ISSN 1831-9424

European Commission

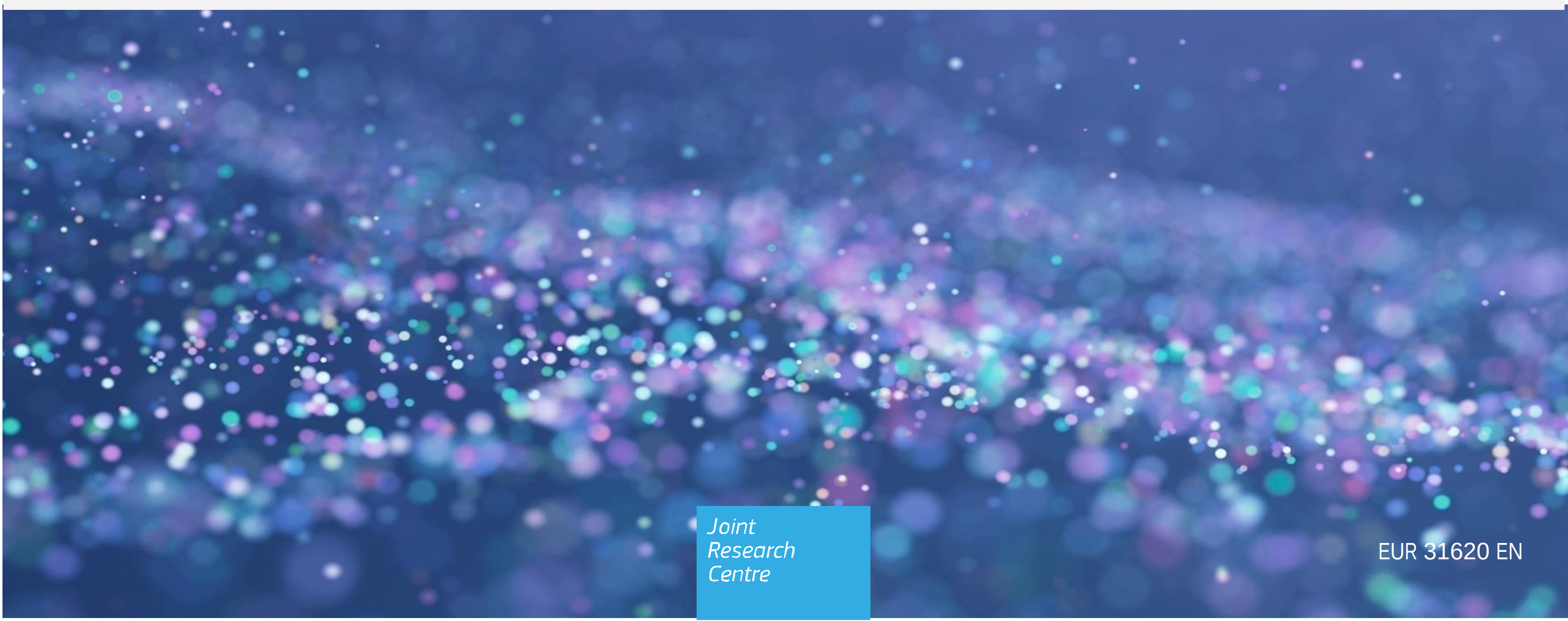
JRC TECHNICAL REPORT

Smart Grid Interoperability Laboratory

Annual Report 2022

Andreadou, N., De Paola, A., Tarramera Gisbert, A., Thomas, D., Wilkening, H., Von Estorff, U., Gonzalez Cuenca, M., Foretic, H., Kotsakis, E., Barboni, M.

2023



Joint Research Centre

EUR 31620 EN

This publication is a Technical report by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policymaking process. The contents of this publication do not necessarily reflect the position or opinion of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication. For information on the methodology and quality underlying the data used in this publication for which the source is neither Eurostat nor other Commission services, users should contact the referenced source. The designations employed and the presentation of material on the maps do not imply the expression of any opinion whatsoever on the part of the European Union concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Contact information
Name: Heinz Wilkening
Address: European Commission, Joint Research Centre (JRC), Westerduinweg 3, 1755 ZG - Petten, The Netherlands
E-mail: jrc-ptt-interoperability@ec.europa.eu
Tel.: +31.224.565368

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC133475

EUR 31620 EN

PDF ISBN 978-92-68-06617-1 ISSN 1831-9424 doi:10.2760/066580 KJ-NA-31-620-EN-N

Luxembourg: Publications Office of the European Union, 2023

© European Union, 2023

The reuse policy of the European Commission documents is implemented by the Commission Decision 2011/833/EU of 12 December 2011 on the reuse of Commission documents (OJ L 330, 14.12.2011, p. 39). Unless otherwise noted, the reuse of this document is authorised under the Creative Commons Attribution 4.0 International (CC BY 4.0) licence (https://creativecommons.org/licenses/by/4.0/). This means that reuse is allowed provided appropriate credit is given and any changes are indicated.

For any use or reproduction of photos or other material that is not owned by the European Union, permission must be sought directly from the copyright holders.

How to cite this report: Andreadou, N., De Paola, A., Tarramera Gisbert, A., Thomas, D., Wilkening, H., von Estorff, U., Gonzalez Cuenca, I., Foretic, H., Kotsakis, E., Barboni, M.. *Smart Grid Interoperability Laboratory - Annual Report 2022,* Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/066580, JRC133475.

Contents

Abstract

The Energy Security, Distribution and Markets Unit has the Smart Grid Interoperability Laboratory (SGIL) situated in two sites, namely Ispra (Italy) and Petten (The Netherlands). The focus activities of the labs 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 goal of European Green Deal. The activities in 2022 are highlighted in this report.

Acknowledgements

The authors would like to thank the project leader Harald Scholz for his forward-looking view on integrating interoperability activities from the electric automotive sector. A special thanks goes as well to former colleagues, Ioulia Papaioannou, Antonios Marinopoulos for all their work in the lab. Finally nothing would have worked without a strong administrative support from the Unit, i.e. Virginie Petitjean and Dima Petrova.

Authors

Andreadou, N., De Paola, A., Tarramera Gisbert, A., Thomas, D., Wilkening, H., von Estorff, U., Gonzalez Cuenca, I., Foretic, H., Kotsakis, E., Barboni, M.

Executive summary

In the new era of energy systems and the need for energy digitalization, the energy grid is being transformed into a smart grid able to accommodate more renewables and manage energy consumption and production in an efficient way with automation playing a key role in this transition.

For this reason, it is fundamental to have state-of-the-art infrastructure to support new policies in the energy area as well as promote research and innovation in the field. It is fundamental that such infrastructure is interoperable to support innovative activities in the smart grid. Indeed, interoperability plays a key role in the digitalisation of the future smart grid, as systems need to be able to exchange information correctly to facilitate the promotion of green initiatives and programs for the update of the energy grid and enhance the role of energy consumers in the new smart grid.

The Energy Security, Distribution and Markets Unit with its two Smart Grid Interoperability Laboratories works to this direction by providing scientific evidence to support energy policies and contributing to the research for more interoperable systems. In this report, we list the activities carried out by our two laboratories in the interoperability field during 2022. Thus, this report provides a continuation of the previous ones, where the interoperability activities in our laboratories were demonstrated. All the high impact activities listed here prove the valuable contribution of our team in the interoperability field and the promotion of innovative energy services in the smart grid.

Policy context

From a policy context point of view, the smart grid interoperability activities are linked to various regulations, recommendations and directives, from which we only list the most relevant ones here.

First, in 2019, the main policy guidelines were introduced by European Commission, namely the “European Green Deal” (EuropeanCommission, 2019) and the “EU fit for the digital age” (EuropeanCommission, A Europe fit for the digital age, 2019). The first one aims at a climate neutral continent, with the scope to reduce carbon emissions by 50% by the year 2030, thus encountering the climate challenge. The second policy guideline aims at better integrating the innovative digital technologies in everyday life; massive data sharing, artificial intelligence, internet of things, blockchains are only examples of such digital technologies. Our laboratories work in the field of energy digitalisation and interoperability of energy systems aiming at the decarbonisation of the energy system, thus serving the above policy guidelines.

In addition, the recently published (2019) Clean Energy Package for all Europeans (CEP) (EuropeanCommission, Energy - EU policies aim to deliver secure, sustainable and affordable energy for citizens and businesses, n.d.), which is a set of Regulations and Directives in the energy sector, has been directly linked to the scientific activities of the Smart Grid Interoperability Laboratories: from monitoring its implementation by the Member States to applying its guidelines in the energy systems in the framework of innovative research projects.

Another initiative launched in 2020, the New European Bauhaus (EuropeanCommission, A New European Bauhaus: op-ed article by Ursula von der Leyen, President of the European Commission, n.d.) initiative, is linked to the SGIL activities. This initiative finds solutions to complex societal problems and links the European Green Deal to challenges of everyday life.

Referring to the most recent policy actions by the European Commission, it is worth mentioning the just published EU Action Plan (October 2022) for digitalising the energy system (EuropeanCommission, EU action plan on digitalising the energy system, n.d.). This report talks about enforcing the energy system and promoting its digitalisation, where the work of the SGIL is cited. Particularly, the work of the SGIL in the formation of a future Code of Conduct (CoC) for Interoperability of Energy Smart Appliances (ESA) is mentioned. This latter work is one out of the Administrative Arrangements (AA) held by the SGIL team with DG ENER (JointResearchCentre, 2023) and aims at creating the basis for future policies by the European Commission. Another AA between the SGIL of the JRC and DG RTD has to do with the Progress on Competitiveness of Clean Energy Technologies; the project monitors the progress of specific Clean Energy Technologies, as the name implies, and the SGIL has contributed to the final report, which has been adopted as part of the Governance Implementation Package (EuropeanCommission, REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL: Progress on competitiveness of clean energy technologies, 2022).

The JRC SGIL works in testing interoperability of digital systems for the energy sector, thus serving all the above policies. Equipped with state-of-the-art instruments and the most updated software along with a concrete methodology for interoperability testing (JointResearchCentre, Power grid digitalisation and interoperability, 2023), it is in the position to test the smart grid systems integration, smart homes issues, and address interoperability in this context.

Key conclusions

During 2022, the SGIL activities have had a high impact in terms of final reports, publications and project deliverables and innovative research tasks. Interoperability has been the core activity of the SGIL, whereas other aspects of the energy systems have also been examined. During this year, the SGIL has achieved the following:

- Undertake an AA with DG RTD and contributed to the final Progress on Competitiveness of Clean Energy Technologies report, which has been adopted as part of the Governance Implementation Package.
- Work under an AA with DG ENER with goal to produce a CoC for ESA, producing already two reports and having successfully run an EU survey and held two workshops with stakeholders.
- Conclude successfully the DRIMPAC project, focusing on demand response in buildings and addressing also interoperability issues among the various systems, producing 3 project deliverables.
- 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.

All the above are results out of hard team work and show continuity with previous and future activities.

Related and future JRC work

The SGIL holds collaborations with many other research centres and laboratories across Europe. Some of them are the Battery Energy Storage Testing facility in Petten (NL) and the European Interoperability Centre for Electric Vehicles in Ispra (IT). The SGIL developed and has been applying a structured methodology for interoperability testing in smart grids. A common European repository for dissemination and open access is being put into practice. The SGIL aims to attract external researchers with their use case, to build up the repository.

As future work, it is envisaged that the SGIL will continue its dedicated work in the field of interoperability for the smart energy systems. Indeed, many of its projects are ongoing, like the ERIGRID project and the AA for the interoperability of ESA, which is expected to be completed once the Code of Conduct is produced (within 2023). Furthermore, there are several periodical activities, like the Smart Grid Lab Inventory, which is held every two years and the Smart Grid Projects Outlook, which are both expected to take place as future SGIL activities. In addition, it is intended to enhance the already established collaborations with the aforementioned laboratories in the field of energy.

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.

Quick guide to this report

Chapter 1 gives a short introduction to the subject and describes shortly the lab.
Chapter 2 describes the EC policy relevance, the motivations and the benefits for all stakeholders
Chapter 3 reports about the activities related to the laboratory.
Conclusions are drawn in Chapter 4.

1 Introduction

Nowadays, it becomes more and more important to have a resilient and efficient energy system to ensure energy security. On the other hand, it is also crucial to have an energy system that does not entirely depend on a single form of energy source, but allows renewable energy sources (RES) to be easily integrated. This modern smart grid consists of multiple elements, which need to perform at high standards: the distribution grid needs to be resilient, ensuring energy supply and accommodate multiple RES; intelligent systems and software need to operate in parallel with the basic grid functionalities in order to guarantee automation and the support of novel energy programs; electric vehicles need to be integrated in the grid without compromising its functionality; smart homes and buildings systems need to be part of the smart grid so as to empower consumers and ensure a better energy management from consumption/ production point of view.

As it can be observed, the smart grid is a complete digital eco-system comprising of multiple systems, hardware and software. It is imperative that all these diverse systems communicate with each other and that information exchange takes place correctly. Thus, interoperability plays a key role in the modern smart grid and it is of vital importance to preserve it among the different elements. The European Commission launched several initiatives to enhance the robustness of the energy system and highlight the role of interoperability. Such initiatives show the importance of the digitalisation of the energy grid and the key role interoperability plays for a fully functional grid. They are:

- The “European Green Deal” (EuropeanCommission, A European Green Deal, 2019), which sets the guidelines for energy-related activities in the smart grid field, defining clear objectives for carbon emissions and aiming at a climate neutral Europe.
- The “EU fit for the digital age” (EuropeanCommission, An EU fit for the Digital Age, 2023), which sets the guidelines for integrating the innovative digital technologies in everyday life, like massive data sharing, artificial intelligence, internet of things, and blockchain technology.
- The Clean Energy Package for all Europeans (CEP) (EuropeanCommission, Clean Energy for all Europeans Package, 2019), which is a set of Regulations and Directives in the energy sector, setting the scene for the rules for any activities within the energy sector.
- The EU Action Plan (October 2022) for digitalising the energy system (EuropeanCommission, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS: Digitalising the energy system - EU action plan, 2022), which talks about how to enforce the energy system and promote its digitalisation.
- Horizon 2020 research program, through which numerous research projects are being financed in the field of energy, promoting innovative programs to enhance the robustness of the energy grid and manage energy efficiently.
- Various Administrative Arrangements to promote the state-of-the-art in the energy field and set the basis for future policies.

The SGIL works in the field of energy and with its high level instruments, it works towards the promotion of interoperability among energy systems. With the structured methodology for interoperability testing and high level use cases in the field of energy management, including demand response, battery storage applications and smart home use cases, the SGIL is a pioneer in the field of interoperability for smart grids. The state-of-the-art infrastructure includes among others a power amplifier, a real time simulator, advanced metering infrastructure equipment, battery energy storage system, photovoltaic panels, home energy management system along with advanced software for control and monitoring. The SGIL participated and participates in several research projects, offering its infrastructure at a network of scientists across Europe, thus enhancing collaborations among scientific groups as well.

The scientific activities that JRC holds in terms of collaborations but also through standalone projects in the energy field, promote interoperability among energy systems and enhance the innovation in the field. With these actions, JRC contributes to the implementation of EU policies aiming at the clean energy transition and the digitalisation of the energy sector.

During 2022, we have made valuable contributions in the field of policy support for future guidelines in energy. Moreover, we have been active in contributing to scientific projects in various topics like energy communities and innovative demand response programs in smart buildings. In all activities, we have used the European Interoperability Testing Methodology in use cases and developed further our modelling and programming activities.

2 Policy background

2.1 European Commission Policy Initiatives

With the participation in the Paris agreement in 2015 (UnitedNations, n.d.), the European Union committed to work towards a more sustainable climate and energy policies by reducing carbon emissions. The agreement indicates the necessity for collaboration among nations to combat climate change and it is predicted to have a review of the countries' achievements every five years. The 2030 Energy strategy of the European commission is in line with the Paris agreement and gives priority to empowering the citizens in the new era of the energy system while enabling business development in the global market.

In 2017, the Tallinn e-Energy declaration (EuropeanUnion, 2017) was signed by all Member States, highlighting the role the digital solutions can play for the energy system and the need for interoperability among such systems. The Digitalising European Industry Strategy (DEI) strategy (EuropeanCommission, Shaping Europe's digital future, 2021), also works towards re-enforcing the role of digital systems for the energy system.

