D10.3.1

Preliminary assessment on energy/cost reduction

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Nomenclature

List of acronyms

AD	Anaerobic digestion
BM	Business Model
CHP	Combined Heat & Power
DoE	Design of Experiments
FC	Fuel Cell
FIT	Feed-in tariff
FW	Food Waste
FWD	Food Waste Dispenser
GHG	Green House Gases
ICE	Internal Combustion Engine
IRR	Internal Rate of Return (of an investment)
NG	Natural Gas
NPV	Net Present Value
OFMSW	Organic Fraction of Municipal Waste
PCM	Phase Change Materials
SOFC	Solid Oxide Fuel Cell
WWT	Waste-water Treatment (plants)

Summary

This report has been prepared in the framework of Work Package 10 of FC-DISTRICT project and represents the preliminary outcomes of the activities carried out within Task 10.3 "Business models for different European regions/market plan – impact of energy/cost reductions and Return of investment" whose final aim is to define market plans and business models for the main items of development, evaluating also energy/cost reductions deriving from the implementation of the innovative FC-DISTRICT business model.

This document is constituted by 7 Chapters herein briefly described:

1. Introduction.
   This chapters presents a brief description of the aim of the analysis carried out (e.g., business models development, and quantification, where possible, of energy/cost reductions) and the framework of such activities;
2. District energy needs, technical specifications and cost functions of FC-district technologies
   This chapter provides a list of technical data necessary to fully characterize the District, and suggests parameters that shall be added to the "District card", defined within Deliverable D.2.1.1.
   This chapters presents as well the technical specifications needed in order to provide costs evaluation of the district considering the impacts associated to energy saving, renewable energy productions etc., at district level. Cost functions of the technologies considered will be as well an essential input to perform the techno economic simulation of district scenarios.
3. Economical and legal framework.
   This chapter presents an overview of economic and legal aspects to be considered towards the adoption of micro-CHP at EU level. The analysis put the basis for further market plans development.
   In particular in this chapter are discussed the following points:
   - Energy prices (depending on final user, overall consumption, etc.) and future trends;
   - Support schemes for the diffusion of the micro-CHP generation (investment support vs. operating support; price-based vs. quantity based, etc.);
   - Competitiveness & ownership structures: Plug & Play, Company Control Model (e.g., virtual power plant), community Micro-Grid;
   - Value chain of key-technologies specifying role of the main relevant actors involved in the FC-DISTRICT model implementation;
   - Stakeholders features and attitudes;
   - Competitors and market potential;
   - Key market drivers and restraints for the diffusion of micro-CHP fuel cell systems;
   - SWOT analysis of key technologies.
4. Scenarios development and Business Models.
   Outcomes of this chapter are:
   - Methodology applied in order to perform a techno-economic simulation of different districts with a number of different technological, economic and legal scenarios;
   - Optimization procedures;
   - Preliminary considerations on Business models derived from the implementation of the novel technologies developed in the framework of the FC-DISTRICT project. The business models will be developed for the five countries selected: Italy, Spain,

Poland, Greece and Germany. The work herein presented is referred to the Italian market and it will be extended for the rest of the counties after M24. A final deliverable will be submitted in M48.

5. Energy/cost reduction.
   This chapter provides energy/cost reduction benefits deriving from the business model enabled by the development of the technologies, and their concurrent application at district level. This analysis strongly depends on the assumptions related to investment and maintenance costs which, in turn, depend on the stage of technical development of the adopted technologies. At this stage technology prices estimations are not fully available within FC-DISTRICT project, nevertheless the methodology to evaluate the energy/cost reduction is herein presented.
6. Acceptance of the BM of Utilities and End Users.
   This chapter focuses on the identification of supporting mechanisms for the acceptance of the Business model, as far as introduced, for Utilities in selected EU countries, that are represented in the FC-DISTRICT Project Consortium.
   Business Model acceptance is strongly influenced by public measures of support which vary across the countries considered.
   In order to assess public utilities interest, to know their opinion towards the model adoption, and to identify the economic mechanisms they are favorable to, a data request will be circulated and bilateral interviews to public utilities will be done.
   The common draft of questions for interviews has been prepared.
   Furthermore this chapter focuses on the acceptance of the FC DISTRICT business model by End Users.
   Preliminary economic benefits related to the implementation of the model for the end users are quantified.
   In order to carry out this activity a questionnaire targeted to end users has been prepared and it will be circulated among the Partners.
7. Conclusions
   Brief recap of the document contents, and final remarks on the assumptions done to extrapolate figures, for the energy and cost reductions benefits, are reported.

In Appendix A templates and questionnaires prepared to collect the necessary information from partners that are developing FC-DISTRICT technologies, and to interview end-users and interested Utilities, are provided. These data will be used to build energy and economic scenarios connected to the adoption of FC-DISTRICT key-technologies in selected district units acting as case-studies.
Such data will be integrated by what also available in the open literature and in the framework of other EU projects on relevant topics and technologies.
In Appendix B tools to be used for the for techno/economic characterization of SOFC micro-CHP units in buildings are also described. In FC-district a defined size and BoP of the SOFC unit is already available. However, a more general assessment will be carried out by including a wider range of solutions, either in term of nominal power of the generator, its efficiency performance, electricity vs. thermal power driven operation, etc.. In this way a more robust investigation on the potential of the SOFC technology in the framework of FC-district scenarios will be offered.
The model for techno-economic simulations will be also available for use to other partners, even though the *user-friendly* feature shall not be a priority. A MS excel-based simplified version of the program could be eventually produced to accomplish the task of delivering a tool easy to use for non-developers. The added value of this step would be the possibility, for instance, to evaluate different case studies inputting into the code relevant data of the building or district unit of interest.

1. Introduction

The aim of this Deliverable is to define a methodology to assess the techno-economic performance of mass interconnection of FC-district units. In this way, a tool to evaluate the energy and cost performance of the micro-CHP SOFC unit installed in a household, commercial building or industrial facility, included in the district unit, is established.
Since every district, and building or household within it, has specific energy demand profiles, different FC system sizes and layouts might be required. For instance, the thermal energy recovered from the hot SOFC exhaust gas can be exploited to produce Domestic Hot Water (DHW) and/or cover a share of Space Heating (SH). Depending on the specific parameters of the selected district, a different layout of the thermal recovery unit is thus required.
Due to the peculiarities of each district, a detailed techno-economic assessment is possible only if case-studies are chosen, for which a well-defined set of technical and economical inputs can be specified. At this stage, a preliminary case on a residential dwelling located in northern region of Italy will be assessed. Further case studies related to Spain, Poland, Greece and Germany will be developed in a second phase (deliverable due at M48).

The SOFC technology is close to reaching commercial maturity. Power generators rated from ~1 kW_{el} up to hundreds of kW_{el} are already available on the market.
As an example, JX Nippon Oil and Gas started in 2011 the commercialization of a SOFC micro-CHP unit for single households located in Japan. The nominal generator output is 700 W and the target retail price for the unit is estimated to be around 6,000 US$ (corresponding to ~4500 €) once market penetration will be established [1][2].
Bloom Energy has also already installed in the US several units rated 100 kW_{el} each, which are able to operate both on grid NG or biogas with a nominal AC electrical efficiency > 50% [3], and is now approaching the residential market with smaller units.
Micro-CHP is still a high-price/low-volume market, but seems to have the tantalising potential to move from niche markets of innovators towards mass markets in near future. Large commercialization of SOFC generators is indeed expected to take place soon – and most probably in the residential sector, where the installation of a 0.5-2 kWel micro-CHP unit in the single household should bring an annual saving on the energy bill that will pay off for the initial investment [4] –, even though technical and economic barriers are still high.

Main **technical barriers** for the SOFC diffusion are:

- limited thermal cycling capability;
- degradation due in-operation thermo-mechanical cycles;
- corrosion/stability issues on the steel interconnectors;
- very limited tolerance, or almost no tolerance, to selected trace contaminants that might be present in non-conventional fuels (e.g., biogas or bio-syngas).
- durability/reliability issues (e.g., in case of fuel shortage).

Main **economic barriers** are:

- potential high initial investment costs (need for supporting schemes in the early commercialization phase);
- potential high maintenance costs (depending on stack life-time, and other catalysts used for gas filtration/cleaning and pre-reforming).

In the framework of the FC-District, the SOFC can play a significant role by:

- exploiting the biogas potential of the district, established through an innovative waste management route concerning food waste. (Notably, the SOFC maintains roughly constant its efficiency when the fuel is switched from Natural Gas (NG) to biogas [5].);
- reducing the primary energy consumption of households, commercial building, or industrial facilities through the generation of electricity and heat in cogeneration mode; the fuel can be either NG or, after purification, biogas from Anaerobic Digestion (AD) treatment of organic waste (either produced and consumed locally, or upgraded into pipeline).

The techno-economic modeling described will serve as a basis to develop new business models that will support market penetration of the FC-District model and related technologies.

AD will feed SOFCs with biogas.

Concerning the SOFC, either small units in single household or larger more centralized plants close the AD digesters will be considered. Since the amount of biogas (both including co-digestion treatment of Waste Water Treatment Plant (WWTP), anaerobic digestion sludge and Kitchen food waste) cannot supply the overall energy needs of the district, NG fuel will continue to play a significant role. Following this consideration, gas Utilities, and not only WWTP managers, will represent key stakeholders for the widespread diffusion of the SOFC technology.

Within the framework of the project, innovative wall-insulating materials will also be developed, and is generally expected that their use will bring a reduction of the space heating consumption of the building. This aspect will certainly influence the optimum size of SOFC to be installed in the household or commercial building.

2. District energy needs, technical specifications and cost functions of FC-district technologies

2.1 District energy needs

In the first phase of this work, the definition of a district unit is necessary. According to district definitions given in the framework of the FC-District project [6], districts consist of different types of buildings: block of flats, offices, small workshops, single family houses, terraced houses, shops, etc. They can be listed as types and their share can be determined. A hypothetical district can be composed of Type1 (T1), Type2 (T2), Type3 (T3) till Type n (Tn) with different shares, what together gives 100% (T1 + T2 + T3 + ... + Tn = 1).

The six most important model district types are identified as following: “Old town”, “Outdated blocks of flats”, “Modern blocks of flats”, “Single family houses”, “Industrial area”, and “Multi-functional development”. Each urban district type may be composed of the following units:
T1 – Block of flats (outdated and modern);
T2 – Single family houses;
T3 – Block of offices;
T4 – Hotels.

Each district typology has been described on the basis of a list of characteristic parameters finally reported in the “district card “(an example is given in Figure 2-1).

I - Old town

Shares	Insulation standard	
	High	Low
T_1	24.0%	56.0%
T_2	0.0%	0.0%
T_3	0.0%	5.0%
T_4	10.5%	4.5%

Ratio residential to non-residential	95%

Development density			
FAR index	3.0		
D_D [m]	High	Medium	Low
	0 - 5	5 - 10	10+

Population density
6000 [inhabitants/km^2]

KFW
408 [ton/year]

Energy performance characteristics						
	Parameter					
	E_{TH}	P_{TH} summer	P_{TH} winter	E_{EL}	P_{EL} summer	P_{EL} winter
	Unit					
Climate SCI	GWh/km^{2}a	MW/km^2	MW/km^2	GWh/km^{2}a	MW/km^2	MW/km^2
B - Athens	205	127.3	39.2	70	33	33
D - Madrid	190	117.3	60	70	33	33
G - Munich	190	55	103.6	70	33	33
G - Warsaw	211	76.5	132	70	33	33
I - Umea	296	11.3	162	70	33	33

Figure 2-1: Example of a ‘district card’ for an ‘Old Town’ district typology [6].

In addition to the characteristic parameters provided in each ‘district card’, additional data might be required as:

- energy flows and savings from the adoption of the FC-based micro-CHP unit;
- optimal size of the installed capacity for the micro-CHP unit according to the building physical and occupational characteristics;
- space and domestic hot water heating demands for the specific building;
- detailed energy profiles;
- realistic Internal Rate Return (*IRR*) for the investment on a micro-CHP cogeneration unit installed in an household, light-commercial building or industrial area.

Detailed energy profiles are therefore required and, on the basis of the above mentioned notes, spreadsheets (reported in APPENDIX A) needed to collect the above mentioned information, have been prepared.

2.2 Technical specifications and cost functions

Energy and economic analysis of different districts will be carried out by taking into account technical specifications and cost functions for the different components including the power generation unit, energy storage devices and building insulation.

A technical assessment of different components is necessary to optimize the energy and economic balance within the different districts.

In particular, our starting assumptions will be the following:

- ***Power generation units will consist of micro-CHP FC systems;***
- ***The designated fuel for the micro-CHP system will be either NG, biogas or mixture of both***

  Micro-CHP units can also operate on different fuels, including fossil fuels from the municipal distribution grid (i.e., natural gas), renewable/recycled fuels from fermentation or gasification of wastes (e.g., biogas or bio-syngas) and carbon-free fuel from renewable power sources (i.e., hydrogen from small-scale wind or solar PV systems). According to the FC-district proposed business models for Food Waste (FW) management and related biogas production and exploitation [8], designated fuel for the SOFC are NG and biogas.

  The biogas composition is already described in [9]. It mainly consists of a mixture of CH_4 and CO_2 and therefore is suitable to be efficiently converted into electricity in a SOFC. The utilization of NG will be taken into account as a technical and economic benchmark case study. Also, the overall amount of biogas to be converted into electricity that can be produced starting from the collection of food waste within a district area is relatively limited compared to the overall energy demand of the same. Therefore, NG will continue to have a central role for power producing depending on the local and nation-wide mix of energy resources available for the generation of power and heat.

