DEMOSOFC

Project n° 671470

"DEMOnstration of large SOFC system fed with biogas from WWTP"

Deliverable number 4.4

Analysis of the electric energy generation in the DEMO: second part

Due Date of Delivery	M62
Actual Submission Date	28/01/2021
Lead Beneficiary	Politecnico di Torino
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Work package	WP4
Dissemination Level	PU
Nature	R
Version	1.0
Total number of pages	14

Abstract:

This document is related to the monitoring of the DEMOSOFC plant in the project. In particular, the document focuses on the electrical production from the 2 SOFC modules installed, SOFC1 and SOFC2.

Keyword list: biogas, SOFC, WWTP, electrical production, electrical energy

Summary

1. Electrical connection layout

Electrical power is produced from the 2 SOFC modules installed within the DEMOSOFC system. Even if the plant was designed (including the control system) for 3 SOFC modules, the project was completed with the operation of only 2 SOFC modules. The following document will thus refer to SOFC1 and SOFC2.

The SOFC1 module was commissioned and started in October 2017, SOFC2 in October 2018.

The AC electricity produced from the SOFC modules is here presented as "electrical power generation". This value is provided by the SOFC modules (internal measurements after the inverter section, which is then transferred to the overall DEMOSOFC control system) and by a dedicated power meter installed outside the systems (the meter can be seen in Figure 1, located after the grid interface cabinet of the SOFC modules).

A dedicated auxiliary components consumption analysis was also performed during the project and is here presented. Auxiliary components are connected to the SOFC modules and/or to the grid (for start-up and shut-down) through the switch Q2.1, visible in Figure 1 and Figure 2. In particular, all the QF labels listed in Figure 2 are the auxiliary equipment connected to the plant, which includes: water pumps, sludge pumps, biogas blowers, chillers and compressor, ventilation of the cleaning container, conditioning of the technical buildings (electrical cabinet room, pumps room, control room, UPS and batteries room), heating lines for winter (to avoid freezing issues), etc.

A complete layout of the DEMOSOFC electrical connections is shown in Figure 3, while Figure 1 and Figure 2 represent the control system views for the electrical section.

