ene.field project

ene.field*

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Environmental life cycle assessment (D3.4) - Executive summary

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Authors: Till M. Bachmann, Federica Carnicelli, Philipp Preiss (EIFER)

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1 Executive Summary

1.1 Introduction and objectives

As part of the demonstration project ene.field, Fuel Cell – micro CHP (FC-µCHP) units are assessed in terms of their **environmental performance in different settings**. The settings vary notably in terms of a home's space heating demand. This, in turn, is a function of the **dwelling type** (i.e. Single Family Home (SFH) and Multi-Family Home (MFH)), its **level of insulation** (i.e. new/renovated and old buildings) and **climate zone** (i.e. northern, central and southern) that vary in terms of outside temperatures that are also a function of solar irradiance. The FC-µCHP systems considered are **complemented with a gas condensing boiler (GCB) and a heat store**. As a second aim of this study, the systems are **compared with** other low-carbon, incumbent techniques, notably **a stand-alone GCB and** for single family homes an **air-water heat pump (HP)**. All homes equipped with these devices are **connected to the electricity grid**.

Four technologies are assessed, i.e. SOFC-µCHP, PEM FC-µCHP, GCB and HP. They are **generic**, meaning that they do not correspond to a specific existing system. All systems compared provide the same function, i.e. their ability to satisfy the heat and electricity demand of a given home in a specific, but generic European setting with an associated energy demand. The amount of heat and electricity produced varies between FC-µCHPs. **Except for the end-of-life** (decommissioning and waste treatment or recycling), the **whole life cycle is assessed quantitatively**. **Following the requirements** regarding how to carry out an LCA of FCs as laid out **in the HyGuide guidance document**,[1] a **critical review** of the study has been carried out by an external panel consisting of three experts.

The environmental performance of FC-µCHP is **substantially influenced by the amount and kind of electricity production replaced**. Two key assumptions were therefore varied, i.e. the power production mix replaced by the FC-µCHP's electricity produced (so-called replacement mix) and the annual amount of Full Load Hours of FC-µCHP systems.

The following **environmental impact categories** were primarily assessed: greenhouse gas (GHG) emissions (termed "climate change"), metal, fossil fuel and other resource uses ("re-

[1] Masoni, P., Zamagni, A., 2011. Guidance Document for performing LCAs on Fuel Cells and H2 Technologies. Guidance document for performing LCA on fuel cells. Retrieved from: http://www.fc-hyguide.eu/guidance-document.html

sources depletion"), water use ("water depletion"), human exposure to airborne particulate matter ("respiratory effects"), and acidification of soils and water bodies ("acidification potential"). Note that this LCA covered many more impact categories.

1.2 MAIN FINDINGS

In the following, first the results for the setting in which most of the FC-µCHP units have been installed in ene.field's field trial, i.e. existing buildings in central climate, are compared with the results of a recent study by Roland Berger Strategy Consultants (2015). Afterwards, main findings are presented for contrasting cases of the investigated scenarios, covering different European climate zones, levels of insulation, single and multi-family homes, and fuel cell types.

The current study generally **confirms the main environment related conclusions drawn by Roland Berger Strategy Consultants (2015)**[2] concerning residential applications of FC-µCHP: the main two drivers for emission savings by heat-led FC-µCHPs relative to a gas condensing boiler installed in single-family homes are a low heat demand of a given dwelling and a high carbon intensity of the electricity production replacement mix. Reversely, the lower the carbon intensity of the replacement mix is (or becomes) the lower the CO_2 emission savings by FC-µCHP systems. Roland Berger Strategy Consultants (2015) limited their analysis to the life cycle stages "domestic heat (and power) production" in single-family homes and "electricity production in the grid". Compared to a gas condensing boiler in a partially renovated semi-detached single family home located in Germany, they found **CO_2 emission savings** by a generic FC-µCHP system of 33%. For a similar setting and considering the same life cycle stages but taking further GHG emissions into account, the current study finds that FC-µCHP systems may achieve CO_2–equivalent emission savings of between 45% and 50%, depending on the FC type, when the electricity production mix replaced is as carbon intensive as a hard coal fired power plant and the heat-led FC-µCHP systems run up to 5333 full load hours per year (data not shown in this summary). When extending the assessment of this setting to the whole life cycle (i.e. including processes other than those in the life cycle stages "domestic heat (and power) production" in single-family homes and "electricity production in the grid"), the CO_2–equivalent emission savings are in the range of what Roland Berger Strategy Consultants (2015)