  Finally, clean biogas could be mixed with NG to feed the SOFC. The desulfurizer already available in NG-fed systems (and generally consisting of a cleaning bed with zeolites or activated carbons) should be able to remove residual sulfur compounds possibly present in the clean biogas stream.
- ***Thermal/electrical storage devices will be included***;

  In order to meet a balance between power demand and production in the various districts, it will be necessary to have components able to store the excess generated power at one time and deliver it when needed by the user [10]. This could be the case of meeting the requirements of thermal and electricity peak demand. For this purpose, the power production network might include units able to store thermal and electrical energy, respectively. In the current FC-District project, fuel cells are used to simultaneously produce heat and electricity, which means that heat is still produced if there is demand of electricity and vice versa. As the fuel cells are decaying as a consequence of frequently turning on and off, storage of energy is a solution to avoid premature performances drop. Thermal energy will be stored in the form of internal energy of a fluid (i.e., water). The capacity of the thermal storage shall be sized according to different technical (e.g., maximization of auto-consumed thermal energy) and economic (e.g., minimization of the pay-back time) parameters.
- ***Building insulation will consider physical and cost features of novel materials for space heating reduction***.

In Appendix A templates for data collection to be filled in by competent partners are provided.

In Appendix C additional technical details about the SOFC technology are provided.

3. Economic and legal framework

The analysis of different scenarios of energy districts requires to take into account a complex economic and legal framework that will play a major role in the diffusion of proposed future energy networks. The framework includes:

1. Energy prices (depending on final user, overall consumption, etc.) and future trends.
2. Support schemes for the diffusion of the micro-CHP generation (investment support vs. operating support; price-based vs. quantity based, etc.);
3. Competitiveness & ownership structures: Plug & Play, Company Control Model (e.g., virtual power plant), community Micro-Grid;
4. Value chain of key-technologies;
5. Stakeholders features and attitudes;
6. Competitors and market potential;
7. SWOT analysis of key technologies.

Concerning a legislative framework apt to support the diffusion of micro-CHP units, there are still many differences at European level, and some Member states are certainly more advanced than others. In particular, Germany and UK have already established dedicated support schemes. In Appendix B current trends in the legislative sector for the EU are described.

3.1 Energy prices and future trends

Energy prices in Europe and worldwide are extremely variable and unpredictable. They also differ strongly according to the final user and the amount consumed.
In
Figure 3-1: the average European (EU-27 zone) energy prices are given for the residential sector. Interestingly, for 2011 a break-even efficiency of ~35% (AC power)[1] is required for the SOFC to reach grid parity. Considering that today's SOFC systems have system electrical efficiencies ranging from 30-35% up to 50-60%[2], it becomes always important to evaluate from an economic standpoint of view the expected saving on the energy bill brought about by cogeneration of thermal power.
As mentioned before, predicting energy prices is a hard to impossible task. However, NG is likely to have a major role in Europe in the framework of more and more low-carbon technologies. Therefore, the NG price is not expected to increase dramatically over the next decades. Also alternative synthetic or biomass-derived fuels with high methane content, such as AD biogas, are likely to have an increasing share in the overall energy mix of countries.

[1] This value is simply calculated by looking at the 2011 gap between electricity and NG prices (Figure 3-1). A micro-CHP overall system efficiency of 35% means that 1 MJ of gas is required to produce 0.35 MJ of electricity; grid parity is thus achieved because for 2011 the same ratio of 0.35 subsists between gas and electricity prices.

[2] A system (AC) efficiency up to 60% is claimed by CFCL Ltd for its BlueGen commercial residential unit (http://www.bluegen.info). Also Bloomenergy (CA, US) reports in its website (www.bloomenergy.com) a system AC efficiency >50% for units running either on grid NG or biogas.

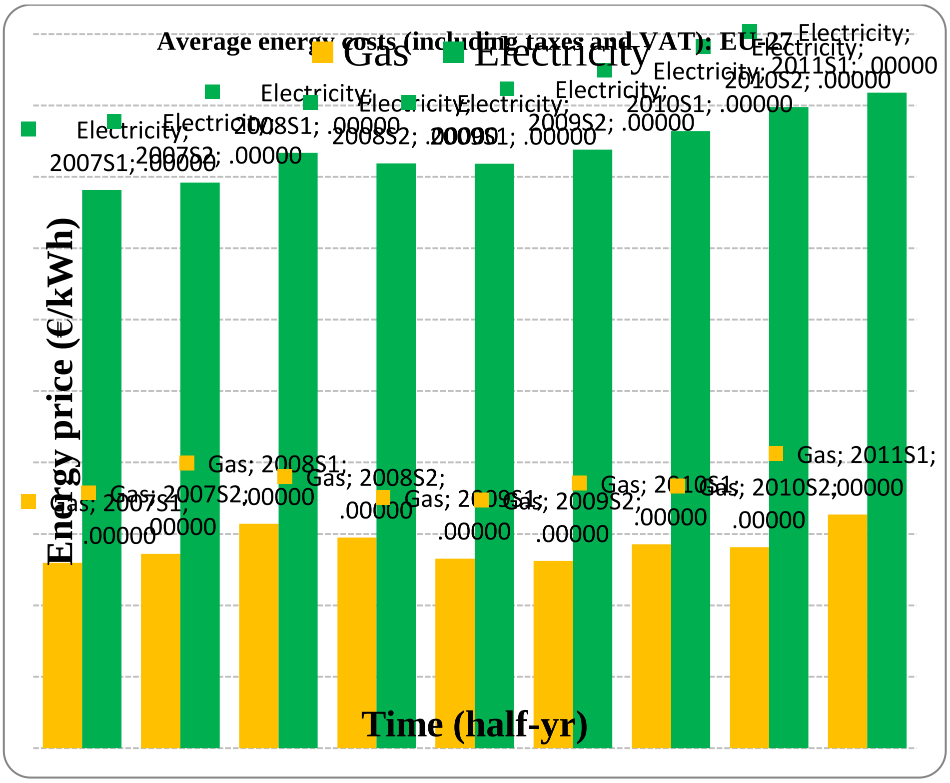

Figure 3-1: Average energy prices in Europe for the residential sector.

3.2 Public awareness, demonstration projects and support schemes for the fuel cell micro-CHP

The European Union has encouraged the diffusion of decentralized power sources based on production features. A first directive was introduced in 2001 encouraging electricity production by renewable energy sources (Directive 2001/77/EC [11]); in 2009 a new directive [12] was introduced repealing the former one.

A legal framework for the promotion of combined power and heat production was established in 2004 with Directive 2004/8/EC [13]. The set framework aims at promoting the development of high efficiency cogeneration of heat and power in order to improve security of supply and primary energy savings, while accounting for specific national circumstances, especially concerning climatic and economic conditions.

EU Member States have adopted different support schemes for the implementation of those Directives. Such schemes generally differ in the level of support granted to individual technologies. Roughly, support schemes can be classified in investment support and operating support [14]. Investment support is provided upfront for the erection of generation capacity, whereas operating support is paid for actual production.

As now, only few EU countries (especially UK and Germany) have introduced specific support schemes for the introduction of micro CHP systems including fuel cells. UK launched in 2009 a *feed-in-tariff* (FIT) [15] program to promote the introduction of micro-CHP (with a maximum capacity of 2kW). Such tariff includes a ‘generation payment’ of 10 p/kWh for all the electricity generated plus an additional ‘export payment’ of 3p/kWh for any electricity that is not consumed in the home and is fed back into the grid. The impact of the FIT on a household with a fuel cell micro-CHP unit installed was estimated by Ceres Power Company [16] around 300 £ (pounds). Recently, the UK feed-in tariff policy was increased to 12.5p per kWh generated to support the diffusion of 1 million of micro-CHP units installed in the UK by 2020 [17][18].

Notably, in Germany the CALLUX program[3] launched a pre-market large field test project to enhance the market readiness of fuel cell units to be installed in the residential sector. The main goal of this project is to prove the field use of the fuel cell technology (PEM and SOFC) in the residential sector, while also training specialized installers and increase the end-user awareness of the energy and environmental benefits connected to this new technology.
The 'Energie U-turn', as it has been termed, has helped the micro-CHP industry position its products as technical solutions that are available now, are effective at cutting, and can reduce peak power demand and provide synergy with renewables. Micro-CHP could prove to be an effective component in any future energy policy vision.

After the Fukushima nuclear disaster, in Japan energy policy priorities focused finally to increase the efficiency of how natural gas is used to include simply meeting peak power demand. Anxiety has been growing over blackouts and fuel costs, and this has led to unprecedented demand for home-grown 1 kWe fuel cell micro-CHP systems, from manufacturers such as Panasonic, JX and Toshiba[4]. It must be said the Japan always led the residential fuel cell sector during the last decade especially, both in term of R&D efforts as well as by covering the demonstration phase with dedicated trial programs (see the recent ENE-FARM project[5]).

3.3 Competitiveness and ownership structures

Electricity generation by individual households (known as micro-generation) is attracting an increasing amount of interest from government, industry and the research community. So far, electricity and gas sectors developed in term of vertically integrated large industrial utilities.
However, with the diffusion of decentralized power sources in residential/commercial districts, the final user becomes directly involved in the production process. In particular, a paramount implication of micro-generation is the more active role for household energy consumers in the development and operation of the energy system. This role has been defined with the concept of energy service co-provision [21][22] that establishes a number of alternative models for micro-generation investments with different degrees of co-provision by both consumers and energy companies.
Different ownership models have been proposed in literature basing on different relationships between the energy company and the consumer, and their respective roles [22][23]. The main micro generation deployment models have been indicating in Plug & Play, Company Control Model and Community Micro-Grid schemes, respectively. The Plug & Play scheme foresees the end-user directly purchasing the generator and thus assuming the whole investment risk and revenues. A Company Control Model would instead see an energy utility owning the generator and leasing it to the end-user with less revenues for the latter but also less financial risk associated. Finally, a Community Micro-Grid scheme would require an infrastructure where energy (either electricity, thermal energy or both) is exchanged among several end-users in order to avoid or smooth the need for accumulation systems and also to build more robust energy provision models that are based on a larger amount of final users.

[3] http://www.callux.net/
[4] http://www.cospp.com/articles/print/volume-13/issue-3/features/micro-chp-japan-continues-to-lead-as-fuel-cells-units-emerge.html
[5] "Japanese group unveils SOFC Ene-Farm residential cogen unit", Fuel Cells Bulletin, 2012(4), Page 4.

3.4 Value chain of key technologies

The value chain and principal stakeholders of key technologies within the FC-district is given in Table 4.

Tank for Food waste (FW) collection and further biogas production: value chain				
Stake-holders	**Role**	**Pros**	**Cons**	**Drivers/Barriers**
End-users (e.g., household)	Collection of food waste by means of Food Waste Dispensers	'Virtuos/green citizen' label	Increased complexity for household waste management	Waste separation is time-consuming, FWDs can reduce the time for collection
WWT plants	Co-digestion of WWT residual sludge and FW	Enhanced biogas production / Possible additional financial incomes due to the larger amount of waste disposed	Potential increase in complexity for the management of the AD process	Limited amount of extra-biogas produced from FW and OFMSW. Good waste selection is hard to achieve.
Local municipal authorities	Directives to make favorable the installation of FWDs within every household/building	Enhanced waste management with consequent reduction of today's landfills extension and possible avoidance to create new ones	-	Logistics and infrastructure (e.g., FW pre-treatment plant) are required for efficient waste collection and temporary storage.
EU	Directives that support alternative/innovative routes for organic waste management	-	-	Achievement of *Horizon 2020* goals / Promotion of *best practices* for waste management
Environment	-	Reduced use of landfills and incineration	-	-

SOFC micro-CHP: value-chain				
Stake-holders	**Role**	**Pros**	**Cons**	**Drivers/Barriers**
End-users (e.g., household)	Adopters of the SOFC technology	Auto-production of electricity and thermal energy (mentality shift from user to producer)	Depending on daily energy profiles and export-to-grid fees, not every household would benefit from the installation of a micro-CHP unit	Saving on the energy bill / Possible limitations on the energy use
WWT plants	Adopters of small cogeneration SOFC power plants	Electrical efficiency higher than competing technologies (i.e., ICEs)	Too high installation costs compared to ICES.	Removal of biogas contaminants upstream of the SOFC
SOFC manufacturers	Seller	-	Effect of trace biogas contaminants that may slip the cleaning unit (e.g., H_2S, siloxanes, halocarbons, etc.)	Diffusion of the SOFC technology and demonstration of its fuel flexibility / Competing technologies (e.g., ICEs), especially considering systems of hundreds of kW_{el}, whose electrical efficiency goes up to around 40%.
Gas utilities	Seller	-	-	The SOFC can run either on NG or biogas or both; so even when biogas is not available, continuous operation is assured by NG.
EU	Directives that support innovative and more efficient technologies for micro-cogeneration	-	-	Achievement of *Horizon 2020* goals
Environment	-	Primary energy saving and GHG reduction depending on actual efficiencies achieved / Micro-cogeneration at the household scale	-	-
National wide authorities	Support schemes for the installation of efficient micro-CHP units	-	-	-

Improved thermal storage and insulation building systems				
Stake-holders	**Role**	**Pros**	**Cons**	**Drivers/Barriers**
End-users (e.g., household)	Adopters of the improved systems	Energy savings	Installation costs	Refurbishment of old houses
Professionals (e.g., architects and engineers working the energy building sector)	Diffusion and installations of the new systems	Enhanced business volumes / New job opportunities	-	Adoption of specific best practice guidelines for the energy saving in buildings adopted the new insulation and thermal storage systems
Manufacturers	Seller	-	-	Diffusion of new technology and practices for energy saving in buildings.
Local municipal authorities	Increase public awareness of new energy saving technologies / Facilitate the legislative framework for their diffusion	-	-	-
EU	Directives that support innovative and more efficient technologies for energy saving in buildings	-	-	Achievement of *Horizon 2020* goals

3.5 Value Chain in FC-District

FC-District integrates an innovative mid-term energy technology (SOFC) with heat management at building and district level (building thermal storage coupled with intelligent distribution networks) to serve the consumer needs for economy-ecology-sustainability.

One of the key issues of SOFC is to operate them continuously, thus avoiding thermal cycles. Under such constraint, an intelligent heat distribution network characterized by enhanced piping solutions (with low thermal loss) and new thermal energy buffer storages at the district level is needed to enable a full, or anyway high, exploitation of the waste heat contained in the SOFC exhaust gas.