In 2018, the Clean Energy Package for all Europeans (CEP) (EuropeanCommission, Clean Energy for all Europeans Package, 2019) was established, which is a set of Regulations and Directives in the energy sector. For example, the Regulation (EU) 2019/943 of 5 June 2019 on the internal market for electricity (EuropeanCouncil, 2019) and the Directive (EU) 2019/944 of 5 June 2019 on common rules for the internal market for electricity (EuropeanCouncil, DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, 2019) defined the rules for a more sustainable energy system and its components. Indeed, the latter Directive and Regulation define in detail the rules for future energy systems including rules for innovative programs, like demand response, the integration of electric vehicles and energy communities, while the importance of interoperability is highlighted.

In addition, in 2019, the newly established European Commission set two important policy guidelines, the "European Green Deal" (EuropeanCommission, A European Green Deal, 2019) and the "EU fit for the digital age" (EuropeanCommission, A Europe fit for the digital age, 2019). The former one aims at a climate neutral continent, with the scope to reduce carbon emissions by 50% by the year 2030, thus encountering the climate challenge. The latter policy guideline aims at better integrating the innovative digital technologies in everyday life; massive data sharing, artificial intelligence, internet of things, blockchains are only examples of such digital technologies.

Another initiative launched in 2020, the New European Bauhaus (EuropeanCommission, A New European Bauhaus: op-ed by Ursula von der Leyen, 2020) initiative, finds solutions to complex societal problems and links the European Green Deal to challenges of everyday life.

One of the most recent policy actions by the European Commission is the EU Action Plan (October 2022) for digitalising the energy system (EuropeanCommission, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS: Digitalising the energy system - EU action plan, 2022). The plan focus on enforcing the energy system and promoting its digitalisation, yet making it clear that digital technologies are of vital importance for the future energy system, while interoperability is fundamental for the co-existence of such technologies.

As it can be deducted from all the above policy guidelines, the energy system is moving towards its digitalisation, where intelligent and innovative digital systems will facilitate the exchange of information on the energy grid and reassure the security of energy supply, while working in an autonomous way. All these innovative digital systems need to work with each other, thus guaranteeing the correct exchange of information. For this reason, interoperability is fundamental for the correct functionality and the evolvement of the energy system, without which, the energy supply and the integrity of the whole system are jeopardised.

As its name implies, the SGIL works in the interoperability field of the energy system, thus contributing to all the above policy guidelines and to a greener energy system, where energy is produced/consumed efficiently; hence reducing its carbon footprint and reassuring a climate neutral continent.

Its work focuses in promoting the interoperability between digital systems and provide evidence for policy support as well as monitor the implementation of existing policies. It is actively involved in European research projects, offering its infrastructure for usage by the scientific partners. It also developed a structured methodology for interoperability testing, which promotes and uses for testing purposes for various use cases including European research projects.

During 2022, the SGIL has been actively involved in monitoring the effort to apply the European Commission policies at European level, by running Observatories and EU surveys and leading review paper works. The monitoring activities have been focused around the Clean Energy Package and its implementation across Europe. Various aspects of the Clean Energy Package were examined and the extent to which they have been implemented in Europe was monitored. Such monitoring revealed interoperability issues among systems in various Member States, which proves that interoperability is an important issue and should be tackled in the most efficient way for a more robust energy system and the correct functionality among its components.

The work of the SGIL was recognised by the EU Action Plan for digitalising the energy system, where the work of the SGIL is mentioned in connection with the creation of the future Code of Conduct for Energy Smart Appliances Interoperability. This latter work is port of one of the Administrative Arrangements (AA) that the SGIL team signed with DG ENER (JointResearchCentre, Smart Electricity Systems and Interoperability, 2023); it aims at creating the basis for future policies by the European Commission. Another AA between the SGIL and DG RTD has to do with the Progress on Competitiveness of Clean Energy Technologies; the project monitors the progress of specific Clean Energy Technologies, as the name implies, and the SGIL contributed to the final report, which was adopted as part of the Governance Implementation Package (EuropeanCommission, REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL: Progress on competitiveness of clean energy technologies, 2022). These two AA are only examples of the collaboration works held between the SGIL and various DGs. These two works have taken place during 2022, the year of activity targeted in this report.

2.2 Interoperability and its role in the Digitalisation of the Energy System

The energy system is moving towards a new era, where automation plays a key role, including the integration of RES and effectively managing energy with programs like demand response. The grid of populated areas is becoming smarter: homes are equipped with ESA and energy communities are emerging. The consumers are empowered, being able to control remotely the functionality of their appliances and managing their consumptions as they wish. In addition, the consumers become prosumers, thus they not only consume energy but also produce it through photovoltaic panels or other alternative ways. In general, the energy grid becomes equipped with intelligent electronic devices (IED) and numerous other intelligent apparatus, ready to provide automatic control of the system and an effective management of the energy along with guaranteeing the security of energy supply.

The energy grid needs to be managed in an effective way, but it also needs to handle big data stemming from all sorts of new applications, like advanced metering infrastructure data for energy consumption and production. Data platforms and hubs are created for this scope to collect data in a more efficient way from the end consumers and further on transmit it to the energy provider. Control mechanisms are necessary along with authentication and encrypting technologies to ensure that data access is guaranteed only to authorised personnel. Automatic control of the energy system devices is also crucial to manage the energy and make the system able to react in emergencies. Communication among different actors of the energy system is necessary as well, like DSOs and aggregators, who need to exchange data correctly for the realisation of the various energy programs. In addition, such actors need to communicate with the various software needed to control the energy system, like Head-End systems, control platforms, network access points.

From all the above it becomes clear that the energy grid is becoming digital with numerous Information and Communication Technologies (ICT) to control and effectively manage the energy produced and consumed. All these systems need to interact correctly with each other and information needs to be exchanged correctly. Thus, interoperability is important and needs to be maintained for the correct functionality of the components comprising the energy system. 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.

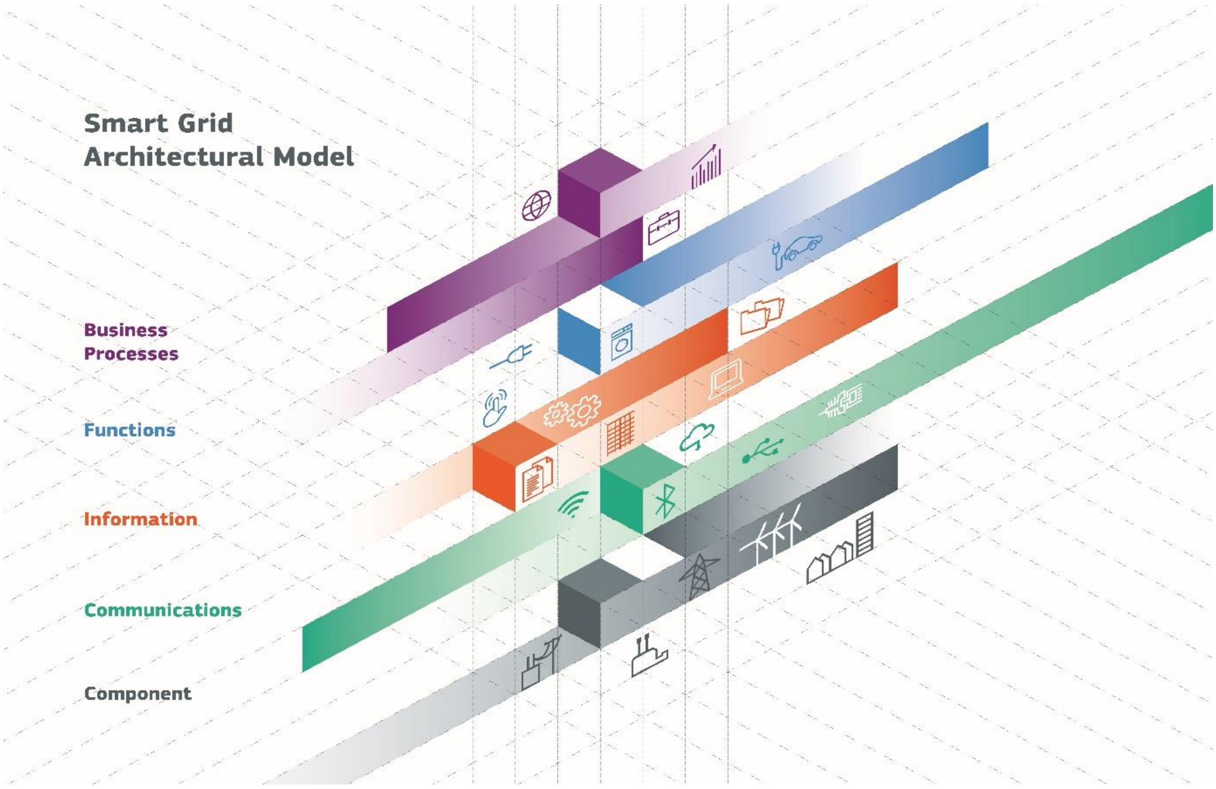
At the same time, interoperability is also crucial for the end consumers of energy/electricity, since it ensures that future replacements of systems/components will not compromise the services offered to them.

Alternatively, interoperability ensures that end customers who choose to change their energy provider or aggregator (in case they have a contract with an aggregator) will have the opportunity to have the same level of services. Therefore, it is fundamental to maintain interoperability to protect customers' rights and guarantee the security of energy supply.

Interoperability entails five layers: component, communication, information, function and business layer. Each layer describes the interactions of systems from a different point of view. Figure 1 shows the interoperability layers, as these are presented by the Smart Grid Architecture Model (SGAM) (CENELEC, 2012). A small description follows:

- the component layer describes interoperability in terms of physical connections;
- the communication layer describes the ability among systems or components to communicate with each other, i.e. the ability to send messages and receive messages;
- the information layer describes the ability of components or systems to correctly communicate with each other;
- the function layer describes interoperability in terms of functions;
- the business layer describes interoperability from the perspective of business applications.

Figure 1. Interoperability layers according to SGAM



Source: JRC, 2018

Given the diversity of the systems and components comprising the energy system, it is obvious that interoperability is not an easy task to achieve. This is because all systems and components follow different standards or protocols and are often based on different technologies, making interoperability between them difficult. 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 from an entity, such as the European Commission, includes to:

- 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, meaning that the role of the European Commission is not limited to the above tasks. However, it can be easily concluded that interoperability is not a straightforward matter and its achievement needs coordinated work from dedicated teams.

The SGIL, as part of the European Commission, works towards this direction, serving the above tasks in the field of interoperability. For this purpose, it created a structured methodology for interoperability testing in the smart grids (Papaioannou I., 2018) following CEN/CENELEC standards. The procedure respects the creation of Basic Application Profiles (BAP) and Basic Application Interoperability Profiles (BAIOP), whereas conducts tests in a structured manner. This methodology is used in the use cases developed by our team.

The SGIL work is not limited to testing interoperability, but it expands in many other fields related to interoperability. For example, the high level equipment of the SGIL usually offered to scientific groups creating new partnerships with them for the realisation of various research projects. Additionally, a tremendous work has been done so far for policy support in the interoperability field, either by providing scientific evidence for future policies or by providing feedback for the application of already existing policies, which assist on monitoring the situation related to interoperability across Europe and beyond.

2.3 The scope of a Laboratory for Interoperability

As it can be concluded from the above Sections, interoperability plays a key role for the digitalisation of the energy grid and there are various ongoing or planned policies that address the issue of interoperability: ensuring that all components communicate properly with each other. However, in a sensitive topic like interoperability, where decisions are made about which system/component can function properly within another system or device, strong evidence and proofs from experimental campaigns are needed. Such testing can take place only in a well-equipped laboratory, such as the European Commission and its in-house research centre, the Joint Research Centre, who can act as a neutral actor and provide scientific evidence for interoperability through laboratory campaigns. For this reason, the role of the SGIL is crucial, as it can not only give scientific evidence about interoperability, but it can also act as a neutral actor in the research and industrial community in the interoperability field.

As it has been aforementioned, the SGIL developed a structured methodology for interoperability testing. This methodology provides an official way of testing systems and/ or components to verify whether they fulfil interoperability requirements. The methodology is supported by several use cases developed by the SGIL team (or others), which show a clear way of how to conduct interoperability tests for smart grids. The SGAM is considered and the whole procedure is based on CEN/ CENELEC documents.

The use cases developed by SGIL were also tested within its premises using its high level instrumentation. The SGIL has a wide network of partners within the research and industrial community especially in the framework of research projects in which it regularly participates.

Moreover, the SGIL team holds many activities in interoperability, thus enriching its knowledge and know-how in the field. Apart from leading test campaigns, it works closely with policy makers providing feedback for new policies and monitoring the application of already existing ones. This way, the team acquires specific knowledge in the field and is in the position to identify gap areas for further testing activities in specific fields.

2.4 Smart Grid Interoperability Lab in Petten

The SGIL in Petten focuses on Smart Home activities. Smart Homes and, in general, Smart Buildings are a core element for the smart grid. As mentioned, they can empower consumers and transform them in active members of the energy grid digitalisation so they become active consumers or prosumers. And they can facilitate the integration of RES and the integration of ESA. In addition, with directly interacting with end consumers, they can promote the adoption of new digital services for the energy grid. This is of vital importance, since the uptake of new services such as peak shaving of energy consumption when there are constrains in the energy distribution either due to grid capacity or generation capacity by renewables. This depends also on the collaboration of the public and the benefits provided to citizens. Therefore, it is fundamental to inform them well and give them the necessary means to participate in novel digital programs and services offered. For this reason, smart homes are considered to play an important role and, by focusing on their activities, the SGIL is pushing for the future smart society.

In the previous release of the SGIL annual report, the available infrastructure in both laboratories, Ispra and Petten, were described and displayed using photographs. In this version, we only list the available infrastructure and give the focus of activities. In the following chapter, we also describe in detail the work of the SGIL in the interoperability field.

In Petten, the infrastructure available is listed as follows:

- 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

Furthermore there is an activity to set up a new moveable and transportable Smart Home Demonstrator as shown in Figure 2. This setup allows simple testing of use cases been defined in the interoperability testing methodology.

Figure 2. New simplified Smart Home setup for interoperability testing.

Source: JRC, 2022

The SGIL in Petten aims at promoting interoperability between smart homes and the smart grid. The role of SGIL is given, but is not limited, as follows:

- Testing interoperability of components or systems from research projects and the market based on proven use cases;
- Improve the visibility and usage of the interoperability testing methodology for smart grids;
- 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;
- Create a collaboration network with European laboratories, research centres and industrial actors to work for common objectives.

2.5 Smart Grid Interoperability Lab in Ispra

The Smart Grid Interoperability Laboratory in Ispra focuses on promoting interoperability for the distribution network. It works on innovative technologies applied on the distribution network along with novel programs promoting energy services. Among others, it examines interoperability issues related to the integration of electric vehicles (EV) to the grid, focusing on the impact when these are introduced at massive scale. It promotes innovative energy programs, like demand response in residential customers and the role of interoperability, whereas it also fosters the creation of a network of laboratories and the creation of energy communities. Its activities also entail policy support for clean energy technologies, by monitoring their implementation across Europe and beyond, also referring to their interoperability barriers. During this year, the SGIL in Ispra has been involved in experimental campaigns with interoperability as its core objective, in the topics of interest during the 7 years of its operation.

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 SGIL Ispra activities is similar to its twin in Petten, with the difference that the focus is here the distribution energy grid. These activities are summarised as follows:

- Testing and promotion of hardware/software interoperability solutions for the electricity distribution network;
- Improve the visibility and usage of the interoperability testing methodology for smart grids with novel use cases and by promoting the Use Cases Repository Website (JointResearchCentre, Smart Energy Systems and Interoperability, 2023);
- 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.

2.6 Who is benefitting from SGIL activities?

The SGIL is the in-house research laboratory for interoperability of the European Commission and serves a multiple purpose, as it can be deducted from the above sub-sections. First, it serves for providing policy support for interoperability in the energy field. For this reason, it collaborates closely with DG ENER and policy makers in the field, giving scientific evidence as feedback for ongoing policies as well as for future policies in the energy field. It serves as the in-house testing facilities of the European Commission for testing systems and components related to interoperability, and being its role as a neutral actor fundamental in the decision making of the interoperability field, i.e. deciding if a system/component is interoperable or not.

As a result, numerous actors are benefitting from SGIL activities, like:

- Consumers, who can benefit from interoperable systems/ components in the market, meaning that with the substitution of a component with another, the system' s performance is not compromised, together with the services that can be offered to them.

- Manufacturers, who can rely on the neutral judgement of the in-house research centre of the European Commission in terms of interoperable systems/ components.
- Policy makers, who can receive first-hand scientific evidence for supporting ongoing policies and for laying the ground for new future policies in the energy field; in the same time they can receive valuable information about possible gaps in the already existing policies.

