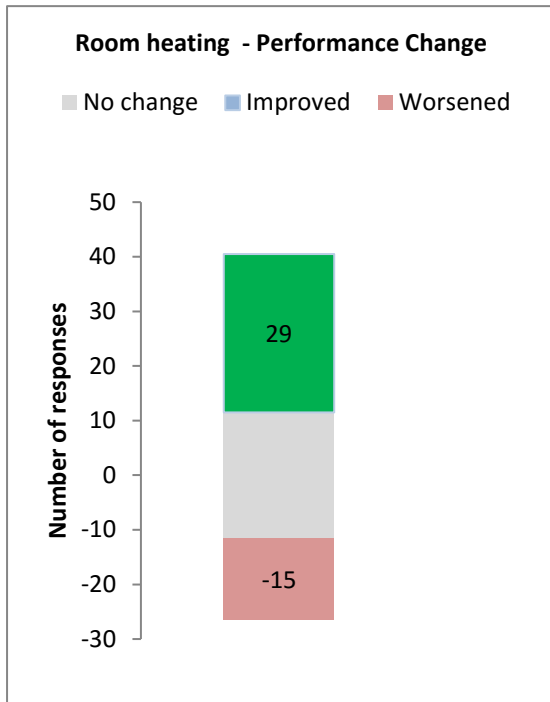


Figure 19: Performance change: room heating

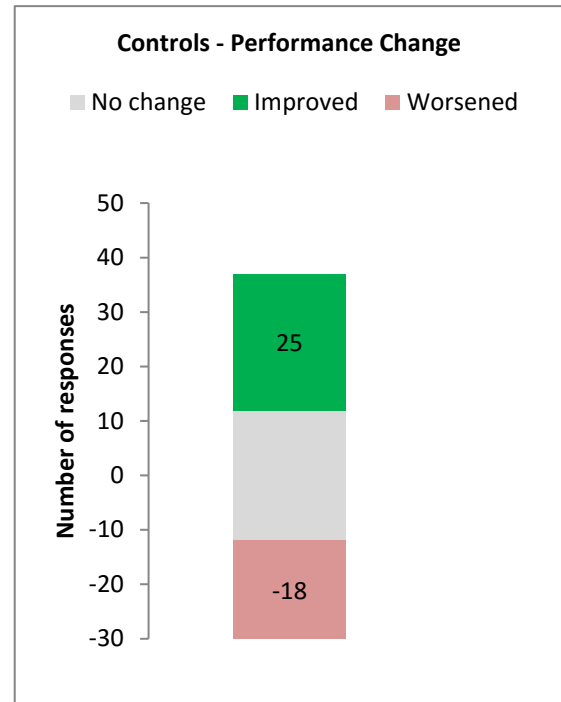


Figure 18: Performance change: controls

Satisfaction with heating and hot water

Overall, satisfaction with heating and hot water provided by the FC micro-CHP system was far higher than user expectations. Satisfaction scored higher across all the criteria compared to the previous heating system. Across all criteria, 46 end-users reported an overall improvement, with only 13 reporting a decrease in performance. Average satisfaction increased from an average score of 3.7 with the old system, to an average of 4.1 with the FC micro-CHP system.

The criteria with the biggest improvement was the perceived environmental performance of the FC micro-CHP system. The lowest scoring aspects were running cost and speed of performance, which had no increase or decrease in score. This is still a positive result as it shows that FC micro-CHP systems provide comparable services with previous systems.

Figure 20 shows the change in the number of end-users that reported increases and decreases in satisfaction across each criteria:

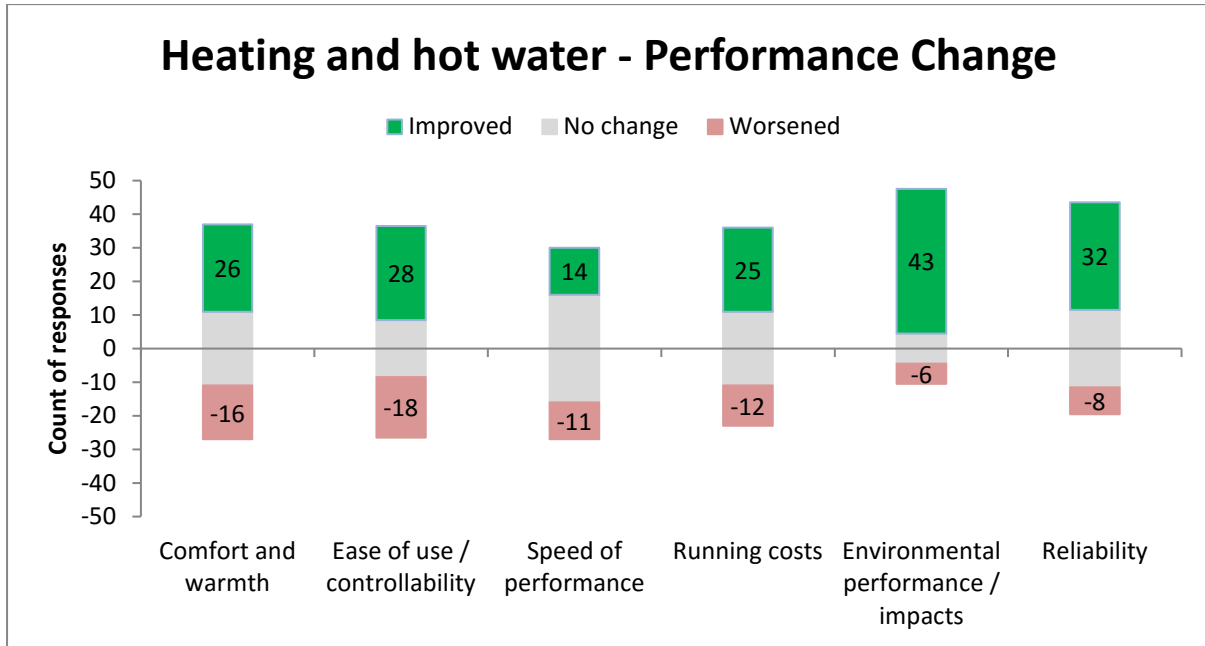


Figure 20: Performance change - heating and hot water

Electricity

Overall, respondents did not expect the FC micro-CHP systems to produce all the electricity they needed, however they were generally satisfied with the amount of electricity that was produced. This indicates that the electricity production of the FC micro-CHP systems exceeded the expectations of the end-users. Table 11 shows the change in the score from the expectation (2 out of 5) to the performance (4 out of 5), and Figure 21 shows that a high number of end-end-users that reported improvements in the performance of the electricity production of their FC micro-CHP system over their expectation.

