Reversible solid oxide Electrolyzer and Fuel cell for optimized Local Energy miX

Mid-term Impact assessment
Deliverable D1.2

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Abstract

This deliverable is part of WP1, of which one of the objectives is to define how the results of the project are assessed and reported throughout the project life cycle. Closely linked with the task T1.3 Innovation management and impact assessment, the present deliverable provides the mid-term impact assessment, following the tools and methods defined in D1.1 Impact Assessment methods and tools. More specifically it gives an overview on how the partners see the impact of the project at mid-term, according to their input given through the answers to the impact questionnaire.
In particular, it breaks down the project impacts per impact category with defined indicators.
The conclusions of this work will be used as an intermediate step to prepare the final impact assessment (Deliverables D1.4 Long-term impact roadmap).

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Introduction and context

REFLEX is a Research and Innovative Action (RIA) project, consisting of activities aiming at developing an innovative renewable energies storage solution, the "Smart Energy Hub" (SEH). The SEH is based on the reversible Solid Oxide Cell (rSOC) technology, that is to say able to operate either in electrolysis mode (SOEC) to store excess electricity to produce H2, or in fuel cell mode (SOFC) when energy needs exceed local production, to produce electricity and heat again from H2 or any other fuel locally available.

The challenging issue of achieving concomitantly high efficiency, high flexibility in operation and cost optimum is duly addressed through improvements of rSOC components (cells, stacks, power electronics, heat exchangers) and system, and the definition of advanced operation strategies.

The specifications, detailed system design and the advanced operation strategies are supported by modelling tasks.

An in-field demonstration will be performed in a technological park, where the Smart Energy Hub will be coupled to local solar and mini-hydro renewable sources and will provide electricity and heat to the headquarters of the park. It will demonstrate, in a real environment, the high power-to-power round-trip efficiency of this technology and its flexibility in dynamic operation, thus moving the technology from Technology Readiness Level (TRL) 3 to 6.

For this purpose, the project includes applied research, integration, testing, modelling and validation activities on a prototype in-field.

Based on the REFLEX Description of Action (DoA), we have organized the impacts in 3 main impact areas where change is expected to happen:

1/ Technical impacts: The purpose is to assess i) the performance/durability of the new cells, stacks and the potential associated manufacturing process, and ii) the efficiency of the power electronics and the overall efficiency of the SEH developed in the course of the project, and iii) the control strategy of rSOC systems.

2/ Economic_impacts: The REFLEX project is expected to i) generate an increase in the economic performances of the industrial partners, ii) increase their attractiveness for new collaborations, and iii) increase the overall competitiveness of the rSOC market by reducing the CAPEX and OPEX of this technology.

3/ Network & Social interaction_impacts: The REFLEX project will create in this context, new human resources opportunities (jobs, PhD, training …) in both the industrial and academic sectors. REFLEX will also generate a number of scientific productions that will increase the general knowledge in the field and leadership of academic partners.

4/ Environment impacts: the purpose is to assess if REFLEX project contributes to i) favor renewable energy storage, its efficiency and the local self-consumption, and ii) reduce CO_2 emissions for building consumption.

With the help of a first questionnaire sent to partners (see Annex 1), we have collected first information on the impact of the REFLEX project.

As stated in the methodology (D1.1 Impact assessment method and tools), some additional activities, to collect and compile updated data, will be organized over the second period to go beyond the first result of the impact assessment presented below and to contribute to D1.4. Long-term impact roadmap.

1. Technical impacts

The first questionnaire sent to partners dealt with the following impact category and indicators:

Impact Area	Impact Category	Impact indicators
1 Technical impacts	1.1 Technology performances	1.1.1 Increase performance of rSOC cells
		1.1.2 Increase rSOC cells durability
		1.1.3 Increase rSOC cells and stacks power
		1.1.4 Increase performance of rSOC stacks
		1.1.5 Increase rSOC stacks durability
		1.1.6 Increase stack thermal management efficiency
		1.1.7 Increase stack operation flexibility
		1.1.8 Increase rSOC system efficiency
		1.1.9 Conduct to new or improved manufacturing processes
		1.1.10 Increase the cells manufacturing efficiency
		1.1.11 Increase the stacks manufacturing efficiency
		1.1.12 Demonstrate Smart Energy Hub (SEH) efficiency in electrical energy management
		1.1.13 Demonstrate SEH efficiency in thermal energy supply
		1.1.14 Demonstrate SEH durability and flexibility
		1.1.15 Demonstrate improvement in power electronics efficiency
	1.2 Scientific expertise	1.2.1 Enhanced skills of staff
		1.2.2 Enhanced productivity
	1.3 Project advancement	1.3.1 Alignment with other initiatives/programs
		1.3.2 Conduct to developments beyond the project expectation
	1.4 Product	1.4.1 Improve advancement of rSOC system parts
		1.4.2 Enhanced the control strategy of rSOC systems
		1.4.3 Increase rSOC system technology performances
		1.4.4 Increase durability/availability of rSOC systems
		1.4.5 Product advancement

At mid-term of the project, in agreement with the DoA, technical impacts are the ones which can be addressed with the most important level of details.