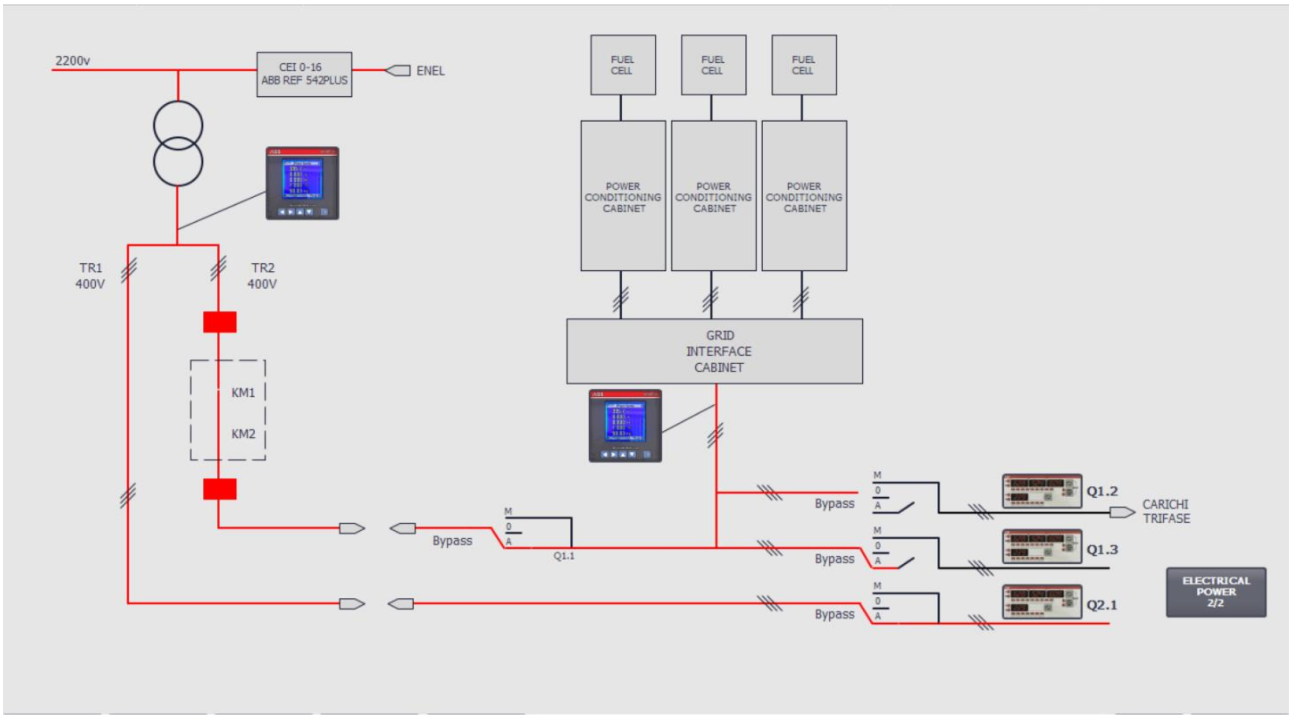

Figure 1. Electrical layout – page 1.

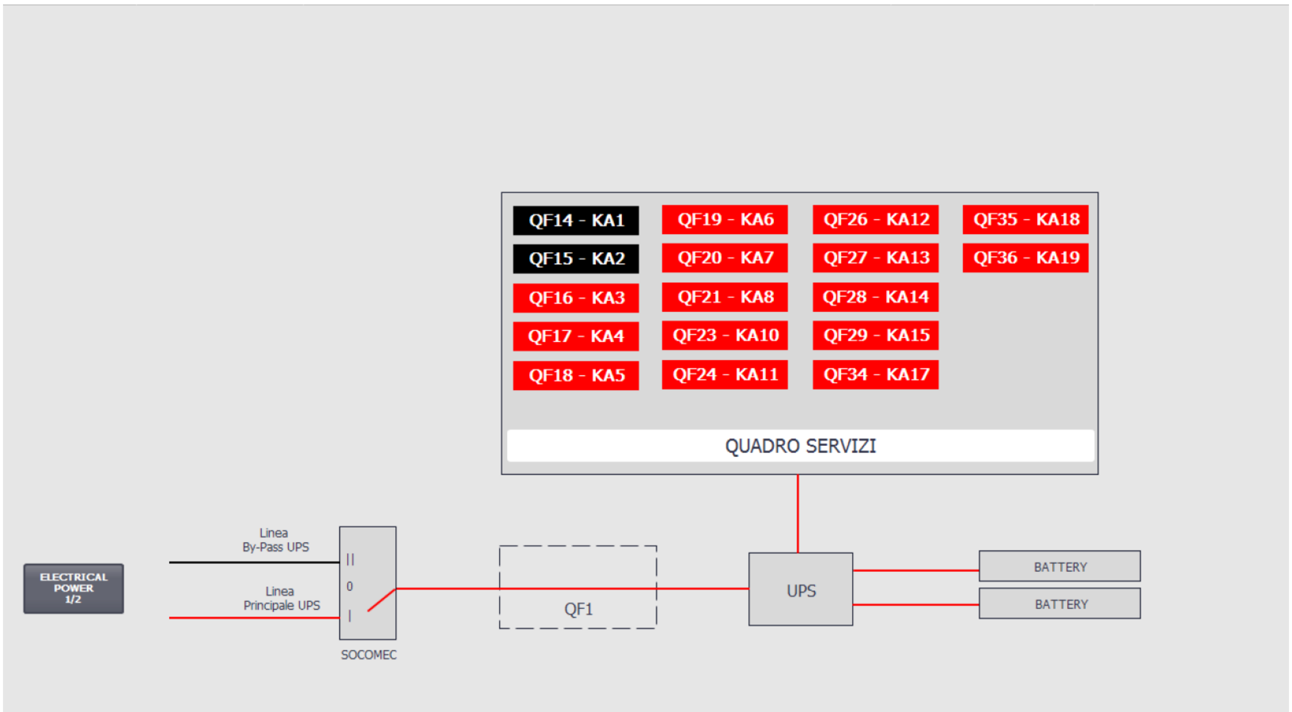

Figure 2. Electrical layout – page 2.

