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Smart Grid Interoperability Laboratory

Annual Report 2023

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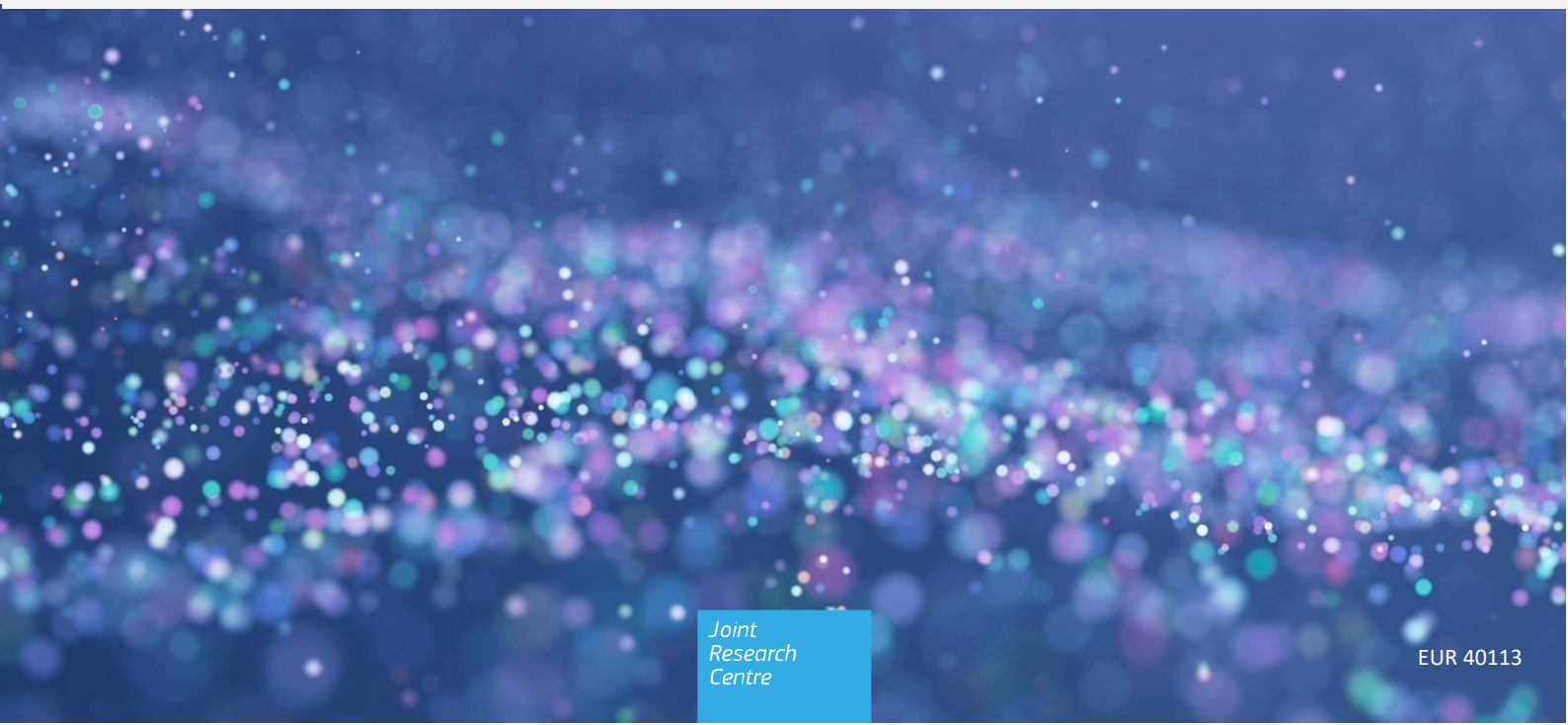

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Contents

Abstract

The Smart Grid Interoperability Laboratory (SGIL) is situated in two sites of the Joint Research Centre of the European Commission, namely Ispra (Italy) and Petten (The Netherlands). The lab belongs to the Energy Security, Distribution and Markets Unit and the activities vary from energy communities, storage issues, demand response programs to remote load control, home automation and energy smart appliances. The goal is to address issues related to energy digitalisation, serving the objectives of the European Green Deal. The activities in 2023 are highlighted in this report.

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Executive summary

The electricity grid and its systems become modern for the realisation of the energy transition. Indeed, systems become automatized to support digitalization and to manage more effectively energy consumption and production, accommodating more renewables to respect European priorities, like the European Green Deal.

Therefore, it is important to have modern infrastructure, exchanging information while preserving interoperability. Interoperability plays a key role, as it guarantees the correct functionality of multiple systems, thus facilitating the promotion of programs and initiatives for the green transition and enhancing the role of energy consumers in the grid.

The Energy Security, Distribution and Markets Unit with its two Smart Grid Interoperability Laboratories is active in performing research for the smart energy grid and in promoting interoperability among the various systems of the grid. In this report, the reader can find the main activities carried out during 2023. The activities are a continuation of previous years' activities and also the basis for future ones.

The activities of the SGIL are directly linked to numerous policies adopted by the European Commission.

In 2019, the European Commission introduced the European Green Deal [1] and the EU fit for the digital age [2], two out of the six European Commission priorities for 2019 - 2024. The first one specifies that the goal is to reduce carbon emissions by 50% by the year 2030, in order to combat the climate change. The second one entails integrating digital technologies in everyday life; among others, digital technologies include artificial intelligence, blockchains, big data analytics, etc, tools which can be used to serve the needs of the European Commission policies. .

Under the umbrella of the European Green Deal, there are many policy initiatives, to which the work carried out by the SGIL is linked. First of all, the Clean Energy Package for all Europeans (CEP) [3], which is a set of Regulations and Directives in the energy sector, that include the Electricity Market, the Energy Performance of Buildings, the Renewable Energy, the Energy Efficiency and the EU Governance.

Other policy initiatives under the same umbrella are the Fit for 55 Package and the REPower. The first one defines the milestones for CO2 emissions reduction in order to finally achieve the ultimate goals set for 2050, whereas the latter one is a policy initiative to help the European Union become less energy dependent on specific countries.

On the other hand, under the second priority mentioned in this Section we have several strategies, like the EU strategy for Energy System Integration and Shaping Europe's Digital Future. They define the targets for example for digital technologies funding and setting goals for the adoption of such technologies by the broader public.

The SGIL has worked and is working to support these policies, to monitor their implementation by the Member States, to form new policies under the framework of the aforementioned ones. An example is the creation of the Code of Conduct (CoC) for Energy Smart Appliances (ESA). This latter work is one out of the Administrative Arrangements (AA) held by the SGIL team with DG ENER [4] and aims at setting the prerequisites of the Energy Smart Appliances in order for them to be interoperable in the market. Another project linked to an Administrative Arrangement (AA) held by the SGIL team and DG RTD is the Clean Energy Technology Observatory (CETO). It monitors specific smart grid technologies, whereas the final report, which makes part of a family of similar reports feeds into the EU Governance regulation.

During 2023, the SGIL activities have resulted in numerous reports, publications, innovative research tasks and outreach activities aiming at networking with experts in the field of interest and advertising our activities to the outside world. The main achievements are listed as follows:

- Work with DG ENER for the goal to produce a CoC for ESA, producing reports and having successfully held workshops with stakeholders.
- Work with DG RTD and contribute to the final Progress on Competitiveness of Clean Energy Technologies report, which has been adopted as part of the Governance Implementation Package.
- Continue the ERIGRID project, addressing, among others, energy communities and storage issues and having successfully contributed in an active energy society within the project framework.
- Produce several publications in its field of expertise.

The above achievements are linked to the previous year's achievements and form the basis for future ones. Indeed, the work carried out in 2023 has been the basis for addressing further categories of ESA and including them in a future version of the CoC. All the above results show continuity with previous and future activities.

The main findings from the work carried out in 2023 are listed as follows:

For the CoC we have concluded that to enable the competitiveness in the sector and keep a neutral position in terms of protocols and commercial solutions, it was needed to use an ontology, in our case SAREF, Smart applications Reference, to enable the semantic interoperability without further mandatory information requirements.

For the CETO project, the main findings are around the examined technologies, the Advanced Metering Infrastructure and the High Voltage Direct Current:

- In a worldwide scale, there are 1.2 billion smart meters installed, with Europe, North America and Australia being the early developers, whereas 123 million smart meters are already installed in the EU. Another geographic area that is expected to play a key role in the AMI field in the future, is Asia Pacific, with second generation smart meters being installed massively.

- There has been a significant increase in the global HVDC installed capacity, which has been tripled since 2010 reaching 350 GW at the end of 2021 and a total length of 100,000 km. It has been estimated that in 2022the HVDC capacity in Europe has been 43 GW, whereas another 63 GW has come from 51 new projects, which are still at planning and permitting phase.

With respect to the research activities carried out, the main finding is that Artificial Intelligence (AI) is a powerful tool for enabling the energy transition, whereas topics like Renewable Energy Communities and Storage are attracting the scientific interest and are key factors for the future grid.

The SGIL team is expected to continue its work in the areas of its expertise in the future. The major projects it is involved in are ongoing, like the CoC with ENER and the ERIGRID project. The importance of the work carried out is highlighted by the fact that it supports main policy guidelines of the European Commission. Particularly for the CoC for Energy Smart Appliances, the work carried out in 2023 belongs to version 1, including only two categories of Energy Smart Appliances. It has been agreed to extend this work to more categories of devices and guidelines to include more protocols.