1.1 Technology performances

The “technology performances” of the project is an impact category based on project monitoring activities over the duration of the project and the internal evaluation of achievements versus the planned objectives of the project.

At M18, cells and stacks activities are terminated and it is possible to assess their performances. For power electronics, some lab tests allow a first assessment of their performances.

For the cells, thorough electrochemical characterization of the cells from Elcogen by DTU has paved the way for improvement of the performance of the single rSOC cells. Electrochemical characterization and long-term test have shown limits for how thin the oxygen electrode area can be when considering long-term durability and led to optimization of the microstructure of both fuel electrode active layer and the fuel electrode support layer. Furthermore, characterization via iV-curves have given insight into limiting conversion rate to away fuel starvation dominated resistance. A generation 2 cell, so called G2 to differentiate it from reference structure called G1, has been defined, reaching the targets of the project in terms of performances in both SOEC and SOFC mode.

So far we cannot state the project has increased rSOC durability, however long-term tests have enabled to monitor durability challenges and thereby provided input to cell improvements required to obtain increased

rSOC at the desired – or close to – operating points, which is a challenge because the cells are operated at high current density and high fuel utilization, and in alternate rSOC modes. So far, in rSOC mode, a degradation rate of 3%/1000h has been achieved in G1 cells following an initial quicker degradation step. It is slighty above the threshold set. Durability is now being assessed for G2 cells.

For the stacks, firstly, stack design was adapted to integrate Elcogen 400-B cell (G1 REFLEX cells), and the integration of such cells validated. Second, the stack design has been modified to minimize pressure drop especially on air side of the cell. A reduction of pressure drop by a factor two was reached. Finally, the modification of the sealing solution design allowed to sustained higher overpressure without fracture. Consequently, it can be said that REFLEX project, jointly with developments on the stacks performed outside REFLEX, greatly contribute to have a performing and more robust stack.

Regarding the heat management efficiency in the stack, REFLEX has increased a lot our general knowledge of the heat management related issues for rSOC systems.

The decrease of the pressure drop by a factor of two in the stack allows us to use 2 times bigger air flow rates than before, which will be very useful for the thermal management in SOFC mode. Even that may not be enough so we have studied several additional system level methods for the thermal management of the SOFC stacks at high current densities.

For the Smart Energy Hub which is not yet operational according to the DoA, its efficiency assessment is not possible yet. However, modelling tasks, which take care of the system efficiency can provide partial information at this stage, with the expectations and challenges. Regarding the stack operation flexibility, we have studied several system level approaches to extend the operational window in SOFC and SOEC modes. On system level, the main contribution for the better efficiency comes from better heat management and optimized operational points. In order to extend and operate the system in efficient and a safe way, we have tested by modelling several BoP-component and control system related methods.

For the specific case of the power electronics efficiency, the emulation phase has shown results below the objective planned in the proposal. Nevertheless, during demonstration phase, efficiency will be the first priority to improve through control strategies. In addition, the implementation of high frequency DC/DC converters with planar transformers, that allow a 100Khz frequency and soft-switching modulation techniques, will be implemented with the aim of reducing switching losses and to obtaining an efficiency higher than 90%.

On the other hand, important goals have been achieved: i) Moving power from one side to the other according to the operating modes of the rSOC; ii) Reaching the set point of power that is given.

The question of power electronics cooling has also been addressed. Although air cooling is the best choice for the design of the DC/DC converter according to the power electronic design, it still needs from a validation stage, which will be done during the second half of the project.

1.2 Scientific expertise

The immediate impact of the project, shared by all partners is the enhancement of skills at staff level.

We identified:

- technical skills gained by partners:
  - Electrochemical impedance spectroscopy and electrochemical measurements at cell and stack level
  - increased skills/know-how on cycling test and appropriate settings/operating schemes
  - Increased skills in analyzing data obtained on different cells.
  - Increased focus on constructive feedback to cell manufacturer.

- Stack design, with specific focus on fluidic and thermal management.
- Stack testing, in rSOC operation.
- System modelling in rSOC conditions, including multistacks modules.
- Power electronics : new and/or improved DC/DC and DC/AC converters as well as battery storage systems.
- System design, including detailed layout and selection of different Balance of Plant components
- System control strategies
- Field test operation and analysis of results (will be active during the second period)
- Overall/realistic project planning skills

- and soft skills:
  - leadership,
  - communication,
  - scheduling,
  - critical thinking,
  - management and quality management.

It can be underlined that for most of the partners this is the first rSOC project where the system will be demonstrated in real operating conditions set by the end user - i.e. not a lab test. This will require that the whole system must be built to cope with these conditions and this will require that most of the partners have to move away from their “comfort zone” in their everyday working.

In the field of Research and Development as in REFLEX, the public-private partnership is an instrument that should meet the numerous expectations of the various actors involved, namely industrials, academics and public research institutes.