Similarly, from a conceptual point of view, a low-voltage low-losses micro-grid for the exchange of electricity within different district units is sought to manage the surplus of electricity that is generated from the single micro-CHP unit.

Ideally, the full and correct implementation of the intelligent heat network coupled with the micro-gird infrastructure should maximize the primary energy saving brought forward by the diffusion of micro-CHP SOFC.

In such a district framework, additional energy savings should be obtained by:

- the refurbishment of old houses and construction of new ones using new wall-insulating materials;
- the recycling of Food Waste (FW)with consequent production of AD biogas (Figure 3.2).

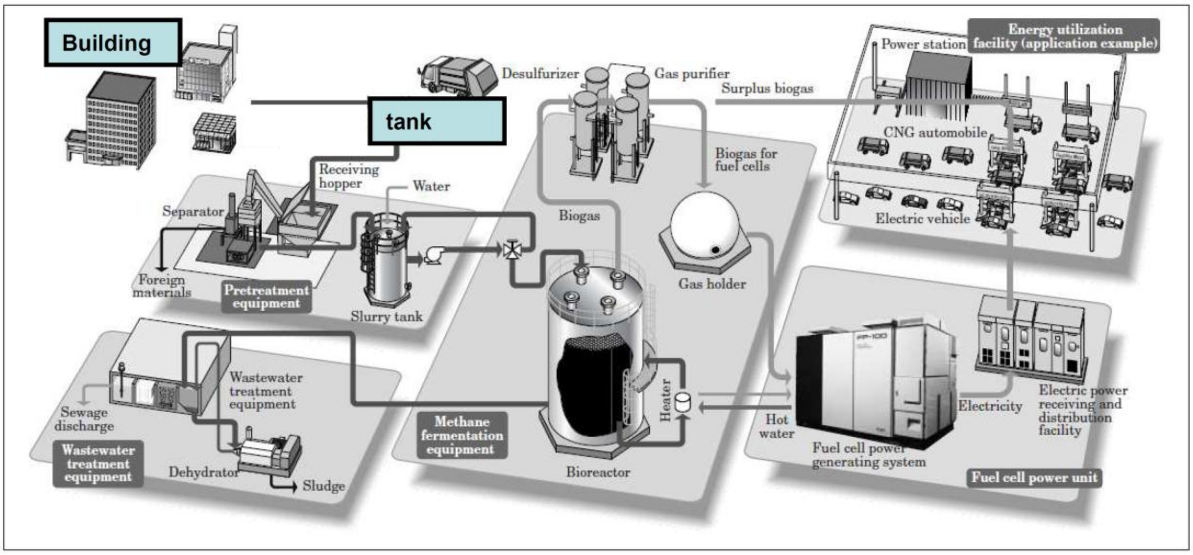

Figure 3-2: FC-district scenario for food waste recycling into biogas [8].

The fact that the SOFC could run also with biogas (other than the conventional NG) is an additional feature and link between two key technologies in the FC-District scenario. The Value Chain for the FC-district scenario relative to the biogas from FW is shown in 3-3 [8], putting emphasis on the food waste recycling route through co-digestion with WWTPs sludge and biogas production.

The proposed Business Scheme aims at gathering food waste, hence solving at the same time the issue of organic waste recycling and decomposing in European houses or district areas. Notably, the structure and organization of waste and wastewater infrastructure is suitable and relevant stakeholders are sufficiently motivated; therefore, the FC-DISTRICT model could provide very high advantages not only in terms of savings, but also in pay-offs and environmental benefits.

Reduced solid waste collection costs and enhanced energy recovery from biogas, make this model favorable than other waste management practices in many cases.

Figure 3-3. FC-district proposed business model for food waste recycling into biogas [8].

3.6 Stakeholders features and attitudes

Energy districts based on micro-CHP fuel cell systems may interest a large variety of public and private stakeholders.

Electricity and gas utilities could take advantages of investing in that solution. Gas utility companies may be positively affected by the diffusion of micro combined heat and power fuel cell systems due to the increase of gas consumption. From the other side, electricity utilities might view the CHP unit as a threat due to loss in electricity sales. However, they might have the interest to change their business paradigm and to adopt a company control model ownership structure aiming at operating a virtual distributed power plant. According to this strategy, the utility owns the micro-CHP and lease it to the end-user. By installing many of these cogeneration units the utility holds at all effects a virtual power plant and maintain its role of electricity/energy provider.

One of the main benefits to utility companies is an increase in customer retention. Since the utility will own the CHP unit, the householder will be tied to that particular supplier.

Gas (and electricity) utilities may also become directly those representatives in charge of the installation and maintenance of the micro-generators. This might be quite strategic as the utility companies may become a priority channel to enter the market, having already wide and established relationships with potential customers.

A major role could be also played by developers of heating appliances such as domestic boilers. Those developers need to approach micro CHP technologies in order to preserve their current market shares. They could represent a preferred channel for the technology distribution (via customer fidelity and service networks).

In broader terms, important stakeholders could and should be national authorities that seek for measures to mitigate global warming (sustainability), while reducing their energy consumption for stability and security reasons (security of supply). Moreover, key technologies of FC-district feature a high rate of enabling potentiality driving competitiveness in several industrial sectors.

Few examples can clarify the above mentioned perspectives. In 2008, Ceres Power, a leading British low temperature SOFC manufacturer, announced a major agreement with Centrica (trading as British Gas) that included a trial program and a volume forward order for residential combined heat and power products. In the framework of this agreement, British Gas is committing its operational resources to support the roll-out of CHP products including training, installation, servicing and logistics. British Gas has also placed a forward order to purchase in aggregate a minimum of 37,500 CHP unit on an escalating basis over a four-year period.

Both Ceres and British Gas have agreed to promote the Ceres CHP product with the aim of achieving substantially greater levels of annual sales over the four-year period. Approximately 1.5 million boilers are installed each year in the UK and it is forecast by industry and governmental bodies that residential CHP could take 30 per cent of this market by 2015.

Similar industrial cooperation has been pursued by CFCL, a leading best-in-class SOFC manufacturer, with gas and electricity utilities and heating appliance producers. Some examples include strategic partnerships with electricity & gas utilities (EWE, E.ON, Shell Global Solutions, GDF Suez, Edison SpA, Tokyo Gas) and producers of heating appliances (e.g., Bruns and Dantherm).

3.7 Competitors and market potential

Several technologies compete as micro CHP systems; among them, internal and external combustion engines are projected to share, at 2015, around 25% of market revenues. Fuel cell-based systems are instead projected to account for 35% of total revenues [24]. Frost and Sullivan [25] reported around 21,000 systems already installed across Europe with 90% of them in Germany. The total capacity installation was 80MW in 2008. The market is still in the nascent stage and is expected to grow at a compound annual growth rate (CAGR) of around 7% from 2005-2015. The market potential for micro CHP can be estimated using the domestic boiler market sales as a base since micro CHP units are ideally targeted as their substitutes. The total potential for the European micro CHP market is above 5 million units annually [26].

Due to such high potential, most of the actual competitors in the field of micro-CHP systems have developed solutions aiming to conquer the residential market. So far, a bit more than a dozen of companies have been involved worldwide in developing the SOFC technology. Those companies can be divided in 1) large and well-established international corporates aiming to conquer a large share of the market or 2) medium sized participants with significant focus on R&D and innovation.

The key factors that drive competitiveness in this field are:

- techno-economic achievements (such as intermediate temperature operation, reliability, durability, cycling time and robustness, lifetime, service & maintenance costs, etc.);
- adopted business model: distribution network, service network, marketing and promotion, key partnership with stakeholders.

3.8 Key market drivers and restraints for the diffusion of micro-CHP fuel cell systems

Several factors drive the diffusion of micro-combined fuel cell systems. Most relevant ones concern with energy saving policy and economics, industrial and environmental impact.

High operation efficiency of fuel cells (e.g., up to 50% or higher) ensures a reduction of greenhouse gases per generated kWh. Moreover, electrochemical conversion of fuels ensures the zero emission of traditional combustion pollutants including particulates, sulfur and nitrogen oxides. From an industrial point of view, fuel cells are considered as an enabling technology by driving industries to redesign their existing products and thus stimulating competitiveness.

A major driver concerns with energy saving potential which is an attractive point from both the public and industrial point of view. The issue of energy saving is mainly related with the high operation efficiency of fuel cell systems and with the capability to run those in cogeneration or tri-generation asset. Fuel cells possess high cogeneration potential, wherein high-quality exhaust heat is available for heating, cooling and additional power generation. A fuel cell unit that has the required power output for an individual residence or business unit is able to partially meet the heat and cooling demand of that user, and it can even re-feed electricity into the grid system. Those features ensure savings in the energy bills and enable governments to address the issue of security of future energy supply.

Another important driver for the diffusion of the technology is related with the research/demonstration support from governmental institutions. Notably, the FCH-JU (Fuel cell and hydrogen undertaking), as a part of the ongoing European Seventh Framework Program, has the aim to define and execute a target–oriented European program of industrial research, technological development and demonstration of hydrogen and fuel cells in the most efficient manner by way of realizing public–private partnerships. This would be instrumental for the stationary fuel cells market participants, as it would require their direct involvement in defining the content of the research and demonstration programs, with greater emphasis on performance and customer requirements. Individual Member states are working to encourage demonstration program related with fuel cell CHP systems. At EU level, the Callux program is probably the most relevant one with small-scale cogeneration units. More recently, the ENE-FIELD project was also launched.

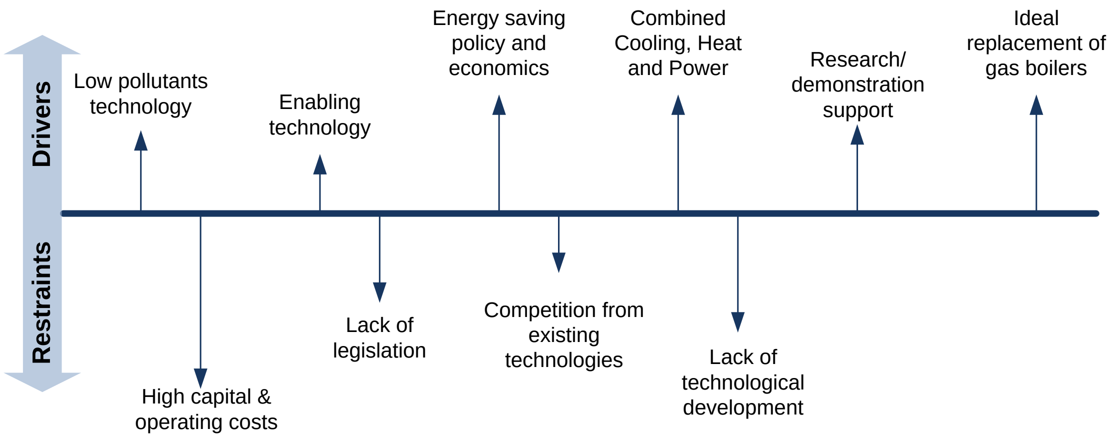

Figure 3-4. Market drivers and restraints. Elaborated from Frost and Sullivan [26].

Despite the above cited drivers, some restraints should be mentioned as main barriers for the diffusion of the technology. They are mainly related with technical and economic factors as shown in Figure 3-4.

High capital and operating costs have been one of the major restraints faced by the fuel cell industry. Another major restraining factor is the scarcity of funds on national levels. In particular, there is quite enough funding to cover the research and demonstration phase while there is not enough support during the product development stage and initial commercialization. Those issues need a specific support legislation at national level aiming at the market uptake and diffusion of the technology.

Another barrier is related with the competition from existing technologies that have already gained end-user acceptance over the years, especially because of their high reliability and durability.

Those issues are related with a further diffusion barrier, namely the lack of technological development. In fact, despite impressive results achieved in conversion efficiency (>60% based on NG LHV), some issues are still open such as the long-term durability, robustness/tolerance to non-conventional fuels and their contaminants and thermo-mechanical cycling. Moreover, low operation flexibility (e.g., slow start-up, limited turn-down capability, etc.) is a major weakness that has still to be addressed.

3.9 SWOT analysis of key technologies

In this section a SWOT analysis for the SOFC and AD biogas production technologies are presented in Figures 3-5 and 3-6, respectively. Concerning biogas attention, particular attention was posed on the 'biogas + SOFC' combined pathway.
Enhanced wall-insulating materials and improved thermal storage systems do not bring any particular threats; the first are useful to reduce the thermal energy demand in buildings and there is no particular coupling with SOFC and biogas production technologies; whereas the second are needed for exchanging heat in distribution networks, but also to increase the amount of thermal heat recovered from the SOFC and harnessed by the end-user. Value chains in section 3.4 of this report already provide a detailed assessments of opportunities, strengths and weaknesses of these two technologies.