3 Policy support achievements

The SGIL has played a vital role in policy support during 2022, having participated in two AAs with DG ENER and DG RTD for providing scientific evidence for policy. The description and the results from these AAs are described in this chapter.

3.1 Providing evidence for monitoring existing policies

The SGIL participates in the AA with DG RTD aiming at supporting the development and implementation of an evidence base for energy policy and research and innovation policies in the field of clean energy technologies.

The work under this AA comprises the execution of the project "Clean Energy Technology Observatory" (CETO) (EuropeanCommission, Clean energy competitiveness, n.d.) and the realisation of the Competitive Project Report (CPR) with respect to Clean Energy Technologies. Particularly for CETO project, it monitors the progress of EU research and innovation activities on clean energy technologies that serve the European Green Deal policy guideline. In addition, it assesses the competitiveness of the EU clean energy sector and its role in the global energy market.

Such work is a periodic exercise and is the basis for future developments in the field, as it gives the necessary background for current limitations in the examined fields, challenges and improvements needed from a policy perspective.

3.1.1 Clean Energy Technology Observatory – CETO

The CETO project, as it has been mentioned in the above, aims at monitoring the extent at which the European Green Deal is being implemented and identifying potential gaps with respect to clean energy technologies. Additionally, it assess the role of the EU energy sector in the global picture. The CETO provides feedback to the policy making process and is expected to enhance the resulting policies in the energy sector.

The SGIL team has worked during 2022 for the CETO project, in particular for the Energy System Integration Strategy (EuropeanCommission, EU strategy on energy system integration, n.d.). The work has been focused on five integration system technologies that can be used for the smart grid. These five technologies are:

- Transmission innovation (TI);
- Grid-scale storage services (GSSS);
- Electric vehicles smart charging (EVSC);
- Advanced Metering Infrastructure (AMI);
- Home Energy Management System (HEMS).

The system integration technologies were assessed by the SGIL team according to various indicators, listed as follows:

- Technology Development and Trends, including technology readiness level, costs and revenues, R&I&D funding;
- Value Chains;
- Markets Trade and Resources, including global market analysis.

The results of the respective analyses are published in a dedicated European Commission Report (Prettico, 2022), making part of the CETO project reports 2022 (EuropeanCommission, SETIS - SET Plan information system, 2022).

The assessment of the system integration technologies was realised by taking into consideration all possible sources of information and thus completing a thorough literature review, along with interviews with stakeholders of interest, who play a key role in the examined technologies; i.e. associations promoting the adoption of any one of the above technologies.

The main conclusions from the detailed analyses that took place are categorized and summarised below.

Transmission network innovation

The transmission infrastructure needs to undergo expansion and capacity upgrades to integrate large amounts of renewable production. The needs for investing on the transmission network are listed as:

- 70% of the planned RES in the decade 2020 – 2030 will be connected to distribution electricity networks;
- 77% of the DSOs participating in the latest DSO observatory exercise declared that they prepare a multiyear network development plan;
- Non-wire investments, aimed at more efficient monitoring and control of grids, should be prioritized given the increasing demand for metals, like aluminum and copper, required for electric cars and batteries manufacturing.

Grid-scale storage services

Storage is fundamental as a technology for system integration in smart grids. The following points summarize the 2022 analysis:

- Several network services can be provided through bulk storage. Additional energy during peak demand can be provided through participation of storage in capacity schemes; frequency and voltage regulation of the system can be achieved through storage; prevention of system congestion can be also achieved;
- It is expected that, in the next 10 years, the growth of new grid storage assets will be exponential all over the world, reaching a cumulative 160GW of power by 2026 and 360 GW by 2030; this trend is led by the US and China, while the EU is lagging in terms of investments and new storage capacity;
- There is expected to be a reduction of batteries cost by 2030 in the order of 40%, whereas the storage grid assets are expected to experience a decrease in their costs by around 30%;
- Storage technologies participated in 36 research projects with an estimated funding of 357.5 M€.

Electric Vehicles smart charging

It is envisaged that the Electric vehicles smart charging market will be the fastest expanding in smart grids. The following points summarize the 2022 analysis:

- There is the need to develop common standards to guarantee the interoperability of charging networks and perform V2G operations;
- The distribution grids should be able to handle the electric vehicles demand in electricity by 2030;
- The market leaders are China, Japan, India, countries in the Asia Pacific, whereas Europe holds a big share of the global smart EV charging market related to revenue.
- From a technological point of view, the technology to support smart EV charging (including its most important types such as V1G, V2G, V2X) is already available and is being been tested through many pilot projects.

Advanced Metering Infrastructure

The focus of our analysis was placed on smart meters. The main points that came out are as follows:

- The smart meter roll-outs in Europe varies a lot depending on the country;
- In terms of technologies, NB-PLC was used widely especially at early stages of smart meter deployment, whereas LPWAN also emerged. There are numerous key vendors not only for smart meters, but also for the other AMI parts, like the HES and the MDMS;
- It is estimated that 1.2 billion smart meters have been installed so far, being USA, EU and Australia their early adopters, whereas there is an importance improvement in smart meter installations in Asian countries, like China, Japan, South Korea. South Asia is considered the area where the largest investments in the sector is predicted for the future.

Home Energy Management System

Such systems are considered to play a key role in the future energy grid, as they empower end customers, they are fundamental for providing energy services to consumers and they facilitate energy management. The following points emerged from our analysis:

- Demand Response programs are expected to boost the participation of consumers in energy management and thus the market for HEMS will be benefitted;
- Countries like Germany and France are leaders in Europe: the German market is foreseen to be the leader in the Europe Home Energy Management Market by Country until 2027, achieving a market

value of $458.9 million by 2027; the French market is expected to showcase a CAGR of 20.3% (2021 - 2027);
- From the industry point of view, the companies that play a key role in HEMS market are (the list is not exhaustive): Cisco Systems, Panasonic Corporation, General Electric, Hitachi Ltd., Honeywell International, Inc., and Johnson Controls International, amongst others. Examples of software companies are: Google, Apple, and Cisco;
- An identified gap in the field is the lack of standards and of interoperability index, which will help identifying the technologies that can be interoperable with each other.

The CETO project is expected to be continued in the future, thus giving a clear idea of the clean energy technologies in the market and the extent at which the European Green Deal policy guidelines are put into force across Europe. It is also expected to give a clear picture of the role of Europe within the global market, thus revealing the impact European actors have in the overall picture of global players in the field.

3.1.2 2022 Competitive Project Report (CPR)

Apart from the CETO project, the work included and described by the AA, indicated the realisation of the CPR with respect to Clean Energy Technologies. This report contains an update of the current CPR indicators and, in alternate years, an assessment of the R&I project developments. The indicators are:

- Technology readiness level;
- Installed capacity & energy production;
- Technology costs;
- Public and private RD&I funding;
- Patenting trends;
- Scientific publication trends.

The SGIL team contributed to the creation of the CPR, where the above indicators were considered to assess the above five Clean Energy Technologies, namely: Transmission innovation (TI); Grid-scale storage services (GSSS); Electric vehicles smart charging (EVSC); Advanced Metering Infrastructure (AMI); Home Energy Management System (HEMS). In particular, the CPR contains a dedicated Section for “Smart Technologies on Energy Management”, where the main findings from CETO project with respect to the five Clean Energy Technologies are described.

As it has been already declared, this CPR is a periodic report depicting annually the developments related to Clean Energy Technologies. The reader is directed to the above Section (CETO project description) to learn about the findings of the five identified clean energy technologies.

3.2 Laying the ground for future policies – Support on the development of policy proposals for Interoperability of Energy Smart Appliances

During 2022 the SGIL has worked closely with DG ENER in the framework of an AA for the project “Support to the development, implementation and review of relevant provisions of EU Energy Efficiency legislative framework, related actions and related governance issues (JRC-TSEED III)”. Particularly, the work of SGIL focused on the work package entitled: “WP 2 - Technical and scientific support to the review of EU Energy Efficiency legislation including energy performance of buildings and products” and more specifically on Task 2.4 related to “Support on the development of policy proposals for Interoperability of Energy Smart Appliances”.

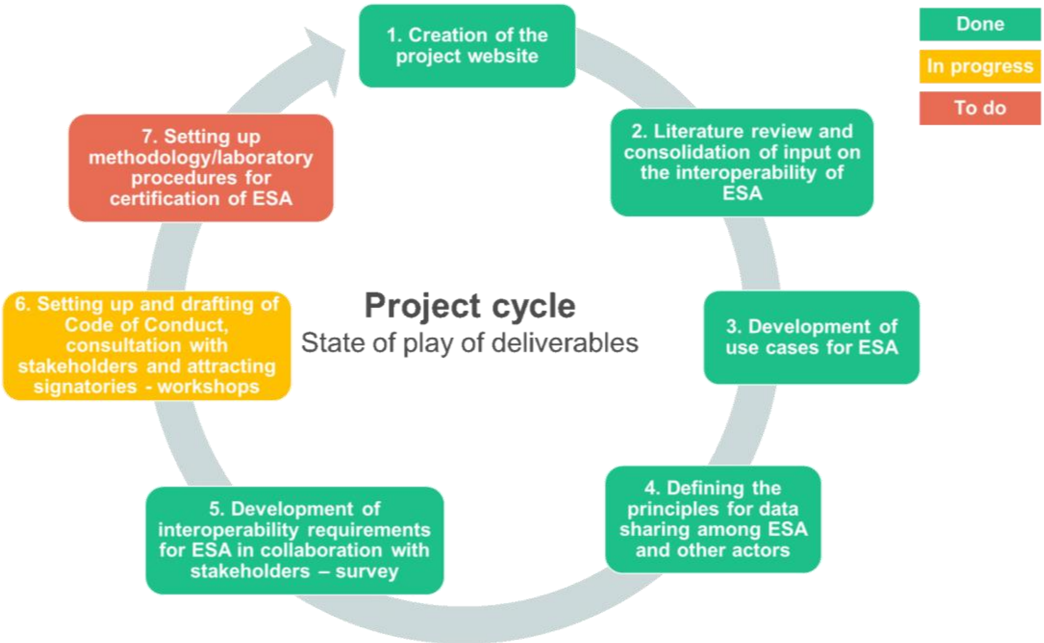
The task, as its name implies, supports the development of new policies for the interoperability of ESA. The SGIL, with its experience in the field of interoperability, was considered as the most suitable entity for this work. The project in total consists of different milestones and sub-tasks. Whereas many of these tasks have been fulfilled during 2022, the final objectives are under elaboration because the project is still ongoing. The list of sub-tasks is showed as follows:

1. Creation of website
2. Literature review and consolidation of input on the interoperability of Energy Smart Appliances (ESA)
3. Development of use cases for ESA
4. Defining the principles for data sharing among ESA and other actors
5. Developments of interoperability requirements for ESA in collaboration with stakeholders – survey

6. Setting up and drafting of a Code of Conduct (CoC), consultation with stakeholders and attracting signatories – workshops
7. Setting up methodology/laboratory procedures for certification of ESA

Figure 3 shows the status of the milestones as by the end of 2022.

Figure 3. Project "Support on the development of policy proposals for IOP of ESA" cycle as of December 2022.



Source: JRC analysis, 2022.

As it is displayed in Figure 3, during 2022, the work of SGIL resulted in finalising 5 tasks for the support on the development of policy proposals for the interoperability of ESA. Task 1 was of a technical nature, meaning that the project website was simply created by a website designer. Tasks 2 – 4 were fully executed by the SGIL team and, as a result, a technical report was published (Papaioannou, 2022). Task 5 had to do with the involvement of stakeholders in the project; hence an EU survey was carried out by the SGIL team, and a report is being produced as a result. In the following subsections we present the summary of these tasks.

The work described here, is intended to be the basis for future extensions of the aforementioned Code of Conduct, providing with specifications for other energy smart appliances and forming the basis for future regulations for demand response. Thus, the importance as well as the challenges for future work are great, as this is the foundation for a series of policy support works in the field.

3.2.1 JRC technical report – **Energy Smart Appliances' Interoperability: Analysis** on Data Exchange from State-of-the-art Use Cases

The report is the result of the work accomplished for Tasks 2-4 of the project. Therefore, it includes: a literature review regarding the interoperability of ESA, several use cases that built up for ESA, and the definition of the principles of data exchange between ESA and other actors.

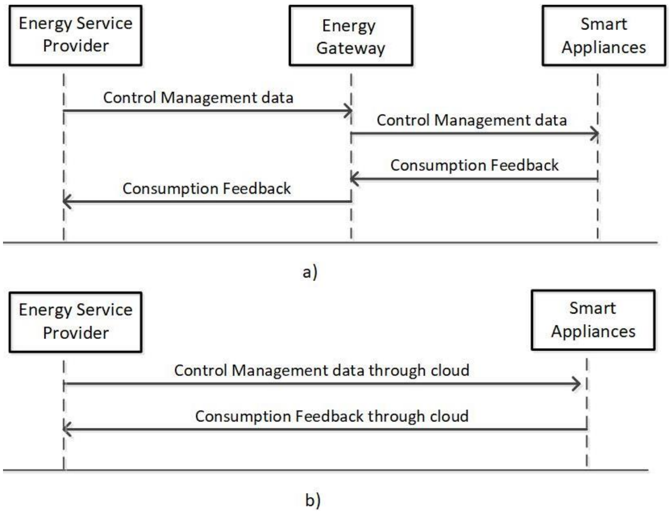
For the literature review, a variety of sources were considered to depict the situation with respect to ESA interoperability and the principles of data exchanging. The list the sources that were considered is here presented:

- First Phase of the Ecodesign Preparatory Study on Smart Appliances (Lot 33): Methodology for Ecodesign of Energy-related Products (MEErP) Tasks 1-6;

- Second Phase of the Ecodesign Preparatory Study on Smart Appliances (Lot 33): Methodology for Ecodesign of Energy-related Products (MEErP) Task 7;
- Interconnect – Deliverable 1.2: Mapping between Use Cases and Large-scale Pilots;
- Interconnect - Deliverable 5.2: Data Flow Management;
- European Smart Grids Task Force - Expert Group 1 – Standards and Interoperability;
- Public Available Specification (PAS) 1878:2021 Energy Smart Appliances – System Functionality and Architecture – This British Standard Institution (BSI);
- Policy Guidance for Smart, Energy-Saving Consumer Devices - The Electronic Devices & Networks Annex (EDNA) of the International Energy Agency's (IEA) Energy Efficient End-Use Equipment (4E) Technology Collaboration Programme;
- Are we getting the best out of Smart Home Technologies? The Role of Usability -– Energy Efficient End-Use Equipment4E- - Electronic Devices and Networks AnnexEDNA – Use Centred Energy Systems.

Following the above sources examined, a categorization of use cases took place. A first categorization of ESA can be as simple enough to distinguish the use cases according to the presence of a gateway or not. Figure 4 shows these two diverse categories of use cases.

Figure 4. Message sequence chart for generic Use Case, a) Communication of energy smart appliances through the home energy gateway, b) Communication of energy smart appliances directly to the energy service provider through the cloud.



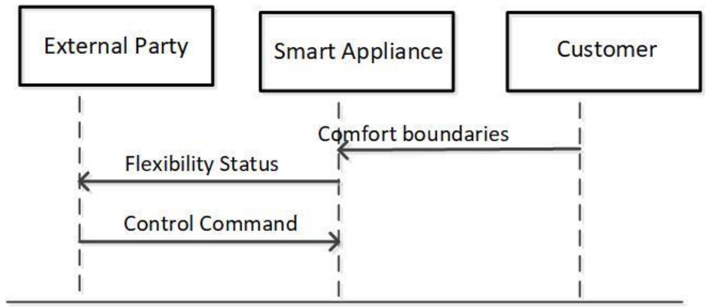
Source: JRC analysis, 2022.

According to the Second Phase of the Ecodesign Preparatory Study on Smart Appliances – task 7, there can be 4 main categories of use cases for ESA, which are:

- Explicit Demand Response Use Cases;
- Implicit Demand Response Use Cases;
- Local optimal energy consumption Use Cases;
- Standalone Demand Response Use Cases.

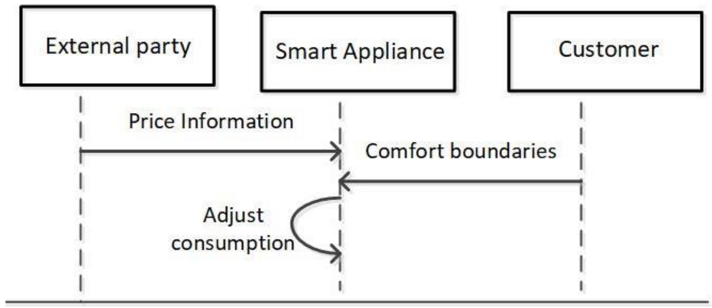
The following Figures (Figure 5 – Figure 8) show the representation of these use cases in terms of message sequence charts.