For private industrial partners, the partnership focuses on having access to certain resources and infrastructures present in universities or public research institutes and to have access to technical skills that it does not have internally. Additionally, the relationship with academic research teams may also allow a company to consider longer-term scenarios and limit its risks.

For public researchers, a partnership can bring new research questions as well as new funding for ambitious projects. Financing or encouraging partnerships aims, on the one hand, at a more rational use of resources by trying to avoid duplication between private and public and, secondly, to reinforce synergies, the potential for national and European innovation and, the competitiveness of the actors concerned.

Innovation requires additional diversity of areas of expertise and a strong relationship of cooperation and trust between the various actors of a consortium. The success of the innovation depends not only on the level of expertise of the actors, but also on the quality of the communication existing between them, and their capacity to make their knowledge available or usable by others, that is to say to explain, decode and decontextualize this knowledge. This communication process allows collective learning as well as the creation and dissemination of new knowledge.

1.3 Project advancement

The REFLEX project is based on results from several past and ongoing other initiatives (mainly European projects funded by the FCH JU). Such information gives a positioning on global partners’ roadmap (private and public ones) which is in line with public funding and roadmap towards SOFC/SOEC developments. It also gives an indication on how key are previous projects results with an exploitation value, how they are transferable and contribute to the European leadership on the topic.

Experience in test protocols, design of set-up, electrochemical and microstructural characterization, stack optimization and testing, as well as modelling already performed in those projects are used a starting point for REFLEX. In particular SOPHIA, ECO, SOCTESQA, BALANCE can me mentioned, most of them gathering 2 or more partners of REFEX consortium.

Also for power electronics and battery storage sub-systems, including its power management and control model unit schema, REFLEX capitalized on a previous EU project (SENSIBLE).

On top of European projects, some national initiatives come.

1.4 Product

The impact indicators at the system level cannot be assessed at this time of the project, while the commissioning of the SEH and the in-field test have not started.

However, components of the system, which are also products can already be commented.

For the cells, thanks to the extensive characterization performed in WP2, a better understanding of cell microstructure/performance relations has been achieved, which will be implemented by Elcogen into production in the future.

Thanks to the optimization of the stack design performed, the stack, as a product as such has been improved. Those findings will be implemented in the manufacturing of the stacks.

The work performed also pointed out the increased focus to be put on test conditions e.g. fuel utilization and ramping for shift between SOFC/SOEC to reach the best performance/durability/efficiency compromise.

Regarding power electronics, the different products and tools proposed by GPTECH are currently in development, being finished the emulation and manufacturing phases. Thus, lab validations, integration and testing phases will be the next steps to be taken. Regarding the DC / DC converter, a first prototype has been built in which we are carrying out numerous tests to verify its behavior in the voltage and power levels required by the rSOC. And, as for the Battery Energy Storage System, once the validation of the storage trays has been completed, the construction of the system is being finalized, and next, the validation tests of the complete system will begin.

Through this project, GPTECH will generate dedicated solutions based on power electronic for the integration of energy storage systems, from electro-chemical base to chemical storage technologies. Therefore, it will be able to address challenges such as those coming from emerging storage systems in addition to satisfy requirements as a consequence of user driven and self-consumption applications.

Finally, all the existing SEH and rSOC systems that are based on CEA stacks are single stack units. This is the first multistack unit and any information how to run multistack units in real system conditions will be vital for development of this field (since all commercial systems will be multistack units).

Some early advancement have been done at ENGIE on system modeling and economical studies to move forward the identification of possible markets for Smart Energy Hubs.

2. Economic impacts

Three categories have been addressed in the questionnaire:

- Economical performance
- Exploitation of the project
- Market/field

Impact Area	Impact Category	Impact indicators
2 Economic impacts	2.1 Economical performances	2.1.1 Reduce CAPEX for SEH and rSOC systems
		2.1.2 Reduce OPEX for SEH and rSOC systems
		2.1.3 reduce LCOE for SEH and rSOC systems
		2.1.4 improvement in the competitiveness of rSOC and SEH compared to other power-to-power technologies
		2.1.5 Increased of turnover
		2.1.6 Generation of revenues from licensing, patents, IPR…
		2.1.7 Increase of partner's profitability
		2.1.8 reorientation of any partner strategy
		2.1.9 Improvement of the partners' strength
		2.1.10 Creation of business opportunity or new innovative company
	2.2 Exploitation of the project	2.2.1 New Industrial exploitation
		2.2.2 New collaborations with academic/industrials/research center
		2.2.3 New International economic collaboration
		2.2.4 New economic partnerships
		2.2.5 Improved university-industry economic cooperation
	2.3 Market/field	2.3.1 Improve the competitiveness of European players in the worldwide market
		2.3.2 Increase attractiveness of the rSOC system for the market
		2.3.3 Access to new markets

2.1 Economical performance

This impact category deals with the economic performance of the project within each partner's organization (mainly industrial partners). It is too early to measure such a performance. Indeed, WP6 dealing with economical and scale-up studies has started in M15, as planned, according to the project Gantt chart, and did not provide results on those parameters so far. However, some preliminary trends can be given.