Table 11: Electricity production - Expectation and Performance, change in score

		Expectation				
		"It will produce all the electricity we need"				
		1 - Very Dissatisfied	2	3	4	5 - Very Satisfied
Performance "Amount of electricity produced"	1 - Very Dissatisfied					
	2					
	3					
	4		●			
	5 - Very Satisfied					

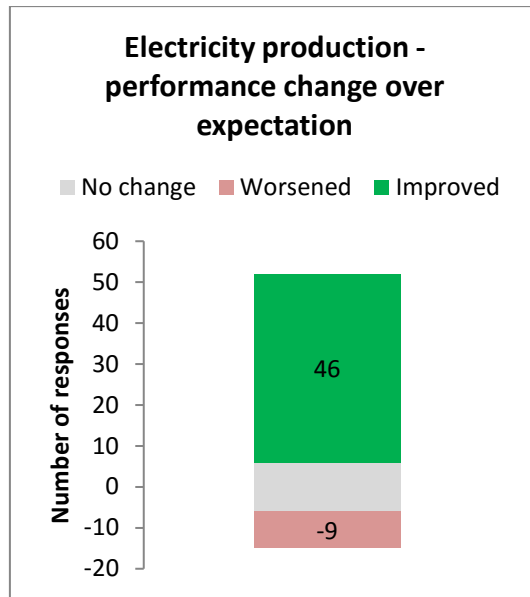


Figure 21: Electricity production – Expectation and Performance

3.8 Failures

An analysis of the rates of failure of the FC micro-CHP systems and the proportion of time that they were fully available was compared with user satisfaction. The system availability was calculated based on information regarding system off time in connection with issues encountered as well as maximum possible availability. Failures encountered were reported by the manufacturers during installation and operation.

Of the 67 FC micro-CHP systems that were reported on, 37 had 1 or more failures in the first year. However, the vast majority of these failures were only for short times: 90% of the FC micro-CHP systems were available for at least 95% of the time.

The number of failures and length of time that the units were not available had no discernible effect on the user’s perception of the FC micro-CHP system’s performance or their perception of its reliability. This may be because heating and electricity was supplied by the back-up systems at times that the FC micro-CHP system was unavailable. This may also be because the participants in the trial acknowledge that failures can happen while demonstrating emerging technologies.

Table 12 shows the number of systems by number of failures, along with the relative duration of system availability and overall satisfaction with the system.

Table 12: Failures, availability and satisfaction

Failures	Number of systems	Availability (%)	Overall Satisfaction
0	30	100.0	4.1
1	13	98.2	3.9
2	16	98.3	3.9
3+	8	86.9	3.9

3.9 Conclusions and recommendations on consumer and installation barriers

In general, the installers found **it easy to install the system** and connect it to the grid. They found the components found in common heating systems the easiest to install and connect. While the more specialised components were found more difficult, **no component had a difficulty score higher than 1.3** on a scale from 0 to 5.

Most installations were completed within 5 days, and the vast majority (80%) of installations were completed in 8 days or less. Although a long installation time could be disruptive to the end-users, and could also make the FC micro-CHP systems unattractive to installers, it is likely that installation times will improve as the involved installers, plumbers and electricians become more familiar with site evaluation, commissioning and installation of the FC micro-CHP systems.

One way of speeding up installations could be by making the most difficult aspects of the installation easier. For example, the fuel cell unit took on average 25% of the installation time, and was rated to be the most difficult component to install. Although the systems were rated to be easy to install overall, the following components were considered by installers to be the least easy:

- Fuel cell unit
- Electrical connection
- Data communication
- Other components

With experience the installers may find these easier, however the ease of installing these could be improved by providing training to installers, or by simplifying the installation of these components.

End-users were generally very satisfied with all the aspects of their FC micro-CHP systems. It is especially worth noting that their **perception** of the **environmental profile** of the technology was **entirely positive**. It is also worth noting that the end-user **satisfaction** with the **electricity produced** is **much higher than their initial confidence** in the ability of the unit to provide the electricity needed by the household. Averaging over the satisfaction of the important factors of environmental performance, comfort and warmth, electric reliability and general running costs gives **an average satisfaction of 92%**.

Although running costs depend on wider political and economic factors and are not completely within the control of the manufacturers, improving the ease of use / controllability of the systems is something that is within the control of manufacturers. This could be down to improved system design, system documentation or after-sales support. The need for greater system understanding is further supported by 4 end-users that reported that they did not understand the systems well enough to use them.

4. SUPPLY CHAIN BARRIERS

4.1 Evaluation of maturity, competition and standardisation levels of today's FC micro-CHP for residential applications in Europe

The main challenges encountered by the FC micro-CHP supply chain today are:

- Further demonstration of performance and durability in real-world conditions is required (this is already on-going in the EU projects ene.field and PACE);
- Significant increase of production volume and reduction of costs of the systems are required, for example by developing outsourcing strategies with suppliers and through increasing economies of scales;
- Simplification of the maintenance and part replacement procedures for the core components of fuel cell micro-CHP products.
- Reduction of system complexity and the costs of components in order to reduce the price of the final end product.

The main limiting factor identified for a successful development of the supply chain is the production volume. In Europe, a relatively limited number of units have been deployed to-date (estimated to be between 1,000 and 2,000 units) and mainly in Germany. The European market need to significantly increase the production volume to achieve cost reduction as seen in the Japanese programme ENE-FARM which has managed to reduce costs of the system by an estimated 25% between 2010 and 2012 through the installation of ~20,000 units⁹. It is estimated that a minimum of 1,000 units deployed per manufacturer would be necessary to achieve cost reduction of 10 to 20% when compared to the current production cost of the systems¹⁰. Additional cost reduction would require a deployment of between 4,000 to 10,000 units per manufacturer. These volumes are anticipated to increase dramatically over the next five years as deployment support by PACE and the KfW 433¹¹ programme (in Germany only) catalyses further uptake. Following – and indeed, during - this manufacturing scale-up many of the issues highlighted below (a sparse network of installers, opening up manufacturers to increased standardisation, improved component supply chains) will likely become increasingly simple to resolve.

Collaborative and standardisation efforts could also help reduce cost through economies of scale and better sourcing strategies placing the FC micro-CHP suppliers in a stronger position for commercial discussions. However, efforts to-date have been limited due to anti-trust concerns and mismatches in the priority areas and short-term investment needs of the different players.

Contrariwise, competition between the suppliers of components is critical to encourage cost reduction and therefore of the final system price. However, the currently fragmented FC supply chain and low production volume send a negative signal to the market's stakeholders and do not encourage cost lowering through competitive behaviours. Perhaps partly due to a lack of standardisation, the FC micro-CHP manufacturers currently collaborate closely with a small group of component suppliers to

⁹ Analyst View: Latest Developments on Ene-Farm Scheme", FuelCellToday, 2013.

¹⁰ Roland berger Strategy Consultants for the FCH JU: Advancing Europe's Energy Systems: Stationary fuel cells in distributed generation (https://www.rolandberger.com/publications/publication_pdf/roland_berger_fuel_cells_study_20150330.pdf)

¹¹ [https://www.kfw.de/KfW-Konzern/Service/Download-Center/F%C3%B6rderprogramme-\(Inlandsf.\)-\(D-EN\)/Barrierefreie-Dokumente/Energieeffizient-Bauen-und-Sanieren-Zuschuss-Brennstoffzelle-\(433\)-Merkblatt/](https://www.kfw.de/KfW-Konzern/Service/Download-Center/F%C3%B6rderprogramme-(Inlandsf.)-(D-EN)/Barrierefreie-Dokumente/Energieeffizient-Bauen-und-Sanieren-Zuschuss-Brennstoffzelle-(433)-Merkblatt/)

develop parts that meet the requirements of their systems which does not encourage a competitive market or the entry of new players.