The SGIL holds collaborations with various research centres and laboratories across Europe and beyond. Among others, it has held collaborations with the Italian research centre, RSE (Ricerca Sistema Energetico), companies from the private sector in Italy, Universities, like University of Trento, the Dutch research centre TNO (Netherlands Organisation for Applied Scientific Research), the Battery Energy Storage Testing facility in Petten and the European Interoperability Centre for Electric Vehicles in Ispra (IT). As a future activity it is also foreseen that collaborations with external experts will be enhanced and the SGIL will attract scientists across Europe to use the existing infrastructure and achieve high level results in the energy field.

In Chapter 1, a short introduction is given to the subject and a description of the lab is given. In Chapter 2, the policy background is presented, in particular, the EU policies to which the SGIL work is linked are listed in detail. Chapter 3 reports about the activities related to policy support, whereas Chapter 4 gives the activities related to H2020 projects. Chapter 5 describes other research activities. In Chapter 6 we present the international partnerships, dissemination and outreach activities. Finally, conclusions are drawn in Chapter 7.

1 Introduction

The energy grid is being transformed into a smarter and more efficient one. Its numerous components play a key role in various policies, showing the importance of each one of them into the resulting smart grid. Indeed, the energy grid undergoes novel changes that require intelligent systems and their efficient coordination. The renewable energy sources (RES) integration, the upgrading of transmission and distribution grid including electronic devices, programs to enhance efficiency of the grid, like demand response programs are only some of the elements requiring to be addressed for the distribution grid., on the consumer's side, the distribution grid has been evolving as well, with millions of smart meters and advanced metering infrastructure (AMI) being implemented worldwide, and electric vehicles, smart appliances and energy management systems penetrating the market.

All the aforementioned elements of the so-called smart grid are playing a key role in European policies, strategies and priorities. For example, the European Green Deal, one of the six priorities of the European Commission for 2019 - 2024 is directly linked to the modernisation of the grid, as energy consumption and its CO2 footprint can play a decisive role for its accomplishment. Indeed, an efficient distribution of energy produced, minimization of transmission energy losses, maximization of resources, an efficient energy consumption, minimization of energy consumption where this is feasible, alleviation of energy peaks are key aspects of decreasing carbon emissions and thus reaching the goals of European Green Deal. This priority comes along with numerous policies, regulations and strategies in order to set rules for all the individual elements that form together the smart grid. For example, the Clean Energy Package with its regulations and directives for the Electricity Market, for the Energy Performance of Buildings, for Renewable Energy, for Energy Efficiency, together with the Fit for 55 Package, the REPower program, are only some of the policies that contribute to the European Green Deal.

Another priority of the European Commission to which energy transition and the smart grid are playing a key role is the EU Fit for the Digital Age. We are living in the digital era, where the world and also the energy grid is transforming into digital. Indeed, there is the need to energy digital transition; the grid is equipped with intelligent devices able to perform automatized measurements and transmit data to control centres. There are now being implemented artificial intelligence systems on the energy grid, whereas technologies are developed to deal with big data analytics and big data processing. Data from smart meters, from sensors, from intelligent electronic devices are needed in order to accomplish smart energy programs and manage energy consumption in the most effective way. Similarly to the European Green Deal, there are policies and strategies that support this priority, like the EU Strategy for Energy System Integration and Shaping Europe's Digital Future, in which the energy grid plays a key role.

As it is clear from the above, the individual elements/ systems of the smart grid play a key role to the policies and the priorities of the European Commission serving to transform the everyday lives of European citizens. It can also be concluded that the correct functioning of all these individual systems together is important, thus interoperability is a number one factor for the success of the future smart grid.

The Smart Grid Interoperability Laboratory (SGIL) is working on aspects of interoperability of energy grid systems and assistance in policy making. It has established strong presence in the field, with the methodology for interoperability testing of smart grids and the creation of several interoperability smart grid use cases to test under this structured methodology during the last years. In addition, the SGIL is increasingly active in policy support initiatives and projects in the field of energy transition,

confirming its important role in the field, providing input for the formulation of new policies , while monitoring already existing ones. Furthermore, it has been active in research projects in the energy field, liaising with high level researchers from other research institutions.

In the 2022 report [5], we have listed our activities in the field, which included the Clean energy Technology Observatory (CETO) project, the initialization of the Code of Conduct (CoC) project on Energy Smart Appliances (ESA), together with other achievements in the field, like the development of use cases for interoperability testing and the successful participation in H2020 research projects.

For 2023, the activities have been a continuation of last year's activities, complementing and advancing the work of previous years. Thus, we have had the publication of the update of the CETO project and the core part of the CoC project for ESA. Lastly, we also had important work in the research field, by the participation in the ERIGRID project and the publication of scientific work in the energy transition field.

2 Lab activities and their role for policies and the energy transition

2.1 Relevant European Commission existing policies

The SGIL works closely with policy makers in order to support new policies or to monitor the implementation of existing ones. In addition, it provides scientific evidence for policy, by conducting scientific research activities in the field of energy transition and interoperability for the smart grids, as its name implies. Our work is related to policies in the energy field, namely the "European Green Deal" and "Shaping Europe Digital Future", and their

- European Green Deal [1]: It is a priority of the current European Commission. Its main goal is to achieve climate neutrality by 2050 while reducing emissions by 55% by 2030. It entails a strategy for green financing and sustainable Europe investment plan, whereas it promotes clean technologies. There are several policies/ strategies to support this priority, listed as follows:
    - Clean Energy Package (CEP) [3]: The idea and proposal for the Clean Energy Package came earlier than the European Green Deal; however, it serves the same scope and supports the priority's accomplishment. Its final approval took place in 2019 and it consists of multiple Regulations and Directives in the field of Electricity Market Design, Energy Efficiency, Renewable Energy, Energy Performance of Buildings and Governance of the Energy Union. The Regulation and Directive that are most relevant to the SGIL work are:
    - Directive EU 2019/ 944 (Internal market for Electricity), [6] and Regulation EU 2019/ 943 (Common Rules for the Internal Market for Electricity), [7]: They make part of the Clean Energy Package and define the rules for a more sustainable energy system and its components. They define in detail the rules for future energy systems including rules for innovative programs, like demand response (DR), the integration of electric vehicles and energy communities, while the importance of interoperability is highlighted.
- Shaping Europe's Digital Future [8]: This policy entails empowering people with new digital technologies; it also involves a data strategy to deal with data volumes and technological change. One of its targets is to achieve that the 80% of the population has basic digital skills, whereas 250 billion are invested to boost digitalization. Artificial intelligence is also used to boost an ecosystem for people, businesses and public interest.

The SGIL works closely for the implementation of the above two priorities as well as the policies developed for their support. These can be listed as follows:

- Digitalisation of Energy Action Plan [9]: this Action Plan has been announced in October 2022 and it entails guidelines for: the data used for energy; the digital electricity infrastructure; cybersecurity issues in the energy system; the control of energy consumption of the ICT sector; the benefits of consumers.
- Implementing act to improve access to metering and consumption data [10]: it focuses mainly on the interoperability of data, especially related to smart meter data and access to it by different actors. This will help operators to improve existing processes and incentivise the development and delivery of new energy services, such as energy sharing and demand response.

- Heat pumps Action plan [11]: The action plan is useful to accelerate the deployment of heat pumps and facilitating their integration in the market. The action plan is crucial, as the heat pumps are considered a key element for achieving the Green Deal.

All the above show the numerous policies on which the SGIL works and it highlights its importance for the overall European Commission priorities for the future.

2.2 Interoperability and its role in the energy transition

With numerous policies in the field, it becomes clear that the grid transformation is a reality and a necessity in the same time. It is important to manage energy effectively, limiting losses and maximising efficiency, whereas RES integration is fundamental in order to minimise the dependency on traditional ways of producing energy and achieve climate neutrality. Smart services are offered by energy providers, like demand response programs, which contribute in the management of energy. In this direction, there are also intelligent electronic devices (IED) and numerous other intelligent apparatus, ready to provide automatic control of the system and guarantee the security of energy supply.

On the other hand, the consumers become empowered, controlling their own consumptions in a better way. Homes and buildings become smart and energy communities are emerging. Indeed, homes are equipped with smart devices, which can be controlled remotely by consumers and buildings are equipped with sensors and intelligent automatic devices, which can be controlled by an energy management system.

All the above indicate that a huge amount of data needs to be handled in order to have the energy managed and distributed in an efficient way. All the intelligent devices placed in the grid, as mentioned above, produce data which are handled by energy managers. In addition, the intelligent applications and smart services offered to customers, produce as well, a huge amount of data. Data platforms and hubs are created to collect data, whereas control mechanisms are important to guarantee data access only to authorised personnel. The various actors of the system, like distribution system operators DSOs, aggregators, energy data managers need to exchange data among them for the realisation of the energy programs. In addition, to control all smart applications and energy services offered to customers, it is needed that dedicated software is developed in order to control the energy system, like Head-End systems, control platforms and network access points.

The energy grid becomes digital with advanced Information and Communication Technologies (ICT), which contribute in controlling the energy produced and consumed. All these different systems need to interact correctly with each other and facilitate the information exchange. Therefore, it is essential to maintain interoperability for the correct functionality of the different systems and components. Interoperability is the key that ensures that different systems understand each other and that the replacement of a component with a similar one from another vendor will not compromise the overall system's performance.

In addition, interoperability plays a key role also for consumers. It ensures that if the consumers change their energy provider, their appliances will still be functioning properly. This ensures the fundamental right for consumers to select their energy provider freely without barriers. On the other hand it ensures that if an appliance is replaced, the whole system's performance and functionality will not be compromised.

Interoperability is dealt in five layers, namely the: component layer, the communication layer, the information layer, the function layer and the business layer. The reader is directed to previous reports in order to get more informed about the different interoperability layers [5].

