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Smart Grid Laboratories Inventory 2022

4th Phase

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Contents

Abstract

This report is the fourth release of the Smart Grid Laboratories Inventory. It presents aggregated information about smart grid research topics and shows the tendencies of the research community. It shows information about the technologies used and also gives more detailed information for specific areas, like standards and infrastructure used by the participant organizations. Numerous smart grid laboratories have been contacted for this scope and information has been gathered about their research activities. In this release, we have joined forces under the EIRIE platform, and we obtained an updated database containing information in coherence with the ETIP SNET (European Technology and Innovation Platforms Smart Networks for Energy Transition) concept. This release is not only an update with respect to the previous ones, but it shows information in coherence with similar European incentives, thus helping the scientific community to comprehend better the state-of-the-art technologies.

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We would like to thank also the ones who helped in realising the previous releases of the project and in particular: the U.S. Department of Energy (DoE) for helping us to identify some of the smart grid laboratories in the USA in the framework of the JRC-DoE collaboration Agreement and the National Contact points for Horizon 2020.

We would also like to thank the colleagues, who had participated and helped in the older releases of the project, Miguel Olariaga Guardiola, Giuseppe Prettico, Marta Poncela Blanco, Arturs Purvins, Catalin-Felix Covrig, Evangelos Kotsakis, Luca Lena Jansen.

We are very grateful to all participant organisations because without their contribution this work could not have been done.

The complete list of participant laboratories together with their websites can be found in Annex 1.

Authors

Nikoleta Andreadou, Ioulia Papaioannou, Antonios Marinopoulos, Marcello Barboni

Executive summary

This report sheds light to the smart grid research being conducted by scientific and industrial communities worldwide. Whereas the concept of realizing this report remained the same with the one used for the previous releases, meaning that a questionnaire has been prepared and participants have been invited to fill it in, there has been a change with respect to the structure of the information obtained.

This time, we have joined our forces under the EIRIE platform, and we obtained an updated database containing information in coherence with the ETIP SNET (European Technology and Innovation Platforms Smart Networks for Energy Transition) concept.

EIRIE, the European Interconnection for Research Innovation & Entrepreneurship is a living dynamic multi-functional platform for all the energy system stakeholders and for all EU citizens to benefit of a series of services:

- Research and Innovation exchange including the results of all EU and National funded projects;
- Synergetic affiliations for R&I, entrepreneurship, etc.
- Education &training;
- Other extra functionalities.

EIRIE:

- Connects the R&I community of EU to enhance collaboration with a wider interest and use of the project results;
- Avoids duplication and optimizes investments;
- Fosters and facilitates entrepreneurship;
- Strengthens the participation of all Member States in support of the fifth pillar of the Energy Union and the energy transition.

Under the EIRIE initiative, it has been created the ETIP SNET group of technologies, in an effort to categorize the broad concept of smart grid research. Thus, the categories of smart grid research according to ETIP SNET are five and these are as follows:

- Integrated Grid
- Customers and Market
- Storage
- Generation
- Digitalization, Communication and Data

Our team, has adopted this concept to maintain a homogeneous way of smart grid research definitions and facilitate the work of researchers. As a result, the categories of smart grid research have been adapted to the aforementioned ones, whereas a careful matching has been made with the categories defined in the previous three releases of the Inventory.

The approach followed for this fourth release is summarised as follows:

- An updated questionnaire has been created that follows the concept of ETIP SNET group of technologies;
- Labs that have been conducting research in the broad area of smart grid worldwide have been conducted and invited to fill in our survey;
- Results have been obtained in an aggregated manner;
- Information has been used for our online Tool, which intends in increasing visualisation among smart grid lab researchers.

The questionnaire used consists of three parts, like in the other releases of the Inventory:

- The first part refers to general questions, like the main source of research funding, investment plans, among others.
- The second part refers to the ETIP SNET Group of technologies identified and focuses on the research actually conducted by the smart grid laboratories. The questionnaire works in a dynamic way, meaning that certain questions pop up only if the participant lab actually works on a specific area.

- The third part focuses on the infrastructure owned by the laboratories and used for smart grid research.

Policy context

There have been various new policy efforts regarding the smart grid activities launched by the European Commission, like the following:

- The Directive on common rules for the internal market in electricity, (2009/72/EC) [1]
- The Directive on common rules for the internal market in natural gas, (2009/73/EC) [2]
- Revised Renewable energy directive (2018/2001/EU), [3] and the revised Electricity Directive (2019/944) [4]
- The Energy Union Strategy [5];
- The Clean Energy for All Europeans Package [6];
- The standardization Mandate M/490 on smart grid [7];

The smart grid research groups in Europe have been working in order to cope up with these policy efforts and laboratories are built in order to support such research activities. On many occasions, consortia and collaboration efforts among lab facilities are sought in order to gain leverage in shared infrastructure and knowledge and reduce the burden of having a single facility covering all areas. Such examples are: The Smart Grid International Research Facility Network (SIRFN) of the International Energy Agency (IEA) Implementing Agreement for a Co-operative Programme on Smart Grids (ISGAN) [8], DERlab [9], the European Network for cyber security (ENCS) [10] and Futured [11].

This report presents information about the smart grid lab research, thus revealing the trends in scientific research and on the other hand, identifying the gaps and guiding further actions to be made. It is worth mentioning, that although the policy context for us remains at European level, the Inventory covers research carried out by laboratories worldwide, in an attempt to depict the worldwide trends and enhance collaboration activities beyond European borders.

To complete the work of the Inventory, an Online Tool has been created in order to enhance visibility of the smart grid lab activities, to foster collaborations between research organisations, policy making bodies and all relevant smart grid stakeholders. It is intended to improve the already existing Online Tool, making it more dynamic, in the sense that laboratories that work on a specific field of smart grids can be found in a straightforward way.

Key conclusions – Main findings

The fourth release of the Smart Grid Laboratories Inventory shows information from 86 labs worldwide. Whereas in previous versions of the Inventory the focus was to find new participants, this year the main focus has been to obtain updated information of the already existing laboratories, especially since the new concept of ETIP SNET smart grid fields has been introduced. As secondary goal, it has been set to find new participants.

Information from 50 labs was collected during autumn 2021, where most of these labs provided an update of the information they had given in previous releases of the Inventory. In addition, the information of other 36 labs was merged from previous releases, including however, only information that did not date longer than 5 years back. Some of the conclusions of this fourth release of the survey are:

- Around 43% of the labs operate with personnel up to 10 people and occupy an area up to 250 m^2.
- The 86% of labs performs R&D on hardware and software research activities, whereas the 91% of them carries out research about the distribution grid.
- Exactly half of the labs have had investments of up to 1,000,000 euros. The period in which these investments are spanned varies; however, half of the labs have had their investments for a period of up to 4-5 years.
- It is interesting to see that funding sources for labs are almost equally split into three parts: own funding (34.38%), national funding (31.25%) and EU funding (34.38%). Given the fact that also non-EU labs are taking part in this survey, it becomes clear how important EU funding is for smart grid research. Indeed, EU funding for European labs, results to 38.4% of all funding sources, with national and own funding being 25.6% and 36% respectively.

- Every lab is specializing in more than one research category. Thus all the research categories attract more than 70% of the labs like: Integrated Grid: 84%, Customers and Market: 76%, Storage: 70%, Generation: 79%, Digitalization, Communication and Data: 77%.
- For the Integrated Grid, 70% of the labs work on microgrids, 47% work on AMI and the most popular standard is IEC 61850.
- For Customers and Market, the active labs in the field work on the following sub-categories: Distributed Flexibility (86%), Smart Buildings (68%), Electric vehicles (68%), energy communities (58%), Electricity market (52%), Smart appliances (51%), Lighting (22%).
- For Storage, the most popular energy storage technology is: Storage electric (87% of the active labs in the field).
- For Generation, the most popular standards are IEC 61850 and IEC 61400, while the most popular areas of research are Solar generation (81%), flexible generation (78%) and wind generation (62%).
- For Digitalization, Communication and Data the active labs in the field work on the following sub-categories:
- Communication networks including devices and systems for signals and data connectivity and solutions (85%), Digital twins (61%), Data and Cyber security including repositories (58%), Artificial intelligence (54%).
- Simulations are very popular for smart grid research, with 65% of labs performing real-time simulations and 61% of labs performing Hardware-in-the-Loop simulations. On the other hand, Matlab is the most popular tool used for simulations, particularly for grid simulations (44% of the labs).
- The most common major infrastructure is: power amplifier, battery energy storage system, grid emulator.
- Finally, the most popular services offered by labs are: Integration and testing of devices (hardware testing, meter, relay testing, high voltage products tests, etc), (33%) and Research and Development support (29%).

The Smart Grid lab Inventory gives a complete picture of the smart grid research carried out by labs not only in Europe, but also worldwide. It gives detailed information about the categories of research, points out the sub-categories and standards used and it also gives an insight on the infrastructure used by labs. The Inventory is a valuable tool in identifying trends in the smart grid research and getting important information about the state-of-the-art in the field.

Related and future JRC work

The JRC and especially the Energy Security, Distribution and Markets Unit has carried out extensive work with respect to policy support in the energy sector and particularly in the smart grid field. By definition, the JRC's role is to provide independent scientific research and support on transformations towards smarter and more interoperable electricity systems. The JRC acts thus as neutral observatory of the emerging power systems and of the development of smart grids in Europe. Different works are carried out towards this direction, some of which are listed as follows:

- The Smart grid projects outlook, listing the smart grid projects in Europe [12].
- The Distribution System Operators (DSO) Observatory, giving information about the European DSOs (grid characteristics and smart grid dimension) [13].
- The assessment framework for the identification of Smart Grid Projects of Common Interest (PCI) [14].

The Smart Grid Laboratories Inventory completes the picture of the aforementioned work and gives a clear idea of the smart grid research worldwide, the infrastructure used and the trends in smart grid research topics.

As future work, the following actions will be performed:

The Smart Grid Lab Inventory will continue to take place periodically, giving updated information on the smart grid research topics and trends.

The Online Tool will be improved so as to show in a dynamic way the laboratories that carry out research on a specific topic, i.e. by introducing filters. This will improve visibility of the labs and will help the user identify in a straightforward way other labs that carry out certain research or that use specific infrastructure.

Quick guide

Chapter 1 gives a short introduction to the subject. Chapter 2 explains the basic concept behind our survey, how it has been structured and the information collected. It also gives an idea of how previous releases were formed. Chapter 3, Chapter 4 and Chapter 5 present the results of the aggregated analysis performed of the data collected. Particularly, Chapter 3 presents generic information collected for labs. Chapter 4 gives the results with respect to the categories of research, their sub-categories and the standards used. Chapter 5 gives the results regarding infrastructure, simulation tools used and services offered by labs. Chapter 6 concludes this report and presents future work to be done.

1 Introduction

In the last years, the electricity grid has been under great transformation. The traditional one-direction flow grid is no longer sufficient to cover the needs in terms of electricity demand and cannot cope up with the request for a so-called greener society. Indeed, the modern world requires every day more and more energy to cover consumption needs. On the other hand, the ongoing climate change and the eminent need for reducing CO2 emissions, require the production of “green” energy. Thus, the electricity grid needs to cope up with great challenges.

One of these challenges is the fact that the grid needs to accommodate the increasing number of Renewable Energy Sources (RES), which contribute to the reduction of CO2 emissions. Such RES are desirable to have, but the energy produced depends on variable factors, like the weather, that makes it really difficult to predict the energy to be produced by them, and thus difficult to manage. In addition, to avoid losses, it is important for the electricity grid to have a balance between supply and demand. It is also critical to achieve consumption of energy where it is produced to avoid transmission and distribution losses. Storage is also another area that needs to be improved in order to avoid losses of energy and maximise balance between supply and demand. Therefore, intelligent and sophisticated systems are required for the grid in order to tackle with such challenges. The management of RES and distributed generation requires complex systems and the bi-directional flow of data on the grid. All these, in addition to the increasing demand of electricity, which is expected to be increased even more due to the electrification of the transport sector and of building heating systems, implies that the transformation of the traditional grid into the smart grid is necessary.

The grid is being equipped with more and more intelligent devices in order to cope up with the advanced needs. Intelligent electronic devices within substations for automatic handling of energy at substation level, Phase Measurement Units (PMUs) are only examples of advanced infrastructure of the grid. Microgrids and islanded grids are also ways of transforming parts of the grid into smarter ones.

The upcoming smart grid means that there is information flow on top of the energy flow of the grid. For the huge amount of information to be produced and handled, intelligent systems, devices and infrastructure are required. Indeed, there is an increasing number of smart meters producing a huge amount of data, smart devices that transform houses and buildings into smart ones, which are only some examples of the smart infrastructure being updated in the grid and for the grid. Therefore, advanced Information and Communication Technologies (ICT) are fundamental for the digitalization of the smart grid.

The bidirectional flow of information is also crucial for modern programs, like demand response, in order to achieve the engagement of citizens for reducing their carbon footprint. In fact, citizens play also a key role in the grid transformation and can contribute in the achievement of smart cities and a “greener” society. Citizens need to be correctly informed about the capabilities of the smart grid so as to be enablers of the new smart grid era.

All the above imply that there is extensive research in the smart grid in various fields. This is proved also by the numerous smart grid projects that have been realised the last years. Indeed, according to [12], there have been launched approximately 950 smart grid projects from 2002 up to nowadays, amounting to 5 billion euros of investments. The numerous subjects of the ongoing research means that there are various groups of scientists that work on the broad topic of smart grid. All this research needs to be backed up by the appropriate infrastructure. Laboratories is where research can be tested and new technologies can be verified. Therefore, it is important to investigate on the infrastructures that are present in Europe and beyond: which scope do these infrastructures serve and how they are used, in which sectors do scientific groups investigate the most are only few of the subjects of interest with respect to the smart grid laboratories infrastructure.

This report intends to shed light to the smart grid laboratories that operate in Europe and beyond. It collects information about the smart grid topics of research, the technologies and standards used as well as the infrastructure that they utilize. An online questionnaire has been created for this scope. Aggregated results are presented in this report with respect to the technologies, standards and infrastructure used by the laboratories.

For this version of the Inventory, we have united our forces under the EIRIE platform, and an updated database is obtained, containing information in coherence with the ETIP SNET (European Technology and Innovation Platforms Smart Networks for Energy Transition) concept.

EIRIE, the European Interconnection for Research Innovation & Entrepreneurship is a living dynamic multi-functional platform for all the energy system stakeholders and for all citizens to benefit of a series of services:

- Research and Innovation exchange including the results of all EU and National funded projects;
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The EIRIE platform:

- Connects the R&I community of EU to enhance collaboration with a wider interest and use of the project results;
- Avoids duplication and optimizes investments;
- Fosters and facilitates entrepreneurship;
- Strengthens the participation of all Member States in support of the fifth pillar of the Energy Union and the energy transition.

The categories of smart grid research for which information is collected, are not only in accordance to the ETIP SNET concept, but they also depict the challenges the smart grid faces, as these are summarized above:

- Generation
- Storage
- The Integrated Grid
- Digitalization, Communication and Data
- Customers and Market

The report presents the topics where research is focused nowadays and helps the reader identify the trends and the state-of-the-art in a straightforward way. The effort and resources invested by the JRC, as the promoter of the creation of an inventory of Smart Grid research facilities, and also by the participating organisations, who dedicate a considerable amount of time and effort to provide the information required, brings different benefits not only to the main stakeholders, but also to the society at large.

2 Survey Description

This is the fourth release of the Smart Grid Laboratories Inventory. The scope has been twofold: to give an update of the situation with respect to smart grid research and also present coherent information with the ETIP SNET concept regarding the fields of smart grid research. In this Section we present the description of the survey and we also give the highlights from the previous releases. In addition, we present a description of the EIRIE platform and the ETIP SNET concept and we also describe the updated online tool to be operating in the near future.

2.1 Previous Releases

2.1.1 First Release – 2015

The initiation of the project dates back to 2013, when the need to create a repository of information regarding the smart grid laboratories came out. As a first action, information publicly available in the internet was searched, in order to create a form of database with laboratories working on the smart grid. However, this method was not efficient, since internet can be a chaotic source of information and creating a concrete database of homogeneous information can be tricky. In addition, the data found in the internet is many times generic and it is not possible to extract detailed information. Thus, the need to create a structured questionnaire came out.

It took almost a year to finalise the survey's questionnaire due to the fact that there were many stakeholders involved for consultation. The resulting questionnaire consisted of more than 170 questions divided in 13 thematic areas / categories of smart grid research. The goal was to have as many multiple choice questions as possible, to facilitate the participants by replying in a straightforward way, but also the final data elaboration for the extraction of statistics. The questions were explained in detail through contextual help text so as to help people in selecting the correct answer. The categories were structured as:

1. Grid Management
2. Distribution Automation
3. Generation and Distributed Energy Resources
4. Storage
5. Sustainability
6. Market
7. Electromobility
8. Smart Home / Smart Building
9. Smart City
10. Demand Response
11. Cyber Security
12. ICT Communication
13. AMI: Advance Metering Infrastructure

The questionnaire was created in a dynamic way, meaning that a group of questions would appear only if a previous question was answered positively. This way of filtering the resulting questions helped the flow of the questionnaire and made the length of the survey adaptable to the number of activities a lab was involved into.

The survey was published in our website, so that any organization, private or public owning a Smart Grid lab facility, would be able to participate. Apart from such publication, a preselected number of laboratories were invited through personal emails to participate in our survey. These organizations / institutions were selected as follows:

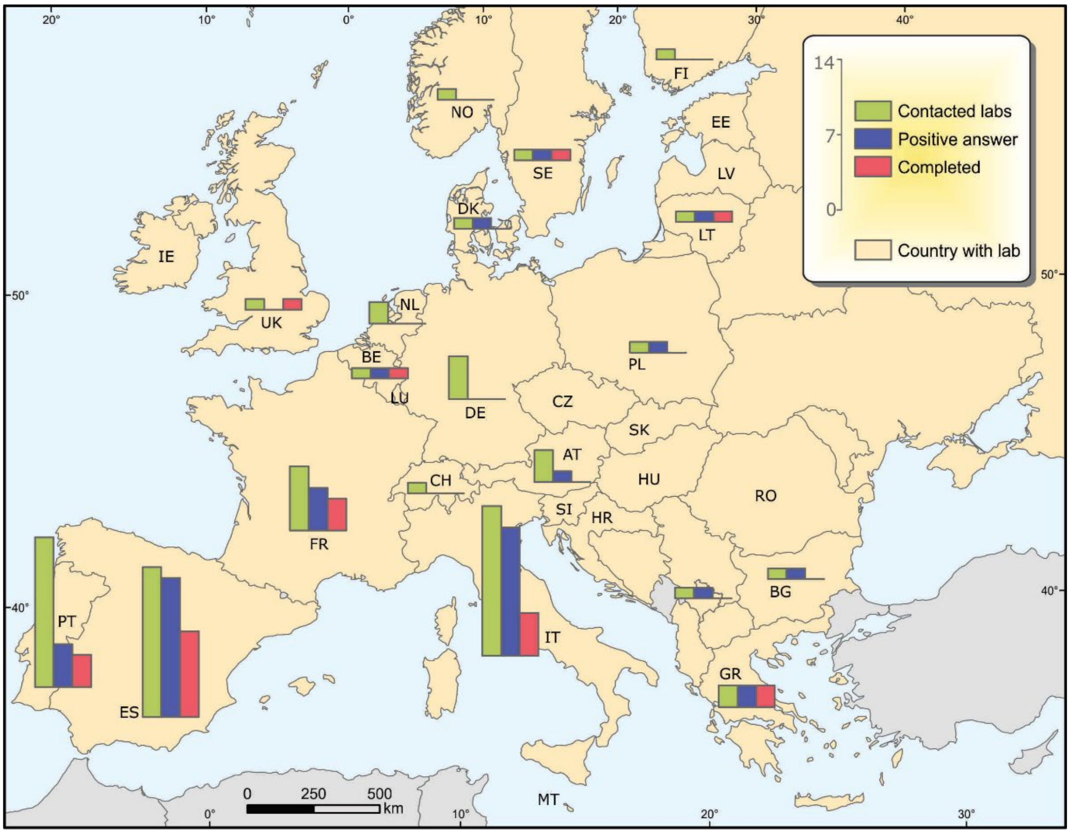
- Initial Internet search
- National Contact Points of Horizon 2020
- Input from internal and external expert stakeholders

For each organization / institution / laboratory, a personal link was created and sent, so as to enable participation. The option "save as draft" had been provided, which facilitated the completion of the questionnaire, meaning that it could be filled in different time moments and also by different people working in the institution.

Data collected was stored in an online repository. On the other hand, a single contact point was identified for each lab and was used for communication purposes. Such data were treated as personal data instead of the rest technical data collected from the survey.

In the first release of the project, the laboratories that took part were 24. The data was processed and results were presented in an aggregated way, so as not to be possible to identify which laboratory had provided a specific answer. Sensitive information, like investment plans was not published. The final report was published early 2015. Figure 1 shows the distribution of the labs by country for the first release. A complete description of the survey, sections and questions can be found on the aforementioned report [15].

Figure 1. Participating labs distribution according to the country in which they are based (please note that there was one US Lab participating not shown on the map.



Source: [15].