[2] Roland Berger Strategy Consultants, 2015. Advancing Europe's energy systems: Stationary fuel cells in distributed generation. FCH JU. p. 184. Retrieved from: http://www.fch.europa.eu/publications/advancing-europes-energy-systems-stationary-fuel-cells-distributed-generation, http://www.rolandberger.de/media/pdf/Roland_Berger_Fuel_Cells_Study_20150330.pdf. (last accessed on 14.07.2017)

found (32% to 36%, cf. Figure 1). When increasing the full load hours to numbers that have been demonstrated in the field trials of the ene.field project, equal to about 6000 h/a, the emission savings further increase to more than 40%. Figure 1 additionally shows the annual life cycle CO_2-Eq savings achievable by FC-µCHPs when further increasing the full load hours and taking replacement mixes corresponding to the German average electricity mix (in green) or to the ENTSO-E mix (in blue). The current study also confirms the Roland Berger Strategy Consultants (2015) study regarding the **substantially lower air pollutant emissions** of FC-µCHPs compared to the alternative systems analysed.

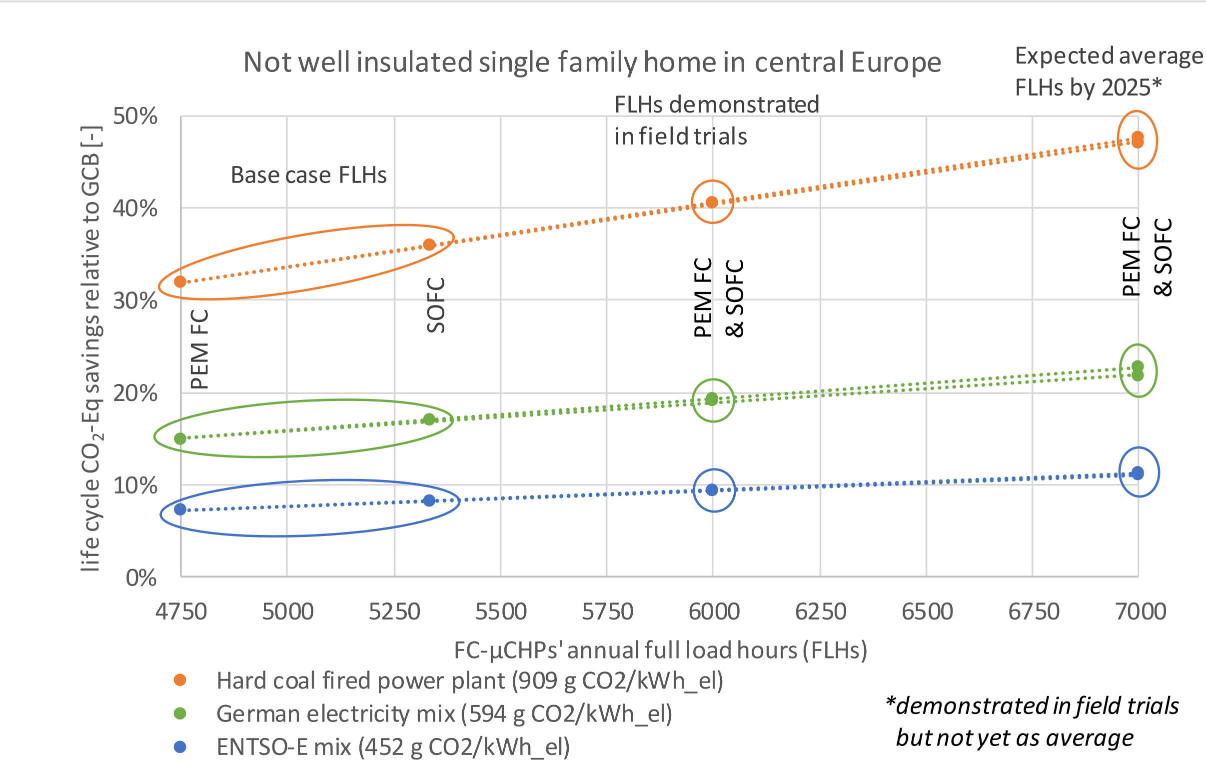

Figure 1: Life cycle CO_2-Eq emission savings by FC-µCHP with backup gas condensing boiler relative to a stand-alone gas condensing boiler as a function of different power production mixes that are replaced by FC electricity, and of different amounts of annual full load hours, for the systems installed in not well insulated SFHs located in central Europe | Source: own compilation using Global Warming Potentials for a time horizon of 100 years (GWP_{100}).

The environmental assessment being wider in scope than the Roland Berger Strategy Consultants (2015) study, the main findings of ene.field's LCA can be summarised as follows:

- In general, the **FC-µCHPs have a better environmental performance and in no case worse than the HP and the stand-alone GCB in all settings** concerning the prioritised impact categories (only "climate change" results are partially depicted graphically in the summary, cf. the next point). According to the HyGuide guidance document, the default case is to assume that all electricity produced or replaced in the grid corresponds to the average European electricity production mix (i.e. the ENTSO-E