Interoperability is not an easy task to achieve due to the nature and complexity of the issue and the diversity of the numerous devices, programs, systems and components that are existing in the market. Indeed, the major part of electrical or electronic devices use different protocols for communication, thus implying interoperability issues not only for the communication but also for the other interoperability layers. For this reason, interoperability is a topic where a lot of work is required and where the role of neutral entities is key to the harmonised functionality of the future energy grid. The work required includes several tasks:

- identify gaps in the interoperability field for the various energy topics;
- identify trends related to the state-of-the-art technological solutions used in practice;
- set rules for the technological solutions needed to be adopted by manufacturers of energy systems/ components;
- lay the ground for future policies around interoperability of future energy systems;
- monitor the work done to ensure interoperability by different Member States;
- conduct continuous work in the field to receive feedback from stakeholders and update on-going policies for interoperability.

The above list is not exhaustive, which implies that the work of the Joint Research Centre of the European Commission is not limited to the above points.

The SGIL is composed of two dedicated laboratories on interoperability issues, one on interface smart grid consumer, and one on the interface within a smart home. Its members work with high quality instruments, enabling them to perform interoperability tests.

For this reason, the SGIL team has created a structured methodology for interoperability testing on smart grids [12] This dedicated methodology has been tested on several use cases, created by our team in the field of smart grids. Such use cases have been designed from scratch, including creation of dedicated testbeds and have been executed in our labs followed by results processing and analysis. The procedure indicates the creation of Basic Application Profiles (BAPs) and Basic Application Interoperability Profiles (BAIOPs), followed by an optional statistical analysis of results.

Furthermore, the SGIL experts work extensively on policy support issues, following the guidelines of the policies mentioned in previous section(s) of this report. As the list is long, it implies the important work performed by SGIL members, providing scientific evidence for policies monitoring and also the scientific basis for the creation of future policies or the updating of existing ones. The SGIL work shows the importance of monitoring the situation related to interoperability across Europe and beyond.

2.3 Smart Grid Laboratories in Ispra, Italy and Petten, The Netherlands

The SGIL in Petten is dedicated to Smart Home activities, as smart homes and smart buildings in general, play a key role for the realisation of the smart grid. Smart homes/ buildings are fundamental, as they represent the energy consumption in the residential and commercial sector. With smart devices and energy management systems, the consumers become aware of their energy consumptions

and thus become empowered to alter their consumption in order to alleviate peaks on the overall grid consumption. On the other hand, these smart devices enable customers to participate to smart energy programs and novel energy services, like demand response programs. The integration of RES and ESA are important aspects of the smart home, as they are key elements for energy management in the residential sector. In addition, the social factor is also critical, as the general public needs to be informed about the potential of ESA and the role of smart homes and buildings in the smart grid. The SGIL in Petten is active in all the aforementioned fields for the promotion of the smart home activities and for the future smart society.

In previous releases of the SGIL annual report, the available infrastructure has been listed and described in detail. In this release, we only list the available infrastructure:

- Smart kitchen
- 2 Battery containers
- Microgrid
- Real Time Simulator
- Diesel generator for power supply
- Solar design panels
- Car charging infrastructure
- PRISM EV charger
- Two control rooms
- Large energy storage units
- Electric vehicle
- Smart Home appliances
- Vehicle to grid charger
- Revised extended electro cabinet
- Home battery and hybrid solar inverter

Figure 1 shows a configuration of a mobile simplified smart grid interoperability lab in Petten.

Figure 1. New simplified Smart Home setup for interoperability testing.

Source: JRC, 2022

On the other hand, the SGIL in Ispra, in Italy focuses more on interoperability issues on the distribution network. It focuses on novel technologies applied on the distribution network along with innovative programs promoting energy services. It works closely with the European scientific community to develop innovative energy programs, like demand response for the residential and commercial sector, whereas it follows the advancements in Artificial Intelligence techniques for the smart grid. In addition, it is active in the field of energy communities, liaising with experts in order to exploit RES for energy communities and involve consumers and prosumers in the future smart grid. In addition, the Ispra SGIL has been active in policy support issues for the distribution grid, investigating on the maturity of technologies that can be applied on the smart distribution grid.

The infrastructures available in the SGIL in Ispra are listed as follows:

- SCADA System
- Energy storage cells
- Energy recovery system
- Advanced Metering Infrastructure
- Power System work station
- Battery Energy Storage System
- Electric vehicle
- Smart meter panel
- 90 kVA Power Amplifier
- Real Time Digital Simulator

The role of the two laboratories is to test and promote interoperability between smart home devices and in general among smart grid actors/ systems/ components. Their role is summarised as follows:

- Improve the visibility and usage of the interoperability testing methodology for smart grids;

- Testing and promotion of hardware/software interoperability solutions for the electricity distribution network;
- Laying the ground for future policies in the field of interoperability of ESA by preparing the CoC on this subject;
- Support energy policies by monitoring the application of relevant policies and strategies across Europe;
- Monitor the implementation of the Clean Energy Package by contributing in the periodic Observatory for the Clean Energy Technologies;
- Research activities in the areas of renewable energy sources integration, network design and simulation;
- Create a network with European laboratories, research centres and industrial actors for common work objectives by actively participating in research projects throughout the last seven years of its operation.
- Create a collaboration network with European laboratories, research centres and industrial actors to work for common objectives.

In the following Chapters, we list the achievements of the SGIL in terms of policy support, scientific activities in the interoperability field, accomplished within 2023. The activities have been a follow-up of the previous year's activities, whereas they are the basis for future activities

3 Policy support achievements

3.1 Clean Energy Technology Observatory (CETO)

The Clean Energy Technology Observatory (CETO) project is a periodic exercise performed by the SGIL of the JRC every year for the last 3 years and it is an ongoing activity. Its scope is to monitor the extent at which the existing energy policies are implemented and how the policies of the European Green Deal are supported. It explores specific technologies and looks into their progress, in terms of certain parameters, which are listed as follows:

- Technology Readiness and Trends
- Value Chain Analysis
- Global Competitiveness.

The CETO report of the SGIL, entitled “Smart Grids in the European Union”, is part of a total of 19 reports under the same project, each one of which addresses different issues regarding clean energy technologies. The total list of reports is shown as follows:

- Overall strategic analysis of clean energy technology in the European Union
- Proposal for a sustainability assessment framework for energy technologies
- Wind energy in the European Union
- Battery technology in the European Union
- Advanced biofuels in the European Union
- Bioenergy in the European Union
- Renewable fuels of non-biological origin in the European Union
- Smart grids in the European Union
- Hydropower and pumped hydropower storage in the European Union
- Heat pumps in the European Union
- Carbon Capture, Utilisation and Storage in the European Union
- Novel thermal energy storage in the European Union
- Concentrated solar power and solar heating and cooling in the European Union
- Smart thermal networks in the European Union
- Ocean energy in the European Union
- Photovoltaics in the European Union
- Deep geothermal heat and power in the European Union
- Solar fuels in the European Union
- Water electrolysis and hydrogen in the European Union

The project is in collaboration with DG RTD, aiming at providing evidence for energy policy and relevant research and innovation policies in the area of clean energy technologies, as indicated by the above list. The work has been in collaboration with multiple units within the JRC, whereas the summary of the findings are published every year in the Competiveness Progress Report (CPR), [13].

The work carried out by the SGIL for the CETO report is focusing on different technologies of the smart grid in order to evaluate the situation in critical sectors in the smart grid. For 2023, the two selected technologies to be monitored have been the:

- Advanced Metering Infrastructure, as the smart meters are a key component for the realisation of smart homes, the provision of smart services and the ultimate realisation of the smart grid.
- High Voltage Direct Current, which is a promising technology for the smart grid for a secure energy distribution.

The main findings from the aforementioned technologies are summarised as follows [14]:

- Advanced Metering Infrastructure:

  Benefits offered to consumers and energy providers:

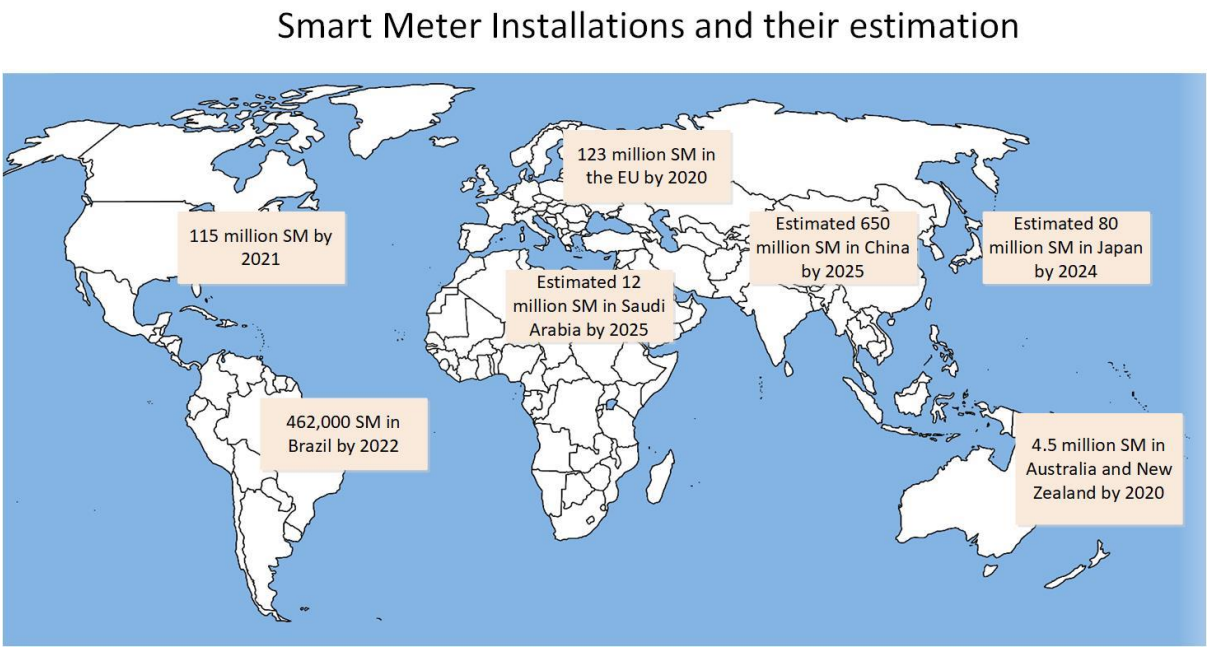
  - Grid management and grid monitoring, like identifying the faults and outages in the network.
  - Empowering consumers by enabling information about their own consumptions, thus facilitating energy savings.
  - Facilitating smart services offered to customers, like demand response programs.