2.1.2 Second Release – 2016

The second report [16] was published late 2016 and was an update of the 2015 release. The main target was to expand the sample of the participant laboratories and give aggregated information on the smart grid research carried out. Indeed, the information published was anonymised and it was not possible to identify the individual contribution of the laboratories. The information shed light to the smart grid research trends and helped in identifying gaps.

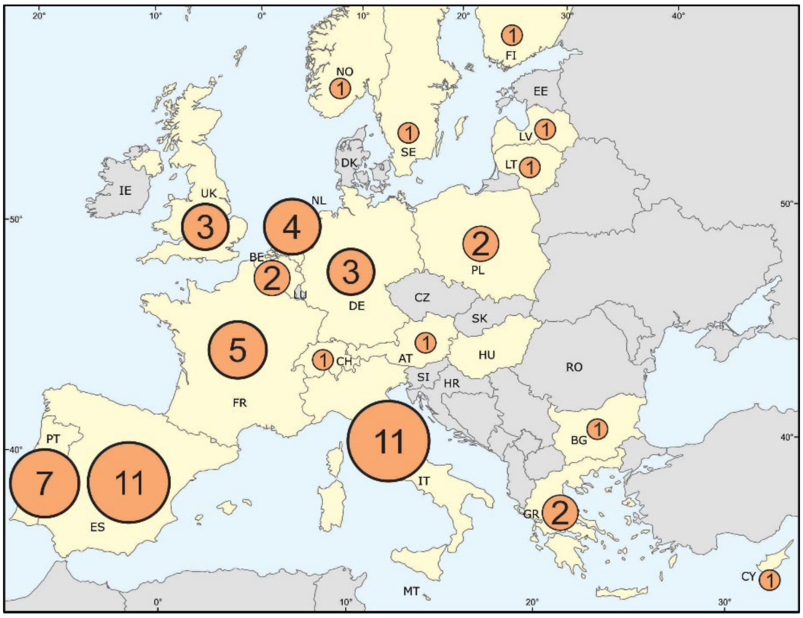
The target of expanding the sample was achieved, since 69 laboratories participated in this release, which led to a sample of 2.87 times larger than the previous sample. More geographical areas were included and especially participants from North America were reached out. This increased visibility of the Smart Grid lab Inventory and gave an idea of what is being used beyond Europe.

For this release, similarly to the previous one, personal data was collected and stored according to the Legal Department's rules and they were treated differently from technical data. Participants were provided with a clear explanation of how their data would have been treated.

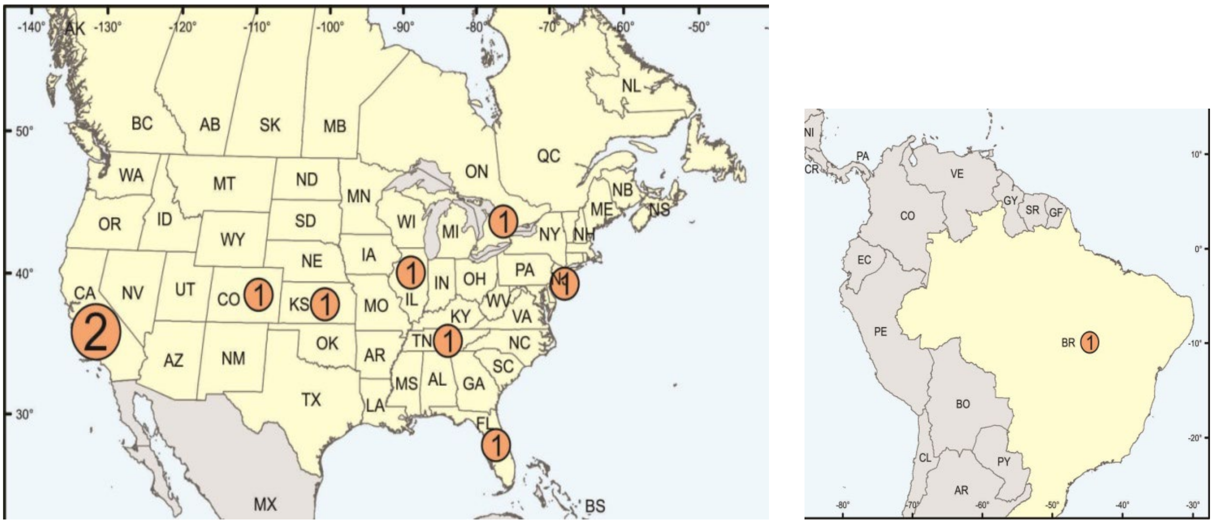
For the second release a continuity approach was chosen. The same structure was used with the first release of the survey and changes to the questionnaire were minimal, since it took place only one year after the first release. Focus was given on gathering information from new participants and enlarging the sample.

Figure 2 shows the distribution of the labs for the second release depending on their location.

Figure 2. Participating labs distribution according to the location in which they are based, a) In Europe, b) in America.



a)



b)

Source: [16].

With respect to the categories of research conducted, Table 1 shows the percentage of laboratory per category for the 2016 version of our survey, showing that Generation and DER, Demand Response and Grid Management are categories that attracted the scientific interest with a percentage of over 70% of labs conducting research in these fields.

Table 1. Percentage of laboratories per activity.

Category	**%**
Generation and DER	81%
Demand Response	76%
Grid management	73%
Storage	70%
ICT: Communication	69%
Electromobility	66%
Smart Home/Building	64%
Distribution automation	61%
Smart City	51%
AMI: Advanced Metering Infrastructure	46%
Market	45%
Cyber Security	42%
Sustainability	33%

Source: [16].

2.1.3 Third Release – 2018

The third release [17] of the Smart Grid Lab Inventory took place late 2018 and the purpose was twofold: to update the situation with respect to smart grid research for the existing labs from the previous release and expand the sample by including more labs worldwide.

The same concept has been used with previous versions, meaning that the structure of the questionnaire remained the same in overall: some general questions at the beginning of the questionnaire followed by questions on the categories of smart grid research. However, some changes were introduced in this release. In particular, the categories were decreased from 13 to 12, since "Sustainability" proved to be a generic category with information that could be included in other categories. In addition, some multiple questions were eliminated to make the questionnaire simpler and shorter and were replaced by free text, were the participants could choose to fill in information or not. In general, the obligatory questions were the ones referring to the categories of core research performed by laboratories, whereas in-depth information was optional for going into details about the topics of research and the means used to accomplish that. Nevertheless, the results revealed that the majority of participants opted for giving also detailed information about their work.

The same concept of data treatment has been used with the previous release. Specifically, a clear explanation has been provided to participants as to how their technical data have been used, with a detailed explanation of the project's activities. In addition, personal data were limited to the contact point from each organisation, in which only our team has access to. Such personal data are only used for communication purposes, such as to communicate to the participants the report or to give updates on the project.

The report that was published, showed aggregated information, similarly to the previous releases, in a way that it was not possible to deduct the information given by each participant individually. The sample was increased to 89 laboratories included in this release, in contrast to 69 of the previous one. More geographical areas were included and the new laboratories were mainly the result of internet search in order to identify more institutions/ labs carrying out research in the field.

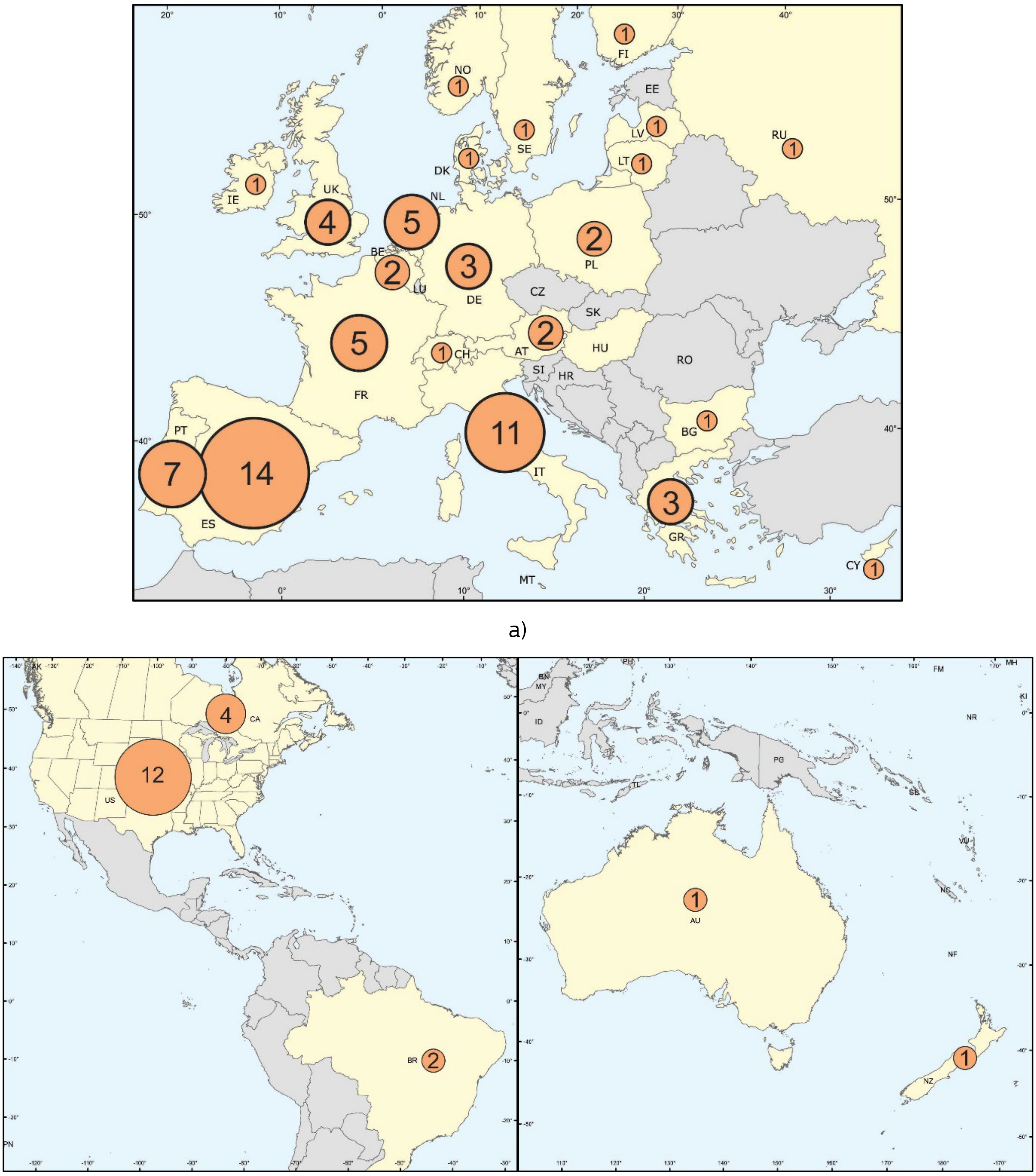
A novelty of this release was the online tool that was realised. It was owned by the JRC and hosted on a European Commission web server. Among other items, the website includes a world map where the research facilities are located. A sub-page under the team's main website of activities was created, showing the core information obtained from the Smart Grid Lab Inventory. In particular, information about the categories of research appeared for each laboratory, whereas the lab's name and its location were used as identification purposes. It should be noted that only public information was used on the website for identifying the labs, whereas personal data were by no means revealed. This online tool increased visibility of the labs and their activities. Table 2 shows the percentage of laboratory per category for the 2016 version of our survey, showing that Generation and DER, Demand Response and Grid Management are categories that attracted the scientific interest with a percentage of at least 75% of labs conducting research in these fields. Figure 3 shows the geographical distribution of the labs.

Table 2. Percentage of labs per activity.

Category	**%**
Generation and DER	85.2
Grid Management	75
Demand Response	75
Storage	70.5
Smart Home/ Building	62.5
ICT: Communication	62.5
Electromobility	61.4
Distribution Automation	59
Smart City	50
Advanced Metering Infrastructure	45.5
Market	44.3
Cyber Security	44.3

Source: [17].

Figure 3. Participating labs distribution according to the location in which they are based in a) Europe, b) the Americas and c) Australia and Oceania.



a)

b)

c)

Source: [17].

The 2018 release of the Smart Grid Lab Inventory also led to the publication of a journal, entitled "Smart Grid Lab Research in Europe and Beyond", [18], in an attempt to further increase visibility of the work done and promote the Inventory for future releases. The paper gave information about the categories of smart grid research carried out by the labs. Not all labs in the 2018 survey were included in the work of this journal, simply because the work was initiated a bit before the survey was closed, so, the sample was the one available when the work was initiated. The paper showed the trends in smart grid research and it focused mainly on public information found on each laboratory website, rather than the detailed information that the survey included. The categories of research remained the same, however, this information could be easily deducted also from the laboratories' websites. Apart from that, the paper gave information also about publications and synergies among the institutions, which was a step further from the survey's information. It also gave an idea of the research carried out in combined categories, i.e. what was the trend of carrying out research in "Storage" and also "Generation and DER", which was an added value of the published paper.

The expansion of the smart grid labs sample and the extra work that followed the 2018 release (journal paper and website), gave another perspective of the work done and rendered it promising for future versions.

2.2 EIRIE Platform and ETIP SNET concept

Before proceeding with the description of the current release of the survey, it is worth explaining the EIRIE platform and the ETIP SNET concept, which have been vital for the development of the current version of the Smart Grid Lab Inventory.

2.2.1 EIRIE Platform

Since smart grid research is getting bigger and bigger and more groups are carrying out research work in the field, there has been the need to have a reference point to unify activities. For this reason, the EIRIE platform was created [19]. The platform intends to provide with the correct tools to stakeholders so as to incentivize further smart grid research and achieve key collaborations for maximising results.

EIRIE intends to establish a group of Research and Innovation stakeholders in the field of smart grids. This group will be composed by policy makers, standardization bodies and experts in academia and research institutions, among others and will represent the EU energy system.

The EIRIE platform is meant to provide the means for smart grid actors for facilitating their work, by giving access to data, information and outcomes from projects realised in the field of smart grid. Therefore, project deliverables, reports and project related results will be accessible through the EIRIE platform. For this scope, a strong search engine will be available to facilitate users in finding information in a straightforward way.

It is intended that the EIRIE platform becomes a central reference point for smart grid stakeholders, where they can find information and launch synergies with other entities. The platform takes into account all existing work and activities in the field. It has / gives access to already existing platforms in the field of Smart Energy Systems, according to [19]:

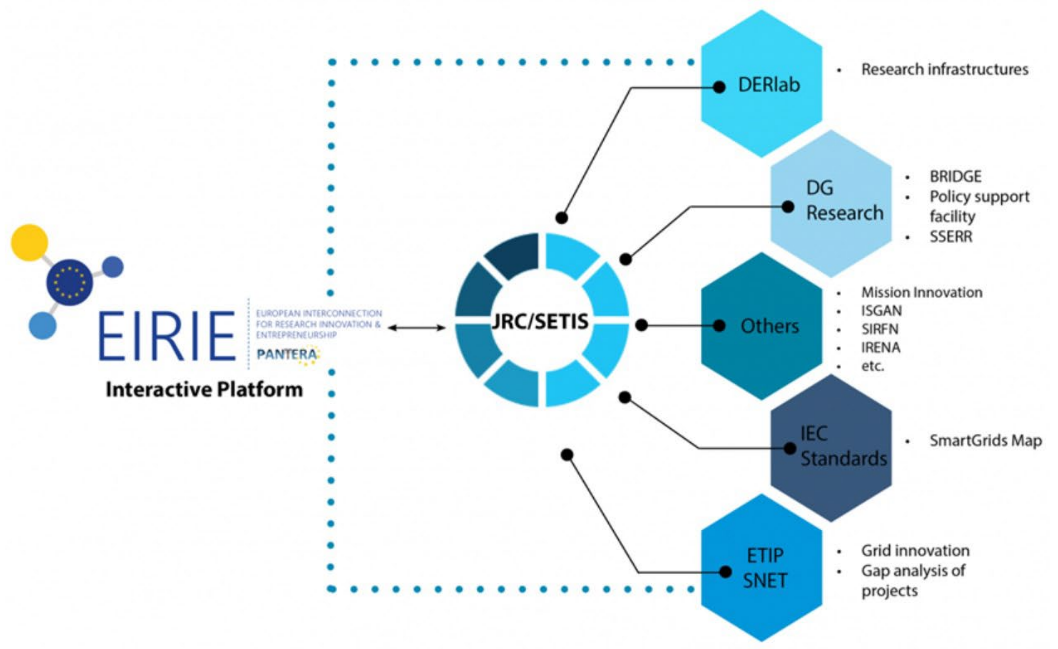
- the Smart Electricity Systems and Interoperability Platform of the Joint Research Centre of the European Commission;
- the Knowledge Sharing Platform of ETIP-SNET;
- the BRIDGE portal;
- the PERA platform of ERANET Smart Energy Systems;
- the Mission Innovation Platform;
- the EU Research Results Platform (CORDIS);
- the DERlab Research Infrastructures database;
- the ASSET platform offering training material in the area of smart grids.

The EIRIE platform offers various services in the following areas:

- Project Evaluation and Reporting Services – it offers access to projects data and results obtained by projects.
- Stakeholder Community building – which increases awareness on regional activities and fosters discussion and collaboration between stakeholders.
- Sustainability and Collaboration Services via online collaborative documents
- Data Search Services through a strong search engine including filtering

In addition, EIRIE intends to offer other services as well, like training services and news and events services. The concept of the interactive EIRIE platform is summarised in the following picture.

Figure 4. EIRIE Platform concept.



Source: [19].

The EIRIE platform is actually the outcome of the PANTHERA project (PAN European Technology Energy Research Approach). It is actually a H2020 project with ultimate objectives to create a forum of smart grid stakeholders and provide with support to the countries that are less active in Research and Innovation field. The project outcome has been to create the EIRIE platform and among others, as indicated above, to create a huge repository of data related to the smart grids, like project deliverables, project outcomes, regulations and standards, use cases and scenarios, information about smart grid infrastructure used.

The R&I status and Continuous gAP analysis (RICAP) is the core process of the PANTERA project. The concept is that long term plans come together with stakeholders to achieve better results. Within the RICAP process, all incoming data and information are classified, categorized, enriched and processed so as to enable results in order to achieve future developments.

2.2.2 ETIP SNET concept

European Technology & Innovation Platforms (ETIPs) have been created by the European Commission as an outcome of the new Integrated Roadmap Strategic Energy Technology Plan (SET Plan) and have united numerous stakeholders and experts from the energy sector. The ETIP Smart Networks for Energy Transition (SNET) are responsible for guiding the scientific community towards the energy transition era. The ETIP SNET duties are among others to [20]:

- Guide stakeholders towards Research, Development and Innovation for future smart networks.
- Prepare and update the Strategic Research and Innovation Roadmap.
- Give updates on the Strategic Research and Innovation Roadmap.
- Contribute in spreading knowledge techniques for bringing research results into development.

The ETIP SNET has five working groups on the topics of: energy system; storage and flexibility; flexible generation; digitalization of the energy system and customer participation; innovation implementation in the business environment.

A project that has worked closely with the ETIPS SNET working groups and followed the concept introduced by ETIP SNET, has been the PANTHERA project [21]. Indeed, the PAN European Technology Energy Research Approach (PANTERA) is an EU H2020 project with the scope to set up a European forum of Research and Innovation stakeholders that work in the smart grid field. The group of stakeholders included policy makers, researchers, standardisation bodies, who are active in the energy system and/ or storage systems.
One of the outcomes of PANTHERA project has been to define the technologies and systems in support of the functionalities in the area of smart grids. With this material, every activity in the smart grid field can be categorised in a broader group of technologies. Particularly, there are 5 groups of technologies, namely:

1. Integrated Grid
2. Customers and Market
3. Storage
4. Generation
5. Digitalization, Communication and Data

The following table shows analytically these 5 groups of technologies and the sub-categories of technologies they include along with their description.

Given the work done under the ETIP SNET umbrella, it has been of vital importance to follow the established categorization of smart grid research also in our Inventory from this and for future releases of the project.

Table 3. ETIP SNET Technologies and Systems in support of the Functionalities.

Group of technologies	Technologies	Description
Integrated Grid	Flexible ac transmission systems (FACTS)	Controllable power electronic equipment that will support the Transmission smart grid operations
	Models, Tools, Systems for the operation analysis, control and the development of the integrated grid including cost elements	Advanced models, tools, systems for the operation analysis, control, state estimation and the development of the integrated grid (TYNDP etc) including cost elements
	HVDC	High Voltage Direct Current overhead and underground grid, including converter stations and HVDC control.
	Forecasting (RES)	Advanced forecasting tools (RES) that will allow a low estimation error and provide an accurate feedback for the actors that need these types of services. E.g. aggregators, operators, RES owners, the market operator etc.
	Asset management	The methodology, procedures, the devices and software that allow the efficient management of assets of the integrated grid.
	Outage management, fault finding and associated equipment (including protection)	The methodology, procedures, the devices and software that allow the efficient management of outages including fault finding of the integrated grid.
	Equipment and apparatus of the integrated grid	All the primary equipment (rated at the rated voltage of the system) and apparatus constituting the integrated grid including Power guards and limiters.
	Equipment sensing, monitoring, measuring for analysis, solutions and control	Equipment sensing, monitoring, measuring for analysis, solutions and control including procedures, peripherals and software that make the integrated grid observable. These include the devices and the procedures that allow PMUs, Phasor Data Concentrators (PDCs), distributed control and GPS to be efficient tools of the smart grid paradigm
	Advance distributed control	Software or hardware devices or procedures that allow advanced distributed control of distributed assets of the grids and actual control process such as intelligent control, hierarchical control, other control schemes, etc
	Feeder auto-restoration / self-healing	Advanced procedures and systems that facilitate the feeder auto-restoration thus implementing the self-healing of the interconnected system
	Smart metering infrastructure	All the procedures and systems that are related to smart meters as devices and complete bi-directional communication link between metering data management systems and end users.