Figure 5. Message Sequence Chart for the generic Use Case of explicit demand response.



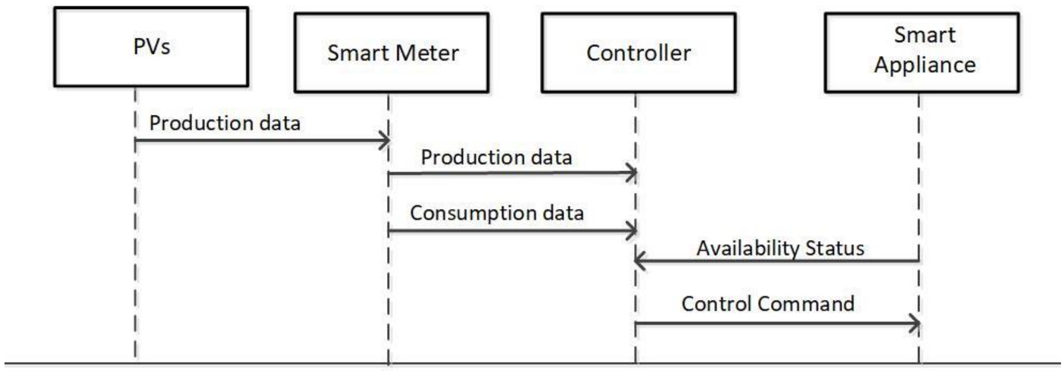
Source: JRC analysis, 2022.

Figure 6. Message Sequence Chart for the generic use case of implicit demand response.



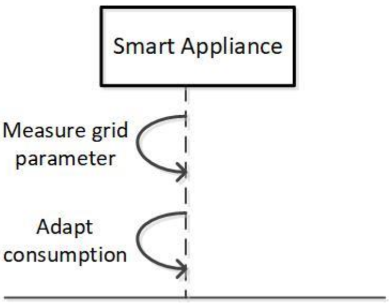
Source: JRC analysis, 2022.

Figure 7. Message Sequence Chart for the generic use case of local optimal energy consumption.



Source: JRC analysis, 2022.

Figure 8. Message Sequence Chart for the generic Use Case of Standalone demand response.



Source: JRC analysis, 2022.

The above categorisation was employed in the report, and all the literature review sources were examined by the SGIL to collect a pool of use cases for ESA. In total, 36 use cases were analysed and the message sequence charts were created, which show the interactions between the several actors. This pool of use cases were used as the basis for further analysis, and all use cases were attributed to one of the four categories mentioned above. The analysis performed revealed that the messages can be exchanged between ESA and the different actors. The SGIL team identified the categories of messages that can be exchanged and the actors that are involved in this exchange procedure. Table 1 shows the categorisation of messages and the various actors involved.

Table 1. Grouping of messages exchanged between the four actors and energy smart appliance.

				0 – Energy Smart Appliance ↕							
				Consumer control point		Energy service provider		Customer		Provider control point	
Data / Messages exchanged				0←1	0→1	0←2	0→2	0←3	0→3	0←4	0→4
Data management	Control Commands (CC) (1)		Switch On/Off	X		X		X		X	
			Schedule of activation/deactivation	X		X				X	
			Schedule time slot: Active/ Non-active	X		X				X	
			Time window duration	X		X				X	
			Override commands / stop activation	X		X				X	
		Energy	Store	X		X				X	
			Reduce	X		X				X	
			Consume (total/end-task/real-time)	X	X		X	X			
			Produce (total/end-task/real-time)		X		X	X			
	Feedback CC (1)		General acknowledge / Update (1)		X		X		X		X
			Conflicting message (1)		X		X				
			User presence or preferences (1)						X		
		Energy	Stored								
			Energy consumed		X		X		X		X
			Energy produced		X		X		X		X
Flexibility	Request		Availability status / Status update	X		X				X	
			Price information/ Tariffs		X		X	X		X	
			Schedule of charging								
			Control override							X	
	Broadcast (1)		Availability status / Status update		X		X		X		X
			Price information/ tariffs	X		X			X		X
			User presence or preferences (1)						X		
			Control overwrite event (external actor)					X	X		
Comfort boundary			Time slots for on/ off					X			X
			Duration of on/ off time slots					X			X
			temperature limits					X			X
Warning / Emergency			Emergency turn On/off						X		
			Warning (1)								
			Overload - consumption exceeds limits	X							
			Critical parameter notification			X				X	
I	a		Manual Switch: On/Off					X			

	Adjust/Adapt consumption					X			
	Activation of a non-smart appliance					X			

Source: JRC, 2022.

The numbers 0-4 showed in the table correspond to: 0 –> ESA; 1 -> Consumer control point; 2 -> Energy Service Provider; 3 -> Customer; 4 -> Provider control point.

The above categorisation of messages indicates the principles of messages to be exchanged to/from ESA. This categorisation was the basis for further work and the rest of the tasks of this project, i.e. the composition of EU survey, subsequent report, and all additional discussions with experts in the field to achieve the ultimate objective, creating the Code of Conduct for interoperability of ESA.

3.2.2 Survey on Interoperability of Energy Smart Appliances (ESA)

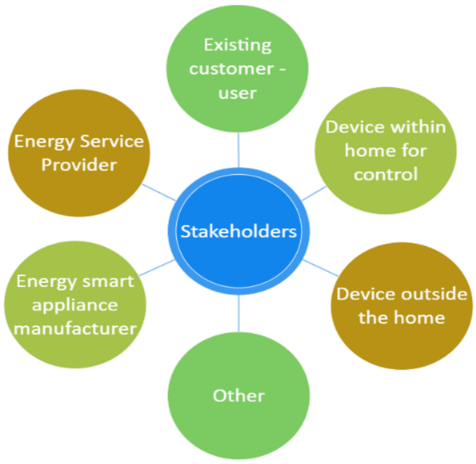
For accomplishing the task of successfully developing the interoperability requirements for ESA, it was considered essential to involve the relevant stakeholders. The goal has always been to involve as many stakeholders as possible since the beginning, so as the final CoC can be accepted by the majority of manufacturers or actors linked to ESA. For this reason, a dedicated EU survey was designed and sent to a pool of interested stakeholders and associations; the results are presented here (Andreadou, 2023).

The survey received feedback from 56 stakeholders in the field of ESA, which is considered a big number of participants given the tight deadlines programmed for the project. Figure 9 shows the types of stakeholders that participated in our survey. Various stakeholders were convened, including, but not limited to:

- Manufacturers of ESA;
- Manufacturers of Device for control within the house;
- Manufacturers of device for control outside the house;
- Energy Service Providers;
- Existing customers.

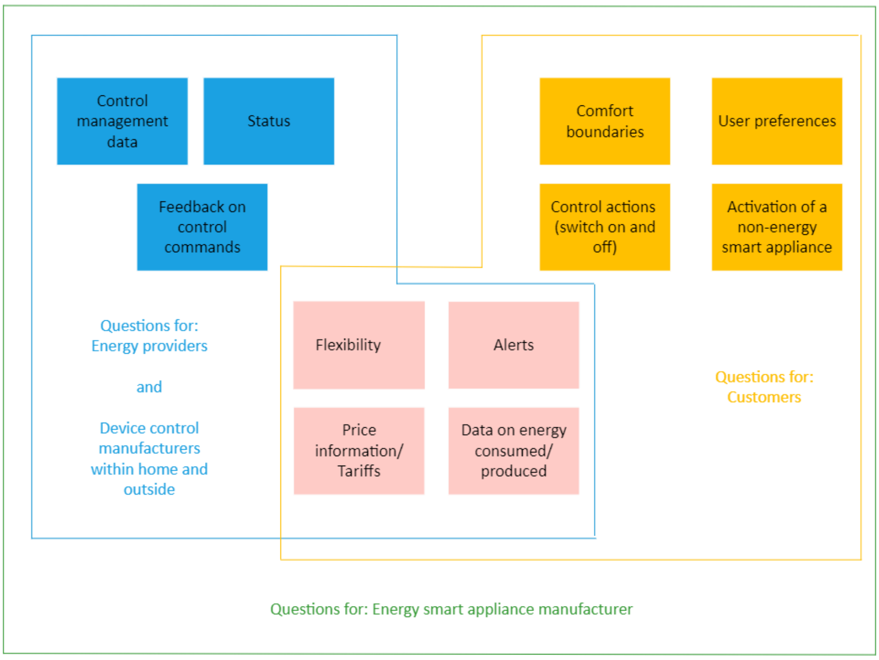
The survey questionnaire was dynamic; not all questions were directed to all participants. In general, there were three sections: general data (to identify type of stakeholder, location of lab, etc); technical data; data related to the acceptance of a CoC. In particular, the technical part of questions was quite dynamic; the questions displayed to each stakeholder were related to their activities. On the one hand, Figure 10 shows the technical data asked to each entity and the nature of the survey's questionnaire. On the other hand, Figure 11 shows the type of messages exchanged between ESA and the different stakeholders.

Figure 9. Type of stakeholder.



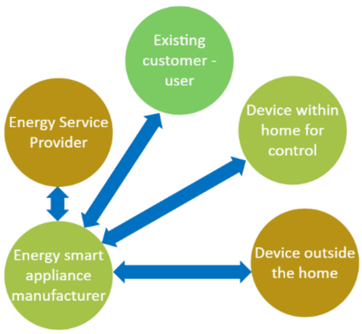
Source: JRC analysis, 2022.

Figure 10. Technical data asked for each entity



Source: JRC analysis, 2022.

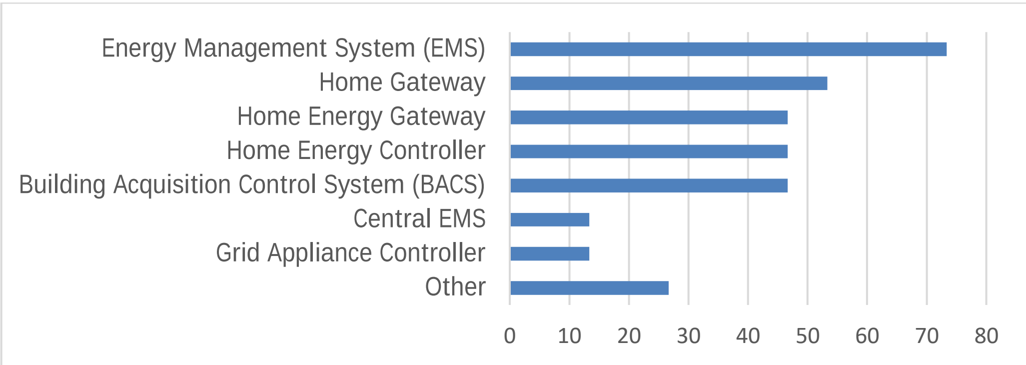
Figure 11. Messages exchanged between the ESA and the different stakeholders.



Source: JRC analysis, 2022.

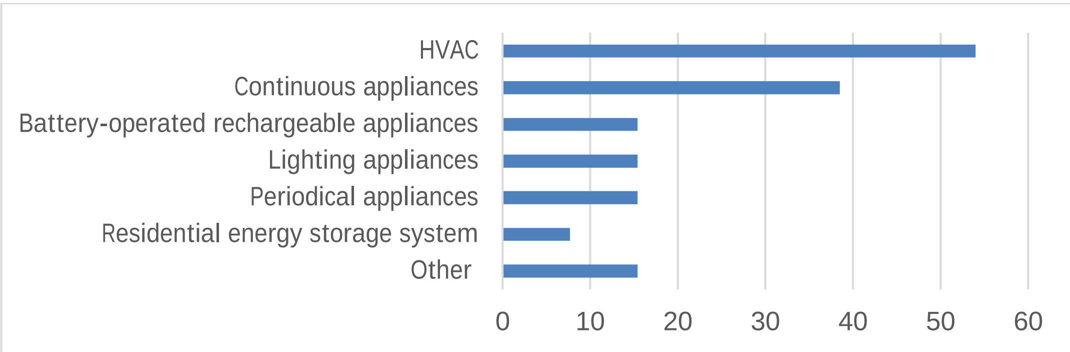
Some of the results obtained through the survey are summarised here. They can provide the reader an idea of the type of device manufacturers and the main messages that are exchanged between ESA and other actors. Figure 12 shows the devices that are manufactured as control devices within the house, where we observe that most manufacturers are related to Energy Management Systems or Home Gateways. The percentages shown are in relation to the overall number of manufacturers of devices for control within the house, according to the survey replies. The reader should take into consideration that the percentage do not add up to a 100% because some stakeholders declare activities in more than one type of device. Figure 13 shows the ESA that are manufactured by our survey participants. Again, the percentages presented are relative to the overall number of manufacturers of ESA.

Figure 12. Manufacturers of devices for control purposes within the house.



Source: JRC analysis, 2022.

Figure 13. ESA that are manufactured in percentage related to the active participants in the field.



Source: JRC analysis, 2022.

Regarding the messages exchanged, the reader is directed to the section, where the types of messages exchanged between ESA and the manufacturers are displayed in detail. At this point, we only present the dominant messages for each category, which is shown in Table 2.

Table 2. Message most offered between the ESA and the different stakeholders.

Between	Message most offered
ESA and Energy Provider	Data management
ESA and Device control within home manufacturer	
ESA and Device control outside home manufacturer	
ESA and customer	Comfort boundaries

Source: JRC analysis, 2022.

The results obtained in the survey also reveal which messages are the most common ones. Moreover, by revealing the principles of data exchange, the survey shows possible areas where the CoC could contribute in setting precise rules for the interoperability of ESA. All this information is crucial for the future CoC and that is the reason why the survey results were taken as the basis for the subsequent discussions with the stakeholders. Only by discussing and directly involving all interested actors, can the future CoC be successful and accepted by the majority of stakeholders.

3.2.3 Workshops and round-the-table discussions with experts – towards the Code of Conduct (CoC)

The survey and its results were the basis for further discussions with the interested stakeholders. In the last two months of 2022, one workshop was held together with one round-the-table discussions with few experts.

The workshop was advertised beforehand and invitations were sent to participants in advance. The participants were mainly those who reacted to the survey, together with some additional stakeholder that expressed interest in the CoC activities. Their contribution was also relevant and beneficial for the final outcome.

The workshop had a double scope:

- To present the results of the survey and the work done in the project so far;
- To launch the discussions about the content of the CoC with the experts.

To achieve an accurate CoC for interoperability of ESA, accomplishing its acceptance by a large part of stakeholders, it was regarded of vital importance to have in-depth and detailed discussions with experts linked to ESA. For this reason, a first round-the-table meeting was set in December 2022 for discussions the matter with some stakeholders that were considered to be essential to the final outcome.

As immediate future steps, set up a second round-table meeting with the experts, for further clarifying pending issues and defining the final content of the CoC, and a second workshop with the stakeholders are planned; they will take place in February and March respectively. In a nutshell, the following steps are described as:

- Set up the second round-table meeting with ESA experts to design the CoC in mid-February 2023;
- Finalize the first draft of the CoC and share it with stakeholders by the end of February 2023;
- Organize the second workshop with all possible invited stakeholders for the end of March 2023;
- Elaborate feedback on the draft of Coc (surveys) and finalize the document by the end of May 2023;
- Beyond the CoC and last milestone of the project; setting up the methodology/laboratory procedures for certification of ESA interoperability.

As it can be concluded from the above, the work done in the framework of this project is of vital importance, since it sets the basis for a future ecosystem where, for the first time, ESA are interoperable regardless of manufacturer. The CoC for interoperability of ESA, by providing manufacturers with a guideline to define the messages that their ESA exchanged with those form other manufacturers, can boost the market of these devices. The document can also help protect consumers' free energy market rights, since by maintaining interoperability, they can enjoy the advantages of the services offered by different energy providers.

4 Horizon 2020 Research Projects

The SGIL has participated in numerous research project since its foundation. In this Section, we analyse the research projects on which the SGIL team has worked during 2022.

4.1 DRIMPAC project

This H2020 research project initiated in September 2018 and was completed in 2022. The acronym of the project is translated into: "Unified DR interoperability framework enabling market participation of active energy consumers" (EuropeanCommission, Cordis - EU Research Results, 2017). As its name implies, the project promotes demand response programs for residential consumers. In addition, it promotes demand response for smart buildings, whereas it also contributes in manufacturing hardware to transform buildings into smart along with sophisticated software to manage the energy consumed and the flexibility offered to aggregators, system operators.