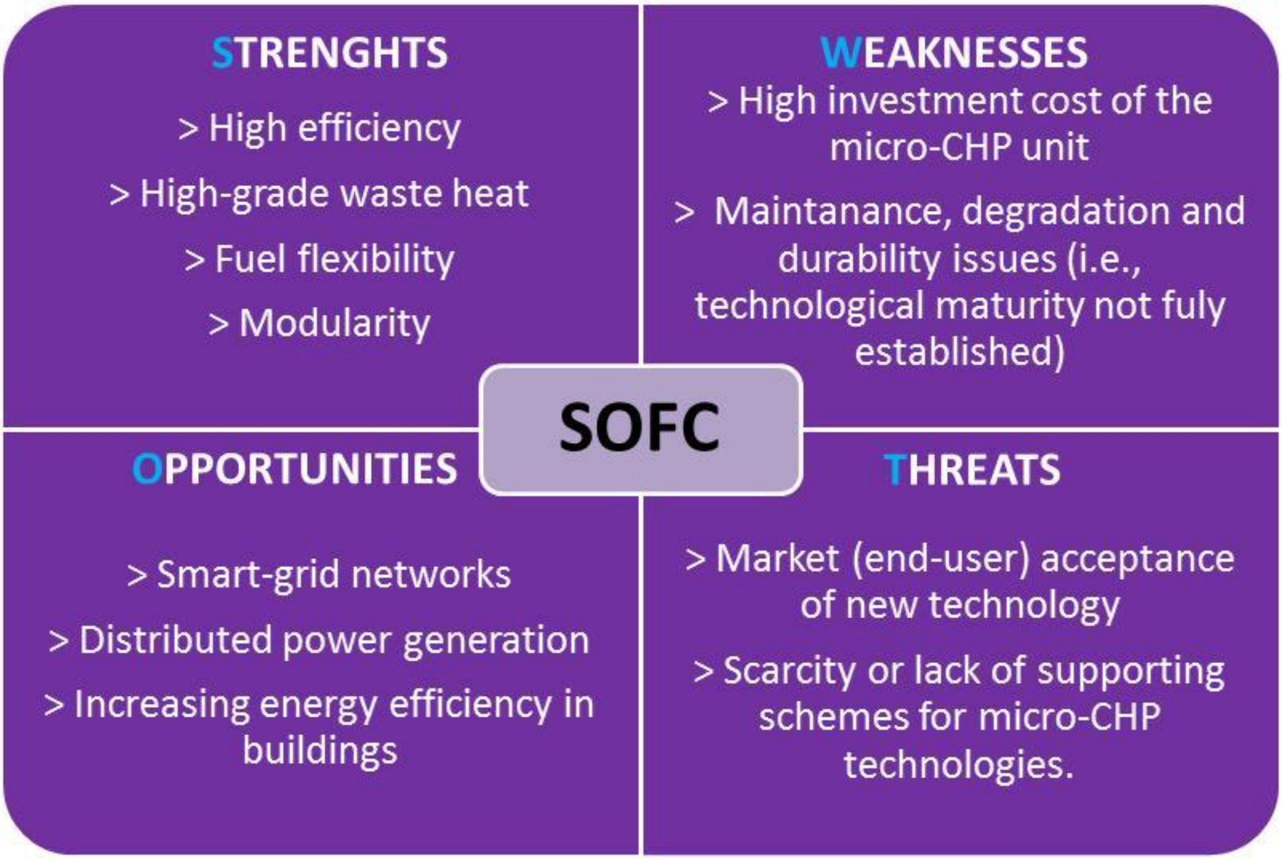

Figure 3-5. SWOT analysis for the SOFC technology.

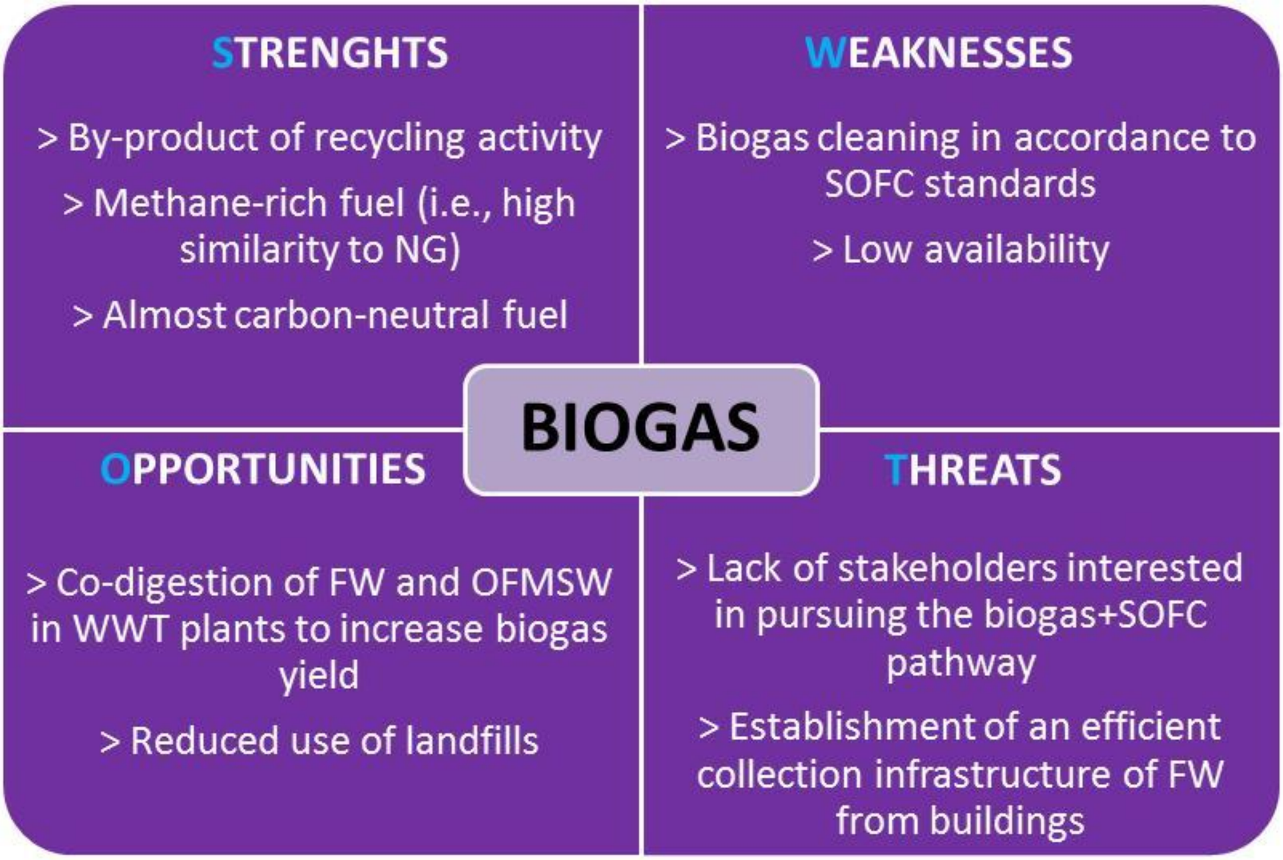

Figure 3-6. SWOT analysis for the AD biogas production route from municipal FW.

4. Scenarios development – methodology and Business Models (BM)

The techno-economic analysis will address different models of districts including technical specifications and cost models of components and considering the economic and legal framework. In particular, the analysis will have the following outcomes:

1. assessment of the methodology for techno-economic simulation of different districts with a number of technological, economic and legal scenarios;
2. Business models.

Each district analysis will constitute a scenario case. It has been decided to analyze scenarios in five different countries: Italy, Spain, Poland, Greece and Germany.

The work herein presented is referred to the Italian market; final deliverable, due on M48, will integrate these preliminary results with analyses for markets in Spain, Poland, Greece and Germany. Input data will be sourced from relevant partners through the request of filling ‘cards’ (technical questionnaires) of which templates are provided in Appendix A.

4.1 Methodology for techno-economic simulation of different districts

Techno-economic analyses of fuel cell based micro CHP system have been already investigated, and some examples can be found elsewhere [26][27][28].

To build an economic simulation of the pay-back time, IRR, etc., concerning an end-user (e.g., in the residential sector) adopting the micro-CHP and other key technologies available within the FC-district, site dependent and user specific data are requested. Therefore, simulations will be built in term of case-studies. For instance, input model parameters that generally vary significantly according to the specific country and sector considered are energy prices. Also, energy demand is quite specific and variable according to the end-user considered.

To fully characterize the techno-economic simulation sensitivity analysis, factorial analysis and optimization procedures are tools used.

In the following, a schematic (Figure 4-1) of the block flow diagram representing the methodology adopted for technical economic evaluation is presented highlighting input data required and output data collected. In chapter 2 the data necessary to be collected for such analysis were briefly summarized, while templates for data collection are provided in APPENDIX A.

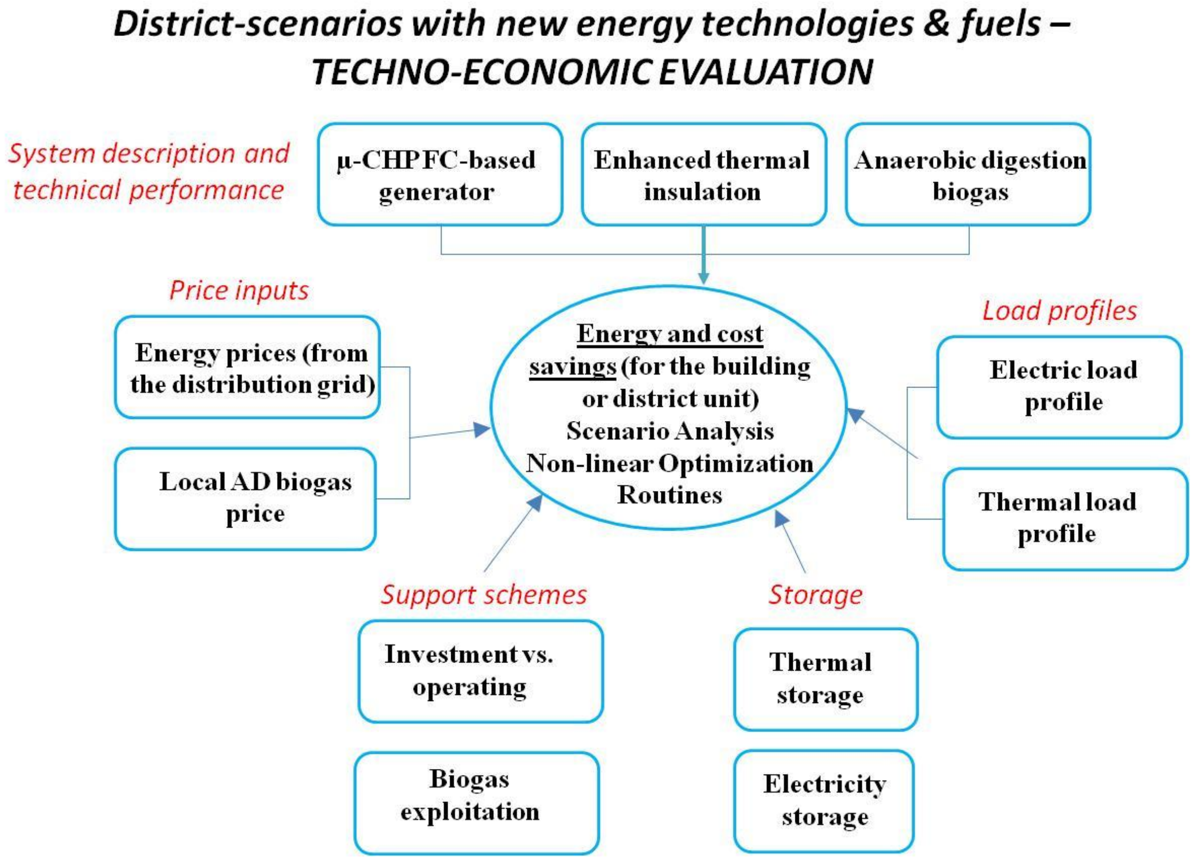

Figure 4-1: Techno-economic calculations for the micro-CHP unit.

The techno-economic analysis can be roughly distinguished in two parts: the first one relates to defining and solving the energy balance around the district unit (e.g., an household or a commercial building) connected to a certain end-user. The energy saving obtained by the installation of the micro-CHP unit (running either on NG or biogas) is evaluated.

The second part is the economical one, where cash flows are evaluated according to externally set energy prices.

For the **energy accounting** (technical modeling), technical specifications of the new technologies adopted by end-users along with daily load profiles are requested. Also the type of fuel used and type and size of energy storage systems, if any, should be defined at this stage. Innovative wall-insulation materials can also affect the analysis by changing the SH need of the selected district unit (building).

For the **economic accounting** (economic modeling), net cash flows deriving from the installation of the SOFC will be calculated considering:

- energy prices for displaced electricity and avoided gas (purchased from the grid),
- potential premium tariffs from support schemes available,
- operation and maintenance costs for the micro-CHP, auxiliary (thermal and electricity) storage systems and insulation materials.

In terms of electricity demand, the SOFC will bring a saving on primary energy only if the net system electrical efficiency will be higher than the average electricity from the grid (the latter being reduced also by transmission losses). From the user perspective, the SOFC will displace a share of the net electricity imported from the grid.

In Figure 4-2 an example of the energy flows in an 'average' residential' dwelling is simulated (the SOFC efficiency is set around 50%, which is somewhat an upper bound value among currently available SOFC micro-CHP units[6]). In principle, surplus electricity will be exported to the grid only when the end-user load profile will be lower than the SOFC output power and the battery pack is at full charge. Otherwise, when a peak load occurs (and SOFC + battery together cannot 'follow' the load), import from the grid will occur. The SOFC nominal power output and battery capacity can be optimized in size in order to minimize the electricity import/export from the grid. At the same time, an economic optimum can be found according to price paid by the grid for the surplus of electricity exported to it.

The expected impact of a micro-grid system within the district is high since it could relax operational constraints on the SOFC and thus enable optimization routines to determine the economic optimum for the micro-CHP system (in term of power output and storage capacity) that does not pose any significant challenge to the stack power core (for instance, fast load following could lead to thermo-mechanical stresses that threat or anyway reduce the generator life).

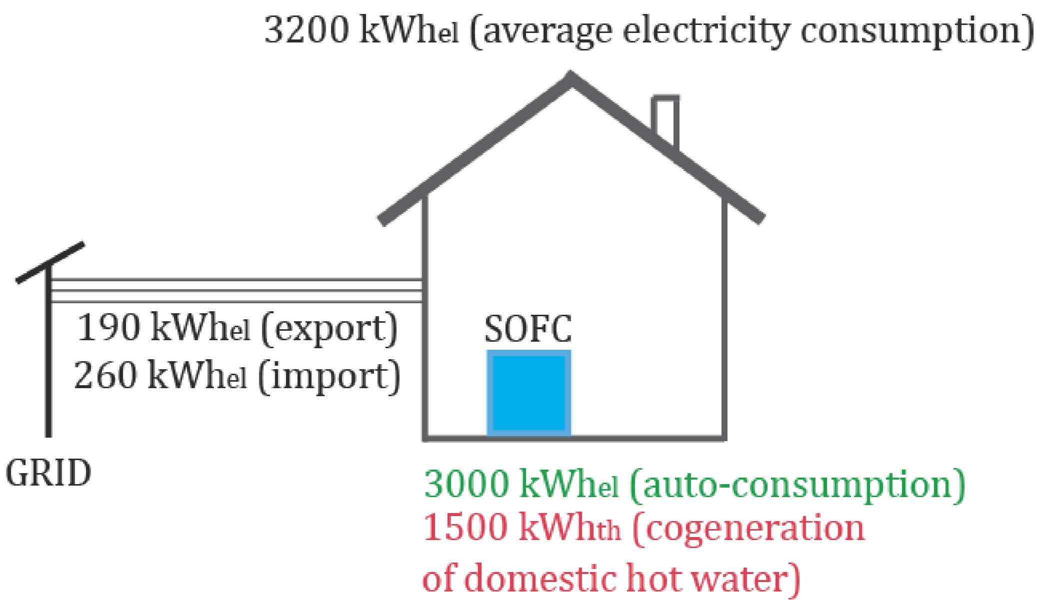

Figure 4-2: Energy flows in the micro-CHP unit.