Customers and market	Distributed flexibility, load, forecast, management & control and demand response including end devices, communication infrastructure and systems	All procedures, controls and devices that facilitate distributed flexibility, load management including explicit demand response and system
	Smart appliances	Smart appliances that allow customer market participation and smart load control.
	Building control, automation and energy management systems	All procedures, controls and devices that secure smart building automation including home energy management, active control, monitoring and market participation
	Electric vehicles	Electric vehicles are vehicles based on battery or fuel cell resource for transport needs including charging infrastructure.
	Energy communities	Its primary purpose is to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates. May engage in generation, including renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders;
	Lighting	Any apparatus emitting light and related systems.
	Electricity market	All elements of the electricity market including platforms that enable wholesale, retail, real time pricing / spot, flexibility, aggregated and peer to peer trading including ancillary services, etc.
Storage	Storage Electric	In the electricity system, apparatus capable of deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy. It includes electrical to electrical or electrical to other through a reversible process.
	Thermal Storage	The main parts and all auxiliary components that form a ready to integrate device capable of storing thermal energy for use at a later stage.
	Power to X	The main parts and all auxiliary components that form a ready to integrate device from technologies facilitating sector coupling that uses electrical power to produce another energy carrier eg gaseous fuel for storing or use otherwise.
	Pumped storage	The main parts and all auxiliary components that form a ready to integrate system to operate as a Pumped storage system which is the process of storing energy by using two vertically separated water reservoirs. Water is pumped from the lower reservoir up into a holding reservoir. Pumped storage facilities store excess energy as gravitational potential energy of water.
	Other Storage	The main parts and all auxiliary components that form a ready to integrate device capable of storing energy other than the above systems.
Generation	Flexible generation	The main parts and all auxiliary components that form a ready to integrate device

	Solar including PV & CSP	The main parts and all auxiliary components that form a ready to integrate systems capable of generating electricity from PV or CSP technologies.
	Wind	The main parts and all auxiliary components that form a ready to integrate systems capable of generating electricity from wind technologies.
	Hydropower	The main parts and all auxiliary components that form a ready to integrate system capable of generating electricity from flowing hydro.
	Hydrogen & sustainable gases	The main parts and all auxiliary components that form a ready to integrate systems capable of generating electricity from hydrogen and other sustainable gases.
	Other generation	The main parts and all auxiliary components that form a ready to integrate systems capable of generating electrical energy other than the above.
Digitalization, Communication and Data	Communication networks including devices and systems for signals and data connectivity and solutions	Any combination of equipment and systems forming a communications network as a group of nodes interconnected by links that are used to exchange messages between the nodes. The links may use a variety of technologies based on the methodologies of circuit switching, message switching, or packet switching, to pass messages and signals including Local Area Networks, Home Area Networks and web-based solutions and cloud services for smart gird operations
	Digital Twins	Any combination of equipment and systems forming Digital twins that are virtual replicas of physical devices that can used to run simulations before actual devices are built and deployed.
	Artificial intelligence	Any combination of equipment and systems forming Artificial intelligence that simulates human intelligence in machines that are programmed-including machine learning- to think like humans and mimic their actions.
	Data and cyber security including repositories	Any combination of equipment and systems offering Cyber security for defending computers, servers, mobile devices, electronic systems, networks, and data from malicious attacks, including generated data from the interconnected system with related repositories other than that related to the MDMS (Meter and Data Management System).

Source: [22].

2.3 The current release of Smart Grid Lab Inventory - 2022

The current release follows the categorization of the ETIP SNET working groups and this is the major innovation with respect to previous releases. However, it is worth mentioning that the Smart Grid Lab Inventory is not the only work in the field of gathering information about smart grid lab research that is being carried out. For instance, DERLab has gathered information in a database about smart grid labs with which they have held collaborations, [23]. Information is collected about the research activities and the infrastructure used by the labs. In order to avoid multiple definitions of the activities in the smart grid field by various working groups, it has been of vital importance to follow coherent terminology and a unique categorization. The ETIP SNET categorization is therefore the one that has been agreed to be followed by the JRC and the DERLab databases.

For this reason, our questionnaire follows the structure of the previous releases of the Inventory. This means that initially there are general questions, like geographical location of the laboratory, number of employees, investments that took place (confidential information), etc, whereas the second part is dedicated to the categories of smart grid research carried out. Instead of 12 categories that we had in the previous releases of the Inventory, this time we have the 5 ETIP SNET categories mentioned in the previous section, namely the: Integrated Grid; Customers and Market; Storage; Generation; Digitalization, Communication and Data.

The questionnaire goes into more details with further questions for each category, like the technologies used and the standards according to which a laboratory works. However, since the categories have changed in this release, it has been required to link the previous categories to the new ones, so as to keep the Inventory's releases coherent and obtain the information needed. Table 4 shows this linking between old and new categories.

Table 4. Linking of old and new categories.

New category	Old Categories
Integrated Grid	Distribution Automation Grid Management Advanced Metering Infrastructure
Customers and Market	Demand Response Smart Home/ Building Smart City Electromobility Market Advanced Metering Infrastructure
Storage	Storage
Generation	Generation and DER
Digitalization, Communication and Data	ICT Communication Cybersecurity Advanced Metering Infrastructure

Source: JRC analysis, 2022.

It is clear that for some of the 5 new categories, more than one old category is linked. The category that covers a big amount of the old information is "Customers and Market". This is because, according to the ETIP SNET technologies definitions, smart home, smart city (energy communities), electric vehicles, flexibility and market research activities are categorised here.

So, the questionnaire of the Inventory of this release has changed with respect to the previous ones as follows:

- The categories of smart grid research have changed from 12 to 5, as explained above;
- The questionnaire has been slightly simplified, in the sense that some of the questions have been eliminated;
- The questions that asked detailed information about an old category have been moved under the umbrella of the new category;
- The general questions part has been slightly changed: some of the questions have been eliminated and others have been added after elaboration.

For the rest, the same concept has been kept, meaning that the questionnaire is dynamic. Certain blocks of questions appear only if others are selected (i.e. if a lab does not carry out research on Storage, the equivalent questions do not appear).

With respect to personal data treatment, the same methodology is used as with the previous versions. Personal data is not asked in the questionnaire, but it is kept in another database for communication reasons only, for example, to communicate updates of the project to participants.

Another novelty in this release is the fact that focus has been given in updating the information of the labs that were already in our database according to the new questionnaire. Expanding the sample of participant laboratories has been a secondary goal this time, unlike the other releases of the Inventory. Since the questionnaire has changed and the ETIP SNET categories of research have been introduced, it has been judged fundamental to have updated information from already participant laboratories. In addition, the first release of the Inventory took place 6 years back, so, in case any laboratory had not yet updated its data since the very first release, the old information has not been taken into account. With this release it was intended to reset the information kept in our database. In the report, aggregated information is published, which is a result of statistical analysis of the data collected.

The results of this release are presented in this report and will be the basis for further activities under this project.

2.4 Online Tool – Future version

A goal of this work is also to update the website where basic information of laboratories is made public. By basic information, we mean the categories of smart grid research that they carry out and the lab's location. This is also information that can be easily extracted from public information in the labs' websites.

The novelty with respect to the online tool is that this time it is intended that the website will be made in a dynamic form, meaning that filters will be introduced, so as to facilitate users to find information about other labs' activities in a straightforward way and identify labs with similar research activities easily. The objectives of this Online Tool are:

- To provide information about past, present and future smart grid research activities.
- To increase awareness of smart grids.
- To enhance collaborations among organisations in smart grids.

The updated online tool will be owned by the JRC and hosted on a European Commission web server. The information will be also visible on the EIRIE platform, which by definition hosts data from repositories in order to function as a hub for stakeholders that need to locate information easily.

3 Results: Participants and General Information for labs

In this Chapter, aggregated results are presented with respect to the collected data. As a first step, information is given about the participant laboratories and their geographical location. In addition, information is given about how the labs have been contacted and how the survey took place. As a following step, general information collected is analysed, like the number of employees, the economic resources of the labs and investment figures, just to name some. Afterwards, the 5 categories of research are analysed and detailed information is presented regarding the sub-categories of research, the standards used and infrastructure that is utilised. For the questions that were introduced in our survey this year, the results presented show aggregated information of the 50 labs that updated their feedback this year. For the rest of the questions, the sample of 86 labs has been used. This is explicitly shown in the following presentation of results.

3.1 Overview – Smart Grid Laboratories Inventory Participants

Similarly to old releases of the Inventory, in this work, the results presented is a blend of new and old entries of laboratories in our database. However, this year there have been two major novelties:

- The categories of the questionnaire have been changed along with some questions.
- Information dating more than 5 years back, has been decided not to be used.

These two factors, have enhanced the idea of focusing on updating already existing information from laboratories in our database. Laboratories that have not updated their information since 2015, have not been included in this release of the Inventory.

As a secondary goal, it has been to find new laboratories for our survey. Likewise the previous releases, an extensive internet search has been made and new potential laboratories for our database have been contacted. In total, around 170 labs (old and new) have been contacted and invited to participate in the Smart Grid Lab Inventory. The labs covered all geographical areas, Europe, America, Asia, Oceania and Africa. Apart from internet search, personal contacts have been used from international conferences as well as contacts given in the previous releases by national contact points. In addition, old contact points have been updated through internet search, since it has been proved that many of the people have changed jobs, or simply no longer worked on their old position, as lab responsible.

As a result, 50 laboratories completed our new questionnaire, which formed a good starting point for our Inventory. Out of these 50 labs, 10 labs have been new entries, whereas 40 of them had participated also in the past, thus updating their information. In addition, we had 4 more labs that had participated between the third and the current release of the Inventory. For the remaining laboratories in our database, who have not updated their information, but did not object in using the old data (indeed, 1 laboratory confirmed that nothing had changed in their research since the 2018 release), the following has been done:

- Labs with information not updated after 2015, have not been included.
- Internet search has been performed for labs with information since 2016 – 2020. For the ones that it was clearly proved to be still active in the field, according to their website have been included in this report.

After the above actions have been applied, 36 labs have been decided to be included in this report, out of which, 20 labs have given their last feedback in autumn 2016, 12 labs have given their last feedback in autumn 2018 and 4 have given their last feedback between 2019 – 2020. It is worth noticing that 2 labs have stopped their activities in the last years, while another one has been sold. With the criteria applied, not all participants from the 2016 and 2018 release have been included here. Instead a careful selection was done. In addition, 2 other labs that had replied in the past, updated their info this year as one lab with multiple activities.

In the results presented, information that is based on novel questions of the questionnaire is extracted from the 2022 labs sample (50 labs). On the other hand, information based on questions included also in the old questionnaires, is extracted from the extended sample of 86 labs (50 + 36).

It is important to notice that our sample remained at the 2018 release levels, when we had information from 89 labs. This time the objective has not been to simply increase the number labs, but to include useful and updated information.

Similarly to the past releases, time has not been our ally also in this version. Increased workload in different time periods makes it impossible for the labs to respond to our invitations at the same time, when the

Inventory takes place. Indeed, there have been participants that replied that due to heavy workload they could have replied only after the deadline of the Inventory would have been significantly due. Therefore, old information re-use has been the solution also for them. Another problem that has been identified, was the lack of contacting the correct person from the first moment. Old databases, contained contact people that sometimes were no longer valid; not in all occasions were we able to find the correct contact point immediately through the internet. With respect to new identified labs, sometimes general email addresses had to be used, which apparently did not give the desired result and our invitation has probably not ended up in the correct people. All of the above factors has limited to the total number of labs in 86, which remains however a good achievement for this year's release.

The majority of the labs are located in Europe, namely 65 labs out of 86. This is explained because JRC is mainly known for its activities in Europe. In addition, since many of these laboratories / institutions are taking part in European funded smart grid projects through Horizon 2020 or similar programs, it is common that synergies are sought and initiatives like the Smart Grid Lab Inventories can be a perfect source of information for them in order to launch new activities and take part in such European funded projects. On the other hand, JRC has always sought for enlarging the sample of labs and include institutions outside Europe. This way, a global picture of the research carried out in the area of smart grids is offered, which gives the opportunity to participants to have an idea of what is being done outside Europe. In addition, synergies among institutions from different geographical areas are more than encouraged and the Smart Grid Lab Inventory can contribute towards this direction. This year, 21 labs are located outside Europe. It is worth noticing that in this release we have the very first participant lab from Africa, an area that had not been covered in the past. On the other hand, there are still no participants from Asia, which is the target for next releases of the Inventory.

Table 5 and Table 6 show the number of labs based on the country in which they are located. It is also shown the number of labs which have updated their information in late 2021. These labs form the sample based on which new information is presented, meaning that information based on new questions introduced in the questionnaire is derived from this sample of labs. In the following, we make it clear where the sample is only the 50 labs that have given updated information in late 2021 or where the extended sample of 86 is used (information merged from the current and the two previous releases).

Table 5. European labs based on the country in which they are located.

Country	2021 feedback	Older feedback	Total
Austria	2		2
Belgium*		1	1
Bulgaria	1		1
Cyprus	1		1
Denmark	1		1
France	2	2	4
Finland	2		2
Germany	1	3	4
Greece	3		3
Ireland		1	1
Italy	6	4	10
Latvia		1	1
Netherlands	2	2	4
Norway	1		1
Portugal	4	1	5
Poland	1		1
Russia	1		1
Spain	10	6	16
Sweden	1		1

Switzerland		1	1
UK	1	3	4
			65

Source: JRC analysis, 2022.

*Belgium gave feedback in 2020 before the Inventory was launched and it was actually a cluster of labs (around 5 labs) participating altogether.

Table 6. Labs outside Europe based on the country in which they are located.

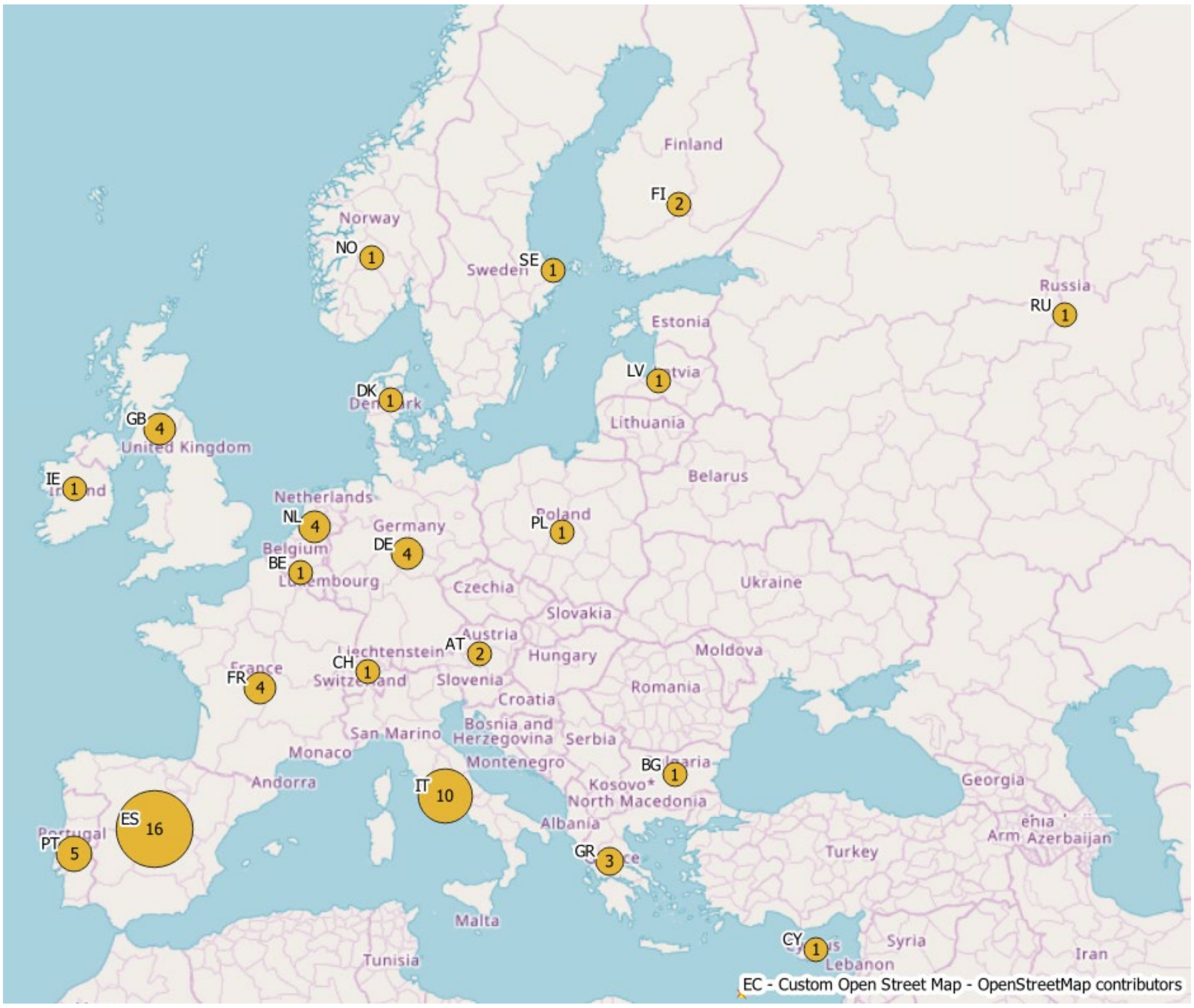
Country	**2021 feedback**	**Older feedback**	**Total**
Brazil	2		2
Canada	1	2	3
USA	2	11	13
South Africa	1		1
Australia		1	1
New Zealand		1	1
			21

Source: JRC analysis, 2022.

It is observed from the above tables that the countries in Europe that have given the most feedback are Spain and Italy. The Inventory had similar results also in previous releases, meaning that the laboratories from these countries are active in creating synergies and desire the maximum visibility for their lab. It also reveals another issue, that probably the correct contacts have not been used in order to identify labs in other European countries. For instance, Germany, France and the UK are little represented in our Inventory with only 4 labs for each country. Given the fact that smaller countries, like Greece and Finland are already represented by 2-3 labs, it makes the reader think that there are more smart grid labs that haven't been contacted or identified yet, especially in countries with a relevant strong economy. Indeed, one of the objectives of the following releases of the Inventory is to reach out more European laboratories especially in the aforementioned countries.

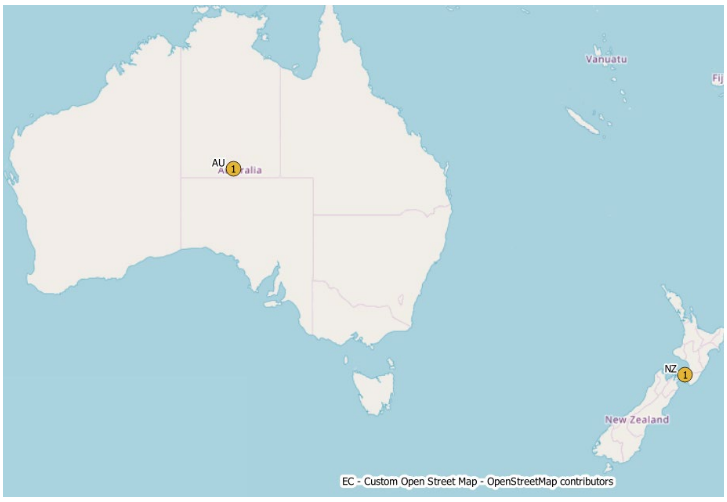
With respect to laboratories outside Europe, it is considered normal that the number of representatives is smaller compared to European labs, since JRC has focused activities in Europe. However, we strongly believe that there is a lot to gain by gathering information about smart grid research outside Europe and that it is important to foster collaborations outside the European borders. Therefore, in the following releases we will continue to focus also in gathering information about laboratories worldwide. One option in order to get more feedback could be to give more incentives to people outside Europe to participate in our survey. An idea could also be to have a similar work done in collaboration with an organization based outside Europe. Nonetheless, it is worth noticing that this year we have had the very first participant from Africa, which is a positive aspect to cover more geographical areas. Figure 5 shows the distribution of the labs according to their geographical location.

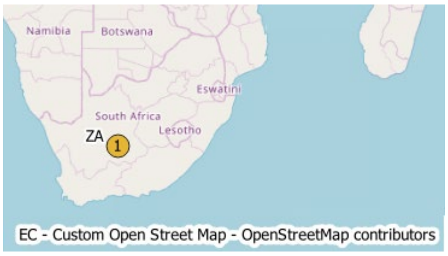
Figure 5. Labs distribution according to the location in which they are based in a) Europe, b) America, c) Oceania d) Africa.



a)

b)





c) d)

Source: JRC analysis, 2022.