mix). For this replacement mix, the FC-µCHPs are compared to the stand-alone GCB in all settings over the entire life cycle by assuming default full load hours of 4750 h/a for the PEM FC-µCHPs and of 5333 h/a for the SOFC-µCHPs. Under these conditions, FC-µCHPs lead to 6-26% lower GHG emissions, 7-49% lower resource uses, 21-65% lower particulate matter induced impacts, 25-73% lower acidification impacts and 54-118%[3] lower water uses. The upper values usually correspond to new buildings located in southern Europe (low heat demand), while the lower values usually correspond to existing buildings located in northern Europe (high heat demand). Moreover, the environmental gain of FC-µCHPs, compared to GCBs, is more evident in multi-family homes than in single family homes because of more electricity production replaced in the grid (resulting from more full load hours at a higher rated capacity).
- **Life cycle GHG emissions of the FC-µCHPs are generally lower and in no case worse than for the GCB and the HP analysed in all of the investigated settings also when changing the replacement mixes or when increasing the amount of full load hours** (data not shown in the summary)**.** Compared to the stand-alone GCB in single family homes[4] with differing insulation levels across Europe over the entire life cycle, heat-led FC-µCHPs, running between 4750 and 5333 full load hours per year, lead to 6-15% lower GHG emissions when replacing an electricity generation mix that is as carbon-intensive as the ENTSO-E mix and to 28-67% lower GHG emissions when replacing an electricity generation mix that is as carbon-intensive as a hard coal fired

[3] When a home's FC-µCHP system produces more electricity than it consumes, water use by power production in the grid is reduced such that a net positive impact occurs. Therefore, reductions are more than 100% compared to the stand-alone GCB.

[4] The sensitivity analysis evaluating a change in annual FLHs has only been applied to single family homes, since the FCs installed in multi-family homes are already assumed to run 6000 FLHs or more in the standard case.

power plant. When additionally increasing the full load hours to 6000h, the corresponding numbers amount to 8-18% and 36-76%, respectively.