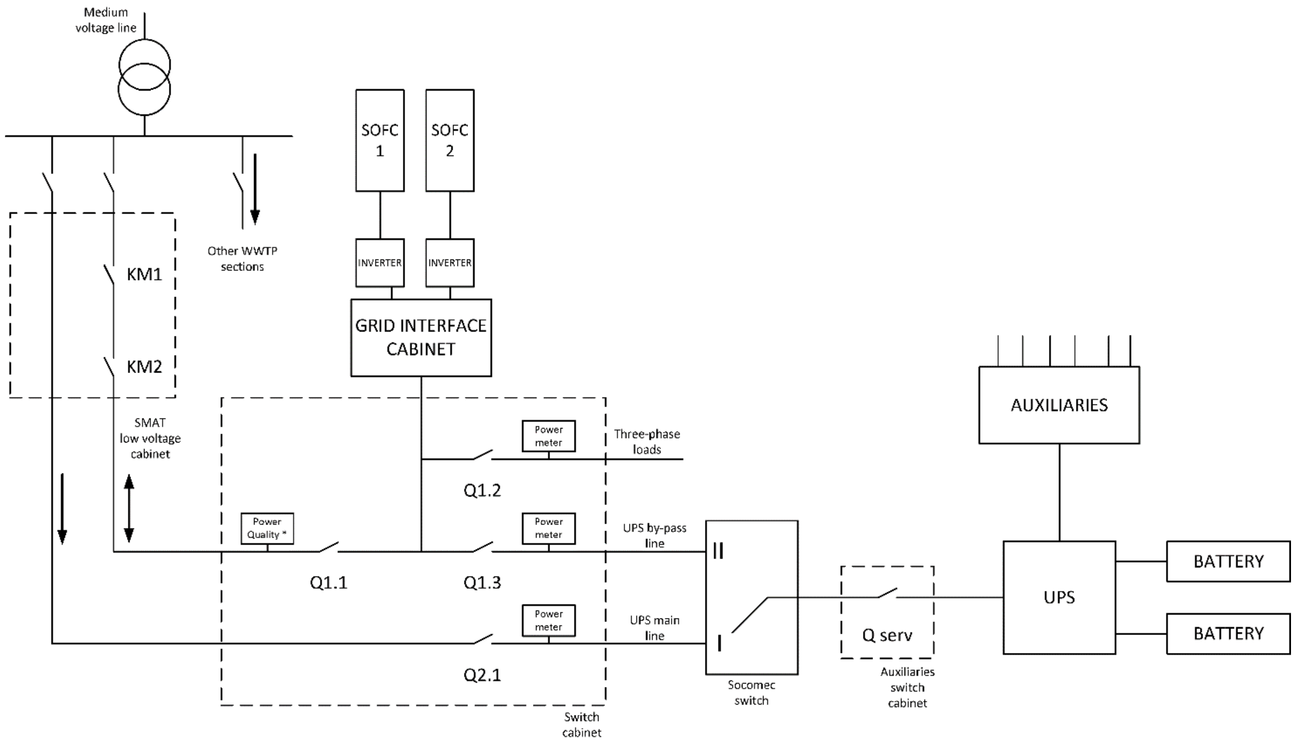

Figure 3. DEMOSOFC system electrical layout.

2. Operation timeline

The 2 SOFC modules have been operated always separately, except for some weeks in February-March 2020. This was not a decision, but a consequence of the different maintenance activities performed on the systems.

SOFC1 operated for the following operating periods:

- October-December 2017
- February-March 2018
- April-June 2018
- August 2018
- September-October 2018
- February-March 2020

During the complete year 2019 and part of year 2020 the SOFC module experienced some planned and unplanned maintenance activities as will be described in detail in D5.4 (Report on the Maintenance of the DEMO system).

SOFC2 operated for the following operating periods:

- October-December 2018
- February 2019-October 2020 (not continuous but with only short stops)

The operation of SOFC2 was more stable and with less interruptions, and the SOFC modules was also still running in October 2020, at the end of the project.

Figure 4 shows a summary of the plant operation described above. The data (especially the capacity factors) are calculated up to October 31st, 2020, the official project end.

		Hours ON - h	Fuel consumption - kWh	Electrical Energy - kWh	Thermal Energy - kWh	Electrical efficiency (%)	Power/Heat Ratio	Capacity factor
SOFC 1	Oct-Dec 2017	1,105	85,087	46,849	19,521	55.06%	2.40	
	Feb-Mar 2018	336	24,742	12,371	8,247	50.00%	1.50	
	Apr-Jun 2018	1,640	167,445	85,640	55,080	51.15%	1.55	
	Aug 2018	63	5,698	2,849	2,295	50.00%	1.24	
	Sep-Oct 2018	785	47,111	22,609	10,625	47.99%	2.13	
	Feb-Ott 2020	3,214	229,514	106,623	70,884	46.46%	1.50	
	Tot. SOFC1	**7,143**	**330,083**	**170,319**	**95,768**	**51.60%**	**1.78**	**50.11%**
SOFC 2	Oct-Dec 2018	1,291	101,104	55,601	35,995	54.99%	1.54	
	Feb 2019 -Ott 2020	8,946	710,397	320,568	233,750	45.13%	1.37	
	Tot. SOFC2	**10,237**	**811,501**	**376,170**	**269,745**	**46.35%**	1.39	**57.87%**
	Tot. DEMOSOFC	**14,166**	**1,141,585**	**546,488**	**365,512**	**47.87%**	**1.50**	**49.31%**

Figure 4. Summary of the DEMOSOFC plant operation.