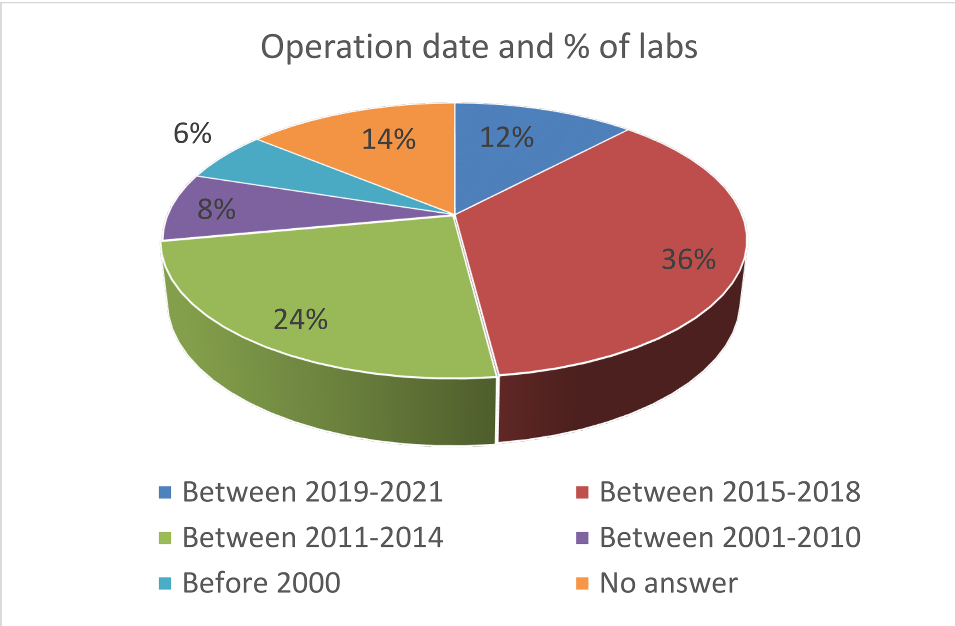
3.2 General Information

Similarly to the other releases, the first part of the questionnaire consists of general information questions. This year we have added some more questions in this part for obtaining some generic information about the smart grid labs. The information obtained has to do with:

- The labs operation date, showing when smart grid labs were established;
- The area of surface the labs cover, revealing information about how big they are;
- The number of employees occupied
- If they hold accreditation for standards
- Intentions for infrastructure expansion
- Fields of activities for labs
- Types of grids for which research is carried out
- Investment and funding information:
  - Investments duration
  - Amount of investments
  - Running costs of labs
  - Funding sources for labs

Figure 6 shows information about the labs operation date. This has been a new question introduced in our survey, therefore, the sample has been the 50 labs that updated their feedback in late 2021.

Figure 6. Operation date and percentage of labs.

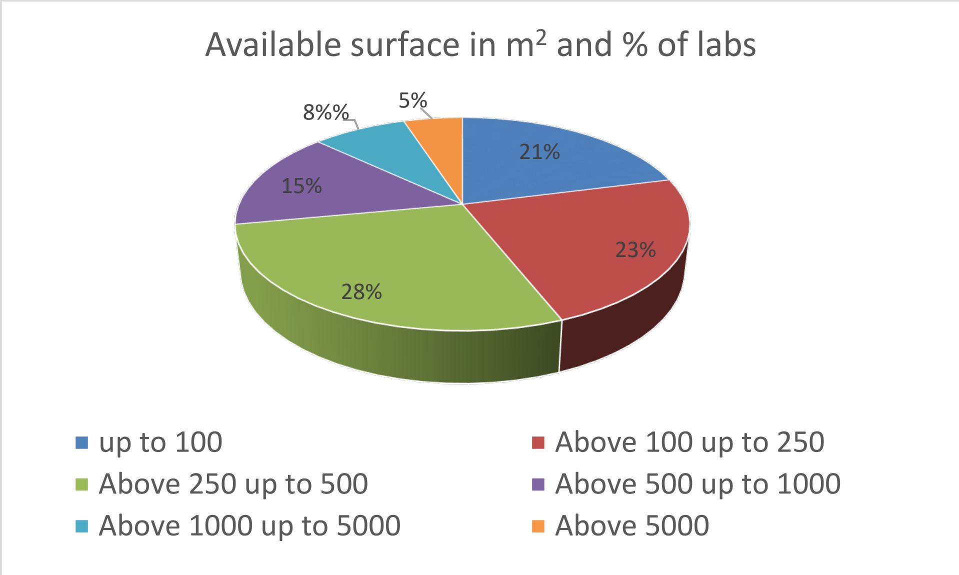


Source: JRC analysis, 2022.

As it can be seen from the graphical representation, almost half of the labs have been established from 2015 and onwards (48%), which coincides with the launching of this periodic exercise, our Smart Grid Lab Inventory. The vast majority of labs have been operating after 2011 (72%, the 48% of labs operating after 2015 and 24% operating between 2011-2014), meaning that the smart grid area has started to become a hot topic for the scientific community the last 10 years. It is worth mentioning that there has been a form of peak regarding the opening of smart grid labs between the years 2015 and 2016, whereas we have recorded the opening of smart grid labs in all years since 2011. The last 2 smart grid labs have opened in year 2021, meaning that there is live interest in the area. It is also worth mentioning that three labs have opened before the year 2000 and are still in operation, with the oldest one being established in 1983.

Figure 7 shows the categorization of labs according to the area in m^2 that they cover. The sample of participants is again here 50 labs.

Figure 7. Percentage of labs and the area they cover.

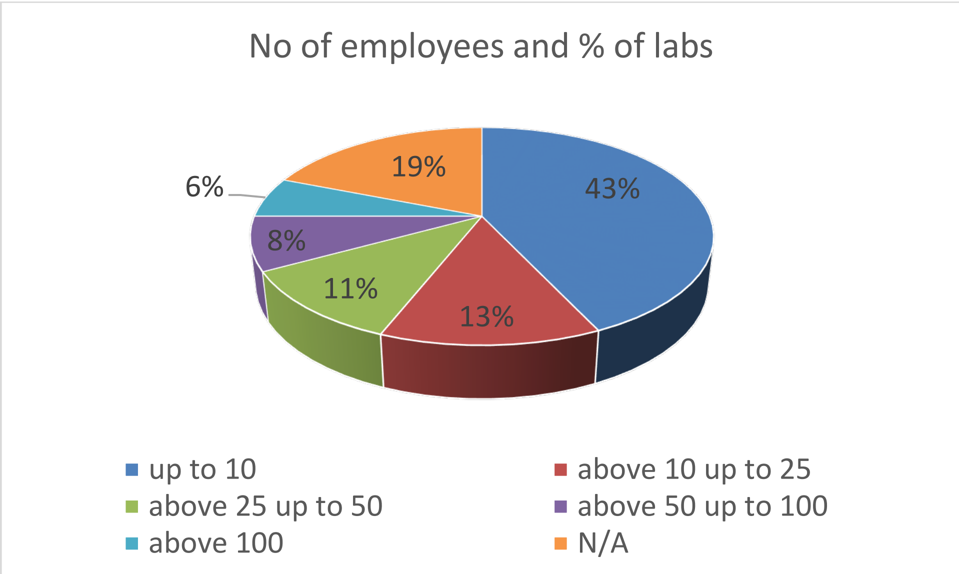


Source: JRC analysis, 2022.

It is clear from the above figure that the vast majority of labs occupies a space up to 500 m^2, whereas the 21% of labs occupies a space up to 100 m^2, meaning that there are quite a few relatively small labs. On the other hand, there are also large labs, covering even an area greater than 5000 m^2.

Figure 8 shows the number of employees and the percentage of labs. For this question, we have information from 86 labs, the extended sample.

Figure 8. Percentage of labs and number of employees.

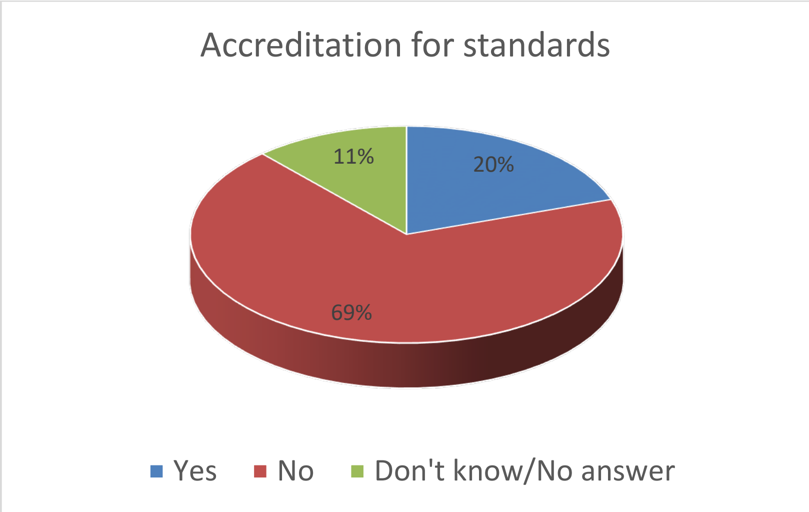


Source: JRC analysis, 2022.

It is obvious from the above figure that a great percentage of labs (43%) comprises of up to 10 employees, meaning that many labs are rather small in terms of personnel. On the other hand, there are labs that occupy more than 100 people, which are considered to be rather large. This information comes also in accordance to the information obtained in the 2018 version of the Smart Grid Lab Inventory, where the 43% of labs occupied up to 10 employees and the 3.4% occupied over 100 employees.

Figure 9 shows the percentage of labs that holds accreditation for standards.

Figure 9. Accreditation for standards and percentage of labs (sample: 86 labs).



Source: JRC analysis, 2022.

The majority of the labs does not hold accreditation for standards, which comes in accordance to the 2018 results, where 74% of the labs had replied “no” to this question. With respect to which standards are the ones for which accreditation is held, the replies varied. Table 7 shows some of the standards given and the number of labs that hold accreditation for them.

Table 7. Standards for which accreditation is held and number of labs.

Standard	No of labs
IEC 17025 (for testing and calibration)	5
IEC 61850 (substation automation)	2
ISO 9001 (quality management system)	2

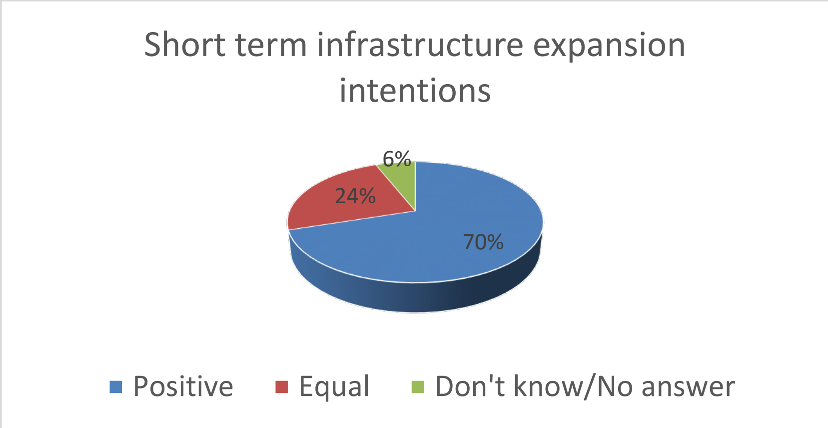
Source: JRC analysis, 2022.

Other standards for which accreditation is held by at least one lab are the:

- UNE-EN 62052
- UNE-EN 62053
- UNE-EN 61000
- IEC 60870-5
- IEC 61131-3

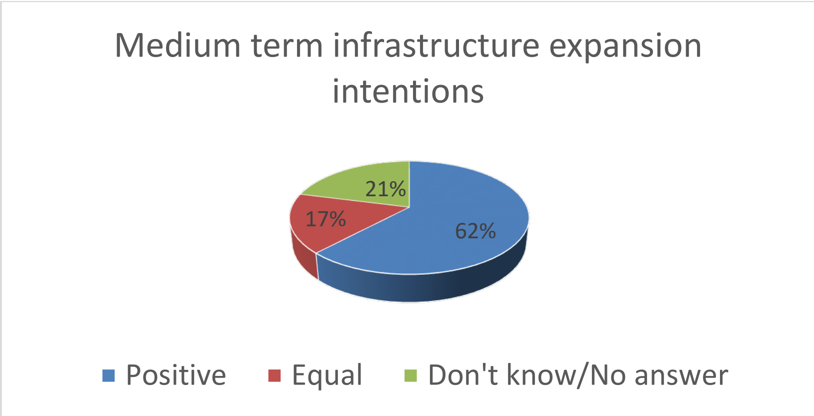
Next, we present the intentions of the labs to expand their infrastructure in the short, medium and long term perspective. The labs have been asked to give their intentions for infrastructure expansion, giving positive, negative replies as well as equal infrastructure possession for the future or replies showing uncertainty about their intentions. For this question, the majority of the labs have given feedback, namely the 74% of the 86 labs. The planned investments are divided in the short term (0 – 5 years), the medium term (5 – 10 years) and the long term period (over 10 years). Figure 10, Figure 11 and Figure 12 show the situation.

Figure 10. Short term infrastructure expansion intentions and percentage of labs.



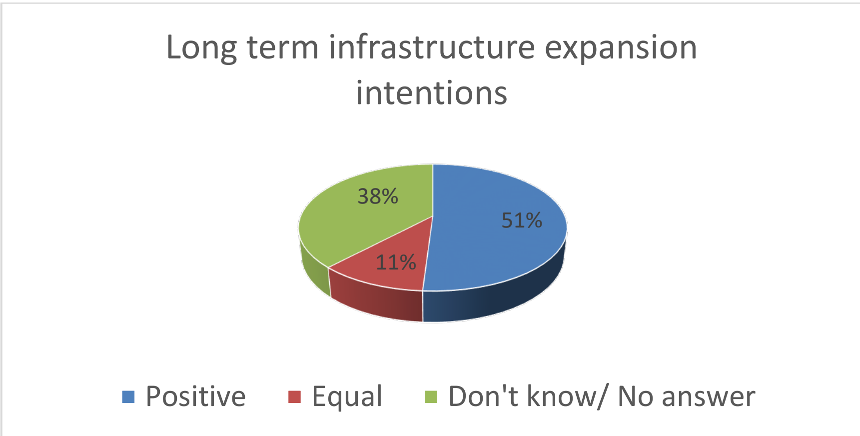
Source: JRC analysis, 2022.

Figure 11. Medium term infrastructure expansion intentions and percentage of labs.



Source: JRC analysis, 2022.

Figure 12. Long term infrastructure expansion intentions and percentage of labs.

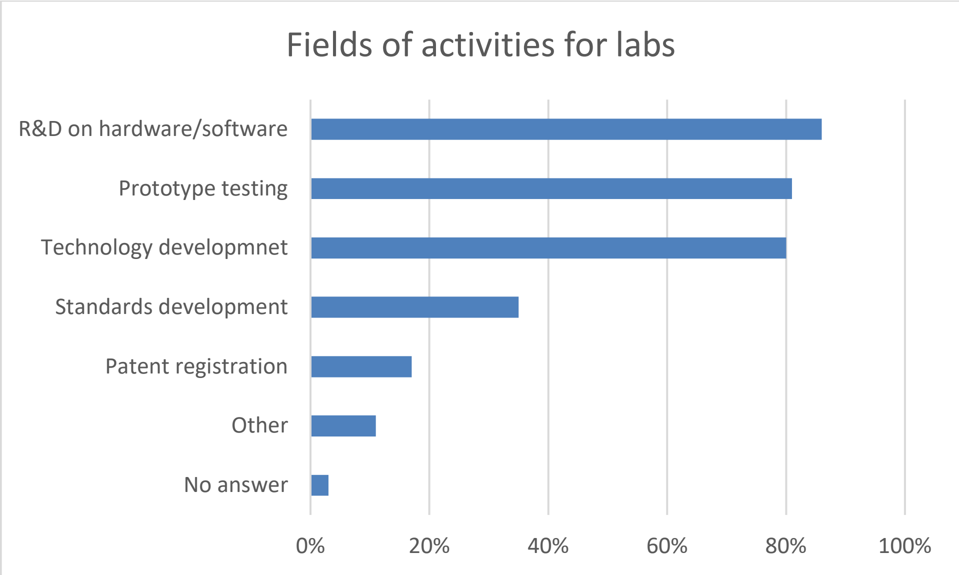


Source: JRC analysis, 2022.

As it can be seen from the graphs, from a short term perspective, the majority of the labs intends to increase the facilities they own (70%). Moving to the medium and long term perspective, this intention drops to 62% and 51% respectively. On the other hand, the uncertainty increases, as more labs do not have clear intentions for the long term perspective. This is shown by the percentage increase from 6%, to 21% and 38% respectively of the labs that do not know if they will expand their facilities in the future. It is worth noticing that no one replied that they will decrease the infrastructure owned, which is logical, since, once an infrastructure acquired, it will remain in the labs' facilities.

Figure 13 shows the fields of activities on which labs are working. The sample here has been the extended one, 86 labs. It should be noted that working in one field does not exclude working in another one. Therefore, many labs work simultaneously on more than one fields. The percentages show the number of labs each field attracts.

Figure 13. Fields of activities and percentage of labs.

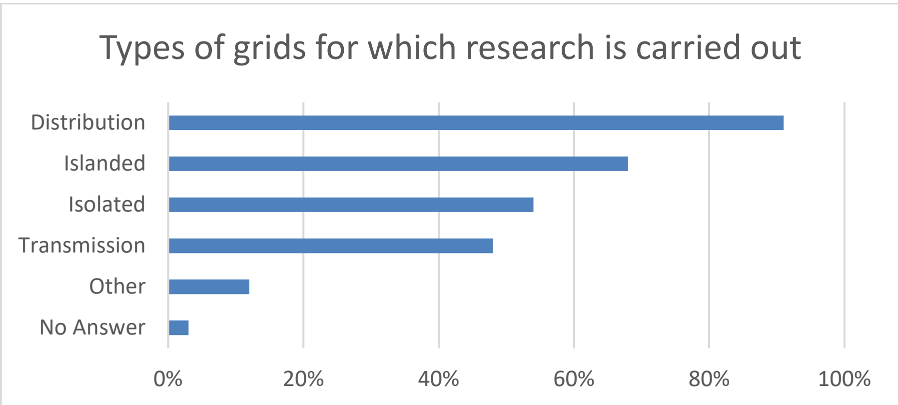


Source: JRC analysis, 2022.

As it can be deducted, there are three fields of activities particularly attractive for the scientific community, namely the R&D on hardware and software (86% of labs), the Prototype testing (81%) and Technology development (80%). Further on we have standards development and patent registration with 35% and 17% respectively. From one point of view, this agrees to the 2018 results, where the first three fields had gathered more than 70% of the labs. However, there is a drop in the percentage of labs performing standards development, which was high in the 2018 release (around 74%).

Figure 14 shows the types of grids on which research is carried out. We have identified at least 4 types of grids as relevant replies, namely the distribution, the islanded, the isolated and the transmission grid. Likewise the fields of activities, working on one type of grid does not exclude working on another. Thus, many labs work simultaneously on many types of grids.

Figure 14. Types of grids and percentage of labs (sample of labs: 86).



Source: JRC analysis, 2022.

As it can be seen from the above graph, the distribution grid is the one that attracts the most the scientific interest (91% of labs), since the vast majority of labs have declared to work on it. The islanded and the isolated grid come next with 68% and 54% respectively, whereas the transmission grid gathers 48% of the labs. Similar percentages had been gathered in the 2018 results for the distribution, the islanded and the isolated grid (90%, 60%, 48%). The percentage for the transmission grid has dropped a bit from 57% to 48% this year.

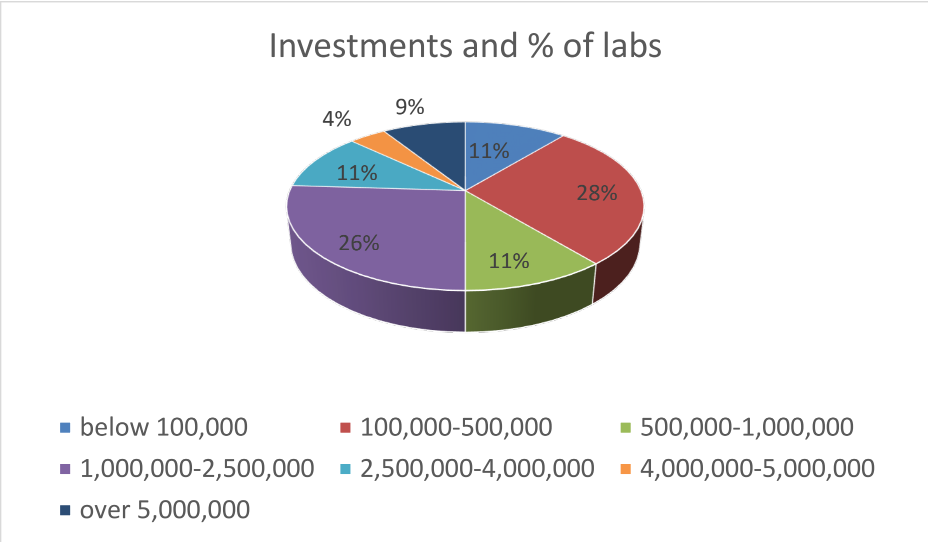
3.3 Investments and Funding sources

In this Section, aggregated information is presented with respect to the investments for the construction of each lab, the running costs and funding sources for the labs.