A shortage of trained personnel with the necessary skills to maintain fuel cell micro-CHP technology may also still be a challenge. A number of the manufacturers in ene.field have reported progress in this area, having trained their networks of field support partners. However, the issue is likely to persist in areas where there has been little fuel cell micro-CHP demonstration activity to-date. Ensuring this issue is addressed will be important to drive down maintenance and installation cost. Options for addressing this include:

- Development of maintenance networks:** Progress on this has been made during the period of the ene.field project and a number of the manufacturers report that they have established strong networks of trained installers. However, these networks are likely to be concentrated in areas that have seen significant demonstration activity. In areas where there have been very few installations to-date, maintenance networks are likely to be sparse, leading to increased driving times to end customers’ properties, and hence higher maintenance / installation costs. Moreover, programmes limited to single countries (such as KfW 433) lead to development of maintenance networks only within single states. This means that while maintenance costs drop within countries with high deployment rates, other areas with lower deployment will continue to suffer from this deficit. This can slow the development of the fuel cell CHP market outside of countries with direct funding. Furthermore, an increase in the total number of trained maintenance and installation providers could lead to an increasingly competitive market, thus driving down the resulting costs.
- Simplification of maintenance:** in the near term, maintenance can be simplified by grouping components unfamiliar to traditional installers into readily removable modules. These can be shipped back to the fuel cell OEM, who can then perform maintenance on these components (e.g. the stack). This has the added potential advantage of recovery of residual components (e.g. the catalyst) should these need to be replaced completely.

4.2 Barriers and opportunities for the development of the FC micro-CHP supply chain

The main opportunities for FC micro-CHP system cost reduction can be regrouped into three main areas of work: increase in volume, system simplification and development of collaborative strategies between key players. Each subsystem will have some potential opportunities for development and therefore reduction of costs.

Table 13: Potential for cost reduction and synergies for development and procurement by component

Components	Areas of possible improvements for cost reductions	Potential synergies for development or procurement
MEA / Stack	<ul style="list-style-type: none"> Stack durability, material used for catalyst: reducing or replacing platinum catalyst for PEM FCs, lowering membrane cost, increasing power density, develop sulphur resistant electro-catalysts, take measures 	<ul style="list-style-type: none"> Develop common research programme in partnership with universities for SOFC and PEM systems on key issues such as: stack degradation, material used for catalyst: reducing or replacing platinum catalyst, lowering membrane cost and optimization of BPP, sealing’s, stack-materials.

	<ul style="list-style-type: none"> to increase recovery of residual value etc. Standardisation and material improvements of stack parts (BPP, sealing's, etc.) Develop high performance catalysts stable at high temperatures (i.e. ~150 °C) for HT PEMFC Improve durability and cycling capability for SOFCs Improve methods for final inspection of MEAs for leaks, shorts, membrane pinholes and other defects prior to assembly in stack. Opportunity for increased automation 	<ul style="list-style-type: none"> Develop manufacturing process for the industry and exchange on findings (e.g tri-sintering for tubular SOFC, Fully automated cathode and barrier layer spraying) Develop common stack for several OEMs. The recent announcements by car manufacturers such as Toyota/BMW¹² and Daimler/Ford/Renault-Nissan to share and develop a common fuel cell technology, could be imitated by the micro-CHP fuel cell industry, as the way forward. However, this entails an inherent risk that using common core technology stifles innovation within the fuel cell market. Bipolar plates and electrodes could be standardised across industry.
Fuel processing equipment	<ul style="list-style-type: none"> Fuel efficient tactical fuel processors for desulfurized fuels Desulfurization cartridge Optimise fuel processor configuration and process parameters 	<ul style="list-style-type: none"> Standardisation. Develop common reformer.
Cooling systems	<ul style="list-style-type: none"> Reduce complexity 	No potential synergies identified
BoP	<ul style="list-style-type: none"> Optimise design of BoP and reduce complexity Other improvements (optimise humidifier) Use liquid metering pumps Protecting coatings for metallic components 	<ul style="list-style-type: none"> Standardisation. Use standards developed by Japanese manufacturers.
Power electronics	<ul style="list-style-type: none"> Durability 	<ul style="list-style-type: none"> Specify inverter. Develop common inverter / standard solution.
Heat exchangers	<ul style="list-style-type: none"> Obtain greater efficiencies by maximising heat recovery. 	No potential synergies identified

The sector is aware of the opportunities around these components but is facing some major challenges in adopting strategies to help to develop the supply chain to a more mature state. An increase in the production volume will require additional support to bring the technology to a more commercially ready state. System manufacturers are now in the most critical period of the deployment of the technology and require political and financial backing. Strong political support and additional funding, as seen in Japan, will be required in the coming years for the technology to enter the next stage of deployment. Collaborative strategies could accelerate supply chain development and cost reduction,

¹² Toyota press release <http://www2.toyota.co.jp/en/news/13/01/0124.html>

but have had limited success up to date¹³. Several factors can explain the difficulties in efficient development of the supply chain:

- The variety of technologies developed for FC micro-CHP applications also has an impact on the potential matching of priority areas for development between different manufacturers. Each manufacturer will follow its own priority agenda in terms of R&D and commercial strategy. However, this also has advantageous consequences – a range of products shows innovation is continuing, and allows the development of a range of products targeting a large section of the heating market, rather than a few niches.
- Collaborative research and development activities are also dependent on the internal timeframes for R&D programmes of each organisation, which tend to be relatively inflexible and difficult to harmonise across manufacturers.
- Competitive thinking and behaviour among FC micro-CHP manufacturers. Collaborative efforts are more likely to be successful if focussed on a limited number of components, for which there is a common need but limited IP has been established by the manufacturers.
- The allocation of resources for collaborative efforts needs to be justified. This can be a problem as the benefits of these activities may not be easily quantified and are shared across the industry players involved in the collaborative effort.

¹³ For example, the VDMA Fuel Cells Association and IBZ Initiative facilitated a group of German manufacturers in a joint effort to develop a common specification for desulphurisation cartridges. Eventually, however, the work did not result in a common specification becoming accepted as a standard.

5. POLICIES AND POLITICS

Micro-CHPs represent a next generation solution for replacing traditional gas boilers in much of the built environment where extensive energy saving renovation and renewable energy solutions are not feasible. This can contribute significantly to the EU policy aim of decarbonising energy consumption of both heat and electricity in the home. Fuel cell micro-CHPs in particular represent a highly efficient alternative for new build. The roll-out of micro-CHP in households and small businesses gives consumers the opportunity to produce their own heat and electricity and become active participants in the energy sector. Consumers are empowered to produce their own, reliable and low carbon electricity, which can be dispatched at times of low intermittent RES production or peak electricity demand (e.g. from electric heating) to balance the grids. The ene.field analysis of FC micro-generation interaction with the electricity grid has also shown that FC micro-CHP system level benefits exist¹⁴. According to scenario projections avoided capital and operational costs in generation and grid capacity, could range on average between € 6000-7300/ kW per year from installed FC micro-CHP capacity throughout the period 2020-2050.