3. Electrical production

The overall electrical production from the two SOFC modules was equal to 1’141.6 MWh, of which more than 70% from SOFC2 (811.5 MWh). The second SOFC module, even if less efficient in electrical terms, was indeed more robust and operated for a high number of hours without interruptions (the stacks installed in SOFC1 and SOFC2 were from different producers).

Figure 5 and Figure 6 show the complete SOFC2 operation. The first figure is linked to the first two months of operation in late 2018, where the SOFC2 system was running stably at 42-43 kW electrical output. During this period, 101.1 MWh were produced.

Figure 6 shows the operation of SOFC2 in 2019 and 2020, where more than 60% of the overall DEMOSOFC electrical production was generated (710.4 MWh). As can be seen the total power production from SOFC2 decreased from 45 kW to around 20 kW: this reduction is partially due to the degradation effect (described in D5.1) but also to the reduction of the current set point. The different impacts cannot be distinguished because, during this operational period, the SOFC2 was remotely controlled by Convion and the set point (0-100%, in ampere/watts) was not available as a data for the analysis.

During spring 2020, SOFC1 and SOFC2 operated in parallel as shown in Figure 7. SOFC1 electrical production was between 10 and 20 kW (reduced power production after the stack maintenance), while SOFC2 was running at around 30 kW. The interruptions in the parallel operation was first due to SOFC2 in end of March 2020, where a planned shutdown was performed for enabling stack recovery. SOFC2 was then restarted in mid-April. The second interruption was generated by SOFC1, due to a problem in the biogas pressure and flow controller (included in the SOFC module). Because of the COVID-19 pandemic restrictions, the onsite maintenance required to solve this issue was not possible.