3.3.1 Investments for the Lab Construction

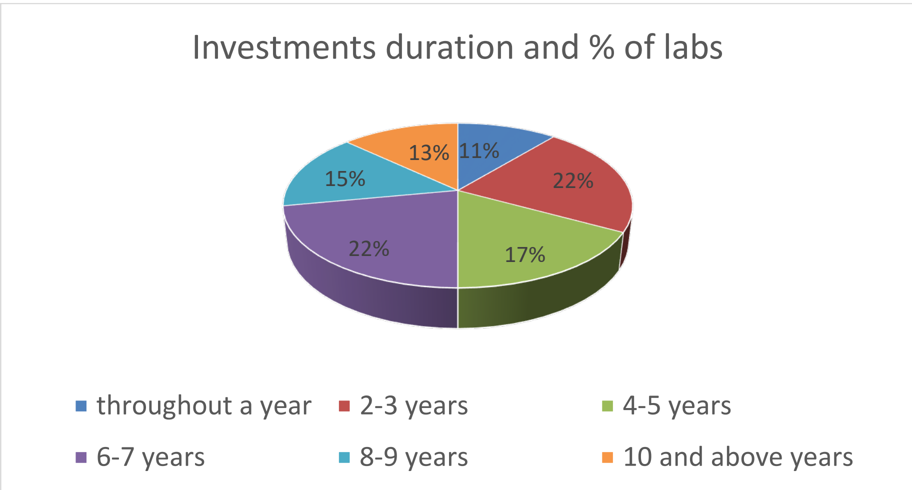
Approximately 54% of the 86 labs has given information about the investments in order to build their lab. Although the number is not very high, the information provided can give a good picture on the investments of the labs. Figure 15 shows the percentages of labs and their investments on lab equipment. Figure 16 shows the duration of these investments and the percentage of labs.

Figure 15. Labs and investments.



Source: JRC analysis, 2022.

Figure 16. Investments duration and percentage of labs.



Source: JRC analysis, 2022.

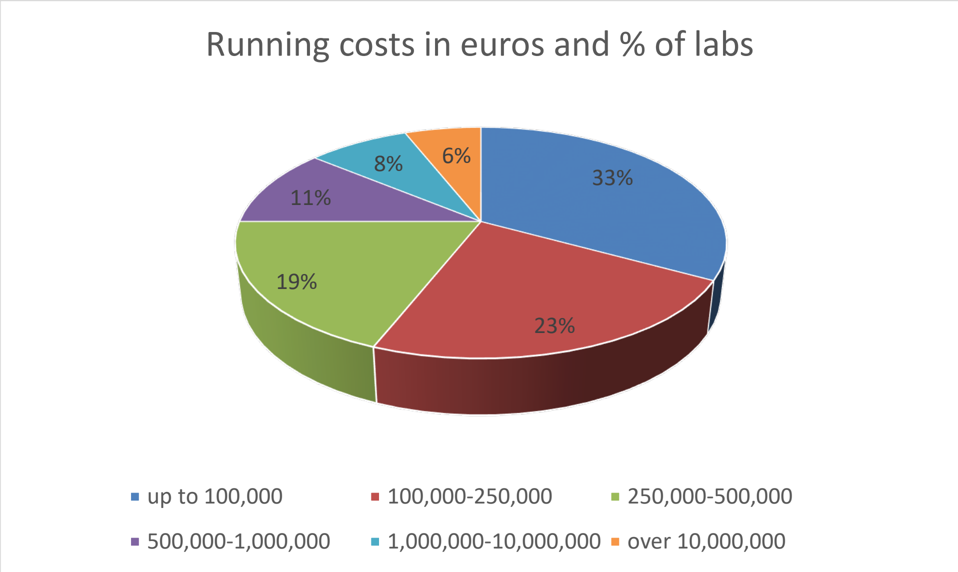
As it can be seen from Figure 15, half of the labs have investments up to 1,000,000 euros. Most of the labs have investments between 100,000 and 500,000 euros. It is worth noticing that the other half of the labs have investments over 1 million euros. The higher the amount, the fewer the labs, as it is anticipated. However, 9% of the labs has investments of over 5 million euros, which is considered a noticeable number, given the amount of money invested. The situation has been similar in the 2018 version of the Inventory where again half of the labs had investments below 1,000,000 euros.

As for the duration of the investments, it is shown in Figure 16 that half of the labs have performed their investments maximum throughout 5 years. The rest of the labs have investments that lasted more throughout the years. However, given the fact that many labs have opened recently, it is not possible for them to have investments for a long-year period. It could be expected that the percentage of labs with investments throughout a longer period may rise with time, as new labs will become more mature. This is proved by comparing the results with the 2018 version of the Inventory, where half of the labs had an investments duration up to 3 years. Indeed, some years later, the same percentage of labs now includes also labs with investments duration up to 5 years.

3.3.2 Running Costs for Labs

Regarding the running cost of the lab, including personnel costs, feedback has been obtained from 56% of the participating labs (48 labs). Despite the fact that it has been explicitly explained that only aggregated information would be revealed for such questions, it seems that many participants have hesitated to provide with an answer. In any case, the feedback obtained gives a picture of the trend in the field. Figure 17 shows the percentage of labs and their running costs.

Figure 17. Running costs and percentage of labs.



Source: JRC analysis, 2022.

As it can be seen from Figure 17, the majority of the labs has running costs below 250,000 euros (56%). It is also worth noticing that a noticeable percentage of labs (25%) has a running cost of over 500,000 euros, meaning that there are quite a few larger labs with high running costs. The situation was similar in the 2018 results, where the labs of the former category gathered a percentage of 54% approximately and the ones of the latter one 27% respectively.

3.3.3 Funding Sources

A new question has been added this year to our questionnaire, aiming to shed light to where labs get their funding from. The question has been formed as shown in Table 8.

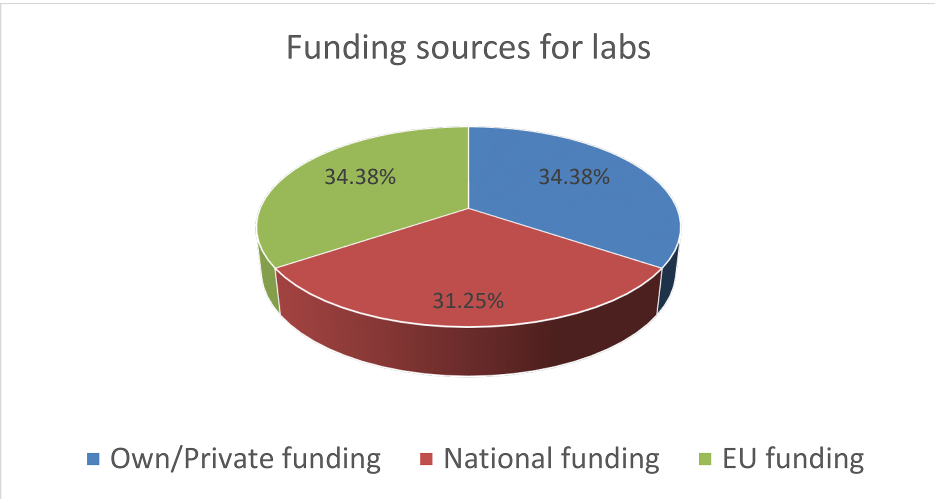
Table 8. Question for main source of research funding.

	No funding/No answer	0-25%	25-50%	50-75%	75-100%	Exclusive funding
Own/Private financing	☐	☐	☐	☐	☐	☐
National funding	☐	☐	☐	☐	☐	☐
EU funding	☐	☐	☐	☐	☐	☐

Source: JRC analysis, 2022.

For this question we had 50 replies, meaning that all of the labs gave an answer. We have elaborated the results in order to present aggregated information. The goal has been to show at which extent private, national or EU funding has been used by the labs. If we could suppose, that all the labs were working as one huge lab, which ones would have been the shares for each source of funding? This has been the key question in this case. Figure 18 shows the situation described above. As it can be seen from Figure 18, overall, the shares of private, national or EU funding are similar, especially with the former and latter one being equal. However, given the fact that in the sample of 50 labs, there have been 6 labs outside Europe, it may be deducted that the EU funding for European labs is a very important source, since they are the ones to have brought this share being equal or greater to the others. With our Smart Grid Lab Inventory we wish to increase international collaborations between labs and increase their visibility, so as to achieve synergies also outside Europe.

Figure 18. Funding sources for labs.



Source: JRC analysis, 2022.

4 Results: Smart Grid Research Areas

4.1 Analysis of Smart Grid Research Areas

In this section we present analytical information for each one of the identified categories individually. As already explained, this year the categories of smart grid research have been 5, namely the: Integrated Grid; Storage; Customers and Market; Generation; Digitalization, Communication and Data. For the labs that had participated earlier than 2021, we linked the categories of research they had declared to these 5 ones, as explained in Chapter 2. For the questions that were introduced in our survey this year, the results presented show aggregated information of the 50 labs that updated their feedback this year. For the rest of the questions, the sample of 86 labs has been used. This is explicitly shown in the following presentation of results. It should be also noted that whereas the major part of the questions are not obligatory, the questions referring to the main areas of work (the 5 identified categories) are compulsory, so, all participating labs have declared the main fields of their research.

Table 9 shows the percentages of labs working in each of the 5 categories.

Table 9. Percentage of labs per activity.

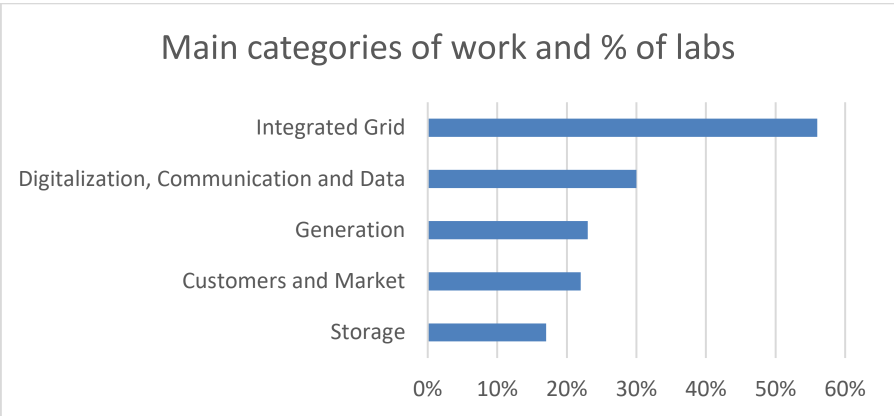
Category	**%**
Integrated Grid	84%
Generation	79%
Digitalization, Communication and Data	77%
Customers and Market	76%
Storage	70%

Source: JRC analysis, 2022.

It is noteworthy that all categories of research gather the scientific interest of 70% and above of the 86 labs. This means that all categories play an important role in the smart grid and research activities are fundamental in all these fields. As it is anticipated, the vast majority of labs, if not all, work on multiple categories. The larger a lab is, the more categories of research it covers.

Apart from the categories of work for the labs, it has been collected information about which one is the main category of work. Figure 19 shows the results. As it can be seen, the Integrated grid has been the most popular answer (56% of the labs), with Digitalization, Communication and Data to follow (30%) and afterwards Generation, Customers and Market and Storage with similar percentages, 23%, 22% and 17% respectively. It should be noted here that for many labs, multiple categories are the main topic of research.

Figure 19. Main categories of work and % of labs.



Source: JRC analysis, 2022.

As it has been shown in Chapter 2, the former 12 categories of earlier releases of the Inventory have been linked to these 5 categories. Whereas some former categories show no overlap, i.e. storage, there are others that refer to activities covered by more than one current categories, like the Advanced Metering Infrastructure (AMI) that refers to activities of the Integrated Grid, Customers and Market, Digitalization, Communication and Data. In the following, we present the aggregated results for each category, analysing specific aspects for the respective category, like sub-categories of work and focus fields. We also present a comparison with the 2018 release's results, whenever feasible.

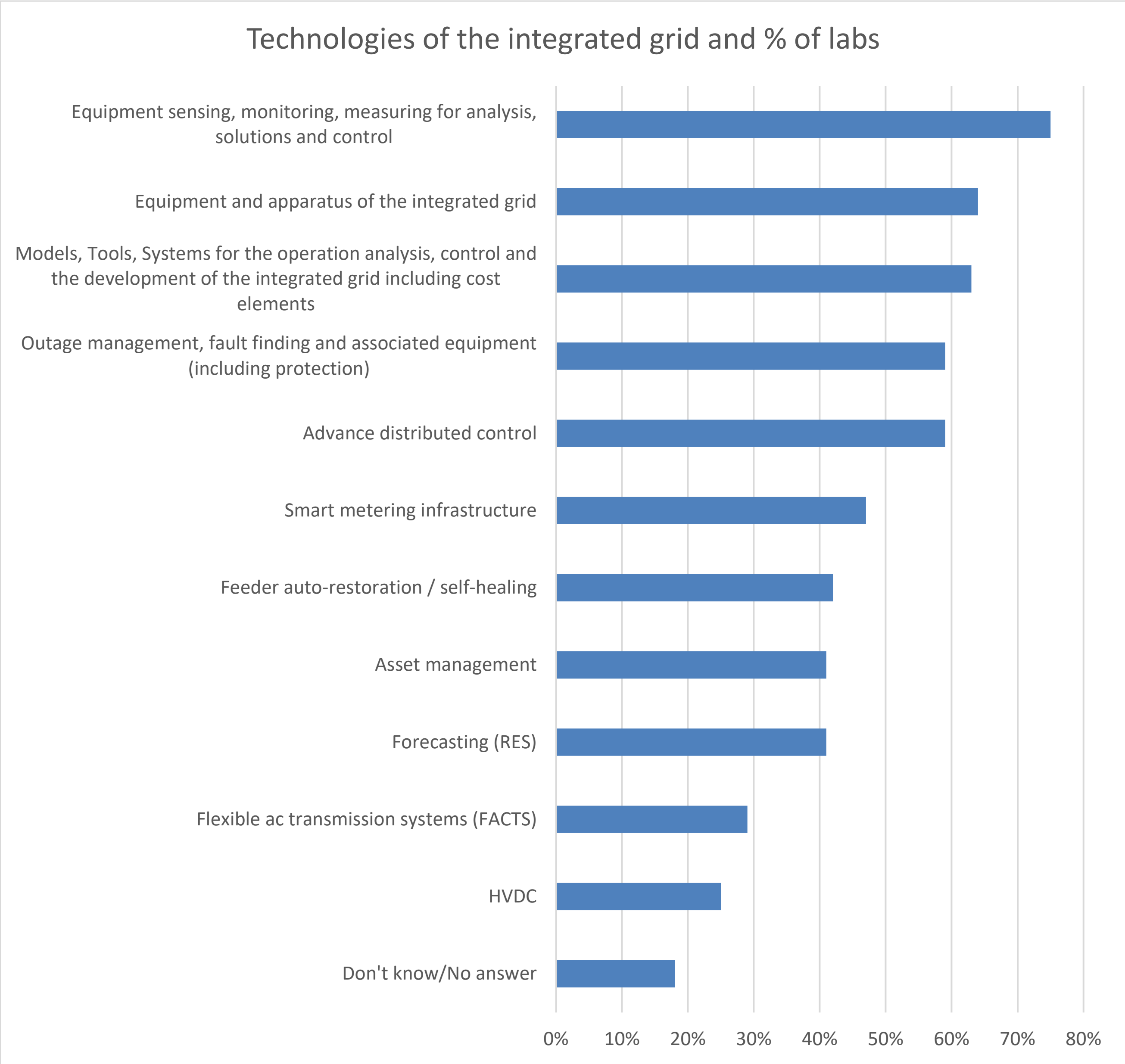
4.2 Integrated Grid

In this section we present the results for the category of Integrated Grid. The technologies and objectives are presented, the standards used and the results for the Advanced Metering Infrastructure usage. The latter one has been a particular sub-category of work, since it has been linked to 3 of our new categories (Integrated Grid, Customers and Market and the Digitalization, Communication and Data). In order to extract the results for this sub-category, we elaborated data from all participants that replied positively to AMI research independently of the category for which they declared to perform such research. Therefore, results have been merged for the participants that replied to have been using AMI for the Integrated Grid and those who use it for Customers and Market and Digitalization, Communication and Data. We present here the results for AMI usage and in particular, we show the technologies and standards used for AMI, as well as the objectives of such research.

4.2.1 Technologies and Objectives for the Integrated Grid

As a first step, we present the technologies for which research on the integrated grid is conducted. These technologies are the ones defined according to ETIP SNET concept, as explained in Chapter 2. Almost all labs has declared to be working on multiple technologies. It should be noted that this has been a newly introduced question, so, the base sample for us has been the 50 labs. Out of these 50 labs, for the extraction of the results, only the labs that have declared to work on Integrated grid have been taken into consideration. Figure 20 shows the results, where it can be seen that the most popular technology is "equipment sensing, monitoring, measuring for analysis, solutions and control" collecting 75% of the participating labs, with "equipment and apparatus of the integrated grid" to follow with 64%. Figure 20 shows in detail all the technologies of the integrated grid as these are identified by ETIP SNET and the equivalent percentage of labs they have gathered.

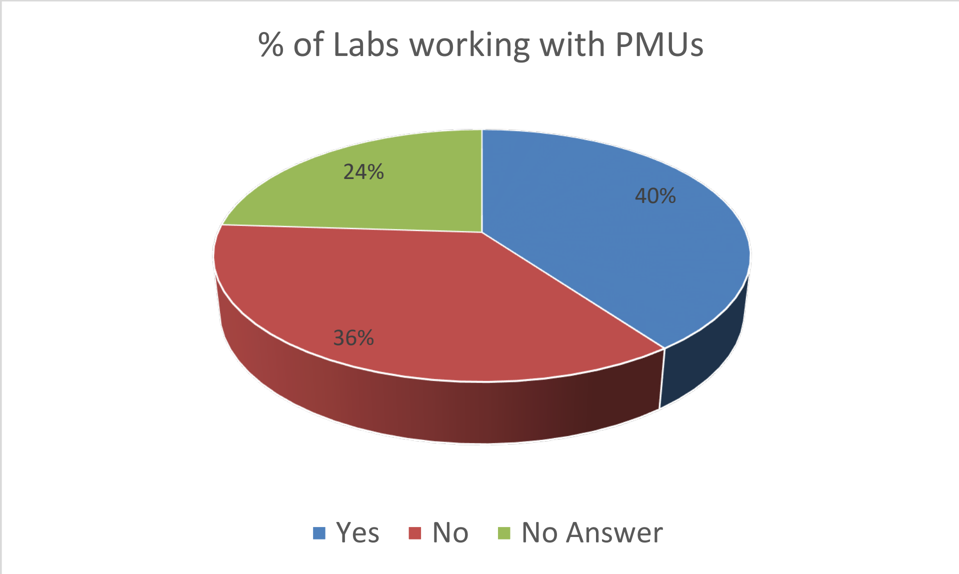
Figure 20. Technologies of the Integrated grid and percentage of labs working on them.



Source: JRC analysis, 2022.

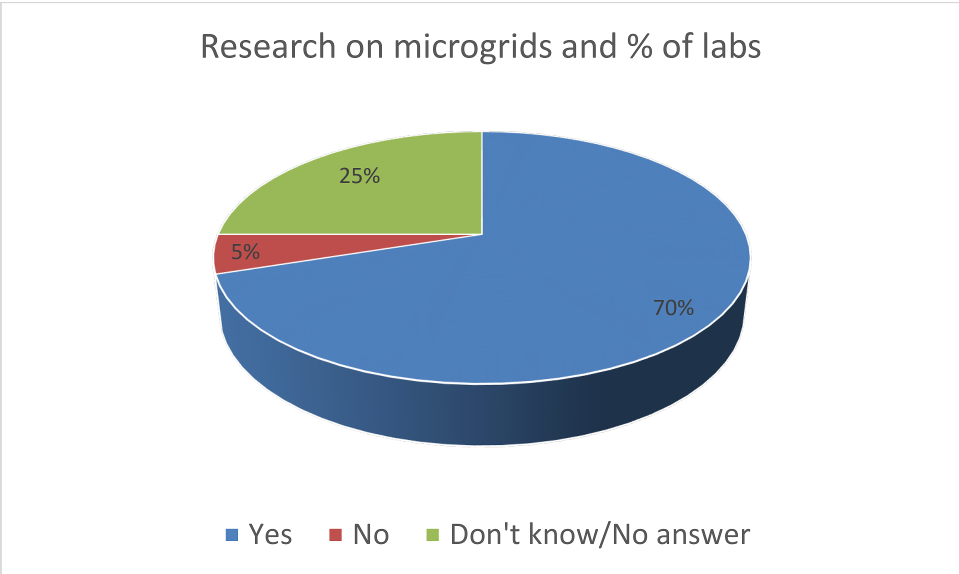
In the following, we present the graphs showing the percentage of labs working with PMUs and microgrids respectively. As these are not newly introduced questions, the sample of labs has been the 86 labs. It can be seen from Figure 21 that the percentages are more or less divided in equal parts regarding the labs that work with PMUs and the ones that don't work (40% and 36% respectively). However, 40% of 86 labs remains a significant number. This is in accordance to the 2018 results, where 43% of labs had replied positively to this question. On the other hand, Figure 22 shows that the majority of labs works with microgrids (70%), whereas a very small percentage of labs (5%) has declared not to work with them. Comparing to the 2018 results, it is seen that back then, the 77% of labs had replied to be working with a microgrid, whereas an 8% had replied negatively. This reveals a trend, that microgrids are still an important field in the smart grid research.