- **The FC-µCHP efficiencies and the full load hours of operation throughout the year are the main FC-µCHP systems' characteristics influencing the final LCA results**. The full load hours vary depending on the size of the FC-µCHP total output relative to the home's demand and whether the FC-µCHP is heat-led or electricity-led. While generally important, the replacement mix is not FC-µCHP system-specific.
- **Different elements of the systems' life cycle contribute substantially to their environmental performance**. The operation of the FC-µCHP, GCB and HP have the most influence on the GHG emissions of the systems. The process of manufacturing these systems is most important for impacts related to resource uses. The electricity supply from / to the grid, and the natural gas supply for the FC-µCHP and GCB operation are important for all environmental impact categories.
- **Measured data obtained from ene.field's field trial was used for plausibility checks** against the values assumed in the LCA. The data also motivated a sensitivity analysis to increase the assumed full load hours. The main obstacle in using field trial data in the LCA itself is the diversity of the real world: the measured units have technical specifications and are installed in dwellings that differ from those analysed in the LCA. This is because there is variability notably in terms of degrees of insulation and size of the dwellings, user behaviour and occupancy, differing rated capacities and modes of operations (e.g. recovery times, night setback) and actual weather conditions (changing especially the heating demand). Resources allocated to the LCA were not sufficient to take account of all of these aspects.
- **Comparison with the literature**: Ene.field's LCA undertook to analyse different systems in different settings across Europe which none of the studies found in the literature did. The studies found are not immediately comparable with this study because of differing scopes, assumptions and the applicable replacement mix. Nevertheless, this study confirms the general finding that FC-µCHP systems with backup lead to smaller GHG emissions compared to gas condensing boilers.

1.3 Recommendations and Outlook

Drawing on the insights gained by the LCA, the following can be concluded:

- **Diversity of systems**: FC-µCHP systems and their modes of operation are diverse. Analysing generic systems for assumed generalized operation modes has given results which are indicative in general terms of the FC-µCHP environmental performance tendency. It is recommended that further work analysing individual existing systems with measured data will provide insights to the manufacturers into which parts of a given FC deserve improvements. For instance, evidence from the ene.field field trials has shown that the full load hours assumed in the LCA may well be exceeded leading to stronger environmental advantages.
- **Flexible modulating systems** allow FC-µCHP powered by natural gas to operate in times when **carbon intensity** tends to be **high in the electricity grid**. In addition, FC-µCHP are independent from insolation and winds. As a result, already the currently available FC-µCHPs can supply heat and electricity also in times when heat demand is high and heat and electricity from renewable sources are less abundant or missing such as in winter. Further techno-economic study of different modes of flexible operation, including an improved grid-oriented operation strategy, could be useful.
- **Hydrogen and other low carbon renewable fuels**: As an innovative technology, FC-µCHP can operate either on natural gas or on hydrogen. Comparative analysis using hydrogen or other low carbon renewable fuels (e.g. biogas and methane from power to gas) would be helpful in understanding the possible future roles of the technology.
- **FC-µCHPs' role on the political agenda**: Energy efficiency is high on the political agenda, especially after the publication of the Winter Package by the European Commission in November 2016. The main priority of this package is energy efficiency, followed by renewable energies and energy access. Thanks to their high efficiency (cogeneration of heat and electricity) and fuel flexibility (e.g. biogas and power-to-gas hydrogen), FC-µCHPs have the potential to play a key role in the ongoing energy transition.
- **Extending the technological comparison**: The comparison of the FC-µCHPs was limited to an air-water heat pump for single family homes and a stand-alone gas condensing boiler for both single family homes and multi-family homes. In all cases, the systems were complemented with electricity from the grid. The resources foreseen in the ene.field project did not allow further low-carbon systems, notably biomass based heating systems, Stirling, Otto or diesel engine-based µCHP, solar thermal or photovoltaic

combined with other heating systems, or district heating, to be evaluated. Further comparisons with other systems would be of value to the sector in understanding its positioning among innovative solutions.

This study exclusively dealt with residential, stationary FC applications. It therefore does not allow conclusions on other FC applications, including in the commercial, industrial and transport sectors.

2 REVIEW STATEMENT

The critical review statement is reproduced below.

PhD Till Bachmann
Master Ing. Federica Carnicelli
EIFER
Emmy-Noether-Str. 11
76131 Karlsruhe, Germany

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Critical Review of the report and study "ene.field Environmental Life Cycle Assessment (D3.4)"

LCA study for review: FUEL CELL MICRO Combined Heat and Power CHP plants.