  The highlights for AMI:

  - In a worldwide scale, there are 1.2 billion smart meters installed, with Europe, North America and Australia being the early developers, whereas 123 million smart meters are already installed in the EU.
  - Another geographic area that is expected to play a key role in the AMI field in the future, is Asia Pacific, with second generation smart meters being installed massively.
  - The value of the AMI market is estimated at 20 billion dollars worldwide.
  - The smart services that can be facilitated by smart meters are: cumulative data for up to 3 years; near real-time data; energy price differentiation; hourly time energy pricing; consumption remote control and critical peak pricing.
  - Smart meters can offer multiple functionalities also for energy providers/ DSOs, like: grid management tasks (network state analysis, outages detection, state estimation, customer monitoring); usage for grid control tasks; distribution planning tasks (automation of LV/MV grid operation, automation of customers' systems), grid asset planning).

Figure 2 shows the smart meter penetration at worldwide level.

Figure 2. Smart meter installations worldwide

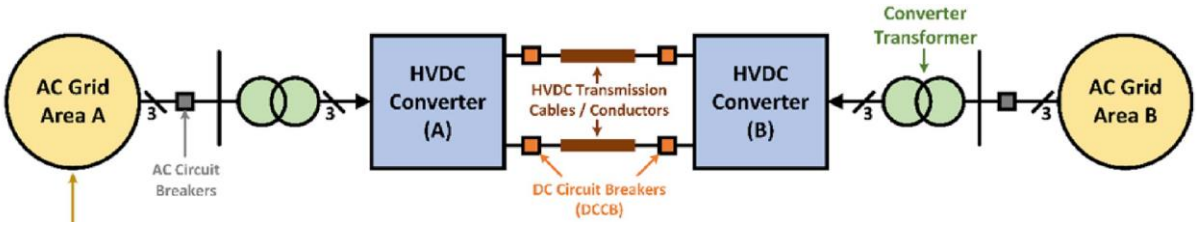


Source: Clean Energy Technology Observatory: Smart Grids in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, 2023

— High Voltage Direct Current (HVDC):

HVDC systems have an increased capacity and low losses when it comes to long distances, thus they favour interconnectivity of the energy systems by linking distant power networks with different frequencies. They also facilitate the interconnection of large offshore wind plants, due to these characteristics. Figure 3 summarises the HVDC transmission layout.

Figure 3. Generic HVDC transmission project layout



Source: Clean Energy Technology Observatory: Smart Grids in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, 2023

The main highlights for this technology include the following:

- HVDC is a mature technology, which however, can be further improved, especially in the field of DC/DC breakers and regarding the use of Cross-linked Polyethylene (XLPE) cables at high voltage levels, over 525 kV.
- There has been a significant increase in the global HVDC installed capacity, which has been tripled since 2010 reaching 350 GW at the end of 2021 and a total length of 100,000 km. It has been estimated that in 2022 the HVDC capacity in Europe has been 43 GW, whereas

another 63 GW has come from 51 new projects, which are still at planning and permitting phase.

- The EU is providing substantial funding to HVDC-related research activities, with 6 funding calls and a total budget of 1300 M€ in the Horizon Europe program.
- It is necessary to have standardisation of products in order to help European companies remain at leadership position in the market, especially regarding cable and HVDC converters manufacturers.
- In order to maintain the supply chain without problems, it is important to have a clear commitment on the HVDC technology and introduce joint procurement procedures for Member States, ensuring that the manufacturing capacity remains acceptable.
- The market of HVDC at worldwide level is estimated to be in the range of 9.48 – 16.96 billion dollars. It is forecasted that the Compound Annual Growth Rate (CAGR) for the next 10 years will be in the range of 7.1% - 10.6%.

3.2 Code of Conduct (CoC) for the Interoperability of Energy Smart Appliances (ESA)

The project of developing a CoC for ESA has reached many milestones during 2023. The goal of the project has been to achieve interoperability among different ESA from various manufacturers.

Overall, the work during 2023 has been the continuation of the work performed in 2022. The objective of the project is to define the pre-requisites of the ESA, and particularly of two categories: white goods and Heating, Ventilation and Air-conditioning (HVAC). It also deals with specific use cases of ESA, and the messages that are exchanged to accomplish them. Namely, the use cases of interest are:

— Flexible start

— Monitor of consumption power

— Limitation of power consumption

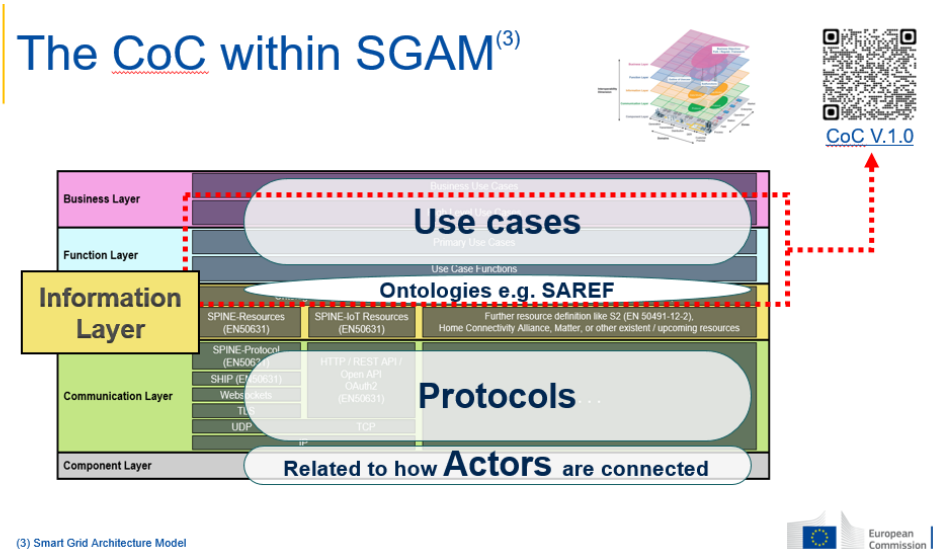
— Incentive table based power consumption management

— Manual operation

The CoC focuses on interoperability issues and it specifies the prerequisites for the messages exchanged among ESA and interested actors to ensure semantic interoperability. The key message is that the manufacturers can use any protocol they wish for achieving interoperability at the communication layer; however, they should guarantee that the messages are mapped to SAREF4ENER ontology, [15], for the information layer. SAREF4ENER ontology has been selected, as it is a popular ontology in the energy field and it can depict the nature of messages for the interested use cases on which the CoC focuses.

Figure 4 shows the CoC and its role within the smart grid architectural model (SGAM) framework.

Figure 4. The CoC within the SGAM

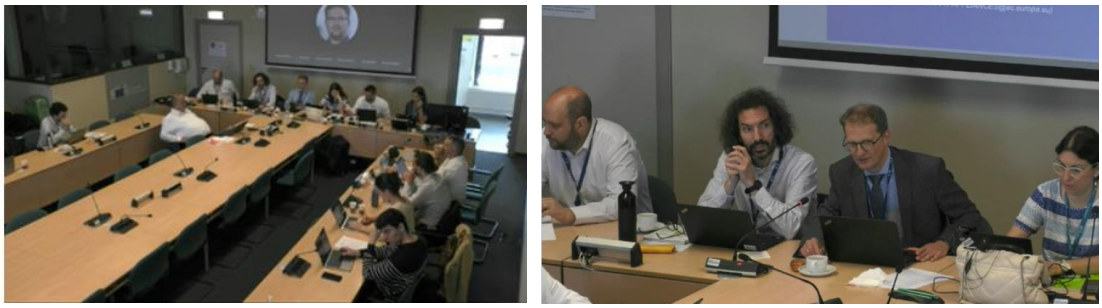


Source: JRC 2023

We can highlight that the extensive work with stakeholders has been strengthened and in particular, we can cite some relevant dates showing the progress of the project:

- The second roundtable with experts on the 13-14 February 2023 in Brussels. Thanks to the contribution of some volunteer contributors, it was possible to conclude a first draft of the CoC to distribute among all the stakeholders interested.
- Once the text was distributed, a survey was launched to collect the input from stakeholders. We got feedback from 52 answers.
- Workshop in Brussels on the 24 March 2023 with 107 participants in a hybrid mode. Thanks to having organised the roundtable with experts before the workshop, we managed to achieve consensus and full engagement on behalf of them regarding the approach made with the first draft of the CoC. What is more, on many occasions, the JRC profited from their experience and invited them to take the floor to address doubts and questions during the workshop.
- The JRC organised a third roundtable with experts on the 26th April in online mode, to discuss some reactions of stakeholders.
- Another workshop was organised on the 23 June 2023 to present the final text of the CoC and start discussing about the methodology of testing.