Figure 21. Percentage of labs working with PMUs.



Source: JRC analysis, 2022.

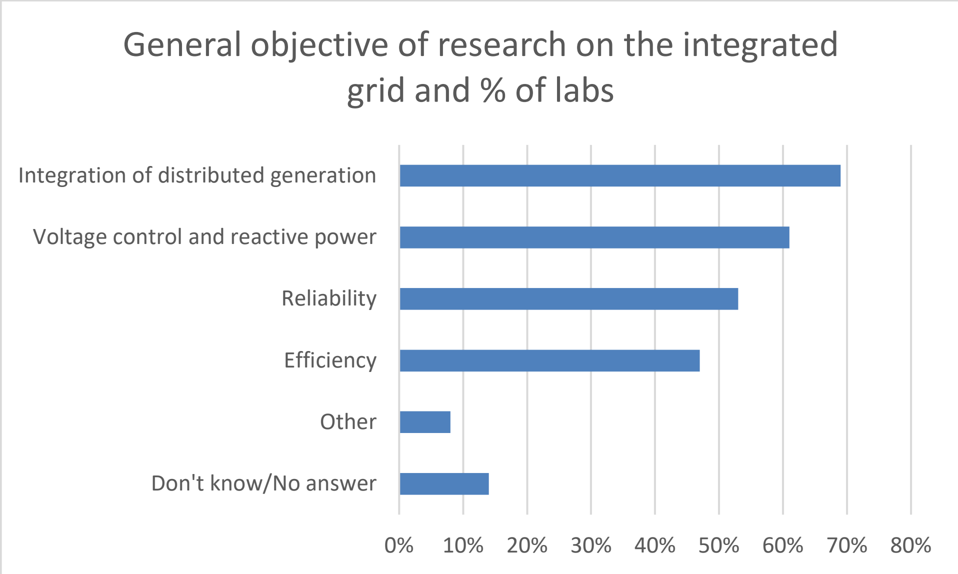
Figure 22. Percentage of labs working with microgrids.



Source: JRC analysis, 2022.

Figure 23 shows the general objective of research on the integrated grid. Again here, the sample has been the labs that conduct research on the Integrated Grid out of the 86 labs. It is obvious that the most popular objective of research here is the integration of distributed generation with 69% of labs with voltage control and reactive power to follow with 61%. These were also the most popular answers in the 2018 survey results (76% and 65% respectively), thus showing consistency. A plethora of replies has been received as other objectives of the research on the Integrated Grid. Table 10 shows the situation, presenting such other objectives which have been declared by at least one lab.

Figure 23. General objective of research on the integrated grid and percentage of labs.



Source: JRC analysis, 2022.

Table 10. Other objectives of research on the integrated grid, Source: JRC analysis, 2022.

Other objectives	
Resilience	ADMS functionalities
Architecture of PAC (protection, automation and control)	Interoperability
Redundancy	Fault protection
Real time power systems simulation	Stability of high voltage transmission system
Hardware in the loop testing	Standards testing and validation
Power system simulation	Development of models for simulation

Source: JRC analysis, 2022.

4.2.2 Standards used for the Integrated Grid

In this Section, we show the standards used for the Integrated Grid. This has been a free text question, so, we received a variety of standards as replies. The sample were the labs that conduct research on the Integrated Grid (out of 86 labs). Approximately half of these labs replied to the question regarding the standards they use. Table 11 shows the standards for the Integrated Grid and the percentages of labs that use them.

Table 11. Standards used for the Integrated Grid and percentages of labs.

Standard	**% of labs**
IEC 61850 - Communication networks and systems in substations	77%
IEC 61970 - Common Information Model / Energy Management	23%
IEC 61968 - Common Information Model / Distribution Management	20%
IEC 60870 - Telecontrol equipment and systems	11%
IEEE 1547 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces	11%
CEI 0-16 (national codes)	9%
CEI 0-21 (national codes)	9%
IEC 61869 - Instrument transformers	9%
IEC 60255-24 - Electrical relays – COMTRADE	6%
IEC 62325 - Common Information Model (CIM) for Energy Markets	6%
IEEE 1588 - Precision Time Protocol	6%

IEC 60947 - Low-voltage switchgear and controlgear	6%
Open ADR – Open Automated Demand Response	6%

Source: JRC analysis, 2022.

As it is clear, the most popular standard used is the IEC 61850 gathering the 77% of the participating labs. The rest of the standards are used by a moderate or small percentage of labs. Apart from the above standards, there have been also other ones mentioned (used at least by 1 lab), which we present here for reasons of completeness (Table 12).

Table 12. Standards used at least by one lab for the Integrated Grid.

Standards used at least by one lab		
IEC 60255-24	IEC 62559	EN 50549
IEC 60909	IEC C37.118	EN 50160
IEC 61000	IEC C37.240	AUS/NZ 477.2:2015
IEC 61131	IEC TS 62257	DLMS
IEC 61499	IEC TS 62898	VDE 4105
IEC 62271	IEEE 551	OCPP/OCPI
IEC 62351	IEEE 1344	SGAM
IEC 62439	IEEE 1815/ DNP3	Modbus
IEC 62443	IEEE 2030	

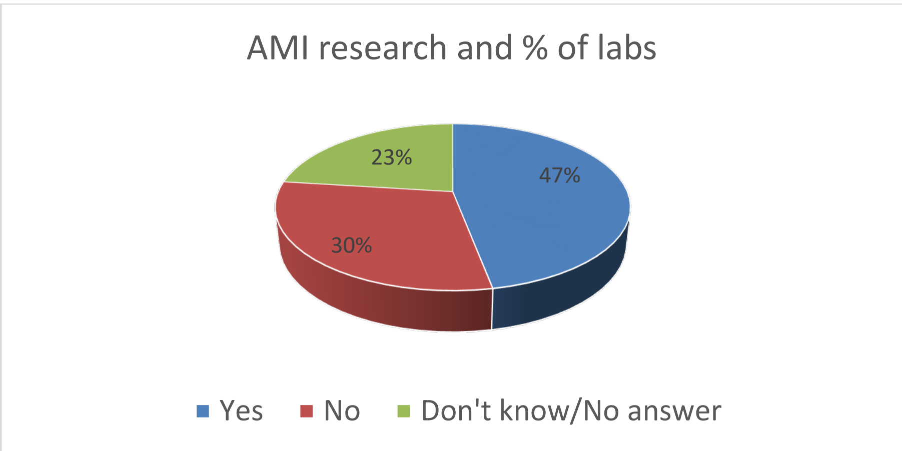
Source: JRC analysis, 2022.

4.2.3 Advanced Metering Infrastructure (AMI)

As it has been explained above, the AMI research field is linked to more than one categories of smart grid research. To present the results here, we took into account first of all the sample of 86 labs. Figure 24 shows the percentages of labs that conduct research on AMI out of the total sample of 86 labs. A bit fewer than half of the labs carry out research on AMI, which still remains a considerable number of labs. Comparing with the 2018 results, the situation has remained similar, where it was shown that the 45% of labs was carrying out AMI research.

The results in Figure 24 have been extracted as follows: we considered (out of the 86 labs) the ones that answered positively to whether they conduct research on the: Integrated Grid; Customers and Market; Digitalization, Communication and Data. Then, we considered the ones that replied positively to the question of whether they conduct research on AMI (total 40 labs). Further analysis of the results for AMI research, refers to these labs.

Figure 24. Research on AMI and % of labs.

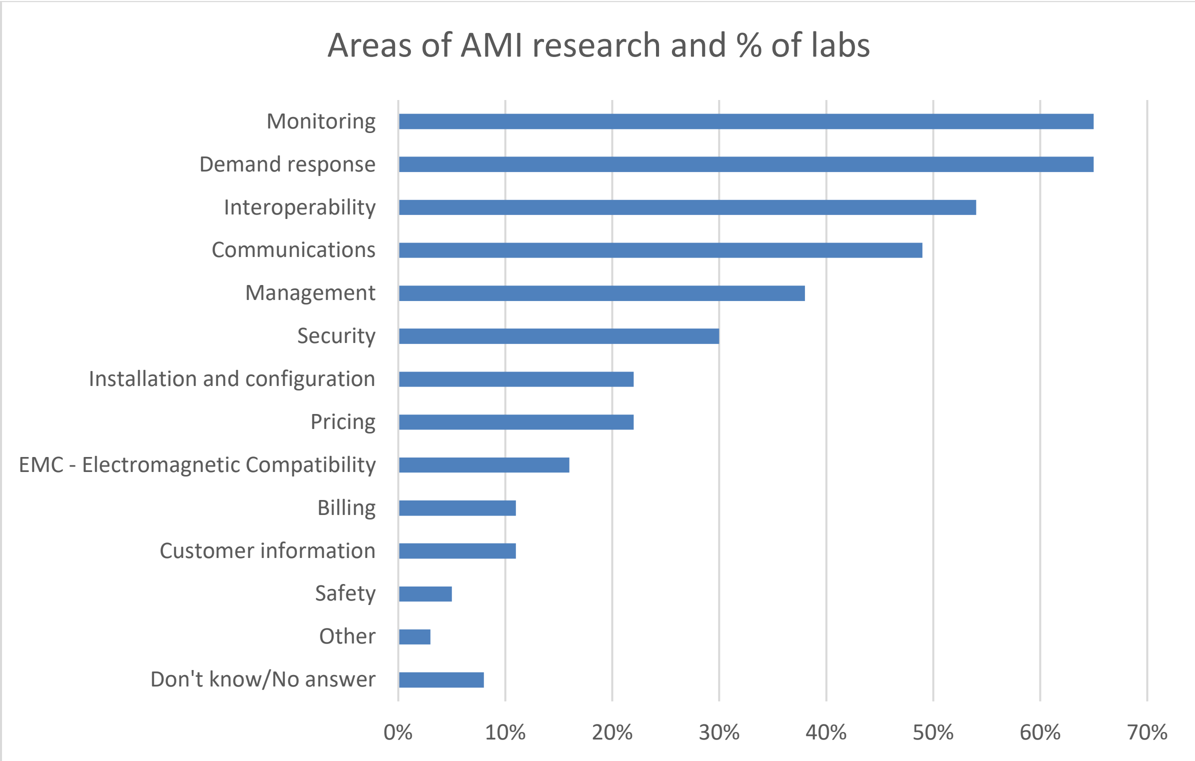


Source: JRC analysis, 2022.

Figure 25 shows the areas of AMI research and the percentage of labs. As it is obvious, monitoring and demand response have been the most popular answers gathering 65% of the labs. Interoperability and

Communications are the areas to follow with 54% and 49% respectively. Comparing to the 2018 results, the first 4 areas have remained the same, however, it is noticed a change in the percentages, since these were: 53%, 43%, 43% and 40% respectively. An increase is noticed in all these 4 areas, especially for demand response where the difference goes up to 22 percentage points. This means that demand response becomes a popular topic and AMI provides the means to accomplish it. It should be mentioned here, that as other areas of AMI research, big data analysis has been declared.

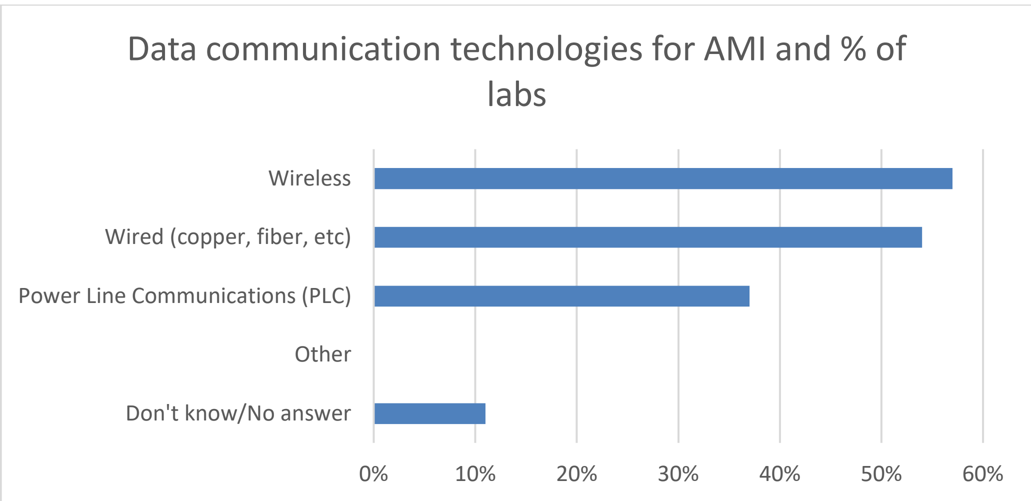
Figure 25. Areas of AMI research and percentage of labs.



Source: JRC analysis, 2022.

Figure 26 shows the data communication technologies used for AMI and the percentages of labs. Wireless communications are the most popular solution, gathering 57% of labs active in AMI. Wired solutions, like fibers, copper, and power line communications come next with 54% and 37% respectively.

Figure 26. Data communication technologies for AMI and % of labs.



Source: JRC analysis, 2022.

When asked to specify exactly which technologies or standards are used for AMI research, various replies have been received. Table 13 shows the percentages of the active labs in the field.

Table 13. Standards / specifications / technologies used for AMI and percentage of labs.

Standard/ technology	% of labs
PRIME	38%
G3-PLC	32%
IEC 61850	25%
Modbus	25%
DLMS/COSEM	25%
ZigBee	12.5%
Lora	12.5%
IEC 61334	12.5%
MQTT	12.5%

Source: JRC analysis, 2022.

Other replies were also collected, shown in Table 14, which presents solutions used by at least one lab.

Table 14. Standards / specifications / technologies used for data communication in AMI.

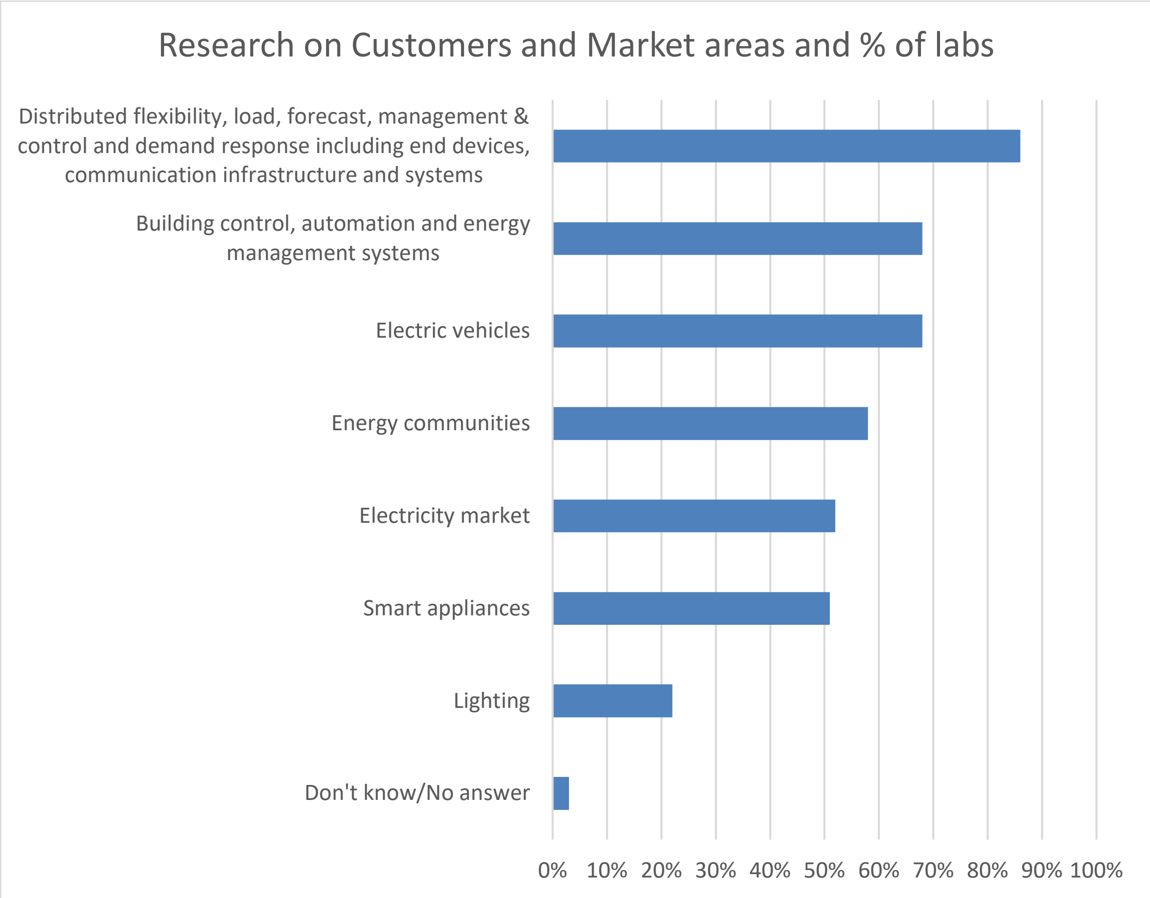
Standards used at least by one lab		
IEC 60255	NB-IOT	OSGP
IEC 62056	LoraWan	Interbus
IEC 870-5-102, -103	Ethernet	RS485
EN 50470-1, -3	Cellular	OPC DA
EN 62053-21, -22, -23, -24	DNP3	M2M
IEEE 1901	WiFi	DCSK
IEEE 1588-PTP	Bluetooth	Bacnet
IEEE C37.112	RF-Mesh	MQTP

Source: JRC analysis, 2022.

4.3 Customers and Market

In this section we present the results for the category of Customers and Market. As it has been discussed in Chapter 2, this category consists of many sub-categories of research. Thus, under this category, we firstly collect information about the technologies/ sub-categories on which work is carried out and afterwards we collect information with respect to these technologies, namely the: Demand Response, Smart Home / Building, Electric Vehicles, Energy Communities (smart cities), Market. These 5 technologies / sub-categories have also been analysed in the previous Smart Grid Lab inventories. The basis for analysis have been the labs that are active on the Customers and Market area (65 labs), whereas for further analysis of the sub-categories, the labs that replied positively for each one of them have been taken into consideration. Figure 27 shows the percentages of labs that perform research on each of the categories identified by ETIP SNET.

Figure 27. Research on Customers and Market areas and percentages of labs.



Source: JRC analysis, 2022.

As it observed from Figure 27, the most popular category of research is Demand Response, in its broader term, collecting 86% of the labs active in the Customers and Market category. Smart buildings/ homes and Electric vehicles are the two categories to follow with 68%, whereas Energy communities and Electricity market are the ones to come next with 58% and 52% respectively.

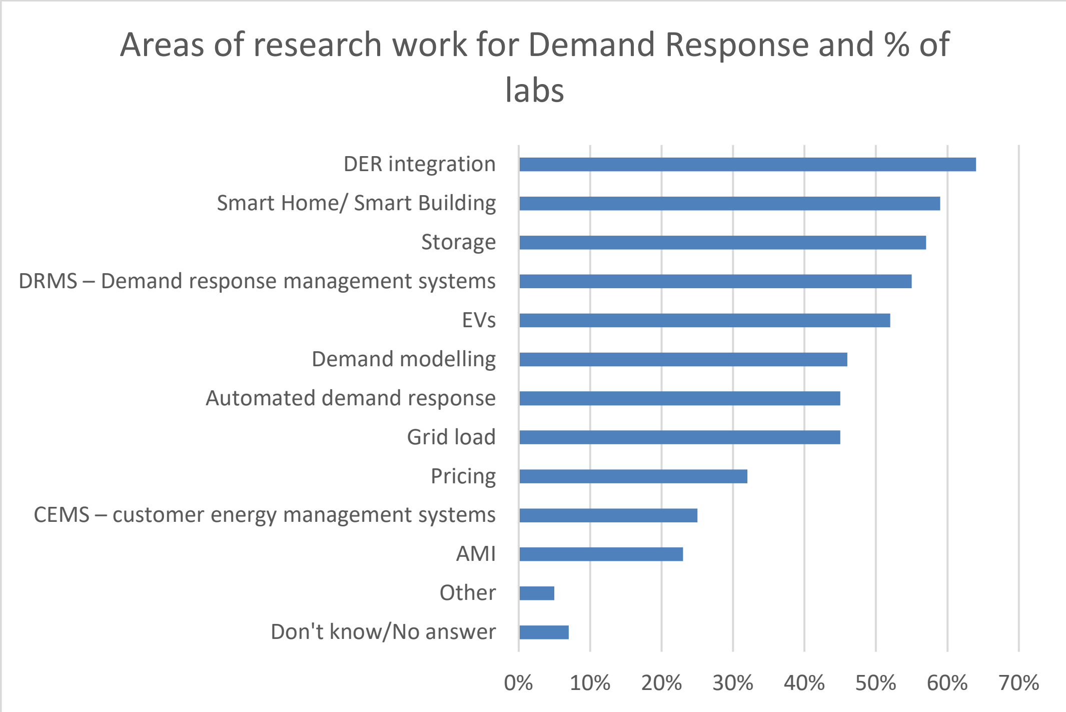
Comparing with the 2018 results, it is observed that there is an increase in the percentages of all sub-categories, where the numbers were 75% for Demand Response, 62.5% for Smart Buildings, 61.4% for Electric vehicles, 50% for Smart cities and 44.3% for Market. However, it should be noted that this time the percentages refer to the labs active in the customers and market category and not to the entire sample. Therefore, a valid comparison cannot be made.