A comprehensive review of the policy and political context affecting FC micro-CHP deployment by the ene.field project concluded that the multiple consumer and energy system benefits of FC micro-CHP are not adequately recognised and rewarded by most policy at the EU and national levels. In addition, administrative barriers for grid connection and accessing support schemes persist, further hindering the large-scale deployment of micro-CHP systems.

At the time of writing the EU level, the legislative process is focusing on establishing an energy and climate framework for 2030, that is consistent with Europe's 2050 goals and its COP21¹⁵ climate commitments, while at the same time ensuring that the 2020 energy efficiency, CO₂ and renewable targets are met. FC micro-CHP large scale deployment will depend on the outcome of EU political negotiations on the Clean Energy for All Europeans legislative Package¹⁶ and the review of the Energy Labelling and Eco-design Regulations for space heaters. Potential risks for FC micro-CHP deployment in the medium to long term, linked to EU level legislation, include: treating renewable energy as a substitute for energy efficiency, putting a greater focus on energy reduction at end user level over energy system efficiency (final energy vs. primary energy efficiency), and promotion of electrification over decarbonisation and support for renewable energy across the whole energy system (electricity, gas, heat networks). Moreover, the upcoming review in 2017-2018 at the EU level of the Energy Labelling & Ecodesign Regulations for space heaters represents an opportunity to amend the methodology for micro-CHP to fully account for the efficiency benefits of these technologies, which is not the case today. The review of the energy labelling framework should also address identified inconsistencies in the methodologies that are currently being used.

¹⁴ [Position Paper on Smart Grid Capabilities](#), ene.field, November 2015

¹⁵ <http://www.cop21paris.org/>, November/December 2015

¹⁶ The [Clean Energy for All Europeans legislative proposals published by the European Commission](#) in November 2016 cover energy efficiency, renewable energy, the design of the electricity market, security of electricity supply and governance rules for the Energy Union, with the aim to extend EU's climate and energy framework to 2030. The proposals are currently going through the EU legislative process, with the European Parliament and Council proposing and discussing potential changes to the Commission's proposals. Adoption of the legislation is expected in late 2018 and implementation at the national level will begin as of 2020.

The active engagement of EU institutions in energy and climate policymaking is also reflected at the national level, with most Member States currently assessing objectives and choices to support their energy and climate transition. This very dynamic political environment can present both opportunities and barriers to emerging technologies like fuel cell micro-CHP. Existing and emerging barriers at the national level are impeding the early market introduction of FC micro-CHP in the short to medium term. Member States are currently implementing energy efficiency legislation at system, building and product levels, which should open market opportunities for FC micro-CHP. However, in many European countries implementation is either lagging behind, not ambitious or comprehensive enough to drive FC micro-CHP deployment¹⁷. Identified barriers include: 1) cumbersome administrative procedures to install FC micro-CHP systems at domestic level; 2) building codes eligibility conditions that do not recognise FC micro-CHP primary energy savings and decarbonisation benefits; 3) unfavourable tariff schemes for electricity self-consumption. In addition, while several countries have laid out support schemes for new technologies, including FC micro-CHP, the administrative burden linked to accessing the support schemes by domestic consumers is particularly cumbersome. One country which has moved to promote deployment of FC micro-CHP is Germany. Germany's approach to developing a favourable and comprehensive framework for FC micro-CHP is now showing positive results, as policymakers and market actors expect significant growth in FC micro-CHP deployment in the next 5-7 years. The German success story can be used to inform policymakers in other EU countries both of the high customer acceptance and the wider energy benefits of FC micro-CHP and what types of policy measures are needed to improve market uptake.

Electricity grid connection of FC micro-CHP involves lengthy and bureaucratic procedures in several countries, which are unsuited to domestic consumers, despite the Energy Efficiency Directive promoting a simple "install and inform" procedure. Very few countries have considered micro-CHP technologies in their comprehensive assessments on the potential of cogeneration or taken action to promote these technologies, as required in Article 14 of the Energy Efficiency Directive. With respect to building codes in several countries, fuel cell micro-CHP is often penalised through assumptions that do not recognise their efficiency benefits, including the adoption of inadequate primary energy factors.

The policy context thus plays an important role for the fuel cell micro-CHPs achieving a swift transition into commercialisation: The ene.field project has shown that the modern European design FC micro-CHP products are both attractive to the customer as already described and provide both energy efficiency and electricity network decarbonisation benefits¹⁸. Given the huge challenge, the EU faces to decarbonise domestic heat **a coherent, steady and predictable policy framework should be put in place recognising the European heating sector's contribution to a more efficient, reliable and cleaner energy system, through advanced products and new business models for products including FC micro-CHP. Policy should inspire confidence in these market players to team up in the spirit of**

¹⁷ Based on policy assessments of the [implementation of the Energy Efficiency Directive \(27/2012/EU\) conducted as part of the CODE2 project in 2013](#), COGEN Europe in its [2016 Cogeneration National Snapshot Survey](#) and as reported by the European Commission in its Policy Conclusions AT Member State, regional and EU levels as part of the [State of the Energy Union 2015 Communication COM \(2015\) 572](#).

¹⁸ Macro-Economic and Macro-environmental Impact of the Widespread Deployment of Fuel Cell micro-CHP, upcoming ene.field report, will be available September 2017 on <http://enfield.eu/category/news/reports/>

technological leadership and commercial innovation and develop a range of offerings to consumers and installers alike, empowering energy prosumers and creating green jobs.

Fuel cell micro CHP is currently a product at an early market stage where volumes are low and hence product cost is high. The weaknesses of standard market processes in increasing volumes for such an innovative product against an established market product are well known. Only a supportive policy framework can accelerate the transition to mass commercialisation of fuel cell micro-CHP, which will bring important benefits to consumers and the energy system at large.

EU level policy and political environment

The recent developments at EU level, reinforced by the COP21 climate agreement at the end of 2015, confirm a strong commitment by EU institutions towards decarbonisation of the energy sector, while improving energy efficiency and further increasing renewable energy share. With the recent publication of the Clean Energy for All Europeans legislative package, as well as the Heating and Cooling Strategy¹⁹, the European Commission is also prioritising energy efficiency actions and greening the energy supply for heating and cooling in buildings. In addition to headline energy and climate policies, the Energy Union also focused on research and innovation in the energy sector, ensuring there is sufficient investment in new technologies at R&D stage.

While fuel cell micro-CHPs are recognised and funded as promising emerging energy technologies at the EU level, there is a need for **more consistency between R&D priorities in the energy sector and the broader energy and climate EU framework**. Aligning the two will ensure that investor confidence remains strong as fuel cell micro-CHP transitions from demonstration trials to early commercialisation and the industry is delivering on its commitment to deliver on its cost reductions targets.