The recovery of thermal power from the SOFC exhaust constitutes a saving that translates in a direct saving on the municipal gas bill since less energy from the distribution line is required to produce hot water (consumed as DWH or for SH).

Again, **the expected impact of thermal buffer energy storage systems is high**. Solutions both at single unit and at district level can be beneficial in term of primary energy saving. In fact, a potential limitation to the diffusion of larger SOFC units (above 1-2 kWe) could be the limited need (and consequently recovery/use) of thermal energy in the warm seasons. In this case, thermal energy storage systems at the district level could be useful to split the SOFC waste heat among different end-users including some large(r) heat utilities that can "accommodate" the extra heat available.

Even for the smaller units (micro-CHP unit below 1 kW), in case the district unit would already have a centralized SH system, the surplus heat would cover only DHW. Since the daily profile of DHW is generally extremely 'spiky' (i.e., concentrated in restricted periods of time throughout the day), local thermal energy buffer solutions would be beneficial.

[6] The SOFC efficiency is

4.2 Governing techno-economic equations

In term of techno-economic calculations, the main equations are provided below.

The SOFC energy balance can be solved once the operational parameters (fuel type, stack current and fuel utilization, *FU*) of the SOFC are defined.

The ideal (molar) flow rate of fuel is the defined as following:

$$\mathrm{n_{fuel,id}} = \frac{1}{\mathrm{FU}} \cdot \frac{\mathrm{I_{stack} \cdot N_{cells}}}{\mathrm{z_j F}}. \quad \textbf{\textit{Eq. 1}}$$

where y_j is the molar fraction the generic fuel species j in the anode mixture, *F* is the Faraday constant, z_i is the number of charges involved in the redox reaction of the same species, I_{stack} is the overall current produced by single the cell and N_{cells} is the total number of series-connected cells available.

The amount of chemical power (provided with a fuel flow feeding the SOFC) required to produce one unit of electricity is given by the following relation:

$$\phi_{fuel} = n_{fuel,r} \cdot LHV_{fuel} = \frac{\eta_{PC} \cdot W_{el,DC}^{SOFC} - W_{aux.}}{\eta_{el,\mu CHP}^{tot}}. \qquad \textbf{\textit{Eq. 2}}$$

where $\mathrm{n_{fuel,r}}$ is the effective amount of fuel consumed by the SOFC to produce a fixed amount of DC electrical power, LHVf molar low heating value of the designated fuel species, $\mathrm{W_{aux.}}$is the power consumption due to parasitic losses (e.g., air blower) , $\mathrm{W_{el,DC}^{SOFC}}$ is the SOFC DC power output, $\mathrm{\eta_{el,\mu CHP}^{tot}}$ is the net micro-CHP fuel-to-electricity efficiency and $\mathrm{\eta_{PC}}$ is the conversion efficiency from DC to AC (including DC-DC booster, inverter and power line filter losses) of the power conditioning line. Due to power line losses, $\mathrm{n_{fuel,r}}$ is always higher than the ideal amount.

Note also that the effective power delivered to the end-user is finally:

$$W_{el,AC}^{SOFC} = W_{el,DC}^{SOFC} \cdot \eta_{PC W_{aux.}}. \qquad \textbf{\textit{Eq. 3}}$$

The specific cost saving (expressed as €/kWh) on the electricity bill by the adoption of the SOFC is calculated as following:

$$c_{el,SOFC} = c_{el,grid-}\, c_{th,NG} / \eta_{el,\mu CHP}^{tot}, \qquad \textbf{\textit{Eq. 4}}$$

where $\mathrm{c_{el,grid}}$ is the electricity price from the grid and $\mathrm{c_{th,NG}}$ is the NG price from the distribution pipeline.

The specific cost saving on thermal energy (due to waste heat recovery from the SOFC to produce hot water) is calculated as following:

$$c_{th} = c_{th,NG} / \eta_{th,boiler}, \qquad \textbf{\textit{Eq. 4}}$$

where $\eta_{th,boiler}$ is the boiler efficiency, whose use is displaced when recovering heat from the SOFC.

To evaluate the yearly (or daily) revenue a time-integral over period of the interest of both SOFC electrical and thermal energy must be evaluated.

For simplicity, the yearly saving (in euro) obtained from the SOFC is:

$$C_{saving} = c_{el,SOFC} \cdot E_{el,auto}^{SOFC} + c_{th} \cdot E_{th,auto}^{SOFC}, \qquad \textbf{\textit{Eq. 5}}$$

where $\mathrm{E_{el,auto}^{SOFC}}$is the overall electricity produced by the SOFC and consumed by the end-user, while $\mathrm{E_{th,auto}^{SOFC}}$ is the overall thermal energy recovered by the SOFC and used either as DHW or for SH.

To have reliable estimates of the integral quantities above mentioned time-dense load profiles are needed.

The overall saving calculated in Eq. 5 can result either diminished or increased according to the price paid by the grid for the surplus of electricity exported to it. Also, not all the thermal energy produced by the SOFC can be recovered to heat because of thermal losses and heat rejection to the environment through exhaust gas. Generally, the amount of the thermal energy recovered by the SOFC can be expressed as:

$$E_{th}^{SOFC} = E_{fuel} - E_{el,DC}^{SOFC} - E_{loss} \,. \qquad \textbf{\textit{Eq. 6}}$$

Once the micro-CHP capital investment cost is available, as well as maintenance costs, the net present value of the investment can be calculated:

$$NPV = -C_0 + \ {}_{k=1}^{n} \frac{C_k}{(1+i)^k} \,, \qquad \textbf{\textit{Eq. 6}}$$

where $-C_0$ represent the initial investment cost, and C_k are the yearly (or monthly) revenues obtained from saving on the energy bill generated by the installation and operation of the SOFC.

5. Energy/cost reductions

5.1 The Italian case study

Main simulation assumptions

In this section a preliminary case study was built to show the implementation of the methodology described above. Of course, such case study will be refined when more reliable data input from competent partners will be acquired. In case of unavailability of critical data from the project, we will integrate by using what also available in the open literature and in the framework of other EU projects on relevant topics and technologies.

To determine a realistic size of the generator to be installed by the residential user, a code[7] will developed that takes into account the following:

- 8 'model days' (one for each season, distinguishing between weekdays and weekends) with 5-minutes averaged measured electric profiles[8];
- energy model of the SOFC generator (to calculate net electricity production and thermal energy recovery);
- real costs of gas and electricity in Italy (reference year: 2011; source: the Italian energy authority for electricity and gas[9]);
- storage of the surplus of electricity in batteries (this option can be either 'on' or 'off');
- *UK feed-in-tariff* (FIT) support scheme available[10] (this option can be either 'on' or 'off').
- 0.1%/1000 hr degradation rate;

The model has also incorporated within it the following assumptions:

- 10 years lifetime of the micro-CHP;
- 90% capacity factor;
- 5% discount rate;
- maintenance costs are neglected due to lack of detailed information.

[7] The code is under development and will be based both on Matlab routines and excel spreadsheets powered by VB macros. More details on its structure and optimization routines are provided in Appendix B.

[8] European and Canadian non-HVAC Electric and DHW Load Profiles for Use in Simulating the Performance of Residential Cogeneration Systems, Annex 42 IEA, 2007.

[9] The AEEG (the Italian Authority for Electricity and Gas) provides average prices paid by the residential end-user for electricity and gas. Generally, different prices are paid according to the overall amount of energy consumed and day-time. On average, the electricity paid by the end-user considered for this case study was exceeding 25 c€/kWh, while the NG cost was ~0,75 €/Nm^3.

[10] FIT support rewards the efficient and clean residential power generation with a premium of 13 c€ (incentive progressively reduced to zero within a period of 7 years) for every kWh_{el} auto-produced and consumed *in loco*, plus additional 5 c€ for every kWh_{el} exported to the grid.

Schematics about the SOFC generator layout is provided in Appendix C. In this first simulation a micro-CHP with internal steam reforming of NG was considered. The generator has a net system electrical efficiency around 45%.
In term of load profiles, the load Italian curve is pretty similar to those of other European countries, and average annual electricity demands are totally similar. We refer here anyway to the 'Italian case study' as the electricity and gas prices used are those exclusively representative of the Italian market.
According to our calculations, the optimal size of the SOFC generator to minimize the net import/export of electricity with respect to the grid is around 400-500 W for an end-user consuming around 3,000 kWh per year (family with 3 persons). In this case, a battery pack able to store up to 1000 Wh might be included to enhance the share of auto-consumed electricity over the total production. This preliminary calculation was recalled here essentially also to show that there might be an optimum size of the SOFC according to user-specific characteristics. However, since a nominal size of the SOFC has been already established in the FC-District framework, the reference case will be also evaluate considering it. Especially for the DEMO plants, we will consider this size to build the energy and economic analysis. However, for a more general assessment of our work, the SOFC size as well as other relevant parameters will be varied in order to have a fair and robust assessment about the energy and cost savings potential of the SOFC in buildings.
For a large family house (6 persons) consuming 8,000 kWh per year, the optimal SOFC size becomes almost 1,0 kWe. Again, a battery pack can be used to store energy during the night and supply extra power during the peaks of demand.

Energy savings in a large household

The overall saving brought about by the installation of an SOFC micro-CHP unit in a large family household (with an electricity consumption around 8,000 kWe per year) is given in Figure 2-13 considering either the solution without or with battery pack. Also, two different economic scenarios were evaluated, i.e., in absence of incentives[11] or with the *feed-in-tariff* (with UK premium prices converted in euros) active.
The allowed price for the SOFC generator that is needed to produce a return of the investment within 5 years was calculated for the large household case (Figure 2-14). Both cases with/without FIT were evaluated. Notably, the battery pack always brings an economic advantage. In fact, storing SOFC surplus electricity in batteries always enhance the annual saving. Also, the cost associated with the battery pack is relatively small and thus the 'SOFC + battery' hybrid solution results more profitable than having only the SOFC.
Note that when the FIT is active, the large is size of the SOFC power generator, the more are the revenues since the premium paid for the generation is very high. For this reason, the size of generator was limited to 2 kWe with such supporting scheme, as it happens with the FIT scheme already adopted in the UK since 2010.

[11] Even in the absence of incentives, the surplus of electricity exported to the grid was assumed to receive a fee of 5 c€/kWh.

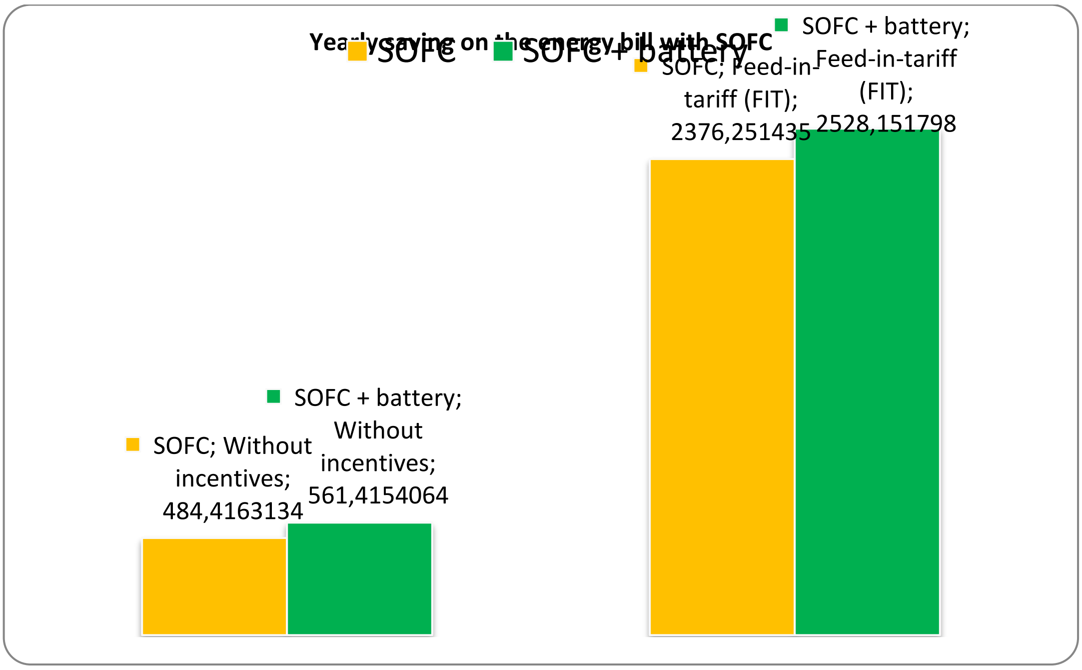

Figure 0-1: Optimization of the micro-CHP unit.