Improved cell performance, especially in electrolysis mode, increases competitiveness of Elcogen cells. It should theoretically give higher chances for those cells for business on solid oxide electrolyzers market. It is however too early to show clear economic fallout at this time of the project.

It is exactly the same for the stack design, which can address also SOEC market.

Already the design phase of the REFLEX system has generated and allowed us to chare al lot of information what is needed to design and run a large rSOC system. So definitely all partners are now in stronger position in this field.

The challenge of the REFLEX project has allowed each partner to grow technologically, which leads to an increase in competitiveness compared to direct competitors.

Regarding the increase of turnover of the companies, and other questions related to the companies, it is also too early.

2.2 Exploitation of the project

Thanks to REFLEX, a collaboration between Elcogen, DTU and CEA has started on testing and validation of new cell generation including a constructive feedback loop between partners providing cell manufacturing and partners providing cell performance/durability results.

Partnership agreement with CEA for stack improvement research and first multi stack module development is also in place between Sylfen and CEA.
A collaboration between VTT and Sylfen on system modelling, also including CEA for stack-related data has emerged.
Finally, a close collaboration between Sylfen, GPTech and USE for the power electronics has emerged thanks to REFLEX.

2.3 Market/field

The main REFLEX output is the commissioning, installation and in-field test of a Smart Energy Hub, as a first generation, being a kind of pre-commercial product for Sylfen. Following the output of REFLEX Sylfen will develop the next generation, which will be the real commercial product.

By now, it is planned that the first steps of exploitation will concern the market targeted by Sylfen, that is to say near-zero energy buildings or eco-districts, where renewable energy is produced and valued locally.

In the frame of WP6, other potential markets have been identified like schools, offices, hotels, health sector, shopping malls, as well as swimming pools and other sports facilities. They are currently being studied in the frame of WP6 by ENGIE.

It can also be envisaged that rSOC technology contributes to the successful integration of large decentralized renewable energies productions, at a larger scale than the above mentioned markets: at the multi MW scale as a support to the electrical grid. This market is different from the one of Sylfen, but cells, stacks and power electronics developed in REFLEX could address this market.

Finally, still for cells, stacks and power electronics, they could also feed the pure SOEC market in addition to the rSOC market targeted by REFLEX and Sylfen.

Europe is at front for SOEC and rSOC technological development. The production of improved solid oxide cells and stacks, as well as efficient and flexible systems put Europe on higher position on the worldwide market.

Most impact indicators can't be assessed at the moment, outputs of WP6 in the second period will allow to provide inputs in the second period.

3. Network & Social interaction impacts

Three categories have been addressed in the questionnaire:

- Human ressources
- Scientific production
- Scientific community

Impact Area	Impact Category	Impact indicators
3 Network & Social interaction impacts	**3.1 Human Resources**	3.1.1 Job creation in the partners organizations (including PhD and post doc)
		3.1.2 Increase number of rSOC systems specialist in Europe
		3.1.3 Enhancement of research and promotion of young mobility in EU
		3.1.4 Increase academic leadership
	3.2 Scientific Productions	3.2.1 Increase the scientific productions on rSOC technology
		3.2.2 Ease networking and professional contacts

	3.3 Scientific Community	3.3.1 Encourage new scientific collaboration
		3.3.2 Encourage new scientific partnership
		3.3.3 Improve University-Industry scientific cooperation in rSOC sector

3.1 Human ressources

A post-doc position has been funded by REFLEX at DTU. Thanks to this position, the post-doc gained new/more advance expertise.
Thanks to REFLEX, the project leader at DTU had the opportunity to be WP leader in an EU funded project, while up to now she was rather involved in national funded projects.
An electronics engineer is responsible for the design of the DC / DC converter for REFLEX at USE.
More generally, in most of the organisations/companies involved in REFLEX, partners were experts in their field, either development/testing/modelling of SOFC or SOEC, or on power electronics, or finally in other energy fields. But none of them were experts in rSOC components and systems. For sure REFLEX has already allowed and will continue during the second half of the project to the partners involved to become rSOC experts.

3.2 Scientific production

An article has been submitted for ECS SOFC XVI in Japan in Autumn 2019, jointly written by DTU, Elcogen and CEA. Another one has been submitted for IEEE conference (IECON2019), written by USE

3.3 Scientific community

Thanks to the different dissemination events, new connections and more information related to SOC industry and research organizations have emerged.

Elcogen collaborated for the first time with DTU for cell testing and optimization, and with CEA for validation of cells into stacks.
DTU and CEA, who collaborated from several years, had the chance thanks to REFLEX to strengthen their collaboration.
GPTECH and USE are working closely to new partners such as SYLFEN, and their collaboration, even existing, has increased with a now application field (rSOC).
VTT also started a collaboration with SYLFEN on system modelling to support the system design.
Finally, interest from other research institutes to collaborate in other projects on rSOC development have arrived for some of the partners.