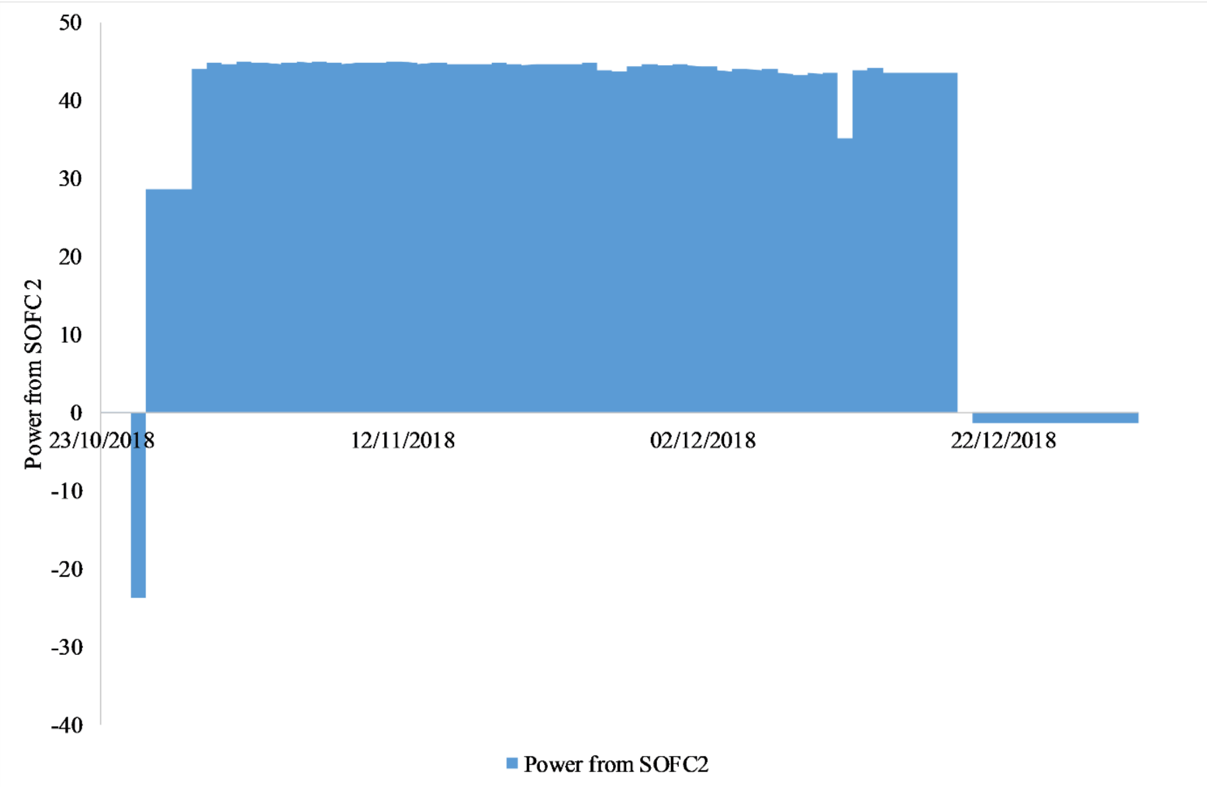

Figure 5. SOFC2 operation between October and December 2018.

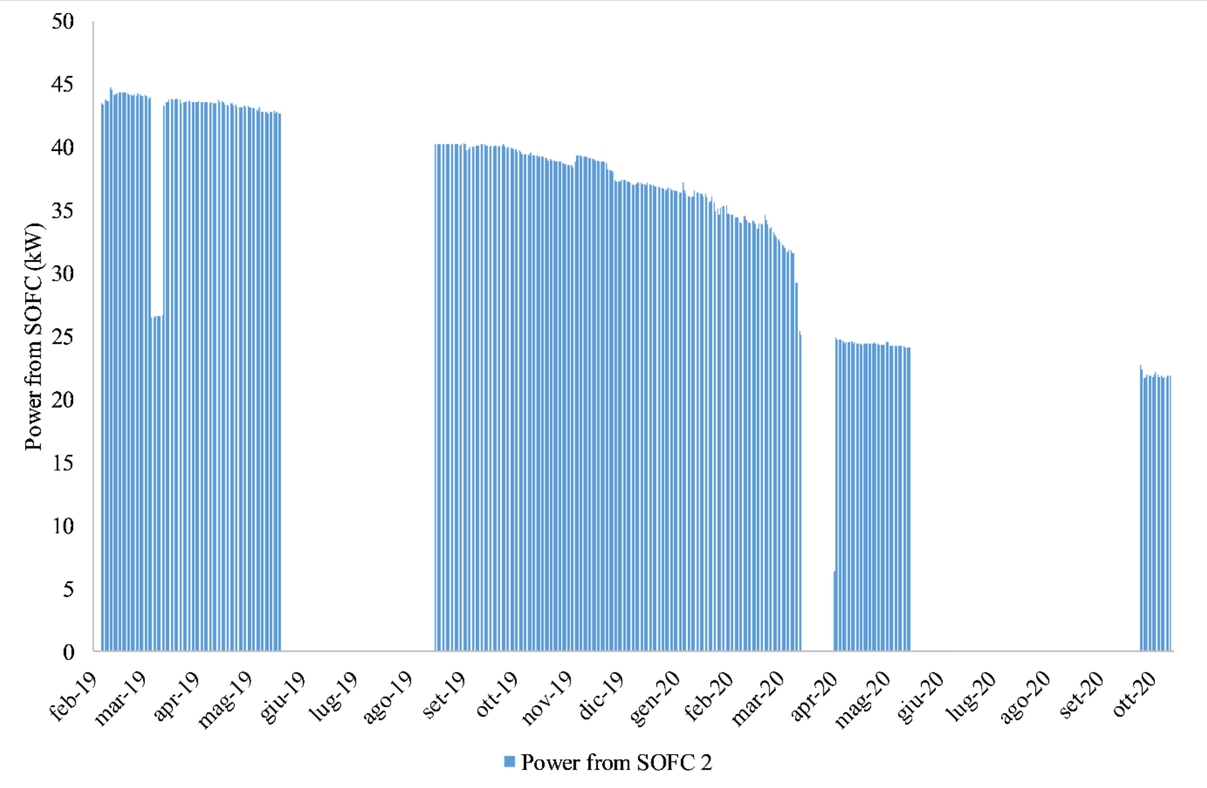

Figure 6. SOFC2 operation between February 2019 and October 2020.