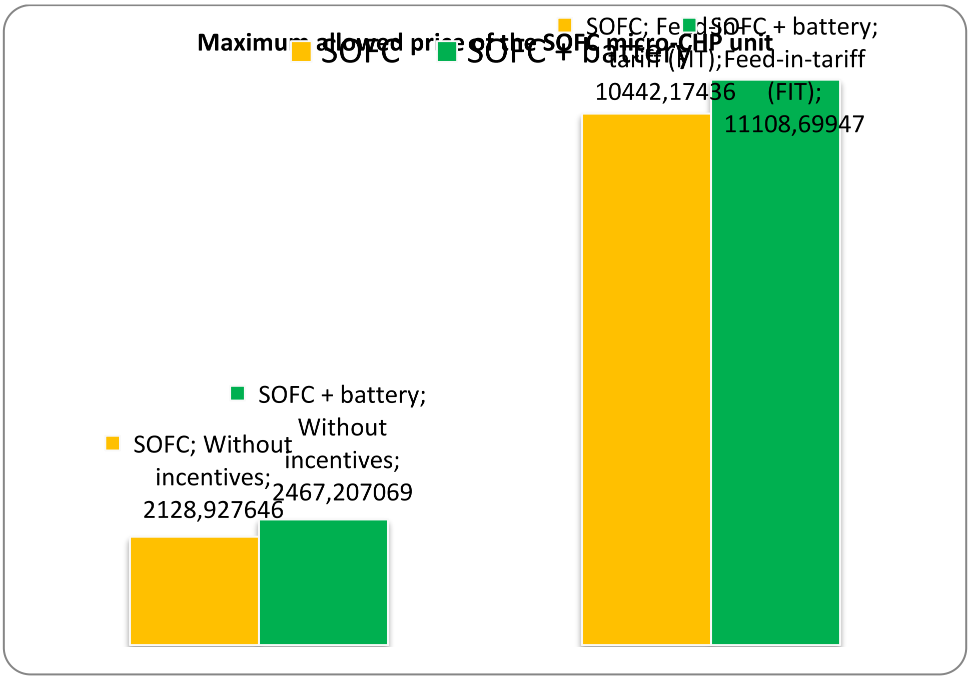

Figure 0-2: Optimization of the micro-CHP unit.

Since the optimal SOFC power output to be installed without FIT is smaller than with such supporting scheme available, the results shown in Figure 2-14 are normalized to the nominal power output of the micro-CHP (Figure 2-15).

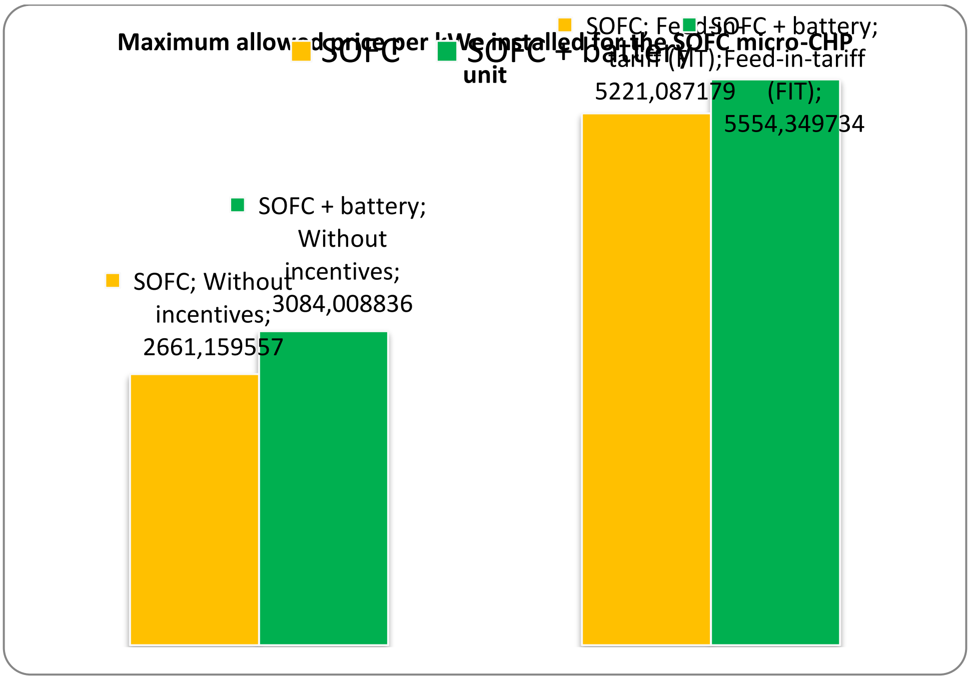

Figure 2-15. Allowed price per kWe of the SOFC generator that enables a return-of-the-investment within 5 years for the residential end-user (large family household).

6. Business models – Preliminary considerations

In order to define business models for the diffusion of FC-district technologies detailed simulations for selected case-studied must be evaluated first in order to obtain energy/cost reductions data. Therefore, at this stage, only preliminary considerations will follow.

Preliminary simulations for an Italian case-study (provided in Chapter 5) consider an 'average' residential dwelling as end-user. Calculations show that the maximum allowed retail price of a 2 kWe SOFC (excluding VAT) would be around 2,000 €. Premium tariffs (e.g., those offered by the UK FIT scheme) can make cash flows significantly more conspicuous and raise the allowed retail price around 5,000 $. Unfortunately, this value remains quite high compared to 2011-2012 costs, which range between 30,000 and 40,000 $ according to the ENE-FARM demonstration project in Japan – that includes manufacturers such JX and Panasonic. It is cut clear that any business model can be successful until the SOFC production costs remain that high.

However, SOFC target prices (upon establishment of mass production) are generally spoken around 4,000 – 6,000 $, according to declarations from some manufacturers; with this more optimistic assumption, and always under the presence of a FIT supporting mechanism, the SOFC might actually produce cost savings and a positive return of investment within 5 years or so. The still high initial investment cost would remain a strong economical barrier for many end-users though. Large energy utilities might play a key role at this point if able to bring forward alternative business and ownership structure models for the micro-CHP. Once the SOFC will prove to be a reliable technology, utilities could undertake the rather high initial investment cost of the fuel technology, while establishing/agreeing with the end-user a fixed saving on the energy bill for a fixed period of time and thus sharing the cost saving generated. Compared to the BMs where the end-user directly owns the technology, such strategy would relief the end-user from the high initial capital investment and support the adoption of the SOFC.

7. Acceptance of the BM of Utilities and End Users

Successful development of a micro-CHP system for residential applications has the potential to provide significant benefits to users, customers, manufacturers and suppliers of such systems. Nevertheless, for a successful market uptake, needs and opinions of end-users (both private individual and companies) and of Utilities must be carefully considered and assessed.
Moreover, business Model acceptance is strongly influenced by public measures of support which vary across the countries considered.
In order to know the opinions of Utilities towards the business model adoption, and to identify the economic mechanisms they are favorable to, a data request will be circulated and bilateral interviews will be conducted.
Regarding end users, their attitude towards an FC District system and their requirements in terms of costs, reliability, safety and comfort will be studied through a questionnaire.

The common draft of questions for interviews to Public Utilities and the draft questionnaire for end users are reported in APPENDIX A.

8. Conclusions

The present documents described the methodology and those relevant data and calculations needed to acquire an understanding adequate to build business models appropriate for the support of key-technologies included in FC-District scenarios.

The starting point of each business model, along with the fundaments for its reliability, are strictly connected to a detailed knowledge of the scenario characteristics (e.g., building type, end-user energy demands, etc.). This set of information is completed by a full awareness on technical and economic aspects of those key-technologies.

To derive a robust and reliable evaluation of the potential of FC-District, case-studies will be built and modelled in order to have a quantitative assessment on the energy saving brought by the adoption of the SOFC, biogas production routes based on FW and the use of enhanced wall-insulating materials and improved thermal storage systems. Synergies and interactions among these different technologies will be also taken into account.

Economic aspects will be evaluated especially with concern to the SOFC-based micro-CHP, for which the initial cost is expected to be high and supporting schemes might be required.

Acknowledgments

The FC-DISTRICT Consortium would like to acknowledge the financial support of the European Commission under the Seventh Framework Program.

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[33] http://www.htee.tu-bs.de/forschung/veroeffentlichungen/paper%20Christian%20Schulz%20Braunschweig%20Germany.pdf BUSINESS MODELS FOR DISTRIBUTED POWER GENERATION WITH COMBINED HEAT AND POWER MICRO-UNITS

APPENDIX A: Templates for data collection

In this section templates for data collection of relevant technical and economic input parameters useful, or even essential, to evaluate the energy and cost savings related to the implementation of new technologies included in the FC-district are provided. The more accurate the data collected, the more reliable will be calculations and the formulation of coherent BMs able to ensure a diffusion of the studied energy-saving technologies.

▪ District energy-profiles: characterization templates

To quantify energy consumption in district – which is one of the most important parameter for successful implementation of micro-CHP systems – it is necessary to know energy performance of particular buildings and their share in the total area of the district.
Time-dense than hourly-averaged energy profiles and also representative of at least each season (also distinguishing between week-days and week-ends) are important to evaluate more reliably the effective micro-CHP electricity production throughout a year. As an example, in [x] the daily load profile of a flat house is given time-averaged at 5 minutes and 1 hour, respectively, on the same graph. It is clear how a too coarse time-averaging is responsible to an excessive 'smoothing' of the electric load profile.
In case the FC micro-CHP unit operates under a load-following mode (as foreseen by many FC manufacturers), it becomes necessary to evaluate precisely the share of the generated power delivered to the household and the one exported to grid.
Similarly, the heat demand profile within a building is variable during the day, especially the domestic heat water (DHW) demand (A-1 and A-2).

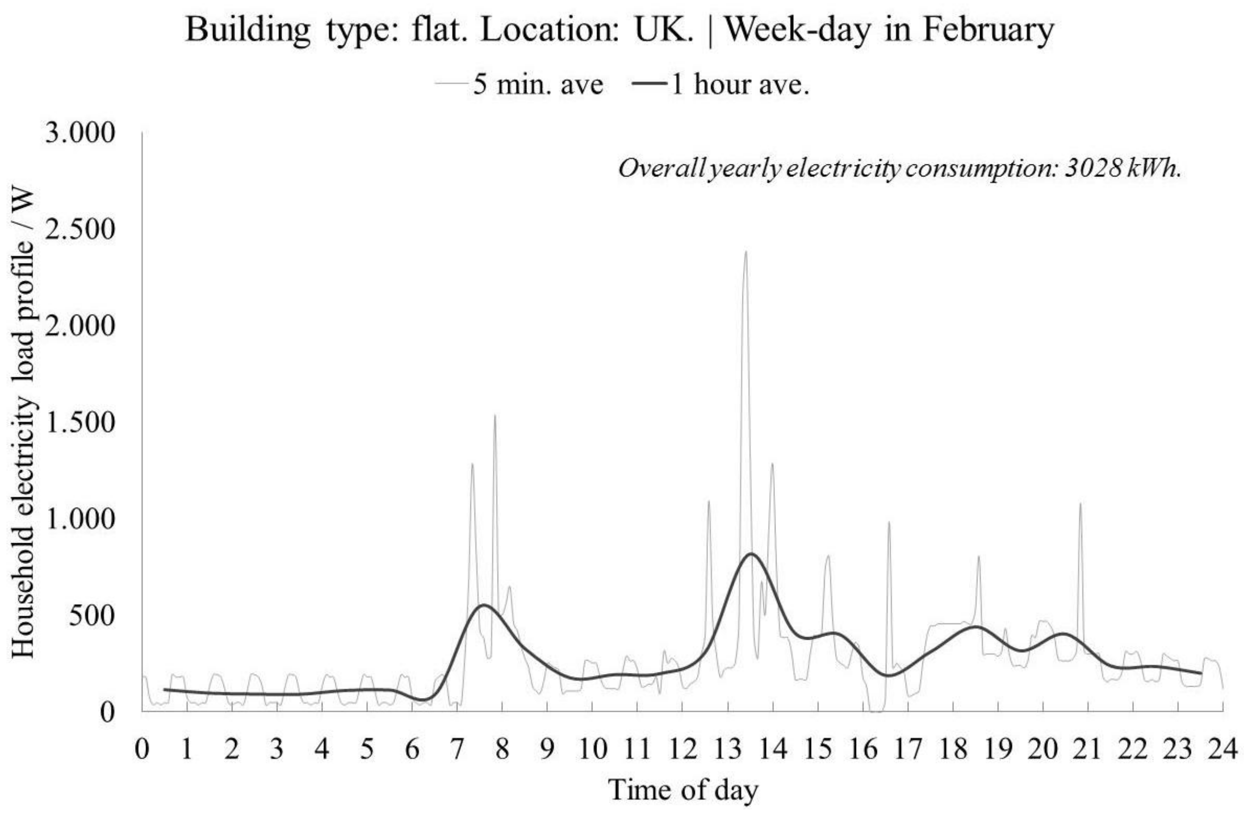

Figure A-1. Example of the electric load profile time-averaged at 5 minutes and 1 hour, respectively, in a flat (FC+COGEN-SIM project, 2007, IEA Annex 42).

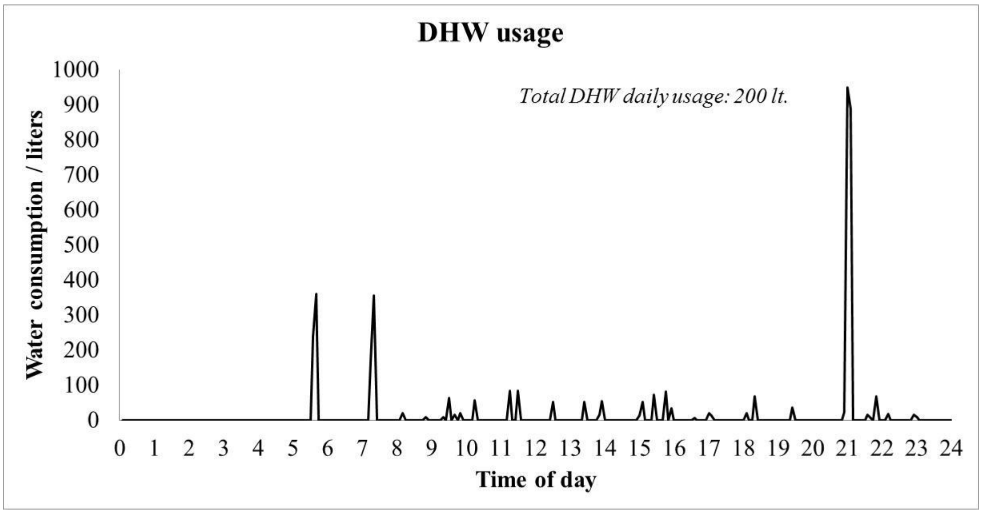

Figure A-2. Example of the DHW usage profile time-averaged at 5 minutes in a flat (FC+COGEN-SIM project, 2007, IEA Annex 42).