It can also be noticed that there is a high interest for project results from both academic and technical interlocutors.
During the second period of the project, ENVIPARK, who will host the SEH for the in-field test, will be at the front of the dissemination of the project results to several communities:

- Members of CLEVER (Cleantech & Energy Innovation Cluster) managed by EnviPark: more than 250 companies are involved for the Industrial Research Projects. It makes him a link between companies and municipal authorities, Energy Utilities and potential stakeholders that could be very useful for the project ;
- Stakeholders group in Italy ;
- Research community (Politecnic of Turin, University of Turin….) ;

- Members of events as “Climathon”involving researchers, students and common people, that took place at Envipark.

4. Environmental impacts

Two categories have been addressed in the questionnaire:

- Energy management
- Emissions

Impact Area	Impact Category	Impact indicators
4 Environmental impacts	**4.1 Energy management**	4.1.1 Favour renewable energy storage
		4.1.2 Increase renewable energy storage efficiency
		4.1.3 Promote local consumption of renewable energy
	4.2 Emissions	4.2.1 Reduce CO2 emissions for building consumption

4.1 Energy management

At this time of the project, before the in-field test, it is not possible to assess those impact indicators.
However, as a general statement, we can underline that rSOC system developed within the project opens doors for hydrogen production and storage from renewable energy surplus through SOE.
Increased cell and stack performance, as well as an optimized system will give higher overall energy storage efficiency.
The design of a new 50kWh storage system has allowed the USE to improve, with respect to previous storage systems, achieving a better efficiency in the BESS system.

4.2 Emissions

A local energy management system allows generation and consumption of clean and renewable energy. This energy self-produced reduces consumptions from centralized grids. Depending on the geography where the Smart Energy Hub is installed, impacts on CO_2 emissions will vary as it is directly linked with the energy mix. In Italy, the CO_2 signature of electricity is quite high, due to highly fossil-oriented electricity generation installations. We are expecting to have significant CO_2 reduction impact with the deployment of Smart Energy Hubs in Italy. The REFLEX project is helping to understand the ins and outs of this market, in order to prepare for commercialization at the completion of the project.

Emissions reduction will be evaluated during the test site period.

5. Conclusion

At M18, at the midterm of the project, the technical performances are the impact category which can be assessed in the most precise way, for components like cells, stacks, and in a preliminary way for power electronics and energy storage. For the system, modelling tasks can give a first attempt.

The expected impacts of the results on the whole value chain are quite hard to measure right now as the project is not closed and the rSOC system not finalized. This item will be closely monitored as soon as the implementation and validation tests will be done during the second period. An impact on the whole value chain is foreseen by the end of the project as the consortium includes Sylfen as the system manufacturer, GPTech as the power electronics manufacturer, and Elcogen as the cell manufacturer.

The analysis of the different indicators of each category can be summarized as follows.

Impact Area	Impact Category	Impact indicators	Result	
1 Technical impacts	**1.1 Technology performances**	1.1.1 Increase performance of rSOC cells	A G2 cell designed has been developed and selected, reaching the targets set in the project	☺
		1.1.2 Increase rSOC cells durability	Ongoing with G2 cells	😐
		1.1.3 Increase rSOC cells and stacks power	Increased cell performance increased the cell power Increase stack power ongoing with enlarged cells	☺ 😐
		1.1.4 Increase performance of rSOC stacks	An optimized design has been defined, coping with REFLEX cells, with improved fluidic and thermal management	☺
		1.1.5 Increase rSOC stacks durability	ongoing	😐
		1.1.6 Increase stack thermal management efficiency	Done thanks to optimized design and modelling	☺
		1.1.7 Increase stack operation flexibility	Modelling done to extend the operational window in SOFC and SOEC modes. Tests ongoing	☺ 😐
		1.1.8 Increase rSOC system efficiency	ongoing	😐
		1.1.9 Conduct to new or improved manufacturing processes	For cells	☺
		1.1.10 Increase the cells manufacturing efficiency	No, not targeted	😐
		1.1.11 Increase the stacks manufacturing efficiency	No, not targeted	😐

		1.1.12 Demonstrate Smart Energy Hub (SEH) efficiency in electrical energy management	Ongoing: modelling tasks done. Tests on the system to be done	😐
		1.1.13 Demonstrate SEH efficiency in thermal energy supply	Will be done during the second half of the project	😐
		1.1.14 Demonstrate SEH durability and flexibility	Will be done during the second half of the project	😐
		1.1.15 Demonstrate improvement in power electronics efficiency	Ongoing: lab test in progress, validation on real SEH to be done in second period	😐
	1.2 Scientific expertise	1.2.1 Enhanced skills of staff	yes	☺
		1.2.2 Enhanced productivity	Greater involvement of staff due to the importance of the project. It is a project that has involved all the staff members (USE) and has provided an improvement in the coordination between all the project partners.	☺
	1.3 Project advancement	1.3.1 Alignment with other initiatives/programs	Yes, with several projects on test protocols, design of set-up, electrochemical and microstructural characterization, stack optimization and testing, as well as modelling, power electronics and battery storage sub-systems, including its power management and control model unit schema;	☺
		1.3.2 Conduct to developments beyond the project expectation	Also focused on USE, the bidirectional DC / DC converter design allows the possibility of applying it commercially in a wide spectrum of application due to its versatility and high efficiency. For the other components, wait for the outputs of the second period.	☺
	1.4 Product	1.4.1 Improve advancement of rSOC system parts	Yes for cells, stacks and to a lesser extent power electronics	☺
		1.4.2 Enhanced the control strategy of rSOC systems	ongoing	😐
		1.4.3 Increase rSOC system technology performances	Will be done during the second half of the project	😐
		1.4.4 Increase durability/availability of rSOC systems	Will be done during the second half of the project	😐
		1.4.5 Product advancement	Will be done during the second half of the project	😐