The following recommendations address the need for more consistency between R&D funding programmes and the other pillars of the Energy Union framework, ensuring that FC micro-CHP contribution towards Clean Energy Package objectives is fully recognised:

- While the Clean Energy Package aims to put consumers at the centre of energy policy, it needs to ensure that consumers, investors and market actors are fully informed to make the most cost-effective choices, while maximise environmental outcomes at the energy system level. EU policy should take an energy systems' approach, which looks at optimum implementation of energy efficiency, renewable energy and decarbonisation measures across the whole energy value chain (energy conversion, transmission, distribution and consumption) and among all energy carriers (electricity, gas, heat). An overemphasis on energy demand reduction at final use, accompanied by an overestimation of the electricity system efficiency (i.e. a lower primary energy factor for electricity), will mislead consumers to choose options that undermine overall energy system efficiency, thus adding strain on electricity grids and increasing energy costs. Therefore, primary energy should be a key metric for measuring energy efficiency improvements at system level. In addition, energy efficiency should be applied across all fuels, including renewable energy sources.
- The periodic updating of the primary energy factor for electricity, at both EU and national levels, should be based on a robust and comprehensive methodology, which takes into

¹⁹ European Commission, 16 February. Retrieved from: [Commission Communication on an EU strategy for heating and cooling](#)

account all energy sources in the electricity mix, fully accounts for electricity network losses, reflects the current efficiency of the electricity system, while allowing for regular reviews of the primary energy factor values. In addition, in order to ensure consumers are well informed, primary energy factors should account for seasonal electricity mix variation in the use and production of electricity, especially in the case of heating.

- Ensuring a level playing field between efficient and low carbon heating technologies, by clarifying in the Energy Efficiency Directive, under the Energy Savings Obligation (Article 7), currently under review (as part of the Clean Energy Package), that energy savings allocated to the heat delivered by micro-CHP can be counted towards the Article 7 energy savings target.
- Reinforcing the removal of grid connection barriers for micro-CHP by requiring “fit and inform” simplified procedures recommended under Article 15.5 of the Energy Efficiency Directive, currently under review (as part of the Clean Energy Package).
- The position of fuel cell micro-CHP should be reinforced, as part of the supply-side measures that can help Member States meet building efficiency requirements under the Energy Performance of Buildings Directive (2010/31/EU) (EPBD), currently under review. Especially for new technologies, it is important that policymakers and building professionals consider at the same time the benefits of all potential measures to improve the energy performance of buildings. Therefore, the comprehensive list of efficient and renewable technologies in the EPBD should be kept in the legislation beyond 2020 (Article 6).
- Fuel cell micro-CHP systems are controllable technologies and can generate electricity during peak load times (or to support the grid needs it), replacing a low efficiency and higher CO₂ intensity electricity mix compared to the average electricity sector. Development of a suitable market framework to allow full participation of FC micro-CHP and similar innovative ancillary service and capacity providers, should be included in the upcoming Electricity Market Design proposals, as well as part of the “smartness indicator” proposed as part of the current EPBD Review proposed in the Clean Energy Package.
- Embedded generation technologies²⁰, like fuel cell micro-CHP, are connected to the grid at local distribution level and do not use any high-voltage grid infrastructure. The grid connection and grid use costs of CHP generated power should thus be calculated adequately, taking into account and/or compensating users for the avoided grid costs²¹. These principles are particularly relevant for the Commission’s work on the treatment of electricity self-consumption, which should be promoted when it comes to fuel cell micro-CHPs.
- The energy labelling methodology in Regulation No. 813/2013 should be clarified to fully reflect the primary energy savings of both the heat and electricity produced by fuel cell micro-CHP. Only by fairly assessing fuel cell micro-CHP efficiency, can consumers become more aware about the benefits of this technology.
- The Heating and Cooling Strategy correctly identifies the heat sector, and buildings in particular, as having important decarbonisation and energy efficiency potential. From the outset it is important that the Strategy reflects the full potential of fuel cell micro-CHP

²⁰ Embedded generation is defined as generating units that are installed on-site, with the owner producing and partly or fully consuming their own electricity.

²¹ This principle is common practice in Germany. In addition, the recently adopted Delegated Regulation (EU) 2015/2402 rewards the benefits cogeneration brings to the electricity system by reducing grid losses and costs through generating the power close to the point of use.

technologies²², and does not narrow its scope to a handful of possible solutions (e.g. electrification of heat). Given their significant benefits in terms of emission reductions (incl. NOx) and energy efficiency gains, fuel cell micro-CHP technologies should be viewed as strong contenders and complementary to the electrification of heat and other preferred options. Particularly as FC micro-CHP is of itself ready for sustainable gas, and due to its high efficiency is an ideal customer solution for renewable gas deployment.

- Innovation in technology is an important part of meeting Europe's Energy and Climate goals. There is a need for a sustained commitment at EU and Member State level to support field trials for emerging high efficiency technologies like fuel cell micro-CHP up to the point where a critical mass is reached in terms of scale at which product volume has driven down product unit cost to a level at which market mechanisms operate effectively. Large-scale demonstration should be put in place to continue initiatives like ene.field, co-financed by the FCH JU, with the goal to reach market-readiness by 2020.

Addressing policy barriers at national levels

Policy support and political commitment for fuel cell micro-CHP is patchy at the Member State level. So far, Germany has made a strong commitment to the technology through the Callux²³ field trial and the roll-out in 2016 of the major KFW433 programme. Other EU countries support fuel cell micro-CHP as part of their broader CHP policies. Yet the majority of Member States do not support the market entry of fuel cell micro-CHPs.

A higher awareness about fuel cell micro-CHP technologies among policymakers at national level would ensure that the regulatory framework does not hinder further uptake of this of this technology.

- Ambitious implementation of the Energy Efficiency Directive (EED) (2010/31/EU) at the national level is key to realising the potential of fuel cell micro-CHP, in line with Article 14. Clarifying eligibility of micro-CHP, along other energy saving end user technologies, as part of the Energy Savings Obligation, defined under Article 7 of the Energy Efficiency Directive, would ensure recognition of fuel cell micro-CHP benefits. In addition, Member States should do more to promote demand response and simplify grid connection procedures for fuel cell micro-CHP as recommended in Article 15 of the EED.
- Electricity grid connection procedures can be very burdensome for the consumer and installer. While in the UK the "install and inform" connection standard has been in place for some time, in other countries such as Italy and France the lengthy (e.g. up to several months) and bureaucratic permission procedures to connect can represent a real barrier.
- Member States should take into account the benefits of fuel cell micro-CHP when implementing the Energy Performance of Buildings Directive. Some countries, like Ireland, have developed methodologies, which ensure that micro-CHP, including fuel cell micro-CHPs, are eligible technologies for improving the efficiency of buildings and meeting the renewable

²² Macro-Economic and Macro-environmental Impact of the Widespread Deployment of Fuel Cell micro-CHP, upcoming ene.field report, will be available September 2017 on <http://enefield.eu/category/news/reports/>

²³ <http://www.callux.net/home.English.html>

energy requirements for new buildings²⁴. In Germany, the building code recognises that micro-CHP displaces inefficient and high carbon electricity²⁵. However, at this stage in some countries, proposals for the upcoming building codes ignored the relative benefits of micro-CHP in their assumptions, applying unrealistically low primary energy factors or grid carbon intensity to micro-CHP (e.g. Belgium and France).