Figure 5. Workshop organised in Brussels on the 23rd June 2024 to present the final text of the Code of Conduct



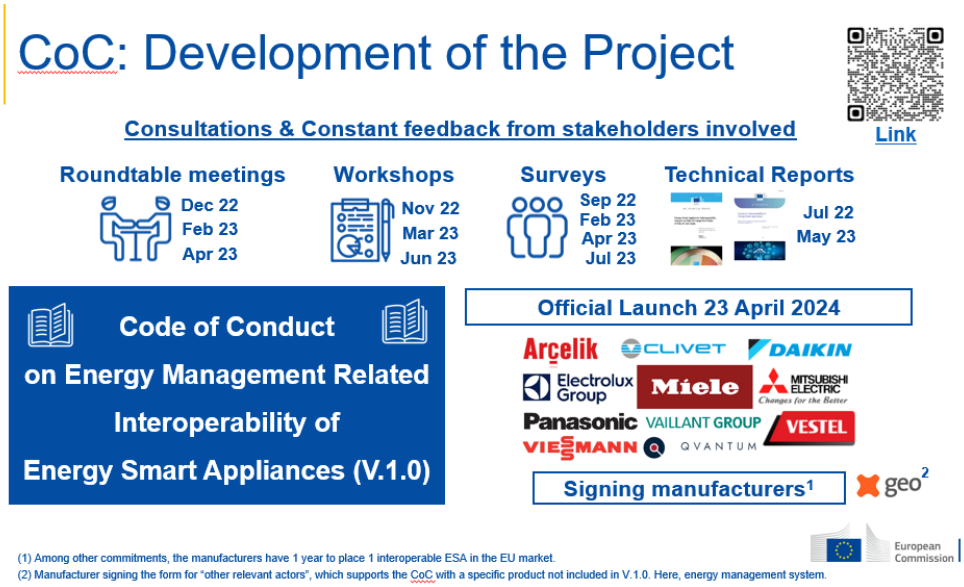
Source: JRC 2023

From July to October 2023, other interactions were carried out with some stakeholders and finally the text was sent to all the participants for a final legal review on November 2023.

In terms of deliverables, apart from the documentation and presentations generated for the aforementioned workshops, in June 2023, the second official report under the framework of this project was published [16]

The main work carried out for CoC project is summarised in Figure 6.

Figure 6. Work for the CoC project



Source: JRC 2023

Within an internal JRC event, we developed an important dissemination action on 16/06/2023 under the framework of internal JRC seminar, targeting the whole JRC with the title of Interoperability, CoC and methodology.

In addition, at an external level, the team in charge of this project received several invitations to participate in webinars and conferences organised by third parties. Some of them are listed below:

- 08/03/2023 Presentation to Applia's members, which is a trade association, representing the home appliance manufacturers. 15/03/2023 Presentation to Smarten association, which is the European business association that integrates the consumer-driven solutions of the clean energy transition. 05/07/2023 ETSI Conference[1] (ETSI IoT Conference – IoT Technologies for Green and Digital Transformation)
- 30/11/2023 Presentation to the Concerted Action for Energy Performance of Building Directive

The current version of the CoC invites the manufacturers to commit to the following [17]:

- Place at least one model of ESA in the Union market that implements the aforementioned use cases within 12 months from the official launch of the CoC.
- Implement the interoperability profiles based on open communication protocols to ensure information exchange for the aforementioned use cases.
- Ensure open security mechanisms for the established communication to guarantee a secured communication, authorisation to access the ESA, and ensure proper control for the usage of private data, respecting the already existing regulations/ legislation in the field.
- Guarantee that the information messages are compliant to SAREF representation and particularly to SAREF4ENER ontology.
- Inform the end-users about the use cases and how they can best benefit from them.
- Collaborate with the European Commission to achieve the annual review of the CoC.
- Register new ESA models in the European Product Registry for Energy Labelling (EPREL) database and indicate the compliance with the CoC, if applicable. The capabilities of the ESA can be realized either physically in the ESA, either represented as digital twin in the manufacturer cloud or as digital twin in a dongle/ adapter, which is connected to the ESA.

The manufacturers declare the implemented use cases together with the ways in which they comply with the requirements on a voluntary basis. The CoC entails multiple annexes in order to help the manufacturers be compliant with the provisions of the document and map the messages exchanged among the ESA to the SAREF4ENER ontology, which has been selected by the JRC SGIL team of experts. The CoC is singed at a voluntary basis by the manufacturers and it is actually the first step towards such an initiative. It is programmed to have further versions of the CoC in order to include more ESA, like photovoltaic panels, electric vehicles and most importantly the energy management systems, which are key components for the communication of ESA. It is envisioned to ultimately develop a regulation out of the current initiative of the CoC.

[1] ETSI IoT Conference – IoT Technologies for Green and Digital Transformation, ETSI IoT Conference 2023 (ETSI IoT Week 2023) - European DIGITAL SME Alliance

4 Horizon 2020 Research Projects

4.1 ERIGrid 2.0

Since April 2020, the team of the JRC Smart Grid Interoperability Laboratory is taking part in the Horizon 2020 EU project, European Research Infrastructure supporting Smart Grid and Smart Energy Systems Research, Technology Development, Validation and Roll Out (ERIGrid 2.0)[2] (https://erigrid2.eu/). The project, which has recently been extended up to April 2025, comprises 20 partner organisations from 13 countries, including universities, research institutes, and a grid operator, and has a total budget of 10 million Euros.

ERIGrid 2.0 aims to expand the research services and tools of research infrastructures, previously developed in ERIGrid project (2015-2020), for validating smart energy networks with the electric power grid as the main backbone. Committed to the holistic and cyber-physical systems-based validation approach, ERIGrid 2.0 fosters system-level support and education for industrial and academic researchers in power and energy systems research and technology development.

The JRC SGIL team participated in joint research activities of the ERIGrid project, which are now completed, and the activities in 2023 have mostly focused on the laboratory access scheme provided to external entities. In the last year, the SGIL received two visits by a team of Fabbricadigitale s.r.l.[3], an IT company with expertise in AI and operating mostly in the sectors of Internet of Things and Digital platforms. The SGIL has collaborated with the fabbricadigitale team to refine and extend the software tool for techno-economic analysis of Renewable Energy Communities (RECs) which has recently been presented in the SEST 2023 conference [18]. The first version of this tool was developed in 2022 in a MATLAB environment and applied iterated random sampling techniques to historical energy data in order to predict the energy behaviour of RECs of different size and composition, estimating also some of their key performance metrics, such as the share of local renewable generation that is consumed locally. With respect to this preliminary version, additional features have been added:

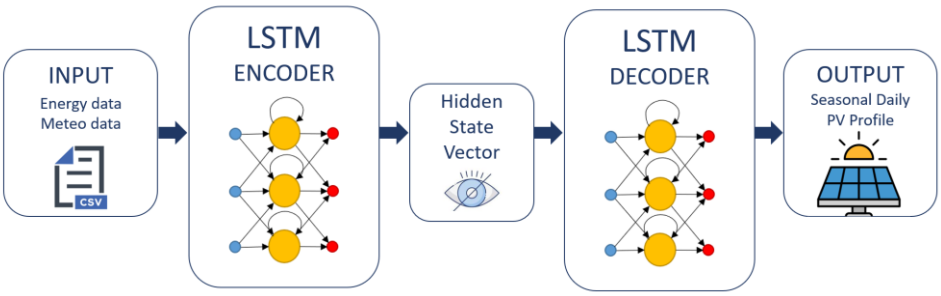
- Development of an AI-powered forecast model

As a potential alternative to the previous modelling approach based on stochastic random sampling of historical energy data, a new Georeferenced Temporal Model (GTM) has been developed. The GTM relies on large external databases and utilises a complex neural network model (see Figure 7) to implicitly incorporate correlation phenomena and other modelling features in the REC forecast tool. With respect to the previous sampling-based method, the GTM approach provides a more accurate modelling framework that explicitly accounts for the impact of weather conditions on the energy patterns of the REC members. Moreover, the GTM method can forecast the REC behaviour without the need for historical energy profiles. If these are not available to the tool user, the GTM can build its REC forecast relying on external database of load profile and PV generation.

[2] (https://erigrid2.eu/)

[3] fabbricadigitale IT Technology

Figure 7. Diagram of the neural network used in the GTM model for REC forecast



Source: JRC analysis 2023.

— Graphical User Interface

In order to facilitate the use of the tool by non-technical experts and potential REC members (e.g. private citizens, public entities, SMEs), the original MATLAB implementation of the model has been converted into a Python version that has been endowed with a graphical user interface (see Figure 8 for an example). In this way, the user is guided in the specification of all the relevant parameters of the REC under exam. Moreover, the presentation of the results has been streamlined, selecting a limited number of key information that are represented at screen and giving the possibility to the user of downloading more detailed data if necessary.