2 Economic impacts	**2.1 Economical performances**	2.1.1 Reduce CAPEX for SEH and rSOC systems	Will be done during the second half of the project	😐
		2.1.2 Reduce OPEX for SEH and rSOC systems	Will be done during the second half of the project	😐
		2.1.3 reduce LCOE for SEH and rSOC systems	Will be done during the second half of the project	😐
		2.1.4 improvement in the competitiveness of rSOC and SEH compared to other power-to-power technologies	Will be done during the second half of the project	😐
		2.1.5 Increased of turnover	Will be done during the second half of the project	😐
		2.1.6 Generation of revenues from licensing, patents, IPR…	Will be done during the second half of the project	😐
		2.1.7 Increase of partner's profitability	Will be done during the second half of the project	😐
		2.1.8 reorientation of any partner strategy	Will be done during the second half of the project	😐
		2.1.9 Improvement of the partners' strength	Improved cell performance, especially in electrolysis mode, increases competitiveness of Elcogen cells. Same for the stack. Already the design phase of the REFLEX system has generated and allowed us to chare al lot of information on what is needed to design and run a large rSOC system. So definitely all partners are now in stronger position in this field. The challenge of the REFLEX project has allowed each partner to grow technologically, which leads to an increase in competitiveness compared to direct competitors.	☺
		2.1.10 Creation of business opportunity or new innovative company	Theoretically, higher chances for business on solid oxide electrolyzers market. The power electronics developed for REFLEX can be used for other applications as well.	☺
	2.2 Exploitation of the project	2.2.1 New Industrial exploitation	bidirectional DC / DC converter design allows the possibility of applying it commercially in a wide spectrum of application due to its versatility and high efficiency.	☺
		2.2.2 New collaborations with academic/industrials/research center	Yes. New collaboration between partners of the project who did not work together before, and reinforcement of the collaboration for others.	☺
		2.2.3 New International economic collaboration	Not yet	😐

		2.2.4 New economic partnerships	Not yet	😐
		2.2.5 Improved university-industry economic cooperation	See 2.2.2	☺
	2.3 Market/field	2.3.1 Improve the competitiveness of European players in the worldwide market	Production of improved solid oxide cells put Europe on higher position on the worldwide market.	☺
		2.3.2 Increase attractiveness of the rSOC system for the market	Yes, but will be assessed in the second period	😐
		2.3.3 Access to new markets	Yes, but will be assessed in the second period	😐
3 Network & Social interaction impacts	**3.1 Human Resources**	3.1.1 Job creation in the partners organizations (including PhD and post doc)	Post-doc position	☺
		3.1.2 Increase number of rSOC systems specialist in Europe	New/more advanced test expertise by PostDoc More generally, in most of the organisations/companies involved in REFLEX, partners were experts in their field, either development/testing/modelling of SOFC or SOEC, or on power electronics. But none of them were experts in rSOC components and systems. For sure REFLEX has already allowed and will continue during the second half of the project to the partners involved to become rSOC experts.	☺
		3.1.3 Enhancement of research and promotion of young mobility in EU	Not yet, could be done during the second period	😐
		3.1.4 Increase academic leadership	First time project management for EU funded project for project leader at DTU	☺
	3.2 Scientific Productions	3.2.1 Increase the scientific productions on rSOC technology	An article has been submitted for ECS SOFC XVI in Japan in Autumn 2019, another one at IEEE (IECON 2019)	☺
		3.2.2 Ease networking and professional contacts	New connections and more information related to SOC industry and research organizations.	☺
	3.3 Scientific Community	3.3.1 Encourage new scientific collaboration	New partnership within the project, and it has also strengthened/improved existing partnership	☺
		3.3.2 Encourage new scientific partnership	Same as 3.3.1	☺
		3.3.3 Improve University-Industry scientific cooperation in rSOC sector	Same as 3.3.1	☺