Commissioner of the study: EIFER, Germany

Practitioners of the study: Till M. Bachmann, Federica Carnicelli, Philipp Preiss (EIFER)

LCA report reference: Version 29 June, 2017

Review panel: Paolo Masoni (panel chair), Ugo Pretato (panel member), Alessandra Zamagni (panel member)

Dear Dr. Bachmann and Ing. Carnicelli,

The review panel has read the final version of your LCA study ("ene.field Environmental Life Cycle Assessment (D3.4)", dated 29/06/2017) and we are glad that you were able to address all the elements that we have pointed out in our review.

The review panel considers this LCA study to be compliant with:

- ISO 14040: 2006 Environmental management -- Life cycle assessment -- Principles and framework; ISO, Geneva
- ISO 14044: 2006 Environmental management -- Life cycle assessment -- Requirements and guidelines. ISO, Geneva
- Masoni, P. and A. Zamagni (2011). Guidance Document for performing LCAs on Fuel Cells and H2 Technologies. Guidance document for performing LCA on fuel cells FC-Guide.

In particular, the methods used to carry out the LCA are scientifically and technically valid, the foreground data used are appropriate and reasonable in relation to the goal of the study, the interpretation in the report reflects the limitations identified and the goal of the study, and the study report is transparent and consistent and suitable for publication with the inclusion of the Critical Review Statement.

Main limitations of the study, that could be addressed in a future update of the study, are:

- Use of generic data instead of primary data from FC producers

ECOINNOVAZIONE srl
Sede legale:
Ponte San Nicolò (PD)
Via G. Rossa, 26
35020 - Italia
Tel. +39 049 8043311
Fax +39 049 8043328

Bologna
Via Martiri di Monte Sole, 4
40129 - Italia
T. +39 051 6098427

eco@ecoinnovazione.it
www.ecoinnovazione.it

C. F. e P.IVA: 04669840284
REA PD n°408653
Capitale sociale € 25.000

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- Discussion on differences among FC technical parameters assumed in the LCA and experimental data might be improved as well
- Use the most advanced AWARE method of water scarcity instead of RECIPE water depletion method
- Perform an additional sensitivity analysis using the European average residual mix for electricity input and substitution.

Formally, this Critical Review is a review by “interested parties” (panel method) according to ISO 14040 section 7.3.3 and ISO 14044 section 4.2.3.7 and 6.3 because the study includes comparative assertions of different heating systems and is intended to be partially disclosed to the public.

The Critical Review has been performed concurrently to the LCA study and comments and recommendations were provided as milestones to each LCA phase. After the comments on the goal and scope phase - based on an LCA draft report and on a conference call among the reviewers and the commissioner of the study/practitioners – the subsequent steps of the review were carried out both by via web conference, and by on-site visit. During the visit it was possible to have access to the LCA model built in Umberto, and to the supporting files. The available primary data were checked on their plausibility but were not verified at the data source.

This Critical Review Statement is delivered to EIFER, Germany. The Critical Review panel cannot be held responsible for the use of its work by any third party. The conclusions of the Critical Review panel cover the full report from the study **“ene.field Environmental Life Cycle Assessment (D3.4)”**”– Final Report – June 29th, 2017 and no other report, extract or publication. The conclusions expressed by the Critical Review panel are specific to the present study only and shall not be generalised.

Moreover, we would like to point out that the review process was conducted in a very open and cooperative relation with you. We had access to all the models implemented in UMBERTO and the opportunity to check data input.

The study was complex and a very high number of different scenario were analysed. We highly appreciate the effort to discuss the results with available literature.

The review panel would like to congratulate you for the interesting study that we consider an important contribution for understanding and quantifying the environmental aspects of fuel cell in micro combined heat and power plant for dwellings.

Ing. Paolo Masoni   Dr. Ugo Pretato   Ing Alessandra Zamagni, PhD