- The benefits of fuel cell micro-CHP are not fully recognised in most Member States. They should thus provide fair reward proportional to the benefits, including primary energy savings, electricity and heat decarbonisation, as well as reduction in grid stress and integration of intermittent renewables. This can be achieved through tariffs, deemed payments, or even up-front one-off subsidy, which will reduce capital cost for interested consumers.
- The full decarbonisation and grid support potential of the widespread deployment of fuel cell micro-CHP²⁶ should be accounted in energy and climate strategies at the national level, while identifying and taking into account renewable gas potentials.
- Field trial support and high level political commitment is needed at the national level for fuel cell micro-CHP to move faster into early commercialisation.

²⁴ The Irish Building Regulations allow micro/small-CHP as an alternative to the requirement that at least 10KWh/m² of heat demand for new buildings should to be derived from renewable sources. This is achieved through a methodology that calculates renewable heat contribution from CHP.

²⁵ The most recent EnEv German regulation compares electricity produced by micro-CHP against a primary energy factor for electricity of 2.8. This entails that micro-CHP efficiently produced electricity displaces electricity delivered to the consumer at an efficiency of 35%, much lower than the annual average efficiency of the electricity grids.

²⁶ Macro-Economic and Macro-environmental Impact of the Widespread Deployment of Fuel Cell micro-CHP, upcoming ene.field report, will be available September 2017 on <http://enefield.eu/category/news/reports/>

6. REGULATIONS, CODES AND STANDARDS (RC&S)

The specific impact of current legislation on FC-based micro-CHP technology is fundamental information for any manufacturer, or policy maker interested in FC micro-CHP deployment and, at the International, European and National level, is fundamental for the development of this technology sector. Polito, as part of the ene.field project, led a review and analysis of the legislative environment surrounding FC micro-CHP with the objective to identify all the possible existing barriers that can affect the spread of the FC-based micro-CHP technology in the European market. In the following, an abridged version of this work²⁷ is presented in the form of the conclusions reached and the recommendations given. An updated version of the full report will be made available on the ene.field website, www.enefield.eu/reports, in August 2017.

6.1 RC&S analysis

Two questionnaires have been prepared and submitted to the FC-based micro-CHP manufacturers, involved in the ene.field project, in order to collect their opinions related to the current status of, respectively, the International and European standards and the European Regulations and Directives and, if necessary, possible suggestions on how improve it.

At the same time, an in-depth research was conducted at a national level with the objective to create a database containing all the legislative documents concerning FC-based micro-CHP systems installation. This activity was also a way for an evaluation of the existing legislative differences from country to country. The research was addressed only to the European countries that are involved in the ene.field installations.

Results and main barriers

The collection of the documentation from both the activities mentioned above allows us to get a clear view of the current legislative panorama.

Referring to the first questionnaire, the one focusing on the European standards, it has been structured according to 15 topics representing 15 typical issues related to the installation process of a FC-based micro-CHP system. In particular, the questions made had the aim to evaluate the quality and usability of a selected number of European standards chosen as representative of the topics.

Two main conclusions arose from the answers collected. The first one is the urgency of an **update** or, somehow, an **improvement** of the contents of current standards treating this technology. The opinion of the manufacturers asked is that around 60% of the standards need to be improved (Figure 22). The inadequacy appears in different aspects of the standards such as, a **lack of consistency** between different standards dealing with similar topics and standards that refer too much to **general systems**.

²⁷ [Position Paper on RCS \(regulations, codes and standards\)](#), ene.field, 2014

Manufacturers opinion on reference standards proposed

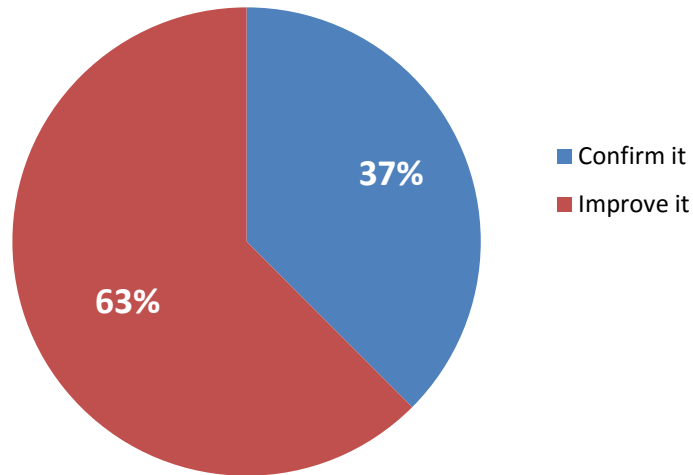


Figure 22: Opinions of the manufacturers on the reference standards proposed for the first questionnaire.

The second conclusion, instead, can be deduced from Table 14 and Figure 23 and is related to the large number of relevant standards and documents suggested by the manufacturers, for possible integration into reference standards, proposed for each topic.

From the table it is possible to note that the number of standards mentioned in the answers of the manufacturers is more than twice the initial number of reference standards proposed. The presence of so many documents referring to installation aspects of FC-based micro-CHP devices, together with the problem of a low consistency among those treating the same topic, constitutes a significant barrier to proper installation and will create confusion on the side of the manufacturers who are interested in the spread of their products throughout Europe. Another key factor, which can be deduced from Figure 23, is that around 19 % of all the documents suggested by the manufacturers consulted for the questionnaire are at a **National level**. In some cases, a Member State has partially accepted a European standard via integrating it with their national version.

Table 14: Total amount of standard/documents suggested as relevant by the authors versus the amount of documents mentioned as relevant by the manufacturers in their questionnaire responses.

Number of standards suggested as relevant by authors	16
Number of standards found relevant by manufacturers	38

Overview of the standards suggested by the manufacturers

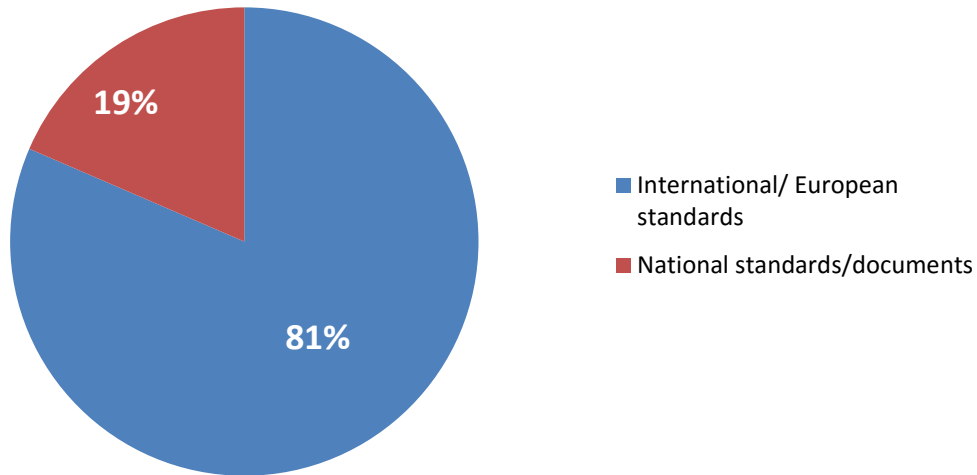


Figure 23: General overview of the standards suggested by the manufacturers with a focus on their origin.