The following template shall be used to collect data of:

- Energy flows and savings from the adoption of the FC-based micro-CHP unit template
- Optimal size of the installed capacity for the micro-CHP unit according to the building physical and occupational characteristics template
- Realistic IRR for the investment on a micro-CHP cogeneration unit installed in an house-hold, light-commercial building or industrial area template
- Space and domestic hot water heating demands for the specific building template
- Detailed energy profiles template

Needed to fully characterize the District.

As an example in Table A-1 the thermal energy use demand for the ‘average’ residential building has been tentatively evaluated by ISPE. The scope of this simple spreadsheet is to highlight how variable can be the thermal energy demand within an household, and in general in a building. Also, it shows how finding the optimum SOFC generator size able to meet both the electrical and heat demand of an household is neither straightforward nor always possible. Economic objectives functions as well as primary energy saving and GHG indexes should guide/determine the optimal size and layout of the micro-CHP unit.

Table A-1: Simulated thermal energy use and recover from SOFC in an 'average' household.

Thermal energy use in a residential building - Preliminary simulation			
		Estimated range	
		min.	*max.*
Average household space heating demand, kWh/m^2/yr	90	*10*	*200*
Heating period, days	180	*90*	*180*
Household size, m^2	70	*50*	*150*
Overall space heating (SH) demand, kW$_{th}$,th	6.300		
Domestic hot water (DHW) demand, lt/day	200	*100*	*300*
Temperature rise for water, K	30	*30*	*45*
Thermal energy for DHW, kWh$_{th}$/day	7,0		
Overall thermal energy for DHW 'cold period', kWh$_{th}$/yr	1.256		
Overall thermal energy for DHW, 'warm period', kWh$_{th}$/yr	1.036		
SOFC electrical power, kW$_{el}$	1,0	*0,3*	*2*
Heat-to-Power ratio	1,5	*0,5*	*2*
SOFC capacity factor	0,9	*0,8*	*0,95*
SOFC thermal power recovered, kW$_{th}$	1,5		
Overall heat from SOFC 'cold period', kWh$_{th}$	6.480		
Overall heat from SOFC 'warm period', kWh$_{th}$	5.346		
Yearly electricity consumption, kW$_{el}$	4.000		
SOFC electricity production, kW$_{el}$	7.776		
'Red lettering' = input data			

In Figure A-3 the thermal energy covered in a household having the same characteristics as input, but with a varying energy performance index, is plotted. Interestingly, with the given SOFC (1 kW electric power output and a heat-to-ratio of 1.5) the amount of heat available in the cold seasons due to cogeneration is even more than what needed by the household if the energy performance index is D or better. Clearly, this only a simulation case to give an idea about how different could be the overall picture from building to building, depending on its specific space heating requirements. In future FC-district proposed business models, the SOFC should be always sized in such way to maximize the saving on the energy bill for the end-user.

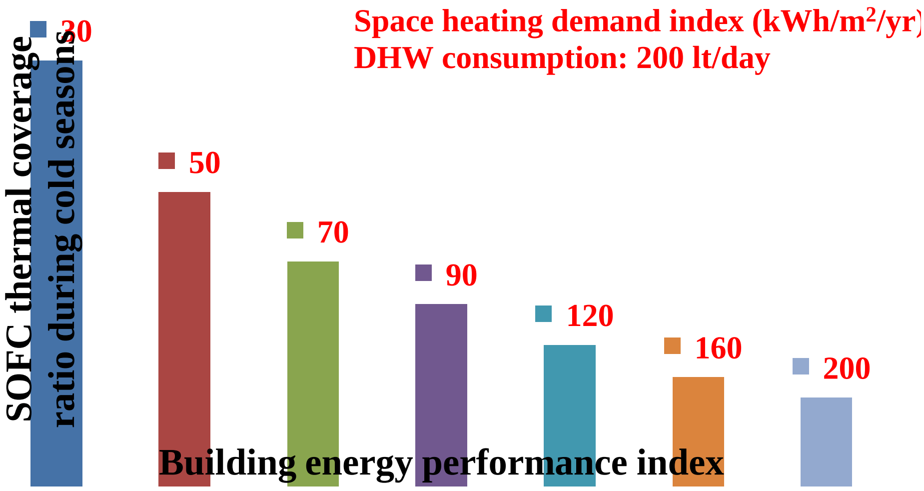

Figure A-3: Simulation of the share of the overall thermal demand provided by the SOFC to the 'average' household according to its energy performance index.

▪ Technical specifications and cost functions of Micro-CHP FC-based system

It is important to define a model of the FC micro-CHP that is able to predict performance and define operational characteristics and limitation of the SOFC.
Hence, templates for data input collection about techno-economic parameters useful for the modeling of the SOFC μ–CHP unit are given below and shall be completed.

Table A-2: Required technical for the techno-economic modeling of the SOFC μ–CHP unit.

Technical variable	Value / Short description
SOFC lifetime, yr	
SOFC size (nominal AC output)	
SOFC (ASR) degradation rate, %/1000 hr	
DC efficiency (also at variable load)	
Heat-to power ratio	
Thermal power recovery	
Power conditioning unit efficiency (including DC/DC converter, line filter, inverter, etc.)	
SOFC power modulation range [±% of AC nominal power]	
Max. allowed power variation (mW/cm^2/s)	
Start-up / shut-down time, hr	
Max. number of full thermal cycles	

The SOFC efficiency and total electrical and heat power available when switching fuel from NG to biogas should be also provided.

Table A-3: Required technical for the techno-economic modeling of the SOFC μ–CHP unit (example).

Technical variable	Possible range
SOFC lifetime, yr	*5-10 yr*
SOFC (ASR) degradation rate, %/1000 hr	*0.1-1 %/1000 hr*
DC efficiency	*30-60 % (LHV, NG or biogas)*
Heat-to power ratio	*0.5-2 (low compared to IC/EC engines)*
Thermal power recovery	*Depending on the electrical efficiency, assuming an on overall heat loss of ~10% of the input fuel.*
Power conditioning unit efficiency (including DC/DC converter, line filter, inverter, etc.)	*~80%*
Hot water tank size, lt	*100-300 lt.*
Fuel type	*…..*
Cost function	*….*

In the Table A-2 all those technical specifications that should be known for the FC generator in order to properly assess its energy performance are requested. As an example, in Table A-3 a possible range of the values for selected parameters has been indicated but it shall be specified by responsible partners (TU-BAF/STAXERA).

An SOFC system cost function should be also provided to enable the evaluation of scenarios where the micro-CHP unit size is allowed to change in certain range. Economic parameter that shall be provided by partners are defined in Table A-4.

Table A-4: Required cost data for the techno-economic modeling of the SOFC μ–CHP unit.

Economic variable	Value / Short description
SOFC micro-CHP total capital cost, $ or €	
SOFC system 'boundary' (what BoP includes and what does not)	
SOFC O&M costs, $/kWh/yr or €/kWh/yr	

- ## Technical specifications and cost functions of thermal storage

Table A-5: Required cost data for the techno-economic modeling of the thermal storage unit.

Technical or economical variable	Value / Short description
Tank feed-in water temperature, °C	
Thermal losses from the tank	
Cost function of the hot water stratified tank, $/lt. (storage capacity)	
Cost function of the heat-recovery unit (heat-exchanger)	

If available from the partners (TU-BAF/STAXERA), specific layout arrangements for the recovery of the SOFC waste (surplus) heat and its integration with the DHW/SH storage tank will be considered.

- ## Technical specifications and cost functions of electrical storage

Besides electrochemical storage in batteries, other devices (e.g., fly-wheels) or super-capacitors are now available to store power. However, given their superior technological maturity, batteries will be considered the preferred buffer to store surplus electricity from the SOFC

Table A-6: Required cost data for the techno-economic modeling of the electrical storage unit.

Technical or economical variable	Value / Short description
Battery typology(e.g., Pb, Li, Ni-Cd, etc.)	
Maximum discharge capacity	
Charge/discharge efficiency	
Lifetime, yr	
Maximum number of load cycles	
Cost function of the battery	

- ## Technical specifications and cost functions of fuel production systems

In the following a list of parameters required to carry out the further cost analysis is reported:

Table A-7: Required cost data for the techno-economic modeling of the biogas production system.

Technical or economical variable	Value / Short description
Biogas price for the end-user, (€/GJ or €/Nm^3	
Clean biogas volumetric composition	
FW disposer cost, €	
Marginal cost for additional FW treatment and biogas production (WWT)	
Additional cost for enhanced cleaning unit (i.e., installation of guard beds) in the SOFC micro-CHP, $/kWe	

- ## Technical specifications and cost functions of Building insulation

Buildings are large consumers of energy in all countries. According to statistics, more than 40% of total energy consumption is used in buildings. A reduction of the energy consumed in buildings is, for that reason, one of the global priorities to be reached in the next decades. To achieve this goal it is necessary to reduce the heat loss by the selection of the building thermal insulation materials. Phase Change Materials (PCM) could absorb or release a large amount of heat upon melting or solidifying. Such unique property could help PCM in building applications to maintain the thermal comfort limiting the use of HVAC systems.

In order to evaluate the effect of innovative wall-insulating in the framework of FC-districts, the following data are required:

- Thermo-physical properties (e.g., thermal conductivity, thickness, etc.) of innovative thermal insulation materials.
- Effect of thermal insulation on the building (thermal) energy consumption.
- Investment cost for the installation of insulation materials.

In terms of the techno-economic modeling of SOFC micro-CHP units running either on NG or biogas and installed in households, the above mentioned data will be useful to evaluate the new energy performance of the building and associated costs.

In Table A-7 it is reported the template prepared in order to collect the needed information.

Technical or economical variable	Value / Short description
Short description of the materials / systems to be used. According to the project proposal plan, retro-fitting of old buildings with innovative materials for external thermal insulation composite systems (ETICS) should be implemented.	
*Thermo-physical and geometrical properties of the new insulating materials (thermal conductivity, W/(m*K), thickness, etc.) vs. the current 'average' buildings situation.*	
Expected SH energy reduction from the adoption of selected wall-insulating materials.	
Cost of function of selected (FC-district) wall insulating materials.	

▪ Questionnaires for End Users

To be developed.

▪ Questionnaires for Utilities

Large gas and electricity utilities especially, but also companies having their business established in the energy sector (e.g., oil companies), are likely to play a dominant role in the diffusion of micro-CHP units. Companies now selling either gas, electricity or both to end-users (e.g., in the residential sector) will be have a clear interest in having an active role with regard to the introduction of micro-CHP units in the market due to their willingness to either maintaining their 'old' customers or eventually seeking new ones by developing new business models. unit will see A questionnaire to be shared among such stakeholders (i.e., energy utilities) was therefore prepared. The list of questions hereafter reported aims to understand the energy utilities' perspective about several critical aspects for the diffusion of micro-CHP unit within the FC-district model.

Questions: SOFC micro-CHP
Q1 (technical)
Which are the most significant *intrinsic* technical barriers for the diffusion of micro-CHP SOFC based system? (e.g., size, cell/stack degradation, the high operating temperature, limited thermal cycling capability, the lack of a dominant cell/stack design, etc.)
Q2 (technical)
Which are the most significant *external* technical barriers for the diffusion of micro-CHP SOFC based system? (e.g., grid infrastructure in case of diffused export of surplus electricity, establishment of micro-/smart-grid, waste heat management, end-user load profiles, etc.)
Q3 (technical/strategy)
Which are the most significant barriers for the diffusion of micro-CHP SOFC based system by large utilities / energy companies? (e.g., training of skilled personnel for the installation and maintenance of units, internal re-organization with the creation of new sales and technical departments, logistics of distribution, etc.)
Q4 (economic)
Which are the most relevant economic barriers for the diffusion of micro-CHP SOFC based system? (e.g., still high production costs, lack of large industrial partnerships, variable energy prices, etc.)
Q5 (legal)
Which are the most relevant legislative barriers for the diffusion of micro-CHP SOFC based system? (e.g., standard & codes for fuel cell technologies, safety codes, etc.)
Q6 (strategy)
Which actions would be needed to achieve / speed up the technological maturity of SOFC? (e.g., large field demonstration projects, more R&D efforts on fundamentals, etc.)
Q7 (strategy)
Which kind of commercial agreements with technology manufacturers would be needed? (e.g., exclusive contracts, etc.)
Q8 (customer relationship)
Which kind of ownership structure would be implemented with respect to the end-user?
Q9 (strategy)
Does your company have an active role in the R&D of FCs (SOFC especially)?
Q10 (marketing)
Which marketing strategies would be effective for increase public awareness and diffusion of new technologies such as SOFC and other key-technologies included in FC-district?
Q11 (market)
Which is the potential of the FC market in Europe?

APPENDIX B: Tools for techno/economic characterization

SOFC energy model

An SOFC energy model will be considered to evaluate the performance of the micro-CHP. Such model should be tuned according to data input provided by other partners. Notably, two main SOFC design are emerging for the residential sector:

- the Catalytic Partial OXidation (C-POX) SOFC;
- the Internal steam-Reforming (IR) SOFC.

In Figure C-1 a schematic of the FC unit built by partner Staxera-EBZ is given. Notably, the NG (or biogas) is converted in a C-POX reactor prior to feed the SOFC. Such solution is a proven option for cost-efficient fuel processing upstream of the SOFC. However, a main drawback of this solution is lower system efficiency generally achieved (max. ~40%, AC). The C-POX is an exothermic process therefore waste heat of the SOFC is not recovered internally as for the SOFC running on internal (direct or indirect) steam-reforming.
In Figure C-2 is proposed therefore the alternative solution where NG (or biogas) is mixed with steam and reformed yielding an overall endothermic reaction. The resulting system is able to achieved a system efficiency up to 60% (AC power).