4 Environmental impacts	**4.1 Energy management**	4.1.1 Favour renewable energy storage	rSOC system developed within the project opens doors for hydrogen production and storage from renewable energy surplus through SOE. Will be assessed during the second period of the project	😐
		4.1.2 Increase renewable energy storage efficiency	Increased cell performance gives higher overall energy storage efficiency. The design of a new 50kWh storage system has allowed the USE to improve with respect to previous storage systems, achieving a better efficiency in the BESS system. Will be assessed during the second period of the project	😐
		4.1.3 Promote local consumption of renewable energy	Will be assessed during the second period of the project	😐
	4.2 Emissions	4.2.1 Reduce CO2 emissions for building consumption	Sylfen rSOC system is designed to reduce CO2 emissions by storing surplus of renewable energy and reuse it without burning carbon-based fuels. The connection with a local grid will reduce the CO2 emissions. It will be evaluated during the test site period.	😐

Legend: ☺ Positive impact / 😐 neutral impact; In progress / ☹ No impact, negative issue

ANNEX 1 – Questionnaire used to collect inputs from partners

SECTION 1: Technical impacts

1.1. Technology performances

- **1.1.1 Does the project have increased the rSOC cells performances?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how? ***What are the result on the cells optimization process (microstructure, interfaces, thickness, size), conversion rate,…***

- **1.1.2 Does the project have increased the rSOC cells durability?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how? ***What are the result on the cells optimization process (microstructure, interfaces, thickness, size), durability, flexibility,…***

- **1.1.3 Does the project have contributed to increase the rSOC cells and stack power?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how? ***What are the result on the cells size increase in terms of unit power for the cell itself and for the stack***

- **1.1.4 Does the project have increased the rSOC stacks performances?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how? ***What are the results on the stacks developed for the project: maximum current density for each mode, stack durability, cells performance dispersion in stack, stack conversion rate,…***

- **1.1.5 Does the project have increased the rSOC stacks durability?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and briefly explain how? *What are the results on the stacks developed for the project: maximum current density for each mode, stack durability,…*

- **1.1.6 Does the project have increased the heat management efficiency in stack?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and briefly explain how? *What are the results on the stacks developed for the project?*

- **1.1.7 Does the project have increased the flexibility of operation of the stack?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and briefly explain how? *What are the results in terms of flexibility of operation in rSOC modes?*

- **1.1.8 Does the project have increased rSOC efficiency?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and briefly explain how? *What are the result on the cell manufacturing efficiency: scrap rate, cell manufacturing time, cell dimensions dispersion, cell performance dispersion?*

- **1.1.9 Does the project conduct to new or improved manufacturing processes?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, which kind of processes? *Please describe shortly these new processes, for cells, stacks, power electronics, Smart Energy Hub, any other BoP components*

- **1.1.10 Does the project have increased cell manufacturing efficiency?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and briefly explain how? *What are the result on the cell manufacturing efficiency: scrap rate, cell manufacturing time, cell dimensions dispersion, cell performance dispersion?*

- **1.1.11 Does the project have increased stack manufacturing efficiency?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how? *What are the result on the stack manufacturing efficiency: scrap rate, stack manufacturing time, stack performance dispersion?*

- **1.1.12 Does the project have demonstrated Smart Energy Hub (SEH) efficiency in electrical energy management?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how? *What are the results on electrical energy management?*

- **1.1.13 Does the project have demonstrated SEH efficiency in thermal energy supply?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how? *What are the results on thermal energy supply?*

- **1.1.14 Does the project have demonstrated SEH efficiency durability/flexibility?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how? *What are the results in terms of durability/flexibility?*

- **1.1.15 Does the project have demonstrated improved power electronics efficiency?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how?

What are the results on power electronics efficiency?

1.2. Scientific Expertise

- **1.2.1 Does the project have enhanced skills of staff?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how? *What are the results on skills of staff?*

- **1.2.2 Does the project have enhanced productivity?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how? *What are the results on productivity (number of articles/ conferences, participation at Workshops…)?*

1.3. Project advancement

- **1.3.1 Does your project is aligned with other initiatives/programs/projects (past or ongoing?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, please indicate in the list which initiatives/program:

RELHY	☐	**HELSTACK**	☐	**Other EU projects (please details)**	☐	**Other national projects (please details)**	☐
ADEL	☐	**NELLHY**	☐		☐		☐
SOPHIA	☐	**BIG HIT**	☐		☐		☐
ECO	☐	**SENSIBLE**	☐		☐		☐
SOCTES QA	☐		☐		☐		☐
BALANCE	☐		☐		☐		

Please for each initiatives/programs selected indicate shortly which results have been re-used, and how you are aligned?

- **1.3.2 Does the project conduct to developments beyond the project expectations?**

YES ☐ ↓ **NO** ☐

If YES, Simply and briefly explain which kind (prototype, simulator, demonstrator, pilot)? Briefly detail them?

1.4.Product

- **1.4.1 Advancement concerning the products/tools which are developed in the project:**

Please, indicate (if you are concerned by these points) the achievement of the development of each product/tool on a scale from 0 to 5:

(0 not initiated; 5 achieved)

	0	*1*	*2*	*3*	*4*	*5*
rSOC cell						
rSOC stack						
rSOC system						
Smart Energy Hub						
Power electronics						
Other BoP component						
Stack/system control strategy						

Please shortly describe your advancement:

- **1.4.2 Does the project have enhanced the control strategy of rSOC systems?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how?