This issue becomes more evident moving to the analysis at a national level: the first element that appears is the **heterogeneity of the standards**, particularly in terms of their range of applicability. The major consequence of this trend is that each manufacturer is forced to tune its products according to the country market in which it aims to enter.

The results obtained by the first questionnaire suggest a need for a common **framework of European standards** that can be considered valid in every country as a possible solution to overcoming the barrier of this heterogeneity of the existing framework of European and national standards. In addition, all the existing connections among standards treating similar topics should be highlighted. This would be very helpful especially for the manufacturers who need a clearer view of the regulatory panorama surrounding FC micro-CHP products.

Referring to the questionnaire dealing with the European Regulations and Directives, the key point raised by all manufacturers is **Energy Labelling**. In other words, manufacturers highlighted that the methodology adopted by the EU in (see the following section) penalizes unfairly FC-based micro-CHP devices because the preferred methodology, introduced by European Regulations, does not seem to be suitable for the specific features of the FC-based cogeneration devices. An accurate analysis has been carried out in order to better understand this problem.

6.2 Energy labelling issue

As anticipated above, among all the outcomes coming from the RC&S analysis performed, the main point of discussion was the one related to **Energy Labelling and Eco-design for space heating**. This

issue is highly relevant today, as the European Commission is preparing a review of Regulations (EU) No 813/2013 & (EU) No 811/2013, foreseen for no later than 2018.

This topic has been examined through a comparison of the two methods set by the European Commission together with an additional method described by a European Standard:

- the “**Commission communication in the framework of the implementation of Commission Regulation (EU) No 813/2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for space heaters and combination heaters, and of the implementation of Commission Delegated Regulation (EU) No 811/2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device**” that has been released on the 3rd of July, 2014;
- the “**Commission delegated Regulation no. 811/2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labeling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device**” that has been released on the 18th of February, 2013;
- the **EN 50465:2015 standard “Gas appliances – Combined heat and power appliance of nominal heat input inferior or equal to 70 kW”**.

The analysis was carried out on a reference system consisting of a micro-CHP device coupled with a boiler as a supplementary heater. The system has been defined with some fixed parameters (Table 15) and was characterized by different configurations of thermal and electrical efficiency.

Table 15: Fixed parameters for the reference system used in the analysis.

Parameter	Fixed value
Electrical output of the FC-based microCHP device ($P_{el,CHP100+SUP 0}$)	1 kW
Thermal output of the supplementary heater ($P_{th,SUP}$)	10 kW
FC-based microCHP device, total efficiency ($\eta_{tot,CHP}$)	90%
Supplementary heater, thermal efficiency ($\eta_{th,SUP}$)	95%

Results and main barriers

The comparison between the three methods leads to the results shown in Figure 24: the **EN 50465:2015** standard proposes the best method for the calculation of the seasonal space heating energy efficiency because it seems to be affected from both electrical and thermal efficiency and not only from one of them.

This result demonstrates that, in fact, FC-based micro-CHP devices are penalized by the methods described in the European Regulation but, due to the binding nature of the European Regulations, these are the only ones that have to be followed for the assignment of the energy class to each energy-

related product. This situation represents a significant barrier because customers are naturally discouraged from purchasing products with a worse apparent performance.

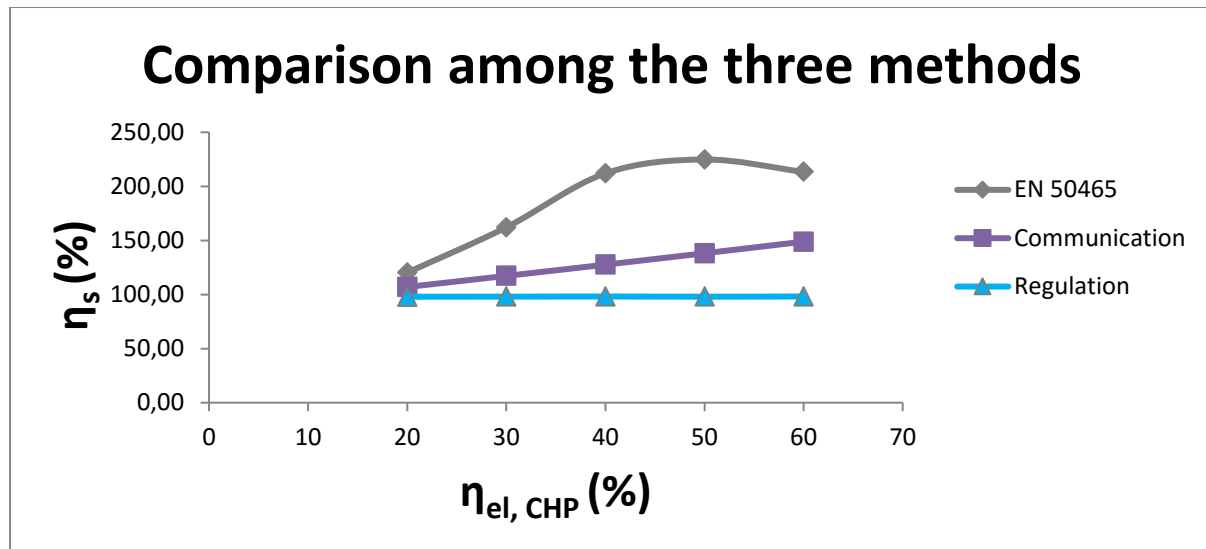


Figure 24: Comparison among the results obtained by the three methods analyzed, in terms of seasonal space heating efficiency, with respect to the electrical efficiency of the FC-based microCHP device.

6.2.1 'Re-scaling' of the energy label

Triggered by the European Commission's proposal for repealing Directive 2010/30/EU, setting the framework for energy labelling across different product groups, the EU institutions have in early 2017 reached political compromise on a new energy labelling framework directive.

Among the different provisions proposed in this new Regulation, there is also the update of the current labelling scale, whose energy classes range from **A+++** to **G** (as reported in the European Regulation no. 811/2013). The proposal is to re-introduce the original scale from **A** to **G** to improve consumer understanding. All the devices initially covered by the labelling scale will be rearranged to an A to G scale, leaving the highest class empty²⁸. This solution has been thought in order to incentivize competitiveness among manufacturers for the development of always better performing devices in terms of energy efficiency. The political agreement between the European Parliament, European Commission and Council, also recognizes that the energy labelling of space heaters (covered by Regulation no. 811/2013 and covering micro-CHP among other domestic heating technologies) was recently introduced and rescaling of these particular products should take place at a later stage, no later than 9 years after the entry into force of the new Energy Labelling Regulation. Based on a

²⁸ "The Commission shall ensure that, when a label is introduced or rescaled, the requirements are laid down so that no products are expected to fall in energy class A at the moment of the introduction of the label and so that the estimated time within which a majority of models fall into that class shall be at least ten years later", art. 7 subparagraph 3, **Proposal for a Regulation of the European Parliament and of the Council setting a framework for energy labeling and repealing Directive 2010/30/EU (2015/0149)**, 27 November 2015.

preliminary timeline, a review of energy labelling for micro-CHP aiming to rescale the label from A+++ to G to A to G should be expected by 2026.