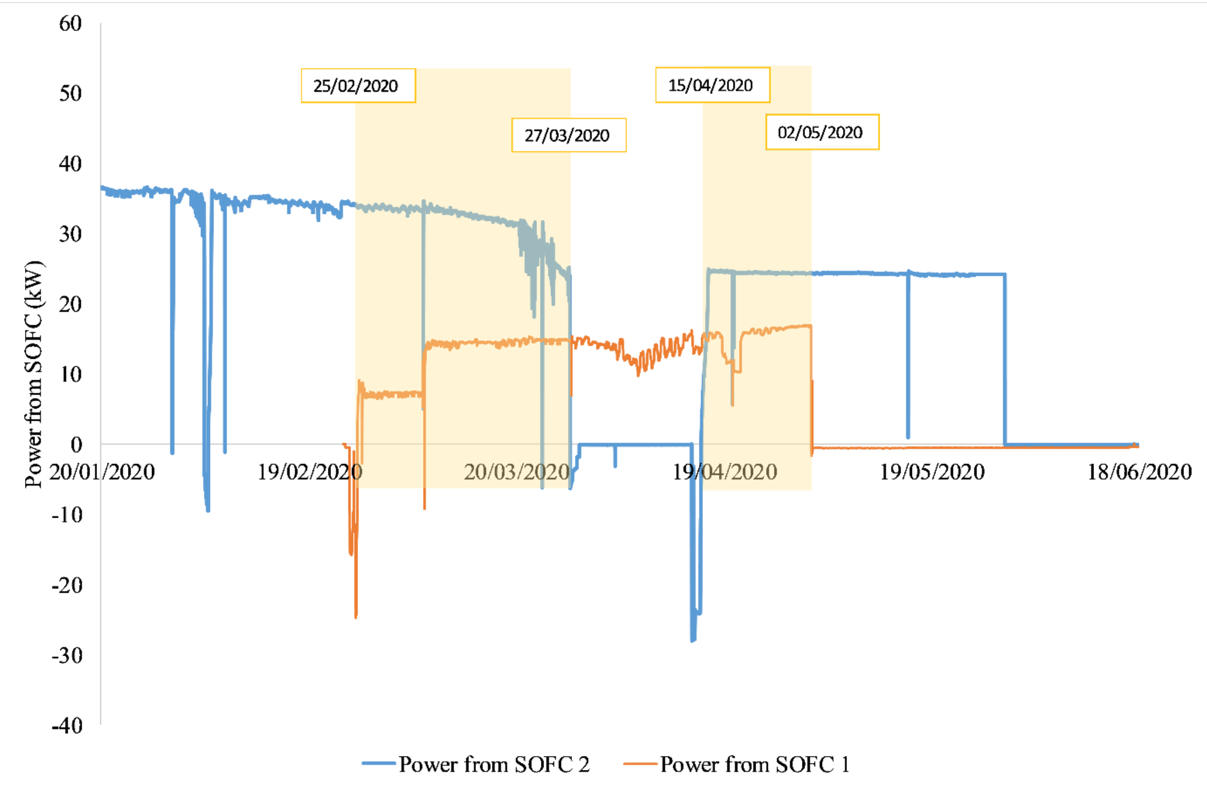

Figure 7. Parallel operation of SOFC1 and SOFC2.

3.1 Auxiliary consumption analysis

The consumptions of the single auxiliary systems have been manually measured on the electric panel through a current clamp on September 26th, 2018 (when SOFC1 was running).

Auxiliary’s consumption (kW) is computed as the product of voltage and current measured by the designated power meter; the value is averaged over the period. Since the air compressor can be switched on the modules or on the grid, both cases are considered.

The auxiliaries globally consume ~11.72 kW. The air compressor, which supplies the module with the compressed air (required only during start-up) also supplies the entire WWTP compressed air line. This component can be loaded (in terms of power supply) on the DEMOSOFC system or on the grid, as noticeable from the two levels of the consumptions visible in Figure 8. When the air compressor is charged on the SOFC the auxiliary consumptions rise to ~17.48 kW.

Even if compressed air is required only during start-up, a lack of pressure in the compressed air line always generated an emergency shutdown on the SOFC modules, and this could happen during grid failures/blackouts, if the compressor is not supplied by the DEMOSOFC area (which keeps running in island mode). For this reason, the compressor was manually switched to the DEMOSOFC supply, to avoid problems during island mode events.