— Open-Access Web-Based Implementation

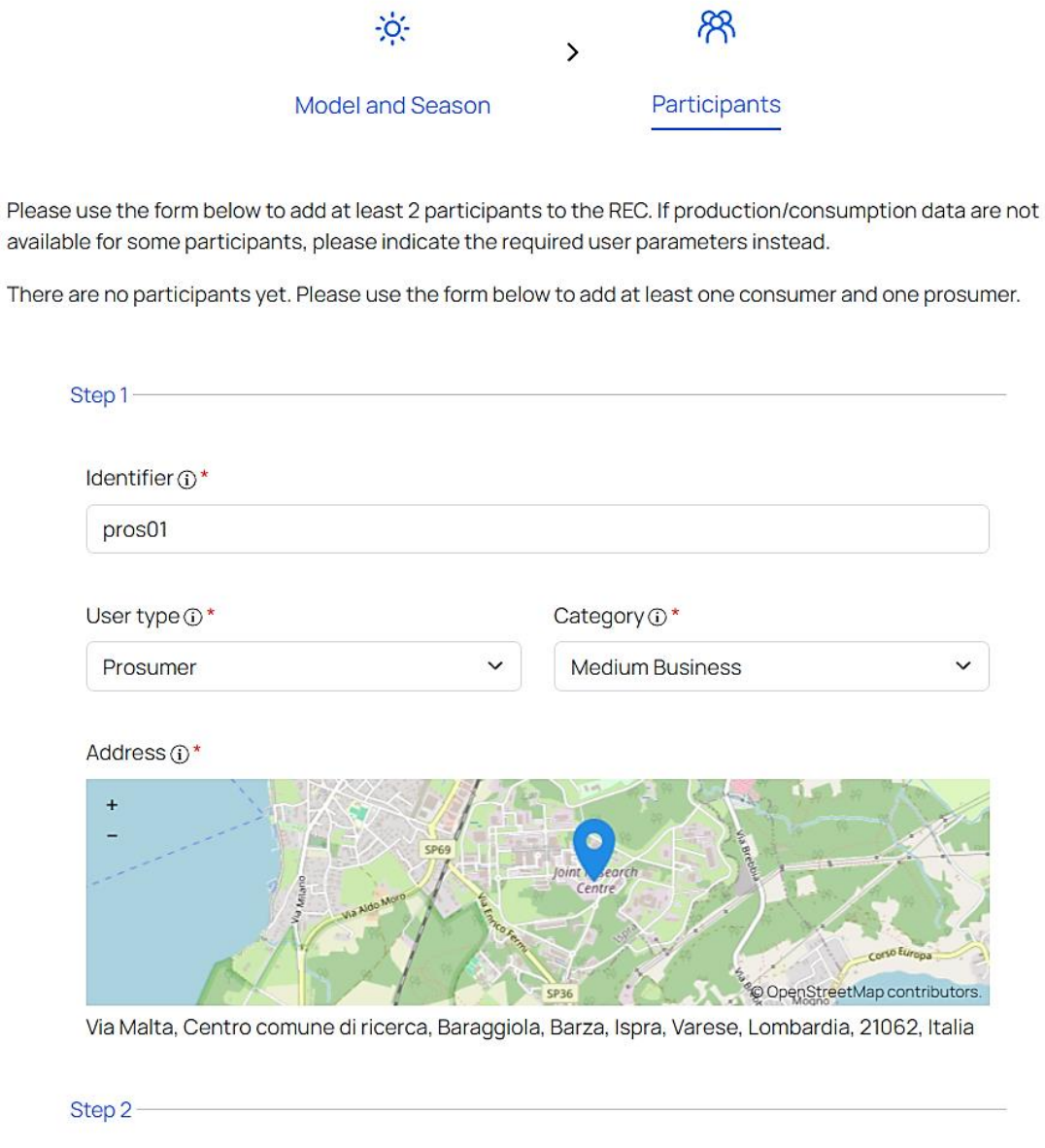
In order to improve accessibility and visibility of the tool, a web-based version of the model has been developed. The whole application is distributed as Docker images and deployed in Docker containers according to the scheme presented in Figure 9. The platform is composed of three modules: i) a user interface module with the web-based implementation of the tool, ii) Application Programming Interface (API) services that act as interface between the user interface and the simulator and iii) the simulator module that performs the mathematical computations associated to the REC energy forecast.

The model developments highlighted above will be presented in a journal paper that is currently under preparation. Moreover, the open-source code of the tool will be uploaded on the code.europa software repository of the Commission[4] and the tool will be made accessible for direct use on the JRC Smart Electricity Systems website. The collaboration with fabbricadigitale will continue in 2024 with two additional laboratory visits, with the objective of extending the REC forecast tool to also include socio-economic metrics.

New Erigrid 2.0 laboratory access activities are also expected in 2024, with visits by the University of Trento (to tackle battery storage degradation) and Ricerca Sistema Energetico (to conduct joint real-time simulations).

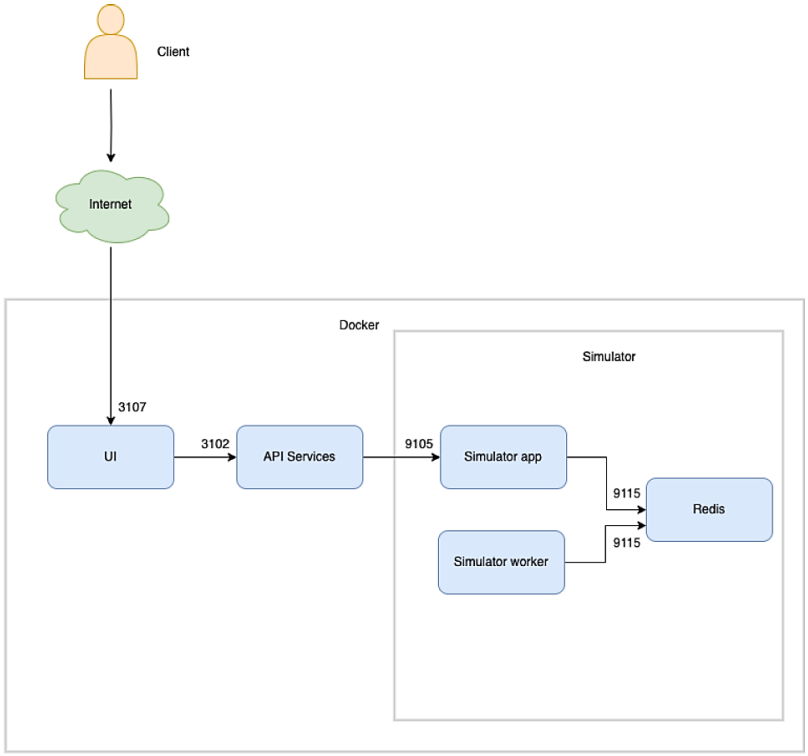
[4] Code.Europa.eu | Joinup

Figure 8. Graphical interface of the REC tool



Source: JRC analysis 2023

Figure 9. Docker implementation of the web-based tool



Source: JRC analysis 2023

4.2 DRIMPAC – further developments

The JRC SGIL has successfully participated in the DRIMPAC project, "Unified DR interoperability framework enabling market participation of active energy consumers".

The project facilitates demand response programs for residential consumers. It addresses the issue of smart buildings and how their participation in demand response programs can be realised. For this scope, it helps in constructing hardware to transform buildings into smart. It also develops outstanding software to complete the task of sophistically managing energy and enabling flexibility offered to aggregators by the residential consumers.

Although the project has been completed in 2022, some follow-up has emerged from it, using the material built during the project as the basis for scientific works. In particular, two publications have been issued and published during 2023, listed as follows:

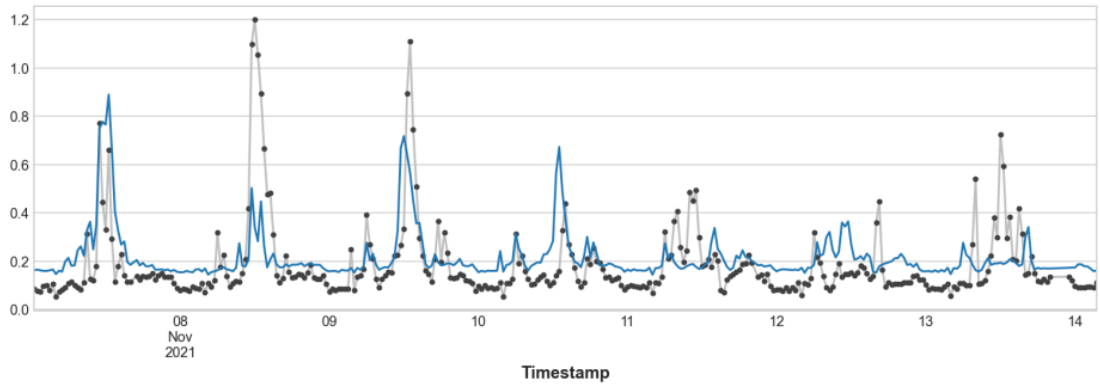
- Ex-ante analysis and baseline estimation for pilot premises using machine and deep learning

As the title implies, the work is focusing on estimating the baseline on pilot sites, meaning the energy that would have been consumed in case no demand response events took place [19]. The work done to estimate the baseline has been based on artificial intelligence and deep learning methods. In particular, this work explains all necessary steps to result in the desired baseline calculation, from data retrieval, exploratory analysis to the development and testing of the models. Three models have been developed, namely: the multivariate regression model, the univariate regression model and a convolutional neural network (CNN) model. The metrics used to validate the accuracy of the models created are the root mean squared error. The results show that the latter model outperforms the other

two, mainly because of its ability to learn the spatio-temporal dependencies in the energy consumption data.

The models presented in the paper calculate the baseline, by processing historical data from the pilot site, which is located in Germany. The 75% of the data is used for training the model, and the 25% of data is used to forecast the baseline and then compare the forecasted values to the actual ones. The paper analyses the way the three models are developed and how they are used to calculate the baseline. Figure 10 shows the actual and predicted values for one week at the German site. The work has been performed in the framework of the DRIMPAC project.