The project enables the participation of active energy consumers. It aggregates the flexibility of residential consumers and handles specific assets within the house. For the transformation of a building into a smart one, the smart box was been designed to communicate with the energy provider or the aggregator. For the facilitation of the messages exchange, a Demand Response Management System (DRMS) was designed, which helps the aggregator or energy provider to receive messages for the flexibility that can be offered by the assets within the house. On the other hand, it facilitates the exchange of command messages with respect to activating a flexibility or not within the house on behalf of the aggregator or energy provider.

The project entailed four pilot sites, where demand response services are offered to the end consumers. The pilot sites comprised of residential users as well as office users; in one of the sites a university campus was used to offer flexibility services to students.

In 2022, the SGIL team contributed in three reports, two of which were led by SGIL members.

Finally, it is worth mentioning that DRIMPAC and its performance evaluation (for which the SGIL team was responsible for) was mentioned in the recent EU action plan for digitalising the energy system (EuropeanCommission, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS: Digitalising the energy system - EU action plan, 2022).

4.1.1 D4.8 - Results validation & consumer satisfaction assessment

The purpose of D4.8 is to define a technical validation and evaluation framework towards assessing the fulfilment of DRIMPAC results to its original objectives; the results are presented here (Thomas, 2022). To evaluate the performance of the DRIMPAC solution, we calculated a number of Key Performance Indicators (KPIs) aiming at capturing the most important aspects of the services developed in the DRIMPAC project. These aspects include both quantitative and qualitative evaluations. The quantitative KPIs include metrics such as energy consumption reduction, energy cost savings, CO_2 emission reduction, etc. The qualitative KPIs measure the user acceptance of the DRIMPAC solution, the validation of the proposed business models, the level of visual/thermal comfort of the user when using the DRIMPAC solution, etc. Overall performance is assessed taking into account the complexity of the developed technologies and solutions. The performance evaluation focuses on full-scale experimental tests and flexibility assessment of applying the DRIMPAC system with a real-life operation model.

The SGIL team led the activities of this deliverable, which to do with the overall validation of the project results and with the assessment of consumers' satisfaction after the realisation of the demand response activities in the pilot sites premises. The report assesses all Key Performance Indicators (KPIs) of the project, which are divided in two categories: quantitative and qualitative KPIs. The first category comprises all KPIs that were evaluated using specific formulas, whereas the second category comprises KPIs that are related to the consumer satisfaction part of the project. The quantitative KPIs assessed in this project are listed as follows:

1. Distributed building demand response reliability – has to do with the number of successful demand response events in relation to the overall demand response events;

2. Energy consumption reduction in pilot demonstration sites and Annualized total energy demand reduction – has to do with the energy consumption reduction achieved after the demand response events took place;
3. Energy cost savings in pilot demonstration sites and Annualised energy cost savings in pilot sites during DRIMPAC interventions – has to do with energy cost savings after the implementation of demand response events;
4. Reduction of annualized CO_2 emissions in pilot sites – has to do with the reduction of CO2 emissions after the implementation of demand response events;
5. Peak load reduction during pilot demonstration activities – has to do with the peak load reduction due to demand response events;

The technical performance evaluation for the quantitative KPIs was performed using programming scripts developed by the JRC for this purpose. The DR data related to the KPIs was analysed and eventually compared with the baseline energy consumption to effectively calculate these KPIs. The analysis shows that the targets of the KPIs examined were either accomplished or very close to the initial target, hence ensuring substantial energy, cost, and emission savings (for example up to 50% in energy consumption reduction and up to 55% peak load reduction). The obtained results point to the DRIMPAC solution as a very promising platform for future real-life implementation.

The list for the qualitative KPIs is shown as follows:

1. User acceptance of Drimpac solution;
2. Visual/thermal comfort preservation – has to do with the comfort level of consumers during demand response events;
3. User acceptance of HCEMaaS service offering;
4. Demonstration and validation of 2 innovative business models for energy retailers;
5. DRIMPAC user acceptance.

The above KPIs are related to the user acceptance of the DRIMPAC solutions and were evaluated after some dedicated questionnaires were presented to ~~the~~ participants. The KPI related to the business models is excluded from the above procedure, as it is about the creation of two or more business models by the DRIMPAC team.

In overall, all above KPIs were validated and thus the project was assessed according to its predefined KPIs. In general, the KPIs proved to be satisfactory in almost all cases, and the overall project acceptance reached the target set from the beginning.

4.1.2 D4.10 – Information and Communication Technology (ICT) system integration & interoperability verification

This deliverable, as the name implies, has to do with the ICT system integration and interoperability. Since the SGIL team focuses in interoperability issues, we contributed to this deliverable by applying the smart grid interoperability testing methodology (Damousis, 2022).

The ICT integration phase involves specific equipment, like the edge equipment (sensors, actuators, smart devices and meters), the gateways and the cloud server that hosts all data processing software modules for buildings that do not possess a Building Energy Management System (BEMS).

Several tests were conducted to verify the interoperability between building components installed at the pilot sites of the residential/ commercial building sector. The SGIL methodology for testing in smart grids is regularly used to design the tests for interoperability by the SGIL team, defining the main use cases, the actors interacting, the Basic Application Profiles and the Basic Application Interoperability Profiles. The test steps were designed to maintain interoperability for the crucial links of interaction. Whereas the design of tests took place by the SGIL team, all tests were executed at the premises of the DRIMPAC partners' laboratories, since all hardware components are in their possession.

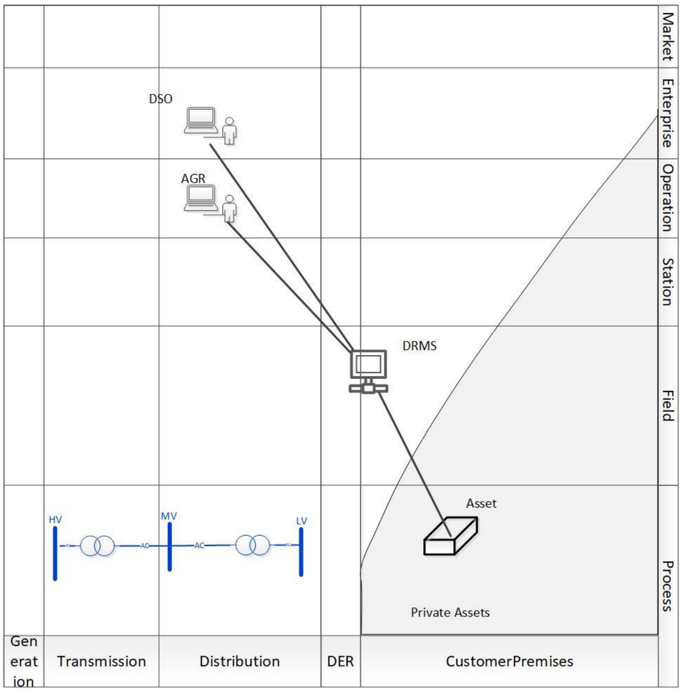
The SGIL identified three main scenarios for testing interoperability, namely:

- Interoperability testing for explicit demand response
- Interoperability testing for implicit demand response tests
- Interoperability test for the Components in the building domain

To give an idea of the actors interacting and the links of interactions for each scenario, we show in the following figures (Figure 14 to Figure 17) the SGAM representation of the component layers, as they were designed for the smart grid interoperability methodology.

For the explicit demand response scenario, the actors interacting are the DSO, the aggregator, the Demand Response Management System and the assets within the house. The concept is that the DSO or aggregator gets to control through the DRMS the assets within the house by sending control commands considering the flexibility that they could offer which is communicated through messages between DRMS and the asset. Thus, the link of interaction that was tested is the link between DRMS – asset. Figure 14 shows this representation.

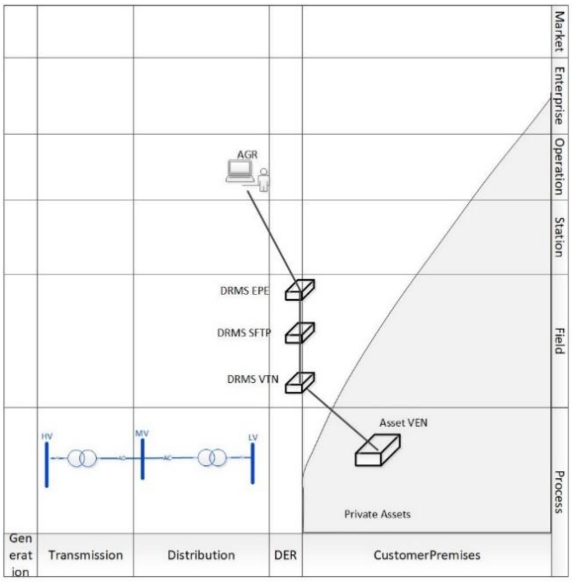
Figure 14. Representation on the SGAM of actors for the explicit DR scenario.



Source: *JRC, 2022.*

For the implicit demand response scenario, the actors interacting are mainly the aggregator, the DRMS components and the asset. The concept is that the asset should receive the price information deriving from the aggregator. The Asset stores the day-ahead information in its database, which is received correctly meaning that communication and information interoperability is maintained. Figure 15 depicts this scenario.

Figure 15. SGAM representation of the various actors for the implicit demand response scenario.



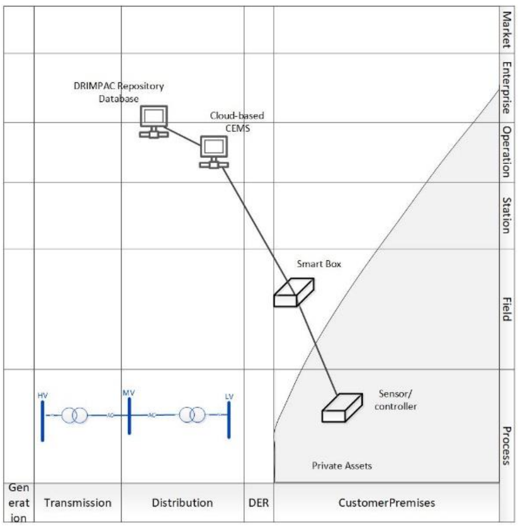
Source: *JRC, 2022.*

For the scenario where the building components are tested, our team identified two critical use cases, which are depicted in the following figures. Figure 16 and Figure 17 show these two use cases.

The first testing scenario involves the following actors: DRIMPAC repository database, cloud-based CEMS, smart box and the sensor/ controller within the building. The critical link of interaction was defined between the cloud-based CEMS and the smart box. The concept is that the cloud-based CEMS receives valuable information through the smart box about the flexibility of the assets, like the sensors, controllers and actuators. On the other hand, the smart box should be able to receive valuable messages from the CEMS to control the assets within the house.

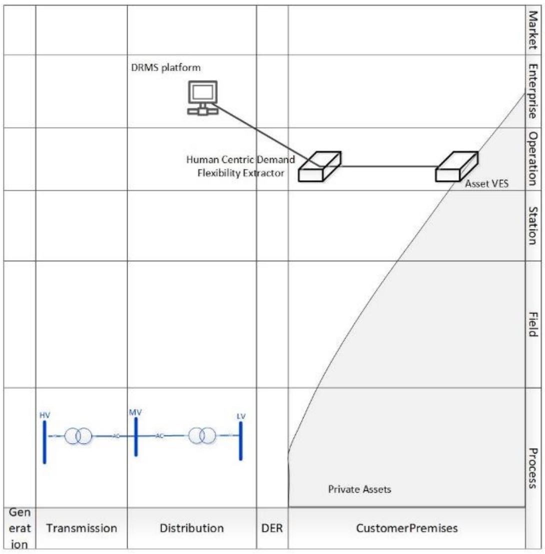
The second testing scenario involves the actors: DRMS platform, Human Centric Demand Flexibility Extractor and a part of the Asset. The critical link of interaction is between the Human Centric Demand Flexibility Extractor and the DRMS platform. The concept is to test the ability of the DRMS platform to receive flexibility messages from the Human Centric Flexibility Extractor to perform flexibility forecasting requests.

Figure 16. Representation on the SGAM of actors for testing the link between the Smart Box and the cloud-based CEMS.



Source: JRC, 2022.

Figure 17. Representation on the SGAM of actors for testing the link between the Human Centric Demand Flexibility Extractor and the DRMS platform



Source: JRC, 2022.

From all the above, it can be observed the importance of the Smart Grid Interoperability Methodology for testing in the smart grids. Only through a structured procedure can interoperability tests take place correctly and the methodology, following CEN/CENELEC standards can give this guarantee. All tests introduced above were physically performed in the premises of the partners' laboratories, after adopting the design of the tests and the tests steps. They were executed with success and interoperability was shown to be maintained.

4.1.3 D5.6 - Report on activities for the definition and promotion of DRIMPAC standardization punch-list

The SGIL, thanks to its role as the in-house research centre of the European Commission played a vital role in providing feedback with respect to the latest policies around energy topics and standardization developments in relevant fields (Andreadou e. , 2022).

For this deliverable, the SGIL team provided feedback with respect to the status of demand response in Europe and beyond and the latest standards in the field. In addition, it reported on the standards used in the framework of the DRIMPAC project and the gaps in these standards related to the DRIMPAC achievements.

Thus, this deliverable reports information about:

- The status of demand response in Europe, considering the latest developments in the field.
- The status of demand response internationally.
- The two standards used for realizing the DRIMPAC project: USEF and OpenADR. The two standards were employed for realizing the DRIMPAC functionalities among the components.
- The DRIMPAC smart building system and the system components along with extensions needed for the existing systems and standards to be compatible with the DRIMPAC framework.

With respect to the demand response status worldwide, some highlights are summarized as follows:

- In Europe, there is an increased interest for demand response development; the markets become more flexible to accommodate demand response and there are actions taken from a regulatory point of view. Specifically for market growth, an increasing growth was noticed between 2020 and 2021.
- In Australia, the demand response market is opened to consumers and aggregators since October 2021 with a wholesale demand response mechanism. Aggregated customers or large industrial customers are of interest to this market, since they can offer large amounts of curtailed demand. To this end, it is also noticeable the importance of aggregating electricity customers.
- In Singapore, changes are planned to take place in existing demand reponse programmes by the end of 2023 with focus in renumeration, penalty and compliance rules.

- In the USA, the Federal Energy Regulatory Commission facilitated the participation of distributed energy resources of more than 100 kW, including demand response, for the six capacity and ancillary services markets it regulates from August 2021.
- In China, regulations on operations and ancillary services are about to come into force to facilitate, among others, load aggregators in participating in power system ancillary services.
- In Chile, a power system flexibility strategy was initiated including regulatory frameworks for demand response.
- In Colombia, tax incentives are given to promote alternative sources of energy, including demand response options.

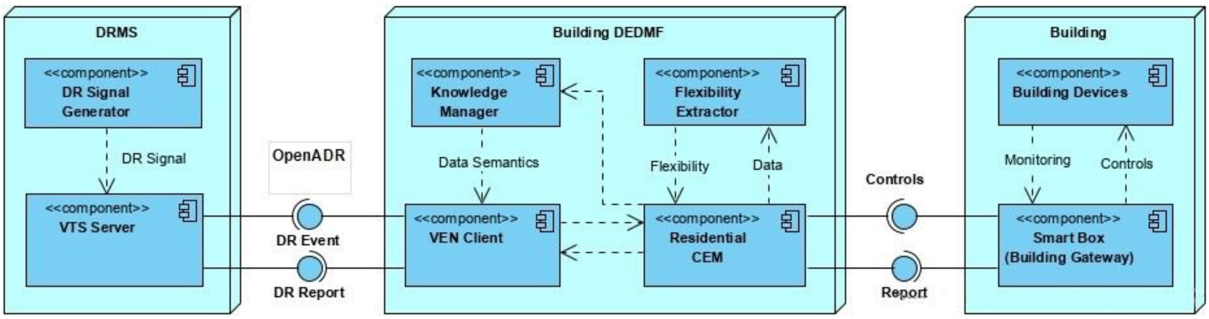
With respect to standardization work, we summarize the main work in the field, including specifications, protocols, etc:

- International Performance Measurement and Verification Protocol – IPMVP
- OpenADR Specification
- Universal Smart Energy Framework – USEF
- Energy management systems – Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) – General principles and guidance – ISO 50006:2014
- EN 13321-1:2012 – Open data communication in building automation, controls and building management – Home and building electronic system
- EN 50491 series – General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS)

For the two standards used by the DRIMPAC the following points summarise the work:

In the DRIMPAC interoperability layer, the OpenADR 2.0b protocol is implemented with the aim to provide standardized end-to-end communication between the market actors and the buildings. Figure 18 shows the architecture used according to OpenADR.