- **1.4.3 Does the project contribute to increase the technology performances of SEH and rSOC systems?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how?

- **1.4.4 Does the project have increased the Durability/Availability of the rSOC system?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how?

- **1.4.5 Advancement concerning the development of component technology:**

Please, indicate the current TRL status of the component list below

	2	3	4	5	6	7
rSOC cell						
rSOC stack						
rSOC system						
Smart Energy Hub						
Power electronics						
Other BoP component						
Stack/system control strategy						
…						

(TRL2: technology concept formulated; TRL3: experimental proof of concept; TRL4: technology validated in lab; TRL5: technology validated in relevant environment; TRL6: technology demonstrated in relevant environment; TRL7: system prototype demonstration in operational environment)

SECTION 2: Economic impact

2.1 Economic performances

- **2.1.1 Does the project have improved the overall rSOC and SEH system CAPEX?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, please indicate the estimation of the costs in € and briefly explain how do you manage that?

- **2.1.2 Does the project lead to any OPEX reduction for rSOC and SEH?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, please indicate your turnover in € and briefly explain how and how much?

- **2.1.3 Has the turnover of your organization been increased since the beginning of the project?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, please indicate your turnover in € and briefly explain how and how much?

- **2.1.4 Have the productions (licensing, patents, IPR…) generated revenues?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how and how much?

- **2.1.5 Has the project contributed to partners profitability increase?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how and how much?

- **2.1.6 Has the project conducted to reorientation of any partner strategy?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how and how much?

- **2.1.7 Has the project strengthened the competitiveness of the partners?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how?

- **2.1.8 Does the project conduct to new business opportunity? New innovative companies?**

YES ☐ ↓ NO ☐ Not Concerned ☐

YES, Simply and briefly explain which opportunity and how?

2.2 Exploitation of the project

- **2.2.1 Does the project conduct to industrial exploitations?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and Shortly comments what exploitations, which sector, short-long term ect …

- **2.2.2 Does the project conduct to new collaboration with academic/industrial/research center?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and Shortly comments what exploitations, which sector, short-long term ect …

- **2.2.3 Does the project conduct to new international economic collaboration?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and Shortly comments what exploitations, which sector, short-long term etc …

- **2.2.4 Does the project conduct to new economic partnership?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and Shortly comments what exploitations, which sector, short-long term ect …

- **2.2.5 Does the project have improved industry/university economic collaboration?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and Shortly comments what exploitations, which sector, short-long term ect …

2.3 Market/Field

- **2.3.1 Does the project have improved the competitiveness of Europe in the worldwide market?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how?

- **2.3.2 Does the project have increased attractiveness of the SOFC systems for the market?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how?

- **2.3.3 Does the project conduct to the access to new markets?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain which market and how?

SECTION 3: Network & Social interaction impacts

3.1 Human resources

- **3.1.1 Does the project have conducted to job creation in your organization?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and shortly details how many, person profile, which position, sector, mission, etc …

- **3.1.2 Does the project have conducted to increase the number of rSOC specialist in Europe?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and Shortly details how and what are the project, renewability, employment?

- **3.1.3 Does the project have enhanced the research and promoted young mobility in Europe?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and Shortly details how (exchange, trainee …)?

- **3.1.4 Does the project have increased academic leadership?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and Shortly details how?

3.2 Scientific Productions

- **3.2.1 Does the project conduct to scientific productions?**

YES ☐ ↓ NO ☐ Not Concerned ☐

To answer this question, please complete the table below with the information about the productions.
(Are considered as scientific productions: the publications, scientific papers abstracts, PhD thesis, MSc dissertations, Lectures, courses…)

Type	Number	Topics	Sector of interest	Type of audience	References	other

- **3.2.2 Does the project ease networking & professional contacts?**

YES ☐ ↓ NO ☐ Not Concerned ☐

If YES, Simply and Shortly explain how (events, workshop, conferences…)?

3.3 Scientific Community

- **3.3.1 Does the project have encouraged new scientific collaboration?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and shortly describe the new collaborator (country, sector, business, etc.…)?

- **3.3.2 Does the project have encouraged new scientific partnerships?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and shortly describe the new partner?

- **3.3.3 Does the project have improved university-industry scientific cooperation in rSOC sector?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and briefly explain how?

SECTION 4: Environmental impacts

4.1 Energy management

- **4.1.1 Does the project have favored renewable energy storage?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and shortly details how

- **4.1.2 Does the project have conducted to increase renewable energy storage efficiency?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and shortly details how

- **4.1.3 Does the project have promoted local self-consumption of renewable energy?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and shortly details how

4.2 Emissions

- **3.2.1 Does the project conduct to reduce CO_2 emissions for building consumption?**

YES ☐ ↓ **NO** ☐ **Not Concerned** ☐

If YES, Simply and shortly details how