Figure 10. Time plot of actual and predicted energy values for a period of one week at the German pilot



Source: JRC analysis 2023

— Holistic Evaluation of Demand Response Events in Real Pilot Sites: from Baseline Calculation to Evaluation of KPIs

This work complements on the previously described article and has been also performed in the framework of DRIMPAC project [20]. It builds upon the baseline estimation methodology and utilises the calculated baseline to evaluate the benefits obtained from the applied demand response events to the residential consumers. For this reason, Key Performance Indicators (KPIs) are calculated, which give a concrete picture about the total savings achieved by the demand response programs applied. The five proposed KPIs are listed as follows:

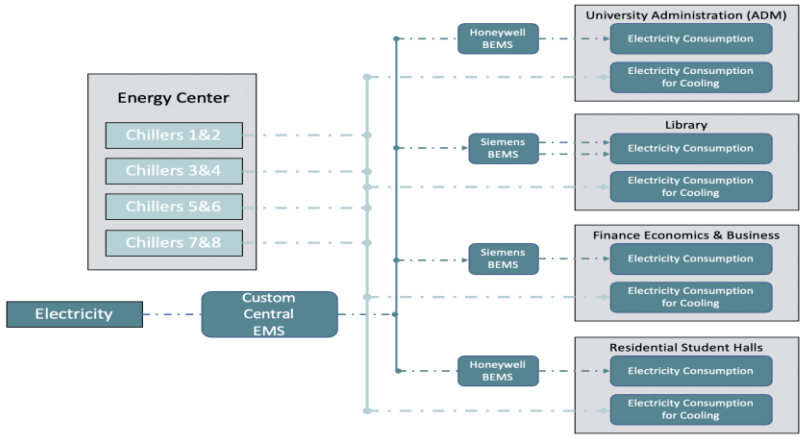
- Distributed building DR reliability;
- Energy consumption reduction in pilot sites;
- Energy cost savings in pilot demonstration sites;
- Reduction of CO2 emissions in pilot sites;
- Peak load reduction during pilot demonstration activities

The work proposes a concrete way of calculating two of the aforementioned KPIs, thus helping in the overall assessment of a demand response program and giving a clear indication of the successfulness of the demand response events.

The proposed estimation methodology for the baseline calculation and the KPIs is applied to two real pilot sites, situated in Spain and Cyprus. Similarly to the previously described work, the convolutional

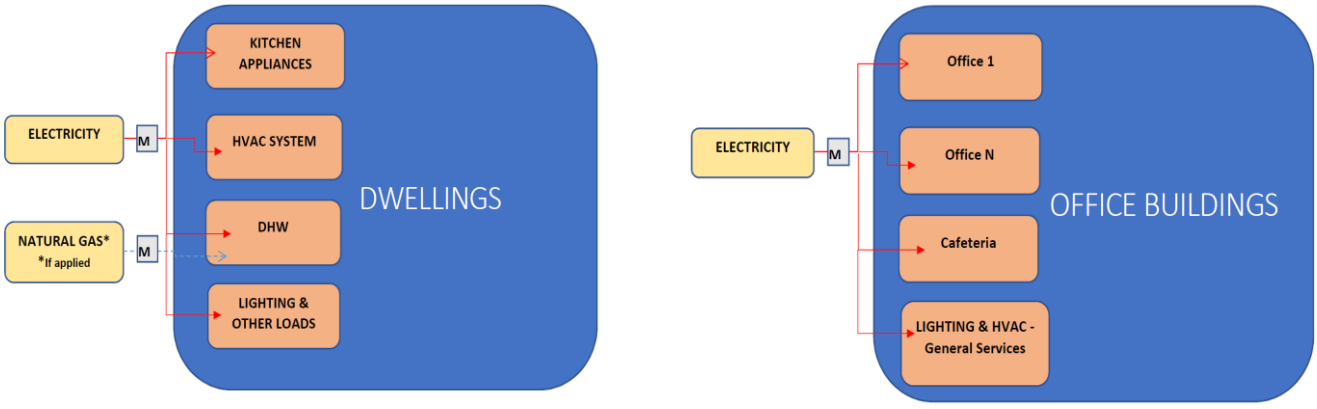
neural network outperforms the multivariate and univariate regression models for baseline calculation. The presented results complete the picture of evaluating a real-life demand response program and show the effectiveness of the selected approach. Figure 11 and Figure 12 show the schematics of the two pilot sites, on which the baseline is calculated and further on the KPIs are evaluated. Figure 11 and Figure 12 give a clear picture of the conditions under which the work has been carried out and highlight the importance of real-life examples, where scientific methodologies are applied. As residential demand response is a sector which experiences great progress and attracts the interest of scientific community, it is fundamental to have real life examples of the baseline calculation together with concrete evaluation of KPIs for the overall evaluation of the demand response programs.

Figure 11. Schematics for the Cypriot pilot site



Source: Supporting a "glocal" energy transition: from local energy communities to global simulation networks, 2023

Figure 12. Schematics for the connections of buildings for the Spanish pilot site.



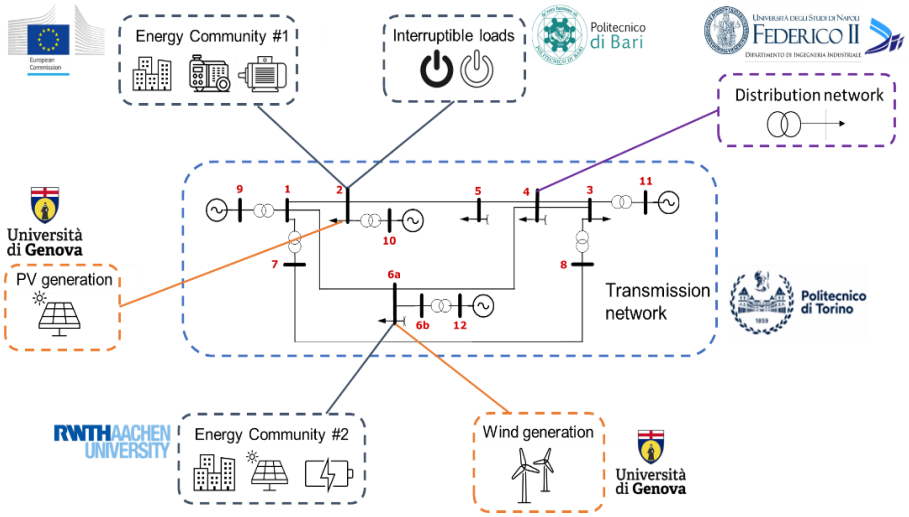
Source: Supporting a "glocal" energy transition: from local energy communities to global simulation networks, 2023

5 Other research activities and collaborations

5.1 Geographically-Distributed Real-Time Digital Simulations (GD-RTDS)

The collaboration established with the Ensiel consortium[5] of Italian universities for the development of an internet-of-lab platform for real-time power system studies has continued in 2023. In particular, a second conference paper that summarizes the research outcomes achieved so far has been presented at the 2023 SEST conference [21]. The paper has been evaluated among the top 50% of the accepted conference submissions and therefore the authors have been invited to submit an extended journal version of their study to Elsevier Sustainable Energy, Grids and Networks. In this context, the laboratory activity carried out by the SGIL team in 2023 has focused on replicating and refining the GD-RTDS experiment conducted in collaboration with the other partners. The electricity grid and the distribution of the different simulated components among the different partners of the activity are summarized in Figure 13. The conducted simulations have demonstrated the capability by GD-RTDS approaches to analyse with efficiency and accuracy some typical problems of the decarbonized power system of the future, such as the necessity to rely on smart technologies and on distributed resources to support the frequency regulation of the grid under critical conditions. Two additional case studies have also been considered, simulating the impact of port electrification on the power system and the management of EV charging with forecasting tools. These additional results have been included in the latest journal paper [22].

Figure 13. Scheme of the GD-RTDS experiment



Source: On the model flexibility of the geographical distributed real-time co-simulation: the example of ENET-RT lab, 2024

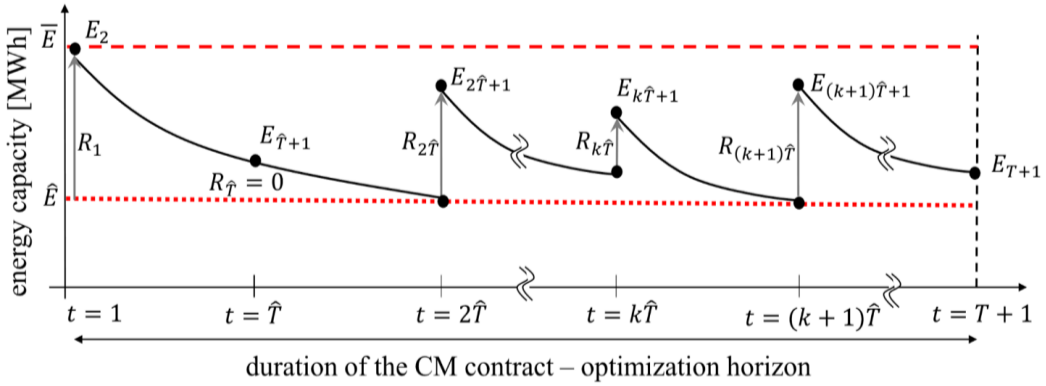
5.2 Combined optimization of battery market operation and revamping

Another research collaboration has recently been established between the SGIL team and the University of Trento on the topic of optimal operation and revamping of battery storage. In 2023, the

[5] About us - EnSiEL (consorzioensiel.it)

joint activity has focused on the development of novel optimization methods for storage batteries that are able to combine the short-term operation of the asset (e.g., daily charge/discharge on the day-ahead market) with the long-term revamping actions, considering at the same time a detailed model of the resulting battery degradation. An example of the revamping policies evaluated by the optimizer and the resulting evolution of the battery capacity over time are represented in Figure 14.