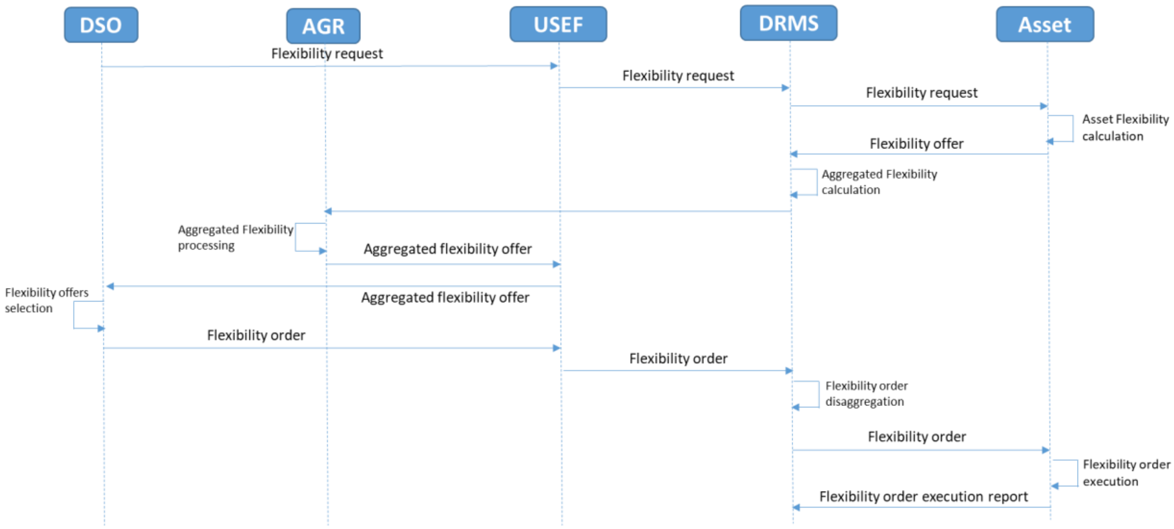
Figure 18. Deployment diagram of DRIMPAC end-to-end communication



Source: JRC, 2022.

Related to the USEF standard, several use cases were extracted from it and modified accordingly to depict the DRIMPAC's needs. Figure 19 shows the demand response scenarios with respect to USEF.

Figure 19. Explicit DR scenario steps



Source: JRC, 2022.

The work concluded in this deliverable identified a gap in the standardization process, meaning that there is a lack in standards for the automation components in the building sector.

4.2 European Research Infrastructure supporting Smart Grid and Smart Energy Systems Research, Technology Development, Validation and Roll Out (ERIGrid 2.0)

Since April 2020, the team of the JRC Smart Grid Interoperability Laboratory has taken part in the Horizon 2020 EU project, ERIGrid 2.0 (https://erigrid2.eu/), which includes 20 partner organisations from 13 countries, including Universities, Research Institutes, and a Grid Operator, and has a total budget of 10 million Euros.

The scope of the ERIGrid 2.0 project is to develop and refine research services and laboratory tools for the validation of smart energy networks. Committed to the holistic and cyber-physical systems-based validation approach, ERIGrid 2.0 aims to foster system-level support and education for industrial and academic researchers in power and energy systems research and technology development.

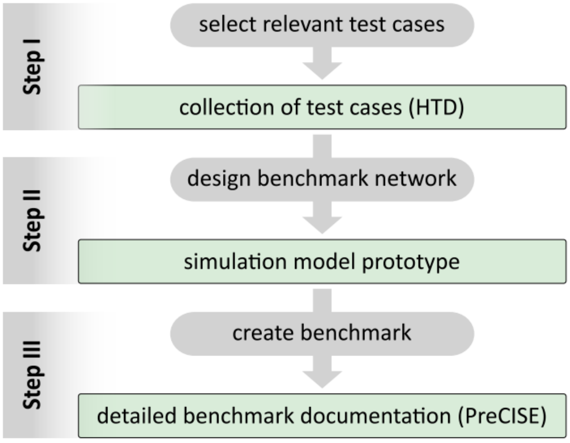
The activities of the SGIL in the context of the Erigrid 2.0 project are summarised in the next subsections.

4.2.1 Development of a novel methodology for open-source documentation of benchmark models for electricity systems.

Building up on previous activities on the design of benchmark models for low-voltage grids, the SGIL collaborates with the National Technical University of Athens and the Austrian Institute of Technology, with the objective of developing a codified methodology for the design and open-source documentation of electricity network models, (De Paola, 2023), (A. De Paola, 2022).

. A testing-oriented approach was adopted in order to facilitate a straightforward implementation and testing of the models, tailoring the design of the benchmark to the scenarios and features of interest. The open-source documentation of the network models relies on two established frameworks: the Holistic Test Description (HTD), used to characterize the test case for which the model is built, and the PreCISE paradigm, which allows to categorize and describe in detail the different components and features of the model. A schematic representation of the overall procedure that was designed for model development and documentation is presented in Figure 20.

Figure 20. Procedure for development and documentation of benchmark models



Source: JRC, 2022.

The use of the PreCISE approach for the model documentation allows to produce a compact characterization of all the relevant aspects of the benchmark model under exam, facilitating its implementation, testing and tuning by external users and practitioners. A comprehensive list of the different PreCISE elements utilised for documentation, together with a short description and some examples, is reported in Table 3.

Table 3. Overview of the aspect of the model documentation covered by the PreCISE approach

	Documentation of ...	**Type of information**	**Examples**
Test Applications	use case	desired dynamic behavior of the entire system	optimal storage operation, consumption reduction, peak shaving
	test case	specific implementation of a use case for an assessment according to a test objective	evaluate performance of peak shaving using a PV surplus and batteries on a sunny day
	test specification	defines how the TC's object under investigation is embedded in a specific test system	define load profiles of PV systems and loads and specify expected controller response
Reference Descriptions	system configuration	static system data	line impedances, network topology, nameplate data
	control function	extrinsic dynamic behavior of individual system parts	solar MPP tracker, constant flow pump, energy market
	input data	exogenous influence on the system and its components	weather data, EV driving patterns, energy prices
Modeling and Optimization	component model	intrinsic dynamic behavior of the system and its components	thermal storage, heat pump, battery, substation
	key performance indicator	provide a measure of performance for a certain system or component	district heat import, costs of electricity consumption
	objective function	maps values of one or more variables onto a real number, intuitively representing some associated "cost"	minimization of operation costs, maximization of exported energy

Source: JRC, 2022.

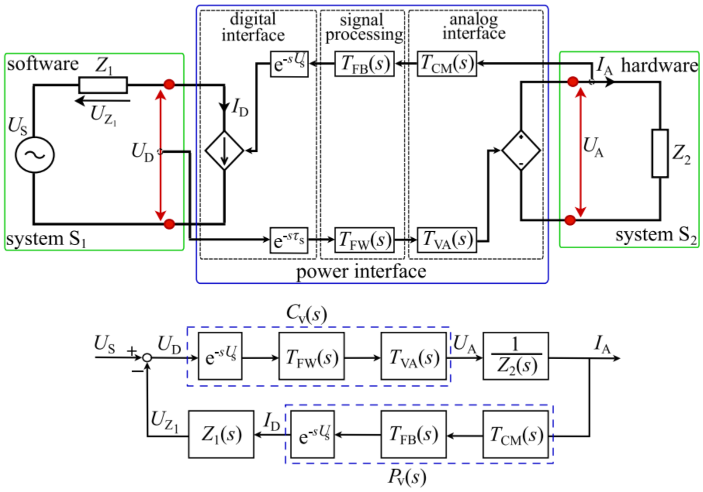
The proposed design and documentation approach was also validated in practice on the test case "*Evaluation of secure transition from grid-connected to islanded operation: Uninterruptible Power Supply*", developed within the Erigrid 2.0 project. First, a low-voltage network was designed for analysing frequency stability and performance of microgrids equipped with grid-forming inverters and operating in islanded mode. Then, the network model was implemented and tested in MATLAB and finally documented according to the developed PreCISE-based methodology. The software models and the full PreCISE documentation are publicly available in the Zenodo project repository. Future work on this topic will focus on disseminating the developed methodology, with the objective of incentivising its use within the energy community, thus supporting the creation of an open-source database of documented benchmark models for electricity networks.

4.2.2 Analytical framework for stability and sensitivity evaluation of Power-Hardware-in-the-Loop setups

The SGIL collaborates with the Austrian Institute of Technology, the University of Strathclyde and the National Technical University of Athens on the development of new analytical tools to assess and improve the stability and accuracy of real-time simulations with power-hardware-in-the-loop setups (G. Lauss, 2022).

Since these simulative approaches are becoming a crucial support in the design and testing of digitalized and interconnected power grids, it is very important to account for the impact of the interfacing techniques utilised to combine the different software and hardware elements, which inevitably introduce disturbances such as sensor noise, switching harmonics, or quantization noise. To facilitate a quantitative evaluation of the impact of external disturbances on PHIL simulation systems, a framework for sensitivity analysis of PHIL setups was developed utilising classical tools of control theory. An example of the laboratory setups under exam and of the associated dynamic modelling with block transfer functions is presented for the case of the Voltage – Ideal Transformer Model (V-ITM) interface in Figure 21.

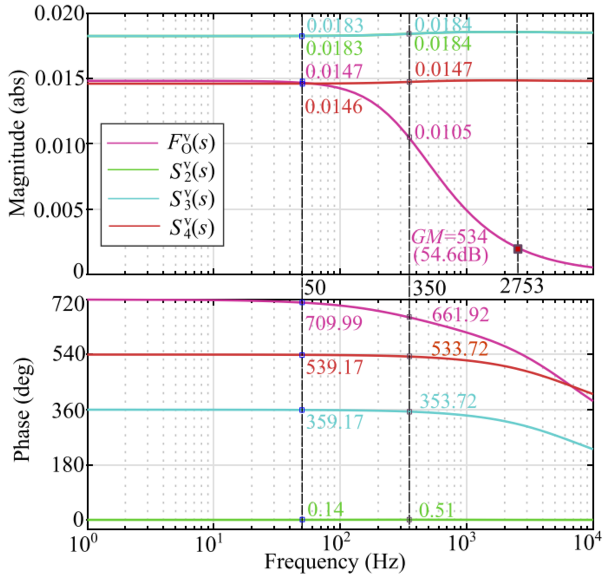
Figure 21. Model and bloc diagram of a PHIL simulation system with applied V-ITM interface.



Source: JRC, 2022.

The SGIL contribution to this research activity was mostly focused on the modelling and theoretical aspects of the analysis, with the application of established linearization techniques to derive a reasonably approximated linear model of the PHIL setup, which is then assessed with standard control theory tools for stability and sensitivity analysis, such as Bode diagrams and the Nyquist criterion. Exploiting the superposition property of this modelling framework, the study quantified in terms of amplitude and phase variations the impact of external disturbances on the relevant electrical quantities of the PHIL experiments, such as the driving current/voltage of the hardware under test. An example of the obtained results for a typical PHIL experiment with V-ITM interface is presented in the Bode diagrams of Figure 22.

Figure 22. Frequency response of the transfer functions relating different external disturbances with the current of the Hardware under test



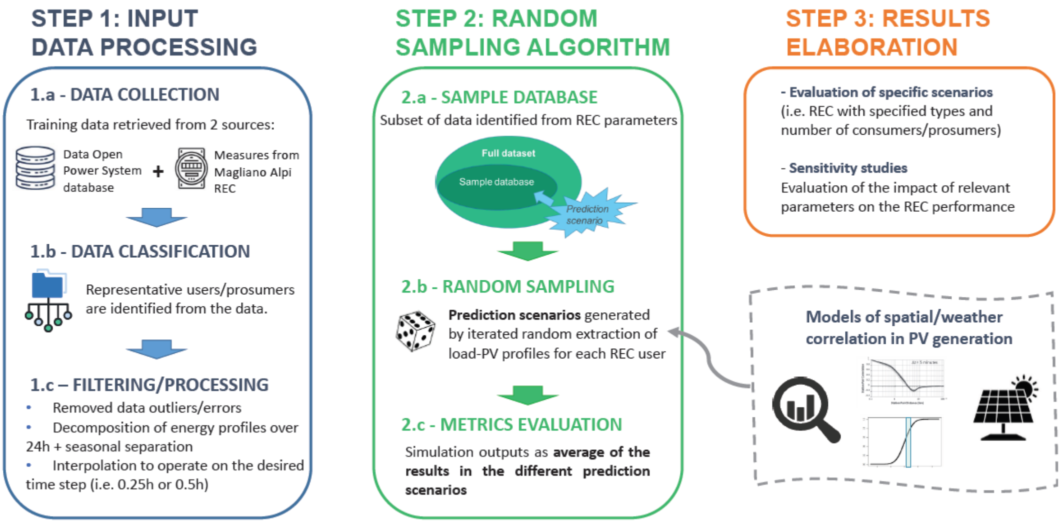
Source: JRC, 2022.

The analytical results were then validated in practice with ad-hoc laboratory experiments that compared the expected theoretical sensitivities of the system with the associated experimental quantities. This allowed to estimate the impact of the linear approximations and modelling mismatches of the considered setups. In general, the outcomes of the study can represent a new resource for researcher and practitioners in the analysis and design of robust and accurate PHIL interfaces.

4.2.3 Software tool for techno-economic analysis of renewable energy communities

In the context of the Erigrid 2.0 Lab Access scheme, the SGIL hosted for two weeks a technical team of the Magliano Alpi Renewable Energy Community (REC), the first Energy Community established in Italy. Here, we present the software tool for techno-economic analysis of renewable energy communities (A. De Paola M. L., 2023). RECs are considered a fundamental tool to support the decarbonisation of the energy system, contributing to increasing public acceptance of renewable energy projects and facilitating private investments in the clean energy transition. At a local level, RECs can provide direct benefits to citizens by increasing energy efficiency, lowering their electricity bills and creating local job opportunities. From a power system perspective, RECs can provide distributed and scalable solutions to support the operation of the decarbonised electricity grid and facilitate the integration of new renewable generation. The Magliano Alpi REC represents one of the first experiments in such sense and, after its first pilot activities, it aims to expand its scope and infrastructure, following the latest developments in the Italian regulation that envisage larger aggregation perimeters for its members. To achieve this result in an effective and efficient manner, it is important to characterize the behaviour of the different potential prosumers and consumers operating in the community. This allows to determine the ideal composition of the REC in terms of different consumers (residential, commercial, industrial) and prosumers. In this context, the SGIL team supported the Magliano Alpi REC in the development of a software tool for techno-economic analyses of energy communities. Thanks to the application of random sampling techniques and the use of historical data of energy consumption and generation, the tool allows to predict the energy behaviour of RECs of different size and composition, calculating relevant technical and economic metrics while accounting for impactful correlation phenomena in the energy profiles of the REC members. The structure of the developed tool is summarized in Figure 23.

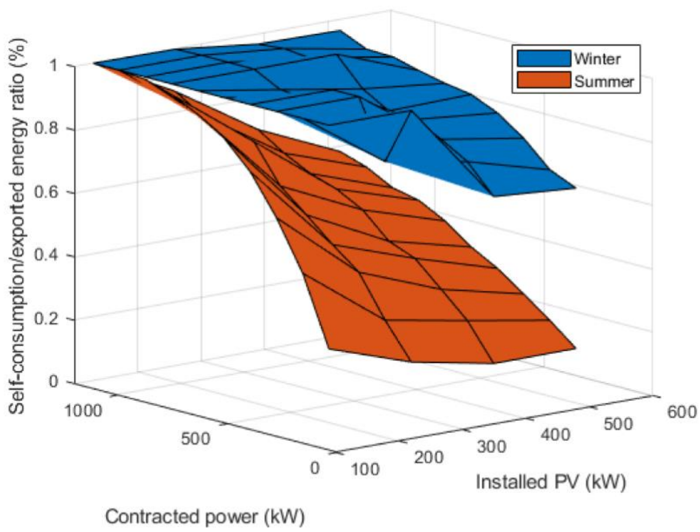
Figure 23. Scheme of the REC predictive tool



Source: JRC, 2022.

After the creation and refinement of the historical database (step 1), based on public data repositories and measurements collected at the Magliano Alpi REC, the tool runs a random sampling algorithm (step 2) to forecast the aggregate behaviour of the community, accounting for its size and users/prosumers composition. Finally, the results are elaborated (step 3) to calculate the desired REC performance metrics (e.g. imported and self-consumed energy) or to perform sensitivity studies on relevant parameters of the community. Ad hoc models developed and included in the forecast algorithm to account for the spatial and temporal correlation between the different PV generators operating in the community. An example of the analyses that can be performed by the tool is provided in Figure 24, where the capability of the REC to self-consume the local renewable generation is estimated for different seasons as a function of the installed PV generation and the total contracted power of the REC members.