This new initiative is still at the beginning of the procedure for being accepted and published, but some issues can arise if it will not be carried out properly:

1. The rearrangement of all the current products available in the market in a smaller number of energy classes (from 10 to 6) is likely to face some disagreements. In fact, devices which were previously assigned to different energy classes could, with the introduction of the new scale, be shifted in the same class, due to general leveling of the existing products.
2. According to this proposal, during the transition period from the old scale to the new one, both scales will be present for each product available in the market. If this change is not accurately managed, this will result in a barrier for consumers who may be confused by the abundance of information supplied.
3. Leaving class A empty, while the heating industry has already deployed innovative technologies on the market (e.g. fuel cell micro-CHP & heat pumps), may incentivize consumers to delay renewal of old heating devices until class A devices become available. At the same time, consumers may give full credit to already existing highly efficient technologies like fuel cell micro-CHP.

6.3 Recommended actions

According to the results obtained from the ene.field deployment experience, which polled 10 manufacturers who have jointly deployed over 1000 FC micro-CHPs in 11 member states, the following should be considered:

- There is a need for the creation of common European standards that can be accepted by all Member States helping to overcome especially the National barriers still existing.
- In order to avoid penalizing FC-based micro-CHP devices in the energy-related products market, it is important to identify a suitable method for the assignment of an Energy Labelling which takes into account the specific nature of this kind of devices and properly accounts for both the electricity and heat generated. From this point of view, the method proposed by the EN 50465:2015 standard seems to be taking the most appropriate approach.

7. CONCLUSION

The policy context is crucial if fuel cell micro-CHPs are to achieve a swift transition into commercialisation: **A coherent, steady and predictable policy framework** should reward the European heating sector's contribution to a more efficient, reliable and cleaner energy system, through **advanced products and new business models**.

At the **European level**, it is suggested that the grid connection and **grid use costs of CHP generated power** take in to account the **lack of use of any high-voltage infrastructure**. Additionally, the energy labelling methodology should be clarified to fully reflect the primary energy savings of both the heat and electricity produced by fuel cell micro-CHP. The position of fuel cell micro-CHP should be reinforced, as part of the energy efficiency measures/technologies that can help Member States meet building efficiency requirements and fuel cell micro-CHP technologies should be viewed as strong contenders and complementary to the electrification of heat and other preferred options.

On a **national level**, lengthy and bureaucratic **permission procedures** to connect can represent **a real barrier to uptake**. Here, inspiration can be drawn from the "install and inform" connection standard in the UK. EU Member States should take into account the benefits of fuel cell micro-CHP when developing and implementing their energy transition strategies. These benefits including primary energy savings, electricity and heat decarbonisation, as well as reduction in grid stress and integration of intermittent renewables. FC micro-CHP large-scale deployment can be achieved through tariffs, deemed payments, or even up-front one-off subsidy, which will reduce capital cost for interested consumers. At this stage of market entry, **field trial support** and **high level political commitment is needed at the national level** for fuel cell micro-CHP to move faster into early commercialisation.

In addition to high level recognition of fuel cell micro-CHP at both EU and national levels, **removing barriers** and fully **accounting for the consumer and system level benefits in building codes, energy labelling and other secondary policy** instruments is key to ensure that the right drivers are in place, once the mass market commercialisation stage has been reached. Promoting innovative business models to accompany the roll out of FC micro-CHP will also help consumers derive further benefits from the technology.

A **lack of a common framework of European standards** is seen as a great hindrance to market uptake. Manufacturers points to a need for updating, improvements or revisions for as much as 60% of the current standards. Issues include **lack of consistency between different standards** dealing with similar topics and **standards that refer to too general co-generation systems** fitting poorly with the reality of FC micro-CHP technology. The **sheer amount of standards** that are in some way relevant to FC micro-CHP installation makes it hard for the manufacturers to keep an overview.

In addition, in order to avoid a penalization of the FC-based micro-CHP devices in the energy-related products market, it is important to identify a suitable method for the assignment of the Energy Labelling, which takes into account the specific nature of this kind of device. From this point of view, the method proposed by the EN 50465:2015 standard seems to be in the right way.

From a supply chain point of view the main challenges for the FC micro-CHP technology is significant **increase of production volume, simplification of maintenance and part replacement** procedures and **reduction of system complexity** and the cost of components. In the same thread, **cost reduction** is necessary for market introduction of the technology. Here the main can be grouped into three main

areas of work: **increase in volume, system simplification and development of collaborative strategies** between key players

From the more technical point of view of **field installation**, the largest problem identified is the sheer **time** some installations take. Here **component standardisation** may be a way of decreasing the required installation time. Additionally, while **training of installers** has progressed tremendously in active markets such as Germany such training may be a barrier for market entry **in smaller dormant markets**.

Lastly, while **customers** participating in the ene.field project were found to be **overwhelmingly positive** to the FC micro-CHP technology two main areas where **improvements** would be desirable were identified: **running costs and ease of use of the technology**. This latter point was most notable when asked about satisfaction with heating and hot water and therefore it should be noted that issues with the backup boiler or heating circuit might just as well have caused this.

ANNEX 1

DEFINITIONS OF ISSUE CATEGORIES

back-up:

this category contains all issues caused by the back-up system.

stack: *This category is also part of CALLUX

this category contains all issues caused by the stack as a central part of the fuel cell system.

reformer: *This category is also part of CALLUX

this category contains all issues caused by the reformer as a central part of the fuel cell system.

stack / reformer:

this category contains all the issues of the stack and / or reformer in case that an assignment of the issue in more detail into the category stack or reformer is not possible.

inverter: *This category is also part of CALLUX

this category contains all issues caused by the inverter as a central part of the fuel cell system.

balance of plant: *This category is also part of CALLUX

this category contains all issues caused by the balance of the plant. The balance of the plant includes all non central components of the fuel cell system. One example is an issue evoked due to problems with a gas valve inside the fuel cell system.

- An issue evoked due to problems with a gas valve inside the fuel cell system.
- Problem with heat transfer and thus the heat exchanger
- Leakage in the system
- Controller problems
- Pump issues.

service:

this category contains the period of time by planned service on the fuel cell system. Delayed related issues e. g. due to wrong installation via the service technician are not part of this category. Those issues have to be assigned to the belonging category.

periphery: *This category is also part of CALLUX

this category contains all issues caused by the system periphery components. One example is an issue evoked due to problems with a water pump in the heating circuit (if the water pump is not part of your system).

other: *This category is also part of CALLUX

this category contains all other issues that are not mentioned above.