Figure 14. Illustrative example of the battery revamping policy



Source: Revenue Maximization for a Battery Storage With Optimal Capacity Revamping Due to Cyclic Fade, 2024

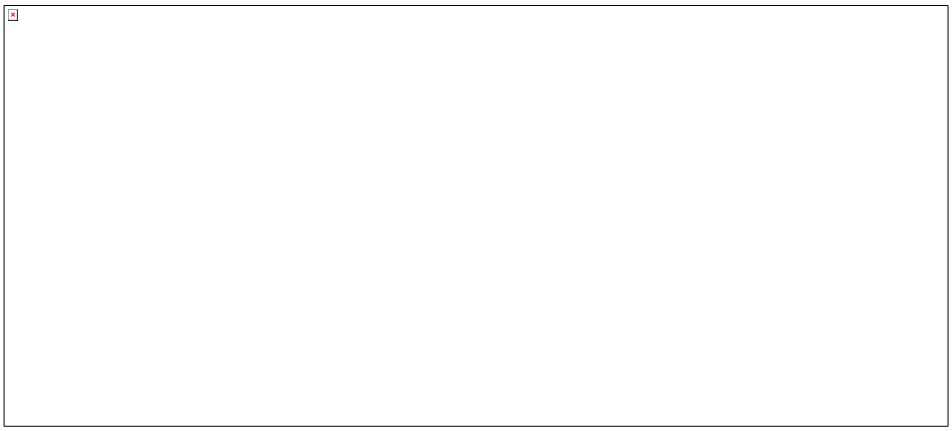
The first preliminary results on the optimization of battery operation (both in the short and long term) have been presented in [23]. The research activity is planned to continue in 2024 under the framework of the Erigrid 2.0 laboratory access scheme. A team from the University of Trento will visit the SGIL for a period of about 4 weeks to investigate extensions of the existing modelling platform, such as the possibility of combining storage with renewable generation and the development of a more robust and accurate description of the battery degradation process.

6 International partnerships, dissemination and outreach

6.1 The EU Action Plan for grids

The SGIL supported DG ENER with technological and scientific expertise for the preparation of the EU Action Plan for Grids, highlighting the most relevant decarbonisation actions put in place by the EU and providing compact and clear description of their scientific rationale and technological impact. The EU Action Plan achieved very significant visibility and impact at the highest political and regulatory levels. The document was presented by the Commissioner for Energy Kadri. Simson at the Joint Ministerial Plenary of the 14th Clean Energy Ministerial (CEM14) in Doa, India, alongside similar plans prepared by Australia, Chile, India, and United Kingdom. The main result of this CEM14 activity has been a proficuous and constructive sharing of expertise and good practices between the different states and international institutions. The approaches and lesson learnt by the single states can provide useful indications for the planning and implementation of the future decarbonisation efforts. In parallel, a joint discussion on decarbonisation priorities and strategies can facilitate networking and international collaborations for a more effective worldwide energy transition. To these ends, the National Renewable Energy Laboratory has released a synthesis report that summarizes the key take-aways of this first cohort of action plans, highlighting the shared common themes of the participants and presenting key messages for energy ministers of the different participating countries and institutions on the best approaches for planning, building and operating the decarbonised power system of the future.

Figure 15. Presentation event of the Grid Action Plans at CEM14 in Goa, India



Source: JRC 2023

6.2 Participation in the International Smart Grid Action Network (ISGAN)

The SGIL team represents, together with DG-ENER, the European Commission in the International Smart Grid Action Network (ISGAN). ISGAN is a Technology Collaboration Programme (TCP) of the International Energy Agency (IEA) and at the same time an initiative under the Clean Energy Ministerial (CEM), is committed to identifying emerging advances, sharing best practices, and raising high-level government awareness on the value and impact of smarter grids. It facilitates knowledge exchange, technical assistance, peer review, and activity coordination among its participants and stakeholders. In 2023, the SGIL team has participated to the ISGAN 25th Executive Meeting in Berlin, presenting the EU landscape in terms of Smart Grids priorities and programmes. There are plans for further

involvement of the SGIL in the joint research activities of ISGAN, with a potential active role in the ISGAN working group 5, focused on developing and managing a network of the smart grid facilities of the ISGAN members.

6.3 Laboratory visits

Like every year, the smart grid labs in Petten and Ispra attract the interest of various visitor groups, resulting in numerous visits both by VIP groups and technical. Here, we list some of them.

Figure 16. Visit to the JRC Petten Lab

Source: JRC 2023

Petten Lab:

- 17/01/2023 Visit of Salla Saastamoinen, JRC Deputy Director General - DDG.2, to the JRC Petten site, where the activities of the lab have been presented.
- 03/05/2023 Senior Management of the JRC; scheduled visit to present to the senior management the accomplishments and the future activities of the lab.
- 16/06/2023 Board of Governors; presentation of the SGIL achievements and future plans for the group.

Ispra lab:

- 17/02/2023 European School visit
- 25/02/2023 Visit of Salla Saastamoinen, JRC DDG.2
- 28/02/2023 Ukrainian Delegation
- 06/03/2023 Symposium for the European School

- 19/04/2023 Visit of Polytechnic of Milano
- 27/04/2023 Visit of Minister Mariya Gabriel
- 12/05/2023 Visit of the school of Gavirate and school of Genova
- 07/06/2023 Visit of the Member of European Parliament Lara Comi
- 08/09/2023 Visit of Rivian Automotive
- 03/10/2023 Visit of representatives of ENEA
- 06/10/2023 Visit of DG CLIMA
- 14/11/2023 Visit of the Tuscany delegation
- 17/11/2023 TEDx laboratory talk
- 28/11/2023 Visit of new colleagues of the JRC
- 15/12/2023 Visit of Austrian Delegation

From the list, it is obvious that the SGIL attracts the interest of multiple visiting groups. Indeed, numerous visits took place during 2023, including high-level representatives, like European Parliament members, foreign delegations, higher hierarchy of the JRC and colleagues from other DGs. In addition, it is also clear that the SGIL is active in outreach activities, including speeches to schools and the local authorities. The Ispra Lab has received more visits, since it is established for more years with respect to the Petten lab. Nevertheless, the main purpose of the visits has been to present the complete SGIL activities both to high level visitors or technical ones. A presentation summarizing the activities in policy support and in the research field is shown to the various visiting groups, adjusted to the audience and their level of expertise.

The SGIL will continue its rich activity in this direction, presenting its achievements in multiple visiting groups and various audiences, thus promoting policy support initiatives and research works with ultimate goal to facilitate the everyday lives of European citizens.

7 Conclusions

This report summarizes the achievements made in 2023 and proves that the activities of the SGIL are fundamental for policy support in the field of energy and also for promoting research in the smart grid. The SGIL is continuously working in the field promoting interoperability and its activities form the basis for future work, while its goals remain aligned with the overall organisational goals and the priorities of the European commission.

The Smart Grid Interoperability Laboratory, with its two branches in Ispra (Italy) and Petten (The Netherlands) is conducting valuable research in the field of interoperability and smart grids. The scope of the work is twofold: to promote research and support policy makers for new policies in the energy field.

During 2023, the policy support activities have been concentrated in two main projects: the Clean Energy Technology Observatory and the CoC for ESA. The first project has to do with monitoring specific smart grid technologies, namely the Advanced Metering Infrastructure and the High Voltage Direct Current in terms of technology readiness level, value chain analysis and EU and global market competitiveness. The findings contribute to the evaluation of the EU Governance.

The second project has been the first attempt for a policy in the field of ESA. It results in the CoC for ESA and defines the prerequisites for maintaining interoperability particularly for White Goods and HVAC. The work during 2023 has been the basis for the later accomplished CoC. The importance of the SGIL work is is reflected in the extension asked to set the prerequisites for more categories of ESA, like Energy Management Systems and PVs.

The SGIL team is a pioneer in the field of research on the smart grid. The work conducted in 2023 has been the continuation of previous works and forms the basis for future activities as well. Indeed, the SGIL team has worked successfully on the ERIGRID project and has conducted research on important topics of the smart grid, like Renewable Energy Communities. Another achievement has been that it successfully used Artificial Intelligence tools for creating models in the energy field, like modelling the baseline for demand response programs and modelling parameters of the Energy Renewable Communities.

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List of abbreviations and definitions

AA	Administrative Arrangement
AI	Artificial Intelligence
AMI	Advanced Metering Infrastructure
API	Application Programming Interface
BAP	Basic Application Profile
BAIOP	Basic Application Interoperability Profile
CAGR	Compound Annual Growth Rate
CEM	Clean Energy Ministerial
CEN	European Standardisation Committee
CENELEC	European Committee for Electro technical Standardization
CEP	Clean Energy for all Europeans Package
CETO	Clean Energy Technology Observatory
CNN	Convolutional Neural Network
CPR	Competitive Project Report
CoC	Code of Conduct
DR	Demand Response
DSO	Distribution System Operator
ESA	Energy Smart Appliances
EV	Electric Vehicle
GD-RTDS	Geographically Distributed Real Time Digital Simulation
GTM	Georeferenced Temporal Model
HVAC	Heating Ventilation and Air Conditioning
HVDC	High Voltage Direct Current
ICT	Information and Communication Technology
IEA	International Energy Agency
IED	Intelligent Electronic Device
IOP	Interoperability
ISGAN	International Smart Grid Action Network
KPIs	Key Performance Indicators
REC	Renewable Energy Community
RES	Renewable Energy Sources
RSE	Ricerca Sistema Energetico
SGAM	Smart Grid Architecture Model
SGIL	Smart Grid Interoperability Laboratory
TCP	Technology Collaboration Programme
TNO	Netherlands Organisation for Applied Scientific Research

XLPE	Cross-linked Polyethylene

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