As noticeable from Figure 8, the most affecting auxiliaries, besides the air compressor, are those related to Biokomp (biogas clean-up) section, which includes both the first area (biogas blow and chiller) and the second one (container including biogas cleaning vessel, compressor and chiller; these components are placed in a closed environment, thus requiring a high ventilation rate for safety reason). Detailed data are available in the Appendix A (Auxiliary consumptions).

The pie charts in Figure 9 represent the consumption percentage of each auxiliary, in both cases with the air compressor loaded on the SOFC or not. Both Figure 8 and Figure 9 show that most of the consumptions are imputable to Biokomp components: the chiller and the blower (42%) and the container (35%) consumes about 8 kW, ¾ of the global internal consumptions. Only a quarter of the total consumptions is related to other auxiliary and among them, a notable part is related to the air-conditioning of the dedicated rooms.

Even if the impact of the auxiliary consumption (10-12 kW) seem to have a huge impact of the electrical production of a single SOFC module (40-50 kW), some considerations should be added:

- It has to be considered that the plant is designed to have three working modules, so if all the three modules were installed, the impact of the consumption of the auxiliaries would have been much lower. Assuming that with three modules the auxiliaries consume 10% more and that the third module could produce as much power as the first, the impact on the efficiency would be more in line with traditional CHP systems like engines.

- The auxiliary components here included are, in part, strongly site-dependent. The first Biokomp section (blower and chiller) was required because the CHP unit was installed far from the digester area. The 4 conditioners were needed because the technical building was divided into three rooms + a UPS separated building. A more complete, simplified and insulated building would require a lower air conditioning load (as shown in the optimization analysis performed in D6.2, DEMOSOFC value chain analysis, and in the D5.5 Handbook on pre-normative issues). The choice of having a huge and closed container for the cleaning system brings to an important consumption of the Biokomp area, even if the pure electrical consumption of the compressor only is around 2-3 kW.

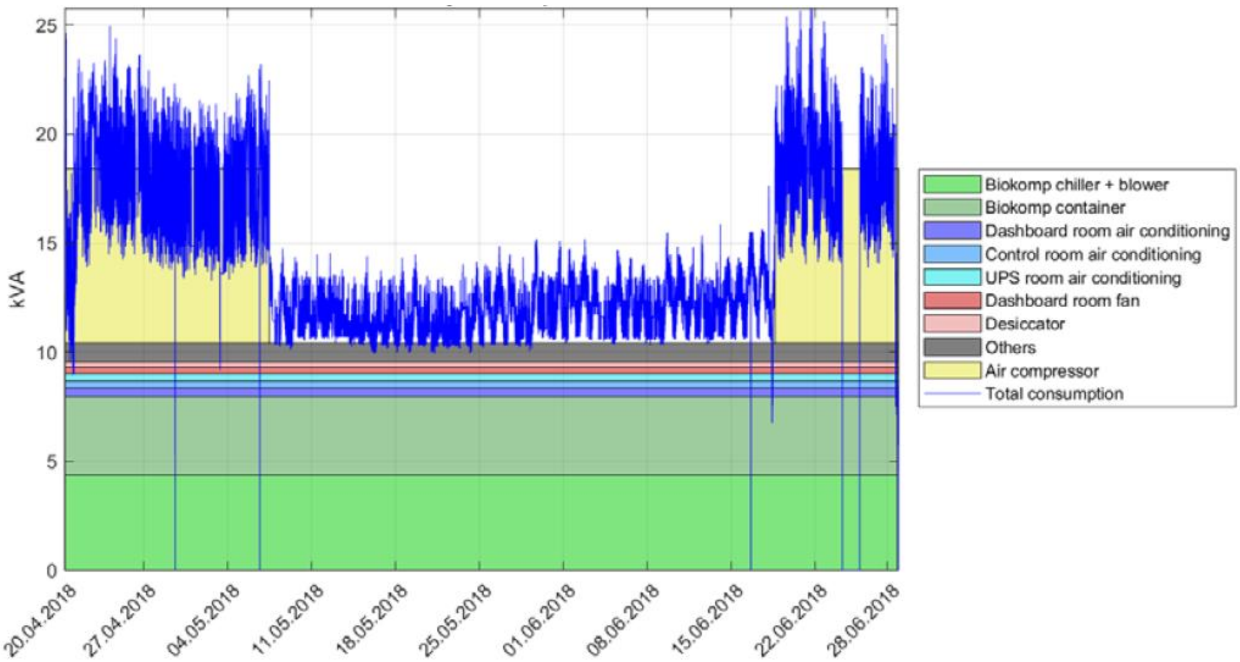

Figure 8. Auxiliary consumption analysis.