Figure 24. Percentage of prosumers export that is self-consumed within the REC



Source: JRC, 2022.

4.2.4 JRC Workshop on renewable energy communities and internet-of-labs

In the context of the Educational and Training Activities of the Erigrid 2.0 project, the SGIL organized a two-day workshop on the themes of energy communities and the internet-of-labs. The workshop, titled

"*Supporting a local energy transition: from local energy communities to global simulation networks*" was hosted at the JRC Ispra site on the 9th and 10th of November 2022. The workshop was organized together with Politecnico di Torino, RWTH Aachen and the Ensiel consortium, with the objective of disseminating the research activities and collaborations of the SGIL and to foster the community discourse on the topics of renewable energy communities and global simulation networks. The event saw the participation of distinguished international speakers from academia, industry and public institutions, which discussed these subjects in the wider context of the energy transition. The first day of the event focused on energy communities, presenting some of the latest success stories in the field and discussing their role in the future decarbonized power system under a rapidly changing regulatory framework. The topic of the second day of the seminar was the internet-of-lab, with a discussion on the impact of this paradigm in supporting the energy transition and the showcase of a live demonstrative experiment that saw the participation of six European laboratories.

4.3 Residential Load Simulation with resLoadSIM

The resLoadSim is a tool for residential electric load simulation developed within the Smart Electricity Systems and Interoperability project. The tool allows prediction of residential electric loads with a time resolution of 1 minute. It uses a probabilistic approach based on statistics to predict the electric load profiles of individual households by summing up the consumption of individual household appliances. Besides using the tool for load prediction, it is also possible to study the potential for load shifting in private households by implementing different control mechanisms, for example, based on variable pricing. The objective is not to develop a specific technology in detail than rather to evaluate the potential of certain technologies and concepts for the energy transition such as demand side management.

Currently resLoadSIM is part of an internal exploratory research project called OptiRELS. This exploratory research project intends to develop a new optimisation-based calibration framework by increasing the accuracy of resLoadSIM. The framework consists of integrating resLoadSIM and generic optimisation tool GenOpt to optimise the parametric input setup assumptions for the household load simulation model. With OptRELS it becomes possible to automatically generate the input parameters for reLoadSIM in a way that resLoadSIM can be applied in different countries, which could vary by the habits of the people and so on.

Since resLoadSIM has been made public-domain available under the GNU licence in 2020 it got a wider user base, which resulted in some collaborations with Teesside University, Uk and the Institute of Physical Energetics, Latvia. This resulted in a joint publication (Kairisa, 2022).

5 European Interoperability Testing Methodology further developments

Here, we list the developments related to the Interoperability testing methodology that have been achieved during the 2022 activities and are a result of the work conducted by the SGIL team not deriving from collaborations in the framework of a research project.

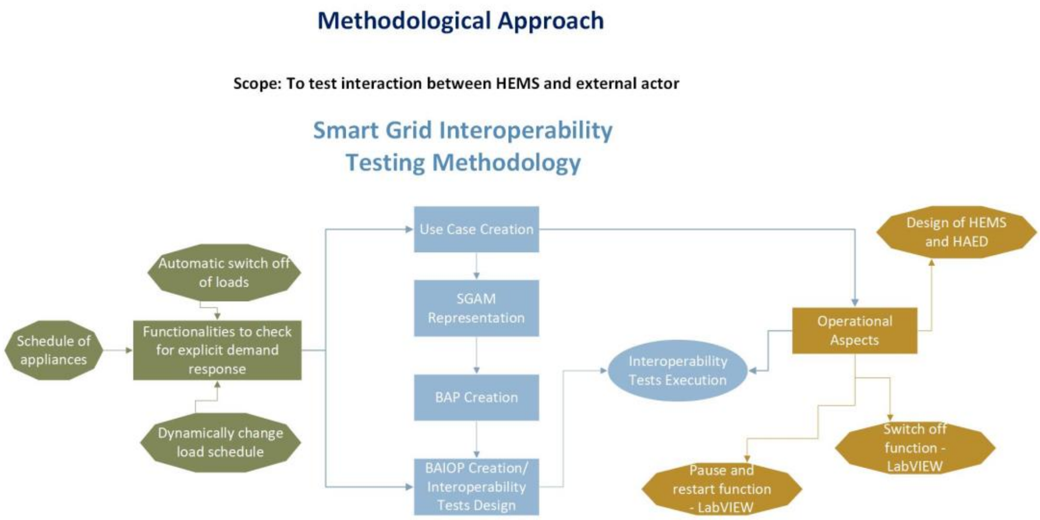
5.1 Interoperability Testing of a Smart Home Automation System under Explicit Demand Response Schemes

This is the work published in a scientific journal demonstrating the Smart Grid Interoperability Methodology and applies it in a practical example containing lab experiments (Andreadou, Kotsakis, & Masera, 2022). The work focuses on interoperability for home automation. Interaction of a home energy management system (HEMS) is examined with an external actor for home/building remote control. We show the importance and the feasibility of remotely controlling domestic loads from outside the house premises, which can be crucial for energy saving operations, such as demand response. We use the Smart Grid Architecture Model and the steps described in the Smart Grid Interoperability Methodology are followed to design the tests and execute them.

For the experimental part, we developed a Home Energy Management System (HEMS) together with a Home Automation End Device (HAED), which is used to transform two normal plugs, and subsequently two normal loads into smart ones. In this way, we created a system for home automation and control. The described configuration is only one possible configuration out of the available ones existing in the market for home automation. LabVIEW programming is used to realize the actual explicit demand response program through remote load control and scheduling.

The methodological approach followed in this work is shown in the following figure. As it can be seen in Figure 25, in blue the steps of the interoperability methodology are depicted. In dark green, we see the functionalities we tested for the explicit demand response scenario, like for example the automatic switch off of loads in case of an emergency, the appliances scheduling for deciding the time moments that appliances would be on and off and the option of dynamically enabling load schedule changes, to represent the exact grid conditions, in case these alter. With brown colour, we can see the operational functions we implemented for the experiments to achieve the remote control of loads, like switching off function in case of emergencies and the pause and restart function to control the functioning of the plugs (the time moments that the smart plugs will be on and off). The figure below shows the links between functionalities, the use case and test description and the link between the operational aspects and how we implemented them to the tests execution.

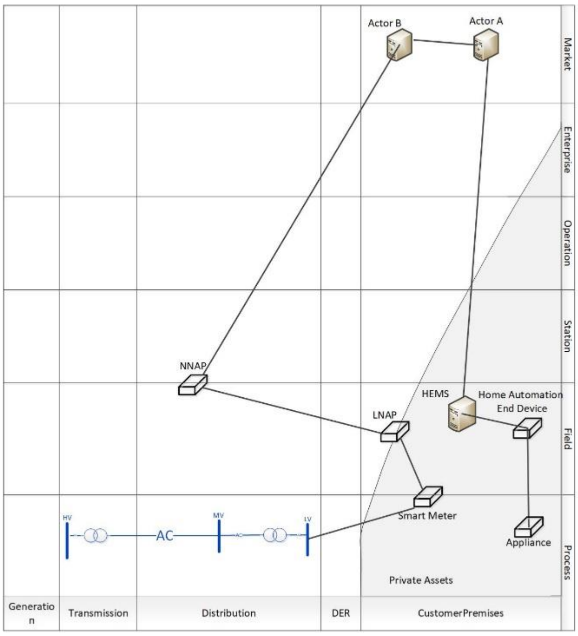
Figure 25. Methodological approach followed in this work.



Source: JRC, 2022.

The various actors participating in the experiment are depicted in the SGAM, as indicated by the smart grid interoperability methodology. The link of interest is between HEMS and the external actor, as we want to show that remote control of HEMS, and subsequently of the Home Automation End device and the loads connected to it, is achieved by an external actor. The goal is to check that the remote control takes place, thus, the smart plugs can be remotely and dynamically scheduled, whereas an automatic switch off of appliances can also take place. This means that interoperability is preserved.

Figure 26. Representation of the use case on the SGAM component layer.



Source: JRC, 2022.

The two layers of interest are the communication and information layer; the first one shows that communication between the actors of interest (HEMS – Actor A) is achieved and the latter one shows that messages are meaningfully exchanged between these two actors, thus the functionalities we wish to achieve for the demand response scenario are accomplished. The steps to arrive to the outcome of the interoperability tests were designed according to the methodology created by the SGIL team. Table 4 and Table 5 describe these test steps and the outcome of each one of them.

Table 4. Steps for communication layer interoperability and outcome of experiments.

n.	Steps	Outcome
1	A dedicated link and a public address which is not related to the customer's private internet connection is established.	Successful
2	Settings at customer point: (a) The web page is activated through the web publishing tool and the port used is defined. (b) The embedded option is selected, which enables to take remote control by an external actor (c) A name is given to this web page, which allows the external actor to identify this specific customer	(a) Successful (b) Successful (c) Successful
3	Settings at the external actor point: (a) Knowledge of the IP address is required, the port used at the customer's premises and the web page's name. (b) The option "request control" is selected.	(a) Successful (b) Successful
4	Test verdict PASS: A message appears: "control transferred", which means that the remote control is successful. FAIL: Otherwise: the communication is not established.	PASS

Source: JRC, 2022.

Table 5. Steps for communication layer interoperability and outcome of experiments.

n.	Steps	Outcome
1	A PASS in the communication layer is necessary	Covered by the communication layer experiments
2	The schedule of specific loads within the house needs to be programmed	Successful programming is achieved
3	Additive functions programmed: (a) Possibility of dynamically altering the load scheduling (b) Automatic switch off of loads in case of emergency	(a) Programming option of dynamically altering the load schedule is added (b) Programming option of automatically switching off loads is enabled
4	The above functions need to be tested in practice—in an experimental configuration	A successful experimental configuration is established and Steps 2 and 3 are executed
5	Test Verdict: PASS: in case Actor A can control the loads within the house remotely; in case the functions programmed are executed FAIL: otherwise.	PASS

Source: JRC, 2022.

The above tables prove that the tests are executed successfully, thus interoperability is preserved. In general, the paper deals with interoperability related to Home Energy Management Systems and explicit demand response functionalities that can be performed from outside the house premises, like remote load scheduling. These two topics are crucial for the future energy smart grids, as controlling loads within the house can boost the services offered to end customers and on the other hand, interoperability plays a key role for the smart energy grid, as this has been explained in earlier sections of this report.

6 Other scientific and experimental achievements

Here, we list the rest of our scientific and experimental achievements that led to publications in scientific or review journals or European Commission reports.

6.1 DR developments - Demand Response Impact Evaluation: A Review of Methods for Estimating the Customer Baseline Load

This work is a review paper published in a scientific journal, and related to the methods available for estimating the customer baseline load, as the title implies (Valentini, et al., 2022). This article presents a structured overview based on a review of academic literature, existing standardization efforts, and lessons from use cases. In particular, the article describes and focuses on the different baseline methods applied in some European H2020 projects, showing the results achieved in term of measurement accuracy and costs in real test cases.

The most suitable methodology choice among the several available depends on many factors. Some of them can be the function the DR product performs in the system, the broader regulatory framework for DR participation in wholesale markets, the characteristics of the DR providers, whereas the list is not exclusive. The evaluation shows that the baseline methodology choice presents a trade-off among complexity, accuracy, and cost.

The paper considers the Demand Response service providers and flexibility services, and particularly the DSO and TSO needs, whereas the role of the aggregators is examined. The objective of the paper is to identify and review the methodologies proposed and used in practice for baseline calculation. It evaluates:

- Reports from industry associations and consulting firms involved in the research of BL definition in the field of DR.
- Scientific publications describing novel methodologies for calculating the baseline.
- Standardization efforts focusing on methodologies for BL calculation.
- Research projects describing the methodologies used in practice for BL calculation.

Table 6 shows the baseline calculation methodologies proposed by the analysed reports and studies from industry associations, as these are presented in the article. Table 7 summarizes the guidelines for baseline calculation, from dedicated standards and protocols. On the other hand, Table 8 gives an overview of what is used in practice related to baseline calculation methodology by the scientific projects realised across Europe.

Table 6. Summary of BL calculation methodologies proposed by reviewed projects

Report / Study	Method/ Guidelines for BL
Xenergy document for the analysis of baselining	Interval metering, based on three components: • Data selection criteria (which days and time periods of data used) • Estimation method (the calculation procedure) • Adjustment method (scales the provisional BL)
CPUC Studies	Standardised M&V mechanisms: • Day-matching methods: good for ex-post impact estimates preferable for use in customer settlement • Regression-based methods: most common/ default option; preferred method whenever ex-ante estimation is also required
CPUC Studies	Standardised M&V mechanisms: • Day-matching methods: good for ex-post impact estimates preferable for use in customer settlement Regression-based methods: most common/ default option; preferred method whenever ex-ante estimation is also required

Report and studies by Ernest Orlando Lawrence National Lab	The models are sorted into two groups: • *averaging methods*: use of a linear combination of hourly load values from previous days to predict the load on the event day • explicit weather models: use a formula based on local hourly temperature to predict the load Other references use Linear regression method modelling: • 15 minute interval, whole building electric load data • weather data effects
Report by Quantum Consulting for the Southern Edison Company	Different methodologies for BL: • For the Day-ahead program, it is suggested to consider changing the 3-day DBP BL method for program settlement • Customer-specific BL: sub-metering used to improve the reliability of impact estimates
DR in wholesale electricity markets: the choice of customer BL	Different methodologies for BLs: • Administrative customer BL, estimate the users' consumption levels using, for example, the last year's data • contractual customer BL approach: for a robust framework that restores efficient DR under full Locational Marginal Price (LMP) payment
Report by Northwest Energy Efficiency Alliance (NEEA)	Different steps for defining the BL: • Establish the boundaries of the facility • Identify the energy sources • Determine the BL period duration and the specific historical time frame • Define Energy Performance Indicators (EnPIs), • BL adjustment is determined
KEMA report by PJM	Several methods for each category: • Average • Matching • Regression Different adjustment tested (Additive, Ratio, Regression-based)
Evaluation on DR by CADMUS Group for PPL Electric Utilities	Different BL modelling approaches: • Several-day matching: when there is highly variable day-to-day consumption in the hours of the event • Regression methods: for 87% of the overall facilities, the regression method is the most accurate one

Source: JRC, 2022.

Table 7. Guidelines for BL calculation according to standards and protocols

Standard/ protocol	Method/ Guidelines for baselining
NAPDR	Specific parameters are defined: BL window (the 10 most recent program eligible non-event days), sampling precision and accuracy, BL window, and exclusion rules
IPMVP	It considers: period selection, reporting period, and types of adjustments. Measurement boundaries are important: 1 retrofit-isolation – key parameter measurement 2 retrofit isolation – all parameter measurement 3 whole facility: the measurements performed at the facility level 4 calibrated simulation: all calculations based on simulations
ISO 50006:2014	EnPI quantifies results related to energy consumption. EnB refers to energy performance during a specific period (reference). A comparison between EnPI and EnB illustrates the improvement in energy performance. To establish an EnB it has to be set the purpose of the calculation and a suitable data period. Collection of data and determination and test of EnB follow.

Source: JRC, 2022.

Table 8. H2020 projects and methods used for defining the BL

n.	Project	Methods and data used for BL
1	ADDRESS	Similar days, historical data
2	AnyPLACE	Load forecasting
3	CITYOPT	Statistical method to calculate the power saved, particularly in energy efficiency
4	CityZen Amsterdam	Historical data; 1-year monitoring
5	DELTA	Regression model based on historical data, weather parameters, type of day used for BL; Standards like ISO, NAPDR, IPMVP are listed
6	DR-BoB	IPMVP for yearly global evaluation of additional energy efficiency measures; historical data
7	DRIMPAC	Standards like ISO, NAPDR, IPMVP are listed; Regression model based on historical data, weather parameters, type of day used for BL
8	DRIVE	Historical data (measurements and smart meter data)
9	ECOGRID	Historical data; price and load forecasts
10	eDREAM	Historical data
11	EnergyLab NordHavn – New Urban Energy Infrastructure	Data collection
12	Flex4Grid	Measurements play key role; control and user groups are used for comparison
13	FlexCoop	Takes into account IPMVP and NAPDR; algorithms are created; user-centric approach is used
14	IndustRE	Historical data
15	NOBEL-GRID	Historical data
16	P2PSmarTest	Historical data used; day-matching plus regression models; window between 5-10 days
17	RESPOND	Measurements for the BL
18	Semiah	Measurements and simulations to get modified load profiles
19	SINFONIA	Energy consumption data for each building within a district simulation for all buildings within the district
20	SmarterEMC2	Measurements are used to define the BL
21	SmartUp	Measurements before and after the event
22	Upgrid	Consumption data plus HEMS simulating BL (simulation tools used)
23	Vulnerable Consumers and energy efficiency	2 groups of customers: control (for the BL) plus intervention group (for DR actions)

n.	Project	Methods and data used for BL
		Historical data; previous similar days

Source: JRC, 2022.