The fields of research above, and especially smart buildings, energy communities, demand response and smart appliances imply the usage of smart meters and in general Advanced Metering Infrastructure (AMI). For this purpose, the participants have been asked about research activities on AMI and the results have been merged with the ones obtained from the Integrated Grid. The reader is directed to Section 4.2.3 for the results with respect to AMI.

4.3.1 Demand Response

Demand response is a popular topic attracting attention by stakeholders and has gathered the 86% of labs active in the Customers and market category. Figure 28 shows the areas of research work for Demand response and the percentages of labs active in this field. As it can be seen, the most popular area of research is the DER integration collecting 64% of the active labs in the field. Under other areas of research it has been listed: Flexibility analysis, clustering and end-devices.

Figure 28. Areas of research work for Demand Response and percentages of labs.



Source: JRC analysis, 2022.

With respect to the standards/ specifications used for Demand Response research, the majority of labs that gave feedback to this question replied to use the **OpenADR** solution (64% of the labs). Other solutions have been mentioned as well, which are summarized in Table 15.

Table 15. Standards used at least by one lab in the area of demand response.

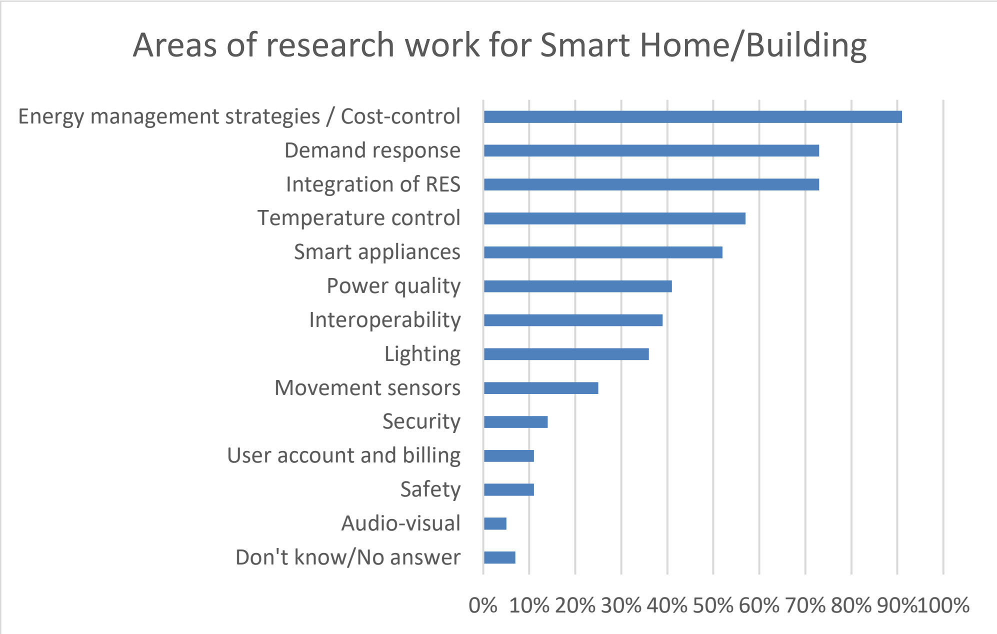
Standards / specifications used at least by one lab	
IEC 61968	IEC 60870-5-104
EN 13757	Modbus
USEF	CIM
SAREF	

Source: JRC analysis, 2022.

4.3.2 Smart Home / Building

In this Section, we present the results with respect to the research conducted on the Smart Building area. Figure 29 shows the areas of research work with respect to the Smart Home / Building area.

Figure 29. Areas of research work for Smart Home / Building.

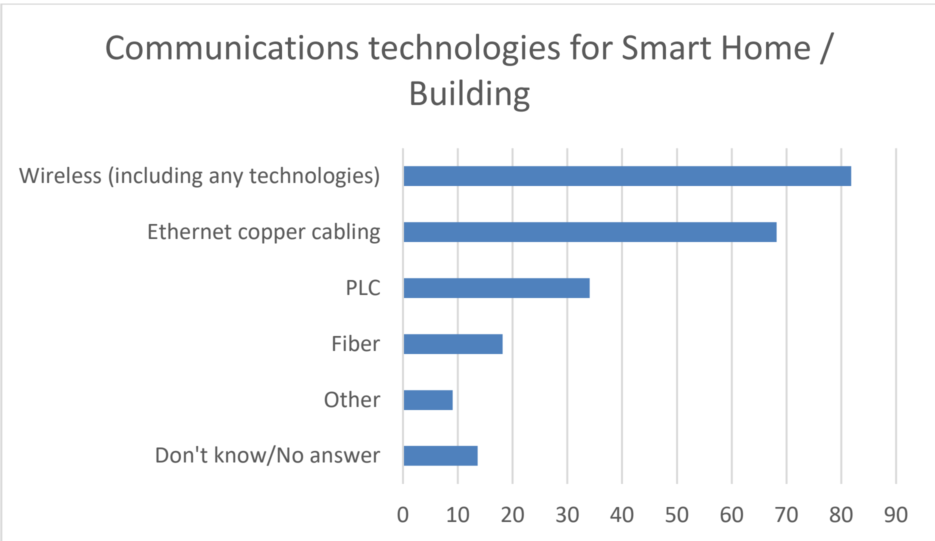


Source: JRC analysis, 2022.

As it can be observed from Figure 29, the most popular areas are: Energy management strategies / Cost control, demand response, integration of RES collecting 91%, 73% and 73% respectively. These have also been the first three areas of research for the 2018 results.

Figure 30 shows the communication technologies used for smart home/ building research. It can be observed that the most popular solutions are the wireless ones (82% of the labs active in the field) with Ethernet to follow (68%) and PLC (34%). These were also the first three options for the results of the 2018 Inventory, which shows coherence.

Figure 30. Communication technologies for smart home/ building research.



Source: JRC analysis, 2022.

With respect to the standards used by the labs in the category of Smart Home/ Building, a plethora of standards has been to be used by the labs. Table 16 lists the ones mentioned to be used at least by two labs. As it obvious also from Table 16, many of the standards listed refer to wireless solutions, which is in accordance to Figure 30.

Table 16. Standards used at least by two labs for the Smart Building sub-category of research.

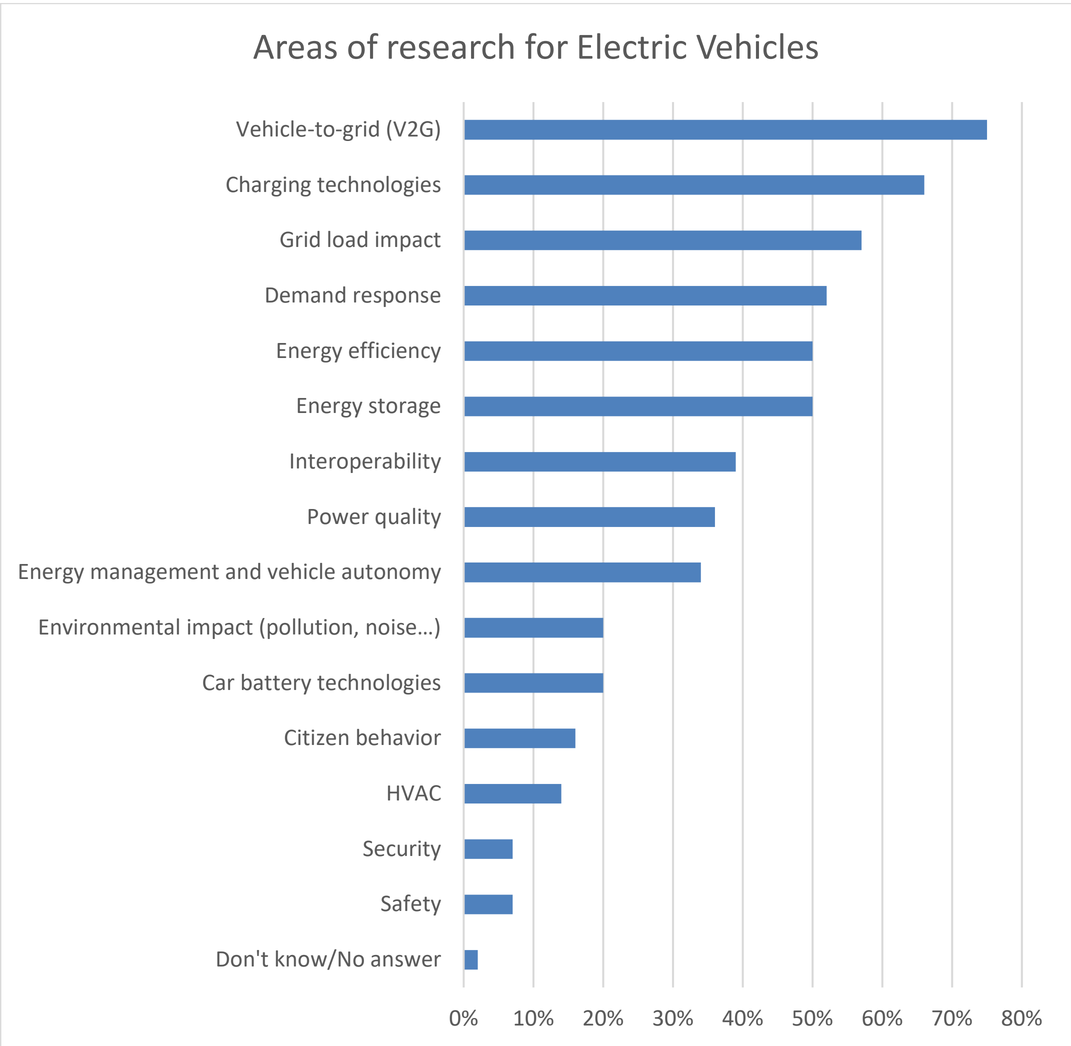
Standards used at least by two labs	
EN 13321	SAREF
IEC 61131	Modbus
IEC 61499	OpenADR
IEEE 802.3	Backnet
Longworks	AS/NZS
ZigBee	KNX
LoRaWAN	ISO 50001

Source: JRC analysis, 2022.

4.3.3 Electric Vehicles

Out of the labs active in the Customers and Market field, 68% carry out research on electric vehicles. Figure 31 shows the areas of research for electric vehicles. As it can be observed, the most popular areas are vehicle-to-grid and charging technologies gathering 75% and 66% of the active labs in the filed respectively. Grid load impact, Demand response, Energy efficiency, Energy storage are the ones to follow with percentages of above 50%. Excluding Energy storage, which was ranked second in the 2018 results, the rest of the listed areas did not change their sequence in terms of percentages gathered.

Figure 31. Areas of research for electric vehicles.



Source: JRC analysis, 2022.

An important issue in the Electric Vehicle (EV) sector is the variability in the available charging topology modes. As shown by the current survey, the IEC 61851 Mode is the most popular for this purpose in all of its modes. Indeed, 50% of the labs active in the field use IEC 61851-Mode 1, -Mode 2, -Mode 3 as charging methodology. Mode 4 follows with 45% of the labs active in the field. In addition to IEC 61851, the SAE (Society of Automotive Engineers) AC or DC mode is also used but at a lower extent. The situation is presented in detail in Table 17. Other modes are mentioned to be used as well, which is shown in Table 18. An important note here is the usage of superfast charging and wireless topologies, like the IEC 61980, although by few labs only.

Table 17. Charging modes and percentage of labs.

Charging modes	% of labs active in the field
IEC 61851-Mode 1 AC slow charging from a regular electrical socket	50%
IEC 61851-Mode 2 AC low charging from a regular socket equipped with specific EVs protection mechanism	50%
IEC 61851-Mode 3 AC slow or fast charging using a specific EVs multi-pin socket with control and protection functions	50%
IEC 61851-Mode4 DC fast charging using special charger technology	45%
SAE AC level 1	9%
SAE AC level 2	9%
SAE AC level 3	9%
SAE DC level 1	9%
SAE DC level 2	9%

Source: JRC analysis, 2022.

Table 18. Charging modes used at least by 1 lab.

Modes used at least by 1 lab	
IEC 61980	SAE J1772
IEC 62196-1	Mennekes
IEC 62196-2	SCHUKO
IEC 62196-3	Chademo

Source: JRC analysis, 2022.

With respect to the standards used in the electric vehicles area, including standards/ technologies for connectors, the situation is presented in Table 19. The connectors solutions are also included, since the charging connectors for EVs and PHEV are a critical part of the whole structure of electromobility labs. Other replies have also been received, which are summarized in Table 20. As it can be observed, CHADemo has been the option used mostly by labs, which was also number one selection for the 2018 Inventory, as the charging connectors' technology. With respect to the most popular communication standards by electromobility labs, the IEC 61851 and the IEC 61850 standard was chosen, which is in coherence with the 2018 results.

Table 19. Standards used in the electric vehicles sub-category and percentage of labs.

Standards	% of labs
CHADemo	40
IEC 61851 - Electric vehicle conductive charging system	24
IEC 61850 - Communication networks and systems in substations	20
OCCP – Open Charge Point Protocol	20
ISO/ IEC 15118 - Vehicle to grid communication interface	16
IEC 62196-2 – "Type 1" - single phase vehicle coupler "Type 2" - single and three phase vehicle coupler "Type 3" - single and three phase vehicle coupler with shutters	12
Mennekes (VDE-AR-E 2623-2-2)	12
SCHUKO	12

CCS	12
IEC 62196-1 - Conductive charging of electric vehicles - Part 1: General requirements	8
IEC 62196-3 - Dimensional compatibility and interchangeability requirements for DC and AC/DC. pin and contact-tube vehicle couplers	8
SAE J1772 - EVs and PHEV Conductive Charge Coupler	8%

Source: JRC analysis, 2022.

Table 20. Standards used by at least one lab in the electric vehicles sub-category.

Standards used at least by 1 lab	
SAE J2847	OpenADR
SAE J2931	CEEPlus
SAE J2954	OPCI
	Yazaki

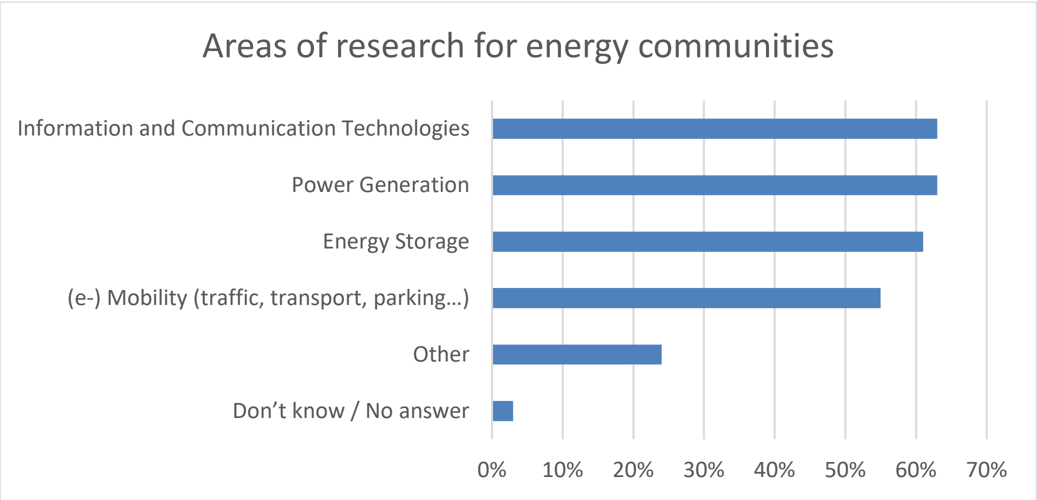
Source: JRC analysis, 2022.

4.3.4 Energy Communities

According to the results obtained this year, the 58% of labs active in the Customers and Market area carry out research on Energy Communities. Figure 32 shows the areas of research for energy communities. As it can be observed, the most popular area is Information and Communication Technologies and Power Generation, collecting 63% of the active labs in the field, with Energy Storage and e-Mobility following with 61% and 55% respectively. It is concluded that all of these areas play an important role for energy communities, since they collect more than 50% of the active labs. Generating energy and storing it appropriately are two important subjects for smart cities, whereas information and communication are also vital for the development of smart cities.

Many other areas of research for energy communities have been mentioned, which are listed in Table 21.

Figure 32. Areas of research for energy communities.



Source: JRC analysis, 2022.

Table 21. Other areas of research for energy communities.

Other areas of research	**% of labs**
Environment (pollution, noise, temperature...)	16%
Government (administration, buildings...)	11%
Local energy markets	8%

Lighting	3%
Urban platform as service provider	3%
Infrastructure Integration	3%

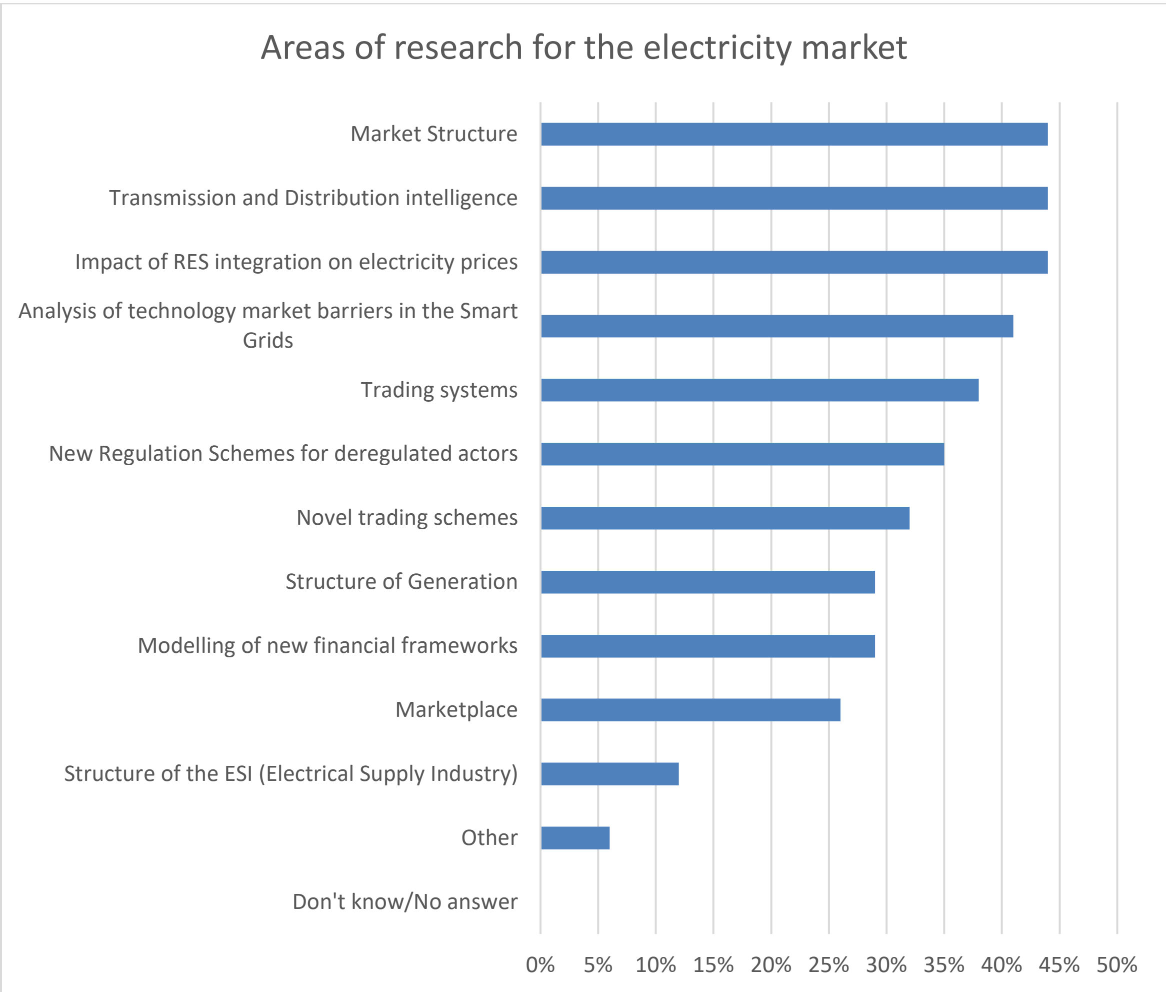
Source: JRC analysis, 2022.