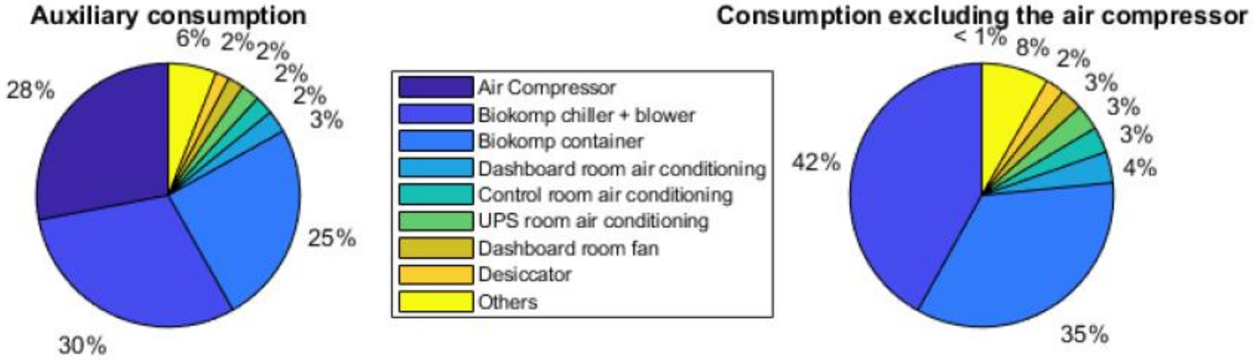

Figure 9. Auxiliary consumption analysis – share.

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 671470. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe research.

4. Appendix A – Auxiliary components

Switch		Tension (V)	Type	Current (A)	P (kW)
QF2	Light UPS room	220	Monophase	0.15	33.0
QF3	Light dashboard room	220	Monophase	0.7	154.0
QF4	External light	220	Monophase	0.3	66.0
QF5	Spare			0	0.0
QF6	Router socket dashboard room	220	Monophase	0.1	22.0
QF7	Wall socket control room	220	Monophase	0.4	88.0
QF8	Air condirioning UPS room	220	Monophase	1.5	330.0
QF9	Air conditioning dashboard room	220	Monophase	1.8	396.0
QF10	Air conditioning control room	220	Monophase	1.5	330.0
QF11	Spare			0	0.0
QF12	Spare			0	0.0
QF13	Dashboard PLC transformer room	220	Monophase	0.1	22.0
QF14	DePR101A	220	Monophase	OFF	0.0
QF15	DePR101B	220	Monophase	OFF	0.0
QF16	DePR201A	220	Monophase	OFF	0.0
QF17	DePR201B	220	Monophase	OFF	0.0
QF18	DePR301A Pump	220	Monophase	OFF	0.0
QF19	DePR301B Pump	220	Monophase	0.2	44.0
QF20	DePR01A Pump	220	Monophase	0.2	44.0
QF21	DePR01B Pump	220	Monophase	OFF	0.0
QF22	Spare	220	Monophase	0	0.0
Extra	Extractor fan of dashboard room	220	Monophase	1.3	286.0
QF23	DeP01 Sludge pump	400	Three-phase	0.1	69.3
QF24	Bio-komp Container	400	Three-phase	5.2	3602.7
QF25	External service socket	400	Three-phase	0	0.0
QF26	Bio-komp chiller and blower	400	Three-phase	6.3	4364.8
QF27	Water-glycole line valves	220	Monophase	0.1	22.0
QF28	Sludge line valves	220	Monophase	0.1	22.0
QF29	Socomec motor	220	Monophase	0	0.0
QF30	Spare	220	Monophase	0	0.0
QF31	Compressed air desiccator	220	Monophase	1.1	242.0
QF32	Convion operator panel	220	Monophase	0.3	66.0
QF33	Sludge macerator	400	Three-phase	OFF	0.0
QF34	PLC dashboard sludge room	400	Three-phase	0.1	69.3
QF35	PLC dashboard control room	400	Three-phase	0.2	138.6
QF36	Air compressor	400	Three-phase	11.6	8002.1
QF37	Heater	220	Monophase	OFF	0.0
QF38	Heater	220	Monophase	OFF	0.0
QF39	Spare	220	Monophase	0	0.0
QF40	Spare	220	Monophase	0	0.0
QF41	Switches dashboard auxiliaries	400	Three-phase	0	0.0