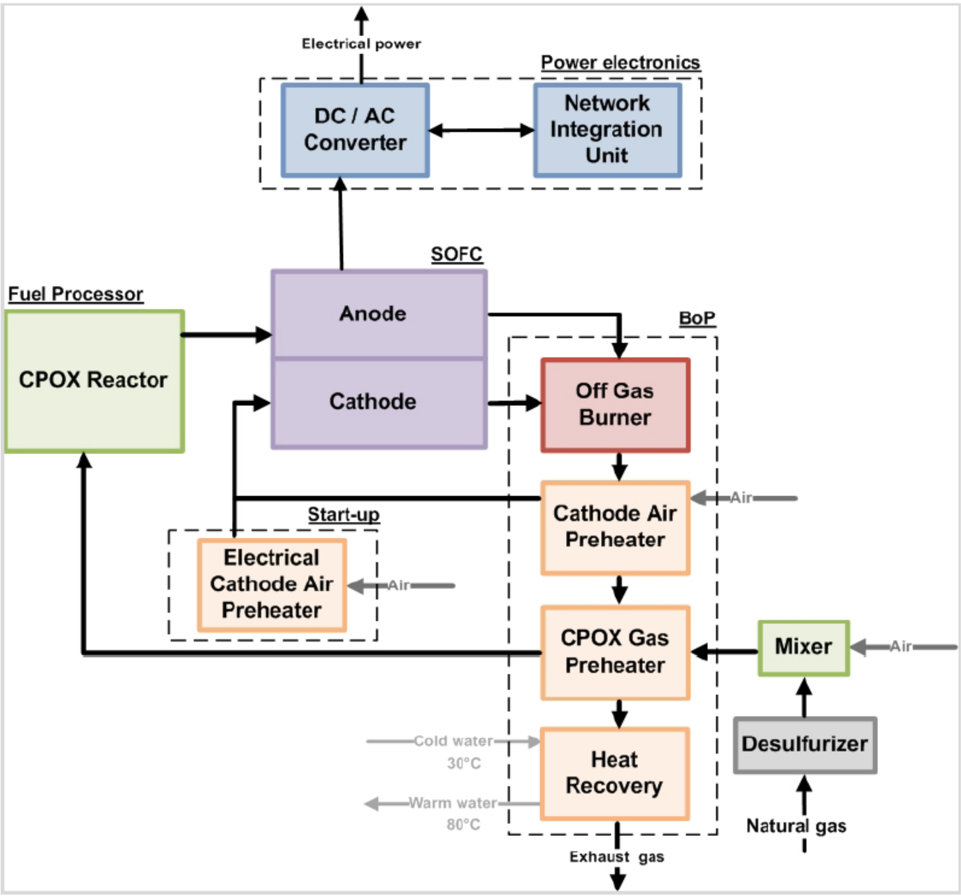

Figure C-1. Schematic representation of the FC-district μ-CHP layout with C-POX fuel processor [7].

In addition to the SOFC unit and surrounding BoP, the heat recovery sub-unit must be also carefully designed according to the specific building unit considered. A distinction between space heating (SH) and domestic hot water (DHW) is certainly required as temperature level, amount needed and seasonality strongly affect the technical solutions eventually chosen.

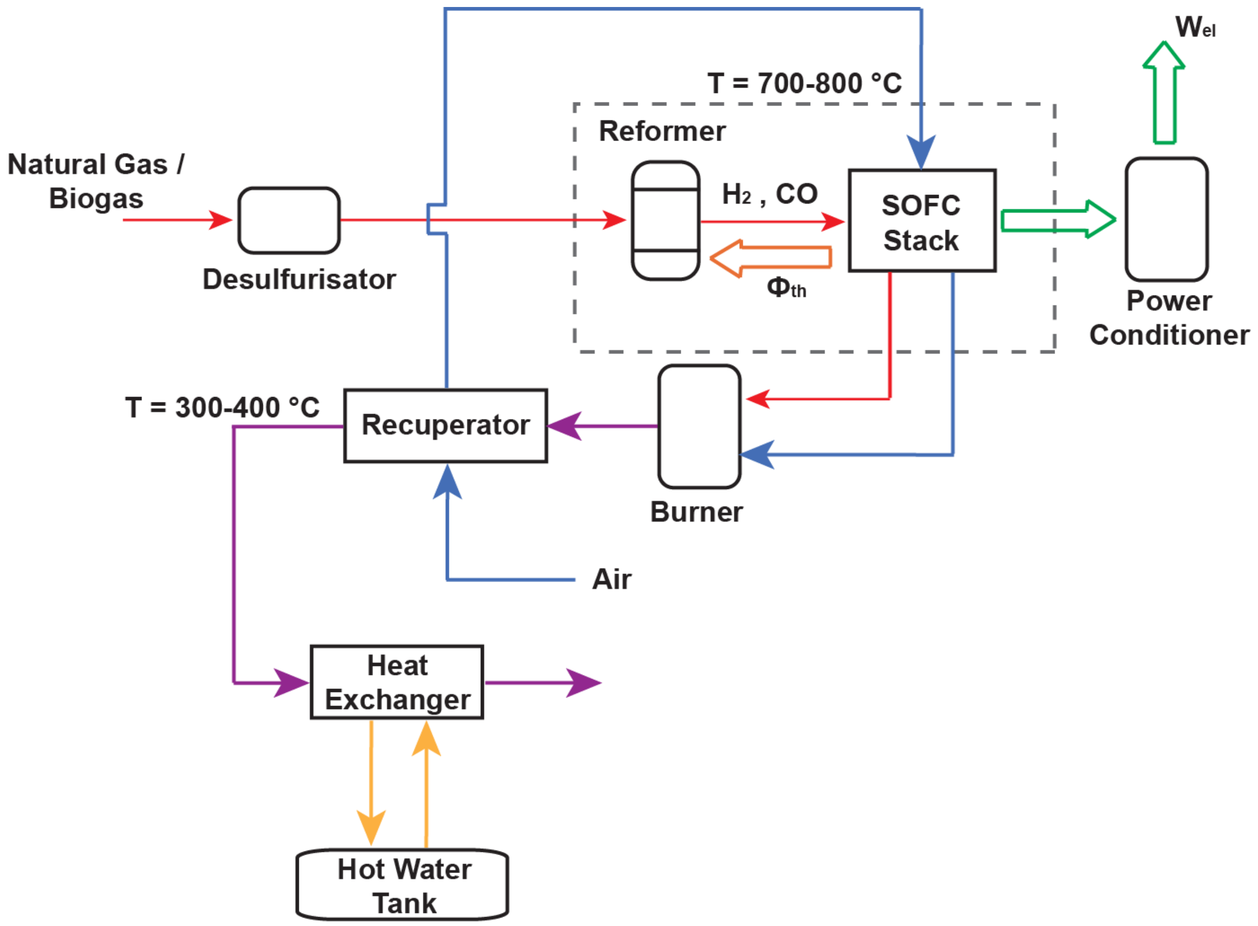

Figure C-2. Schematic representation of the FC-district μ-CHP layout with steam-reforming fuel processor.

Sensitivity analysis background

Sensitivity analysis aims to identify variables that have an impact on the energy balance and economics of FC-districts. Independent variables may belong to different groups concerning with performance of key-technologies, resources availability, economic and legal framework. As an example, performance indexes of key-technologies whose impact could be worth to be investigated through a sensitivity analysis might include the following data collected by means of questionnaires and reported in APPENDIX A:

- (electrical) efficiency of CHP unit;
- lifetime and degradation rate of CHP unit;
- heat-to-power ratio;
- power conditioning unit efficiency;
- biogas yield from FW;
- kitchen food availability;
- prices of key-technologies;

- Learning curve of new technology (e.g., efficiency and cost changes of the SOFC from early stage commercialization to mature market penetration);
- Support and ownership schemes available in countries selected for building FC-district case-studies.

Variable to be optimized could be instead energy saving, share of auto-consumed energy, total revenues, pay-back time and IRR.

It is of interest to identify the impact of the different independent variables on interesting dependent variables. First, the significance of each independent variable will be evaluated through a computer analysis by means of a statistical approach basing on factorial design and analysis of variance method (ANOVA) [29][30][31]. Significant variables within a certain degree of confidence will be thus considered for a subsequent analysis in which the derivative of each dependent variable will be evaluated with respect to the different significant independent variables.

The analysis has the main outcome to identify decision variables for subsequent evaluation of the FC-district, including the identification of drivers and restrains and design of the business model.

Scenario development by means of Design of Experiments (DoE) methods

Factorial and sensitivity analysis have the capability to identify key factors either driving or retaining the FC-district implementation. However, in order to develop systematically the energy and business models of the FC-district, it could be of interest to apply advanced mathematical methods basing on statistics. Design of experiments (DoE) with regression models and response surface analysis has been identified as a powerful tool to properly manage the complexity of different scenarios [32]. The application of this method features the capability of obtaining analytical relations between the dependent variables and the analyzed independent variables. The order of regression polynomials depends on the adopted design of experiments: non-linear regression models could be obtained by using face centered or central composite designs. The regression models allow to represent multiple responses by plotting contour plots and response surfaces. Moreover, they allow to apply constrained optimization methods in order to maximize one

or more dependent variables. In the regression models the coefficient linking the independent and dependent variables are not a-dimensional, because they represent the sensitivity coefficient linking these variables when the regression models are expressed in the physical form.

Therefore, the unit measures are consistent in a regression model due to the procedure applied to obtain them.

The method will be applied on a computer experimental analysis mode by designing properly the simulation campaign. A flow diagram of the analysis is given in C-3.

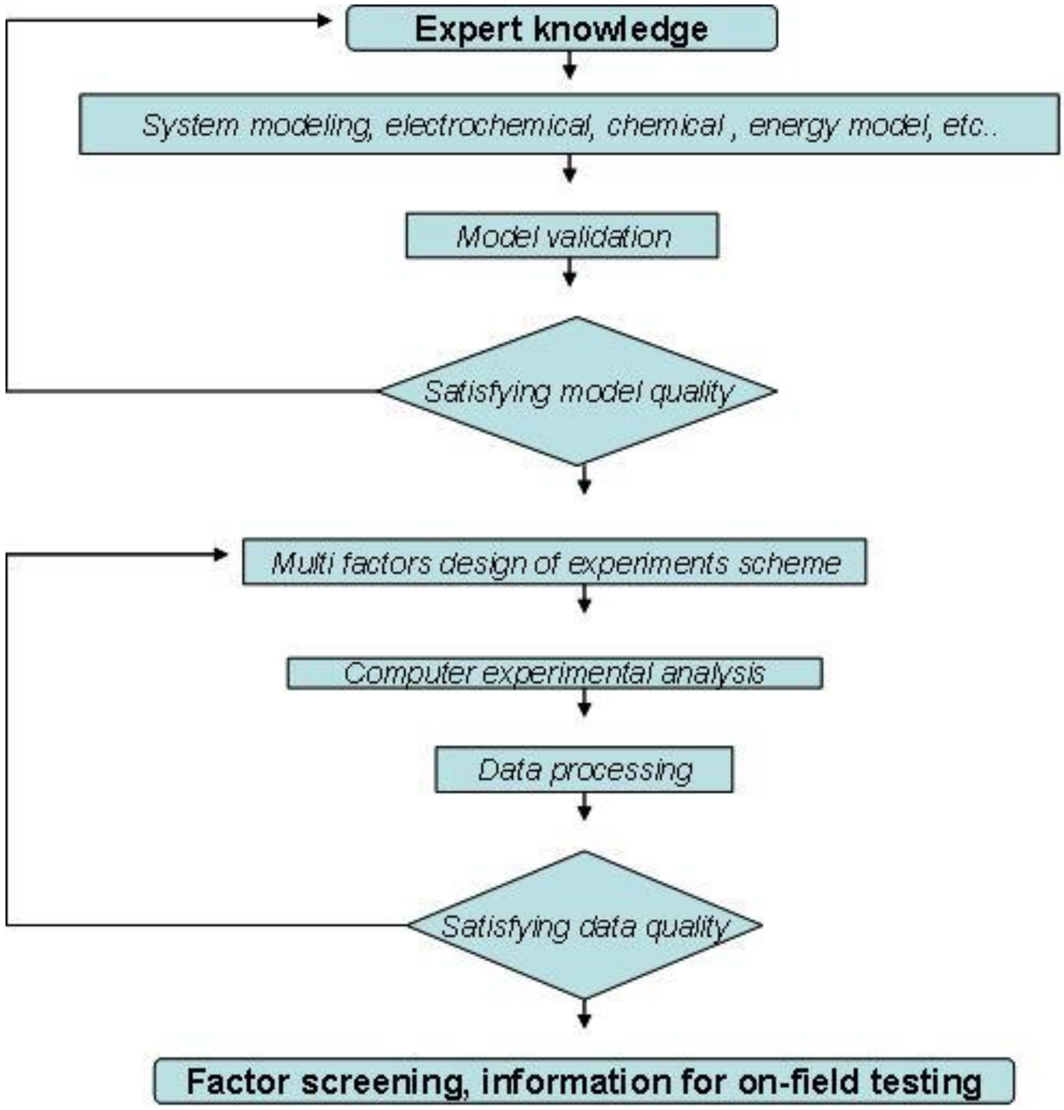

Figure C-3. Flow diagram of the statistical analysis based on DoE methodology.

Optimization procedures

Non-linear programming techniques for the optimization of constrained problems will be used to evaluate which is the optimum SOFC generator size to maximize the end-user energy bill saving, IRR, NPV, etc.

The above mentioned will be defined as the objective function (e.g., minimization of IRR); at the same time, the main decision variables will be also defined along with constraints (equality and inequality constraints) and LB-UB on both decision and dependent variables.

The resulting optimization routine will be an important final step to properly evaluate the potential of the micro-CHP unit in the selected environment.

Clearly, the reliability of the final outcomes will largely depend on the accuracy of input data, such as energy prices, energy demand profiles, technical specifications and operational constraints for the SOFC, etc.