The choice for the methodology for baseline calculation depends on several parameters, like the complexity of the method, the accuracy, the estimated cost for its implementation and the target group to which the baseline methodology is directed (i.e. industrial users, weather sensitive users, residential users, etc). Given the fact that there are plenty of parameters that determine the final choice of the methodology for baseline calculation, there is no best method, but rather a most suitable method depending on different parameters.

6.2 Sharing unused storage in energy communities

The SGIL investigated several aspects of citizen and renewable energy communities and developed tools to empower and engage the end-users to actively participate in energy services, so to minimize their final costs and support the reduction of the buildings carbon footprint. Our latest scientific contribution proposes a local market design to share unused storage in local energy structures and led to the cited journal publication (D. Thomas, 2022).

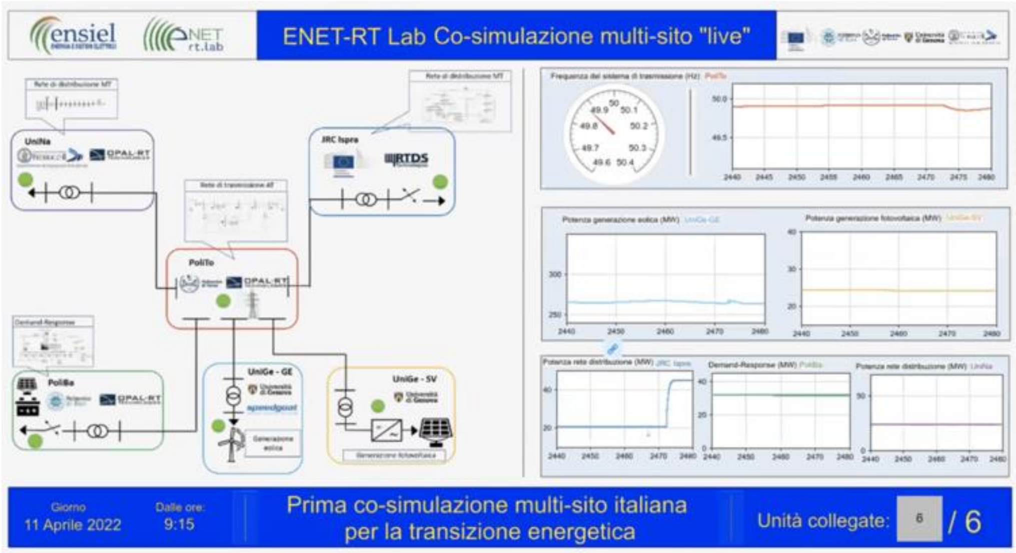
6.3 Blockchain Applications and Roadblocks in the Energy Transition

The SGIL presented part of its work related with blockchain applications and roadblocks in the energy transition in the IEEE 2022 Workshop on Blockchain for Renewables Integration (BLORIN), leading to the cited conference publication (D. Thomas, Blockchain Applications and Roadblocks in the Energy Transition: Joint Research Centre Testing Campaigns and Policy Recommendations, 2022).

6.4 Design and laboratory implementation of geographically-distributed real-time simulations of electrical networks

In 2022 the SGIL established a strong collaboration in the field of real-time simulations with the ENSIEL consortium (academic organisation that includes several Italian universities) and RWTH Aachen. Here, we present the results of this collaboration (G. Benedetto, 2022), (G. Benedetto A. M., 2023). The objective of this partnership is the development and promotion of the internet-of-labs paradigm, i.e. a new extended approach to laboratory real-time experiments that allows the pooling of resources and knowledge from multiple research centres. The research activity focuses in particular on the possibility of performing geographically-distributed real-time simulations where each single laboratory simulates only a part of the power system under exam, ensuring that the relevant simulation signals are exchanged with the other participants with the necessary speed to ensure stability and accuracy of the whole experiment. Such approach can significantly strengthen the potential support of real-time simulations to the design and analysis of the decarbonised grid of the future. In fact, the possibility of dividing the simulation among multiple laboratories allows to consider systems of larger size and higher complexity. Moreover, the geographically-distributed framework can provide remote access to costly laboratory infrastructure to other research centres that might not be able to afford it, making real-time simulations more accessible to the whole research and engineering communities. The technical work conducted with the Politecnico di Torino, Università di Genova, Università di Napoli, Politecnico di Bari and later also with RWTH Aachen gave significant insights on the most suitable modelling approaches, interfaces and communication protocols for geographically-distributed simulations. On this basis, the potential applications of the internet-of-labs were publicly demonstrated in two public events: the inauguration of the *EnSiEL National Energy Transition Real-Time Lab* in Turin on the 11th of April 2022 and the JRC workshop in Ispra on the 11th of November 2022. An example of the real-time console that used for the live presentation is provided in Figure 27.

Figure 27. Live console of the first public demonstration conducted with the Ensiel consortium



Source: *JRC, 2022.*

7 Conclusions

The Smart Grid Interoperability Laboratory, with its two branches, in Ispra (Italy) and Petten (The Netherlands) is conducting important work in the field of smart grids and interoperability. The work is conducted both in the field of testing infrastructure/ components and systems, but also in the field of policy support.

The structured methodology for interoperability testing created by the SGIL team serves as a basis for testing use cases of interoperability. During 2022 it has been used for several use cases, like for example: to test interoperability with respect to home automation systems and remote control of residential loads by an actor outside the house; to test interoperability of building components for applying demand response programs in the residential sector in the framework of a H2020 research project.

In terms of research projects, the SGIL has been very active in the field, with its participation in two research projects during 2022, providing results not only with respect to interoperability, but also in the field of smart grids, like energy communities, storage issues. It renders available its infrastructure to the scientific partners with whom it collaborates for promoting high level experimental activities.

The SGIL is a pioneer in the field of energy policy support, with its work being appraised by the policy makers and by the published EU Action Plan (October 2022) for digitalising the energy system. The 2022 activities prove that SGIL is active in policy making by contributing in laying the ground for novel policies for interoperability as well as contributing in monitoring already existing policies and the extent at which such policies are being implemented. The SGIL team performed thorough work in monitoring and reporting the EU role in the global market related to smart grid clean energy technologies.

The current report proves the expertise of the SGIL in the smart grid interoperability field and makes it clear that its role is fundamental in the scientific community and in the policy making field. The achievements described in this report prove the continuity of the SGIL activities with past and future work. Regarding future work, it is made clear that the SGIL has a lot to offer in the field and future outcomes are expected to transform the smart grid world.

References

A. De Paola, D. T. (2022). Benchmark Models for Low-Voltage Networks: a Novel Open-Source Approach. *Open Source Modelling and Simulation of Energy Systems (OSMSES)*, (pp. 1-6). Aachen.

A. De Paola, M. L. (2023). "A Predictive Tool for Techno-Economical Analyses of Renewable Energy Communities. *SEST 2023 - International Conference on Smart Energy Systems and Technologies.*

Andreadou, e. (2022). *DRIMPAC Deliverable 5.6: Report on activities for the definition and promotion of DRIMPAC standardization punch-list v2.*

Andreadou, N. G. (2023). *Survey on Interoperability of ESA: Supporting the development of policy proposals for ESA.* Publications Office of the European Union, In press.

Andreadou, N., Kotsakis, E., & Masera, M. (2022). Interoperability Testing of a Smart Home Automation System under Explicit Demand Response Schemes. *Energies*.

CENELEC, C. (2012). *CEN-CENELEC-ETSI Smart Grid Coordination Group Smart Grid Reference Architecture.* CEN CENELEC.

D. Thomas, I. K. (2022). Blockchain Applications and Roadblocks in the Energy Transition: Joint Research Centre Testing Campaigns and Policy Recommendations. *IEEE Workshop on Blockchain for Renewables Integration (BLORIN).*

D. Thomas, I. K. (2022). Sharing unused storage in local energy markets utilizing physical storage rights: A non-cooperative game theoretic approach. *Energy Storage*, 105755.

Damousis, e. (2022). *DRIMPAC Deliverable 4.10: ICT system integration & interoperability verification.*

De Paola, D. T. (2023). Testing-Oriented Development and Open-Source Documentation of Interoperable Benchmark Models for Energy Systems. *IEEE Open Journal of the Industrial Electronics Society*, 42-51.

EuropeanCommission. (2017). *Cordis - EU Research Results*. Retrieved from Unified DR interoperability framework enabling market participation of active energy consumers: https://cordis.europa.eu/project/id/768559

EuropeanCommission. (2019). *A Europe fit for the digital age*. Retrieved from A Europe fit for the digital age: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age_en

EuropeanCommission. (2019). *A European Green Deal*. Retrieved from A European Green Deal: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

EuropeanCommission. (2019). *Clean Energy for all Europeans Package*. Retrieved from Clean Energy for all Europeans Package: https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en

EuropeanCommission. (2019). *European Green Deal*. Retrieved from A European Green Deal: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

EuropeanCommission. (2020). *A New European Bauhaus: op-ed by Ursula von der Leyen*. Retrieved from A New European Bauhaus: op-ed article by Ursula von der Leyen, President of the European Commission: https://ec.europa.eu/commission/presscorner/detail/en/AC_20_1916

EuropeanCommission. (2021). *Shaping Europe's digital future*. Retrieved from The Digitising European Industry initiative in a nutshell: https://digital-strategy.ec.europa.eu/en/library/digitising-european-industry-initiative-nutshell

EuropeanCommission. (2022). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS: Digitalising the energy system - EU action plan.* European Commission.

EuropeanCommission. (2022). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS: Digitalising the energy system - EU action plan.*

EuropeanCommission. (2022). *REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL: Progress on competitiveness of clean energy technologies.* European Commission.

EuropeanCommission. (2022). *SETIS - SET Plan information system*. Retrieved from CETO reports 2022: https://setis.ec.europa.eu/publications/clean-energy-technology-observatory-ceto/ceto-reports-2022_en

EuropeanCommission. (2023). *An EU fit for the Digital Age*. Retrieved from An EU fit for the Digital Age: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age_en

EuropeanCommission. (n.d.). *A New European Bauhaus: op-ed article by Ursula von der Leyen, President of the European Commission*. Retrieved from A New European Bauhaus: op-ed article by Ursula von der Leyen, President of the European Commission: https://ec.europa.eu/commission/presscorner/detail/en/AC_20_1916

EuropeanCommission. (n.d.). *Clean energy competitiveness*. Retrieved from The Clean Energy Technology Observatory: https://energy.ec.europa.eu/topics/research-and-technology/clean-energy-competitiveness_en#the-clean-energy-technology-observatory

EuropeanCommission. (n.d.). *Energy - EU policies aim to deliver secure, sustainable and affordable energy for citizens and businesses*. Retrieved from Energy - EU policies aim to deliver secure, sustainable and affordable energy for citizens and businesses: https://energy.ec.europa.eu/index_en

EuropeanCommission. (n.d.). *EU action plan on digitalising the energy system*. Retrieved from EU action plan on digitalising the energy system: https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_6229

EuropeanCommission. (n.d.). *EU strategy on energy system integration*. Retrieved from EU strategy on energy system integration: https://energy.ec.europa.eu/topics/energy-systems-integration/eu-strategy-energy-system-integration_en

EuropeanCouncil, E. P. (2019). *DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU.*

EuropeanCouncil, E. P. (2019). *REGULATION (EU) 2019/943 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on the internal market for electricity.*

EuropeanUnion. (2017). *Tallinn e-Energy declaration.* Talinn.

G. Benedetto, A. M. (2023). Supporting a "glocal" energy transition: from local energy communities to global simulation networks. *International Conference on Smart Energy Systems and Technologies - SEST.*

G. Benedetto, E. B. (2022). Ensiel National Energy Transition Real Time Lab: Ensiel National Energy Transition Real Time Lab: a Novel Tool to Shape the Future Energy System. *AEIT International Annual Conference .*

G. Lauss, Z. F. (2022). A Framework for Sensitivity Analysis of Real-Time Power Hardware-in-the-Loop (PHIL) Systems. *IEEE Access*, 101305 - 101318.

JointResearchCentre. (2023). *Power grid digitalisation and interoperability*. Retrieved from Smart Electricity Systems and Interoperability: https://ses.jrc.ec.europa.eu/digital-grid-interoperability-under-test

JointResearchCentre. (2023). *Smart Electricity Systems and Interoperability*. Retrieved from Smart Electricity Systems and Interoperability: https://ses.jrc.ec.europa.eu/development-of-policy-proposals-for-energy-smart-appliances

JointResearchCentre. (2023). *Smart Electricity Systems and Interoperability*. Retrieved from Support on the development of policy proposals for energy smart appliances: https://ses.jrc.ec.europa.eu/development-of-policy-proposals-for-energy-smart-appliances

JointResearchCentre. (2023). *Smart Energy Systems and Interoperability*. Retrieved from Smart Grid Design of Interoperability Tests (SG-DoIT): https://ses.jrc.ec.europa.eu/sgdoit

Kairisa, E. M. (2022). Scenario-Based Modelling of Residential Sector Consumption: A Case Study in Latvia. *Latvian Journal of Physics and Technical Sciences*.

Papaioannou I., T. S. (2018). *Smart grid interoperability testing methodology.* Publications Office of the European Union, Luxembourg.

Papaioannou, I. A. (2022). *Energy Smart Appliances' Interoperability: Analysis on Data Exchange from State-of-the-art Use Cases.* Publications Office of the European Union, Luxembourg.

Prettico, G. D. (2022). *Clean Energy Technology Observatory: Smart Grids in the European Union – 2022 - Status Report on Technology Development Trends, Value Chains and Markets.* Publications Office of the European Commission, Luxembourg.

Thomas, e. (2022). *DRIMPAC Deliverable 4.8: Results validation & consumer satisfaction assessment.*

UnitedNations. (n.d.). *United Nations: Climate Action*. Retrieved from The Paris Agreement: https://www.un.org/en/climatechange/paris-agreement

Valentini, O., Andreadou, N., Bertoldi, P., Lucas, A., Saviuc, I., & Kotsakis, E. (2022). Demand Response Impact Evaluation: A Review of Methods for Estimating the Customer Baseline Load. *Energies*.

World Bank Group. (2018). *Survey of International Experience in Advanced Metering Infrastructure and its Implementation.* Retrieved from World Bank Group - Energy and Extractives Global Practice Group: https://openknowledge.worldbank.org/handle/10986/32468

List of abbreviations and definitions

4E	Energy Efficient End-Use Equipment
AA	Administrative Arrangement
AMI	Advanced Metering Infrastructure
BACS	Building Automation and Control Systems
BAP	Basic Application Profile
BAIOP	Basic Application Interoperability Profile
BEMS	Building Energy Management System
BL	Baseline
BSI	British Standard Institution
CEN	European Standardisation Committee
CENELEC	European Committee for Electro technical Standardization
CEP	Clean Energy for all Europeans Package
CETO	Clean Energy Technology Observatory
CPR	Competitive Project Report
CoC	Code of Conduct
DR	Demand Response
DRMS	Demand Response Management System
EDNA	Electronic Devices and Networks Annex
EMS	Energy Management System
EnB	Energy Baseline
EnPI	Energy Performance Indicators
ESA	Energy Smart Appliances
EV	Electric Vehicle
EVSC	Electric Vehicle Smart Charging
GSSS	Grid-Scale Storage Services
HAED	Home Automation End Device
HBES	Home and Building Electronic Systems
HEMS	Home Energy Management System
HTD	Holistic Test Description
ICT	Information and Communication Technology
IEA	International Energy Agency
IED	Intelligent Electronic Device
IOP	Interoperability
KPIs	Key Performance Indicators
LMP	Locational Marginal Price
MEErP	Methodology for Ecodesign of Energy-related Products
PAS	Public Available Specification

REC	Renewable Energy Community
RES	Renewable Energy Sources
R&I&D	Research and Innovation and Development
SGAM	Smart Grid Architecture Model
SGIL	Smart Grid Interoperability Laboratory
TI	Transmission Innovation
UC	Use Case
V-ITM	Voltage-Ideal Transformer Model

List of figures

List of Tables

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

Open data from the EU

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

Science for policy

The Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society

EU Science Hub
joint-research-centre.ec.europa.eu

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

@eu_science

Publications Office
of the European Union