4.3.5 Market

The 52% of the labs active in the field of Customers and Market carry out research on the electricity market. Figure 33 shows the areas of research for the electricity market. As it can be seen, the percentages for each area are relatively moderate. There are numerous of different areas identified by the ETIP SNET concept. Ranked at first positions are the Market structure, the Transmission and distribution intelligence and Impact of RES integration on electricity prices gathering 44% of the labs active in the field. The detailed situation is depicted in Figure 33. As it can be seen, the differences between the different areas are minor in percentage points, showing that there is more or less equal interest in different activities.

Comparing to the 2018 results, apart from the Market structure, which was ranked first also back then, the rest of the areas have changed their ranking. However, the differences are not major, since 9 areas range between 29% and 44%.

Figure 33. Areas of research for the electricity market.

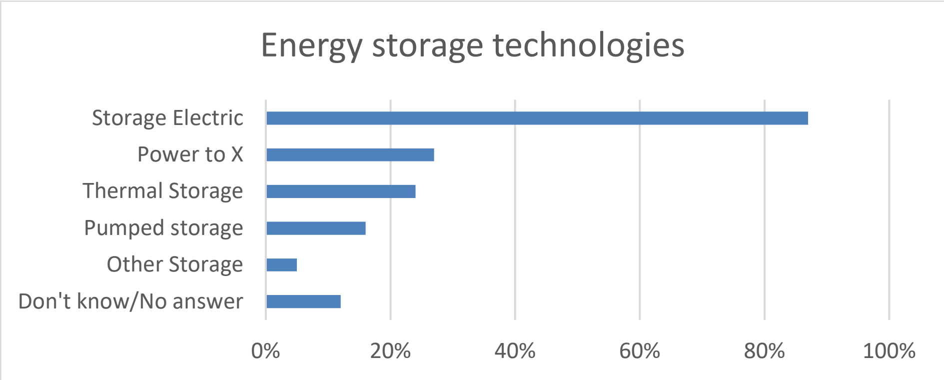


Source: JRC analysis, 2022.

4.4 Storage

In this section we present the results for the category of Storage. As it has been discussed earlier in this Chapter, the 70% of the participating labs carries out research on storage (60 labs). The analysis that follows this category of research refers to these labs that are active in the field. Figure 34 presents the percentages of labs that work on specific technologies regarding energy storage. As it can be observed by the graph, the majority of labs active in the field performs research on electric storage (87%). Other technologies are also the topic of research, like Power to X, Thermal storage, Pumped storage with percentages of 27%, 24% and 16% respectively. The results are in coherence to the 2018 results, where battery energy storage had collected the 81% of the participating labs. Other energy storage technologies that have been listed are shown in Table 22.

Figure 34. Energy storage technologies and percentages of labs.



Source: JRC analysis, 2022.

Table 22. Other energy storage technologies listed by at least one lab.

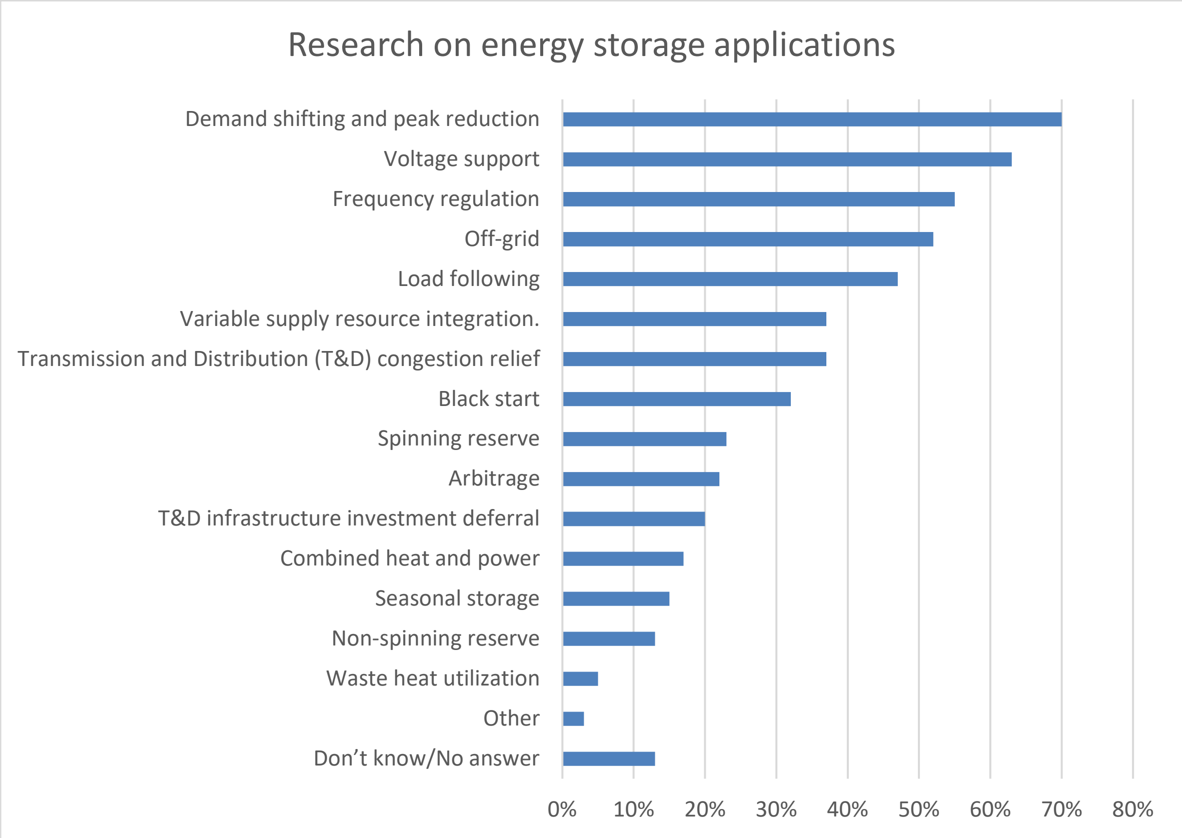
Other energy storage technologies
Kinetic Energy storage (flywheel)
Super capacitors
Magnetic storages using Halbach arrays
CAES

Source: JRC analysis, 2022.

As far as Energy Storage applications are concerned, it is noted that many of the smart grid labs conduct research on many subtopics simultaneously. The most popular topic is demand shifting and peak reduction with 70%, while voltage support follows behind with 63%. Frequency regulation and variable supply resource integration attract also more than half of the active labs in the field. The details of the topics and the equivalent percentages are shown in Figure 35. It should be noted that the aforementioned storage applications were also the first 4 ranked in the 2018 Inventory, showing coherence among results.

As other storage applications, the Electric traction and smart charging of electric vehicles have been mentioned at least by one lab.

Figure 35. Research on energy storage applications.



Source: JRC analysis, 2022.

With respect to standards used for Storage research, few replies have been received; only the 20% of the labs active in the field have given a standard with which they work. It should be noticed that the IEC 61850 standard has received the most of the replies among the labs, whereas the rest have been mentioned by one lab. Table 23 shows the standards for Storage research.

Table 23. Standards for Storage research.

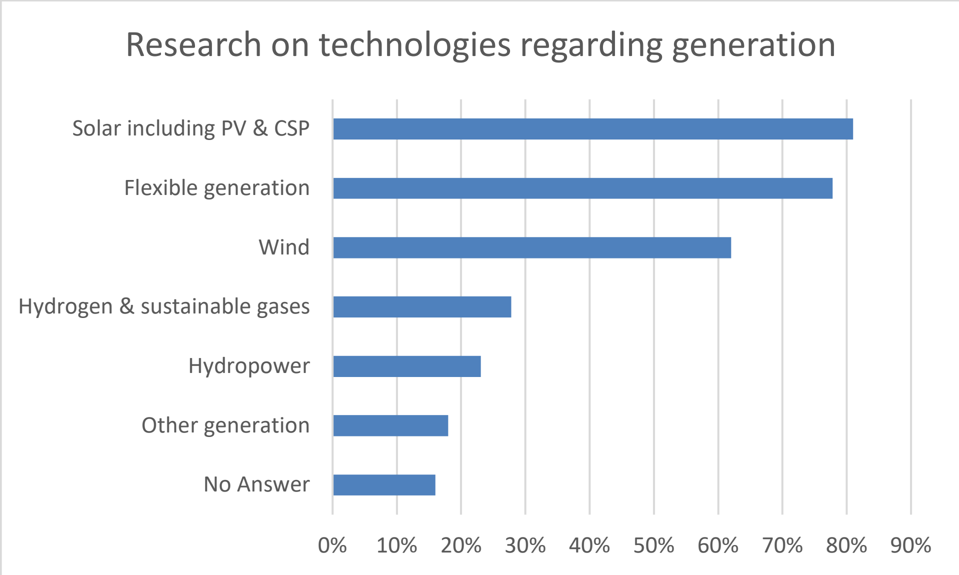
Standards used for Storage research	
IEC 61850	IEC 50272
IEC 60870-104	IEC 61427
IEC 61970	national code CEI 0-16
IEEE 1547	national code CEI 0-21

Source: JRC analysis, 2022.

4.5 Generation

The percentage of labs that carries out research on Generation is 79%, as it has been seen earlier in this Chapter. Here, we present the detailed results on research carried out in this category, and as it is normal, the sample of labs is the 68 labs active in the field. Figure 36 shows the technologies on which research is carried out regarding generation. As it can be seen, the most popular technologies are Solar, including PV and CSP (81% of labs), flexible generation (78%) and wind (62%). Other technologies come next, like hydrogen and sustainable gases and hydropower with lower percentages, 28% and 23% respectively. As for other technologies, Table 24 presents the results received. It shows the replies that have been given by at least one or two labs.

Figure 36. Research on technologies regarding Generation and percentages of labs.



Source: JRC analysis, 2022.

Table 24. Other technologies regarding generation, declared by at least one lab.

Other technologies regarding generation, used by at least one lab	
Gas power plant	Biomass
Microturbine	Fuel cell
Waves	Shipboard
Inverter based generation (power electronics)	Conventional (Diesel)
CHP	Nuclear power plants

Source: JRC analysis, 2022.

With respect to the standards used for generation, Table 25 and Table 26 show the situation. Table 26 shows the standards used by at least one or two labs. As it can be observed, the standards used mostly are the IEC 61850 and the IEC 61400 for wind turbines.

Table 25. Standards used for Generation and percentages of labs.

Standards used or generation	**% of labs**
IEC 61400 - Wind Turbines	30%
IEC 61850 - Communication networks and systems in substations	30%
IEEE 1547 - IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems	20%
IEC 60904 - Photovoltaic devices	15%
IEC 61724 - Photovoltaic system performance monitoring	15%
IEC 61727 - Photovoltaic (PV) systems. Utility interface	15%
EN 50438 - Requirements for the connection of micro-generators in parallel with public low-voltage distribution networks	15%

Source: JRC analysis, 2022.

Table 26. Standards used for Generation, at least by one or two labs.

Standards used at least by 1-2 labs	
IEC 60891	IEC 61970
IEC 61000	IEC 61869
IEC 61194	IEC 62271-37-013
IEC 61215	IEC 62351

IEC 61499	IEC 62446-2
IEC 61730	AUS/NZ 4777.2:2015
IEC 61968	

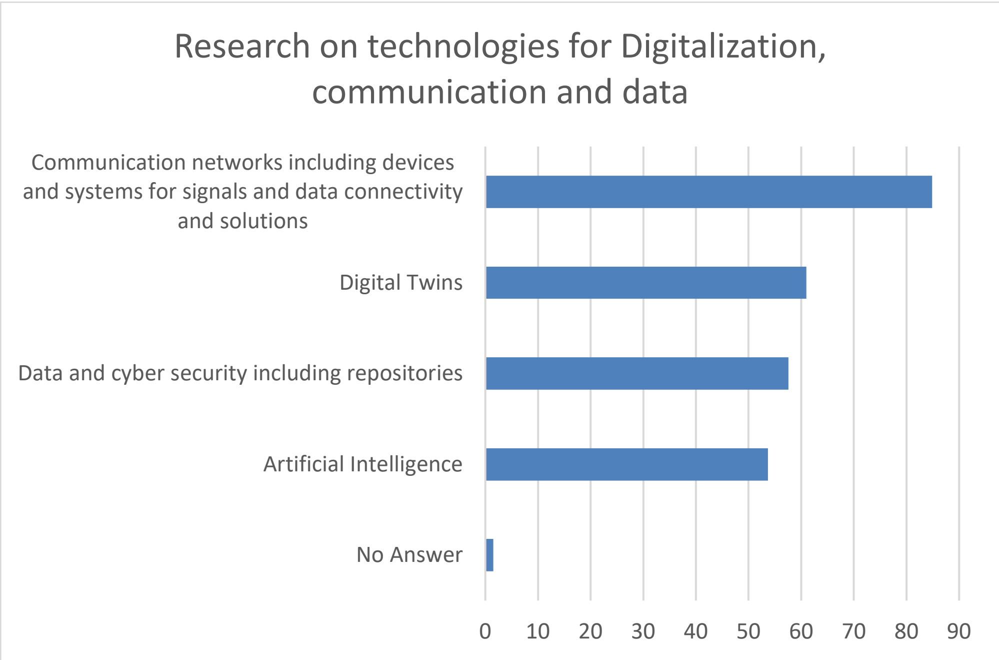
Source: JRC analysis, 2022.

4.6 Digitalization, Communication and Data

Digitalization, Communication and Data was ranked third among the categories of smart grid research, with a percentage of 77%. First of all, it is worth to see in which areas of Digitalization, Communication and Data research is carried out. Figure 37 shows this situation. As it can be observed, the majority of the labs active in the field, perform research on communication networks. The rest of the areas identified by the ETIP SNET, namely the Digital twins, Data and cyber security, Artificial intelligence have collected 61%, 58% and 54% respectively.

In the following, we present details with respect to communication networks used for research and cyber security, which were also topics under thorough investigation in the previous releases of the Inventory.

Figure 37. Research on technologies for digitalization, communication and data.



Source: JRC analysis, 2022.

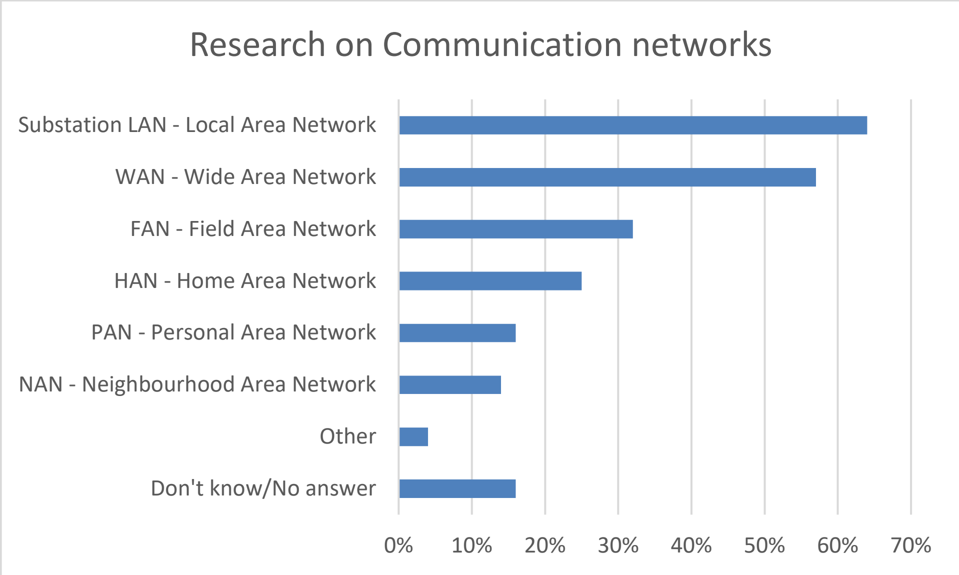
It should also be mentioned at this point, that Digitalization, Communication and Data entails also AMI research, as indicated in Chapter 2. The reader is directed to Section 4.2.3 for the results with respect to AMI, as these have been presented in the Integrated Grid Section.

4.6.1 Communication technologies

Here, information about research performed on communication technologies is presented. Wireless or wired solutions are investigated and information about the networks on which the labs work is presented. This latter information is presented in Figure 38.

As it can be observed, the Substation Local Area Networks are the ones to attract the most the scientific interest, gathering 64% of the active labs, whereas Wide Area Networks, Field Area Networks and Home Area Networks follow with 57%, 32% and 25% respectively. Comparing with the 2018 results, it is observed that the first four ranked communication networks remain the same. However, there has been an increase in the interest in the listed communication networks and especially for the first two, the Substation Local Area Networks and the Wide Area Networks, with the difference going up to 17 and 15 percentage points respectively.

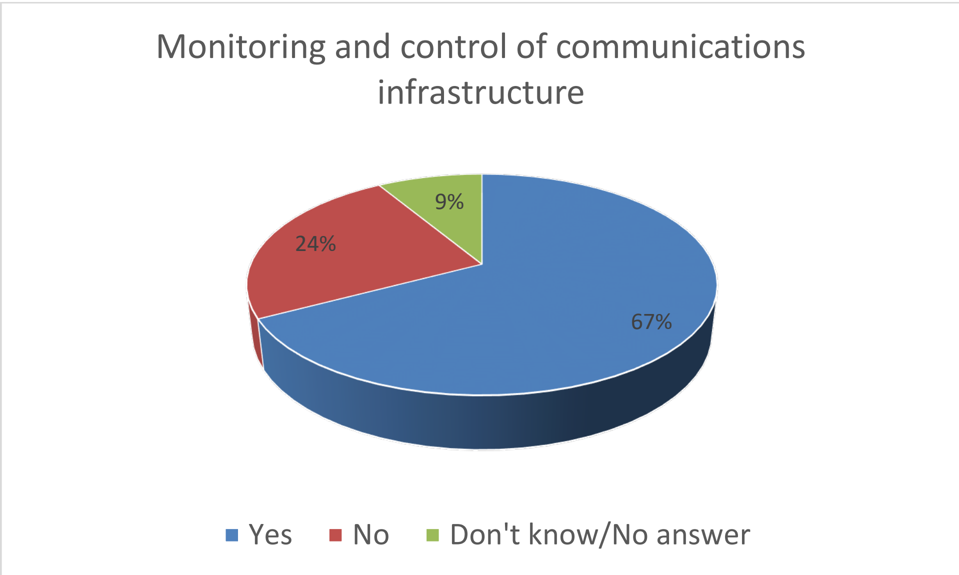
Figure 38. Research on Communication networks.



Source: JRC analysis, 2022.

Another interesting aspect is whether or not labs carry out research on monitoring and control of the communications infrastructure they have. Figure 39 shows this situation. It is noteworthy that 67% of the active labs in the field carry out such research, whereas 24% doesn't. This shows a trend in the field, that monitoring and control is a very important aspect of research.

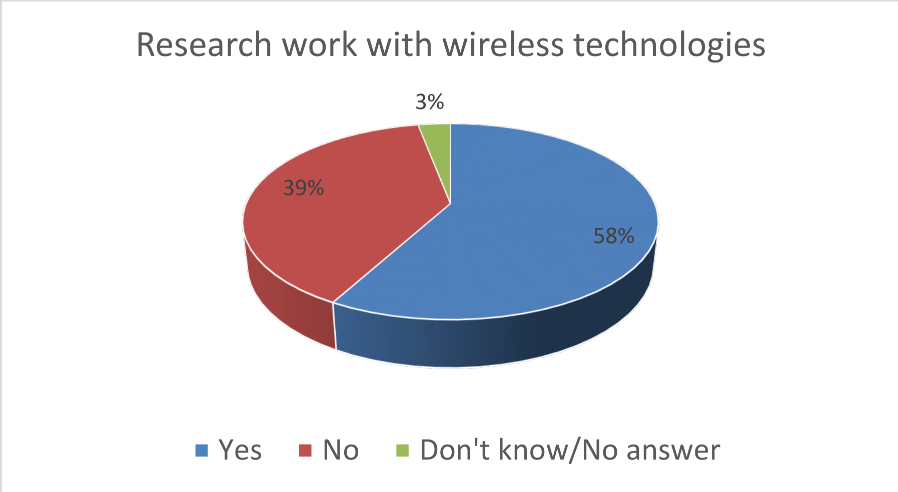
Figure 39. Monitoring and control of communications infrastructure.



Source: JRC analysis, 2022.

Since data communication is an important aspect of the smart grids, proved also by the fact that 77% of the participating labs are active in this category, it is interesting to see which technologies are used for this scope. Figure 40 shows the percentage of labs that uses wireless technologies for research purposes. It can be observed, that the majority of labs uses wireless technologies for research purposes (58%) on the smart grid. It is also noticeable that a relatively high percentage, 40%, does not use wireless technologies. These numbers are coherent with the 2018 results.

Figure 40. Research work with wireless technologies.



Source: JRC analysis, 2022.

With respect to the wireless technologies that are used for research purposes, the solutions vary a lot. Table 27 shows these technologies used and the percentage of labs that utilizes them, out of the ones that are active in the field. In addition, there have been other technologies mentioned at least by two labs, which are not included in Table 27, since the equivalent percentage would have been too low. These technologies are shown in Table 28. It can be observed, that the most popular solution is the WiFi, gathering 43% of the active labs in the field. WiFi was also ranked first at the 2018 results. However, 5G, which is now ranked second was much lower in the list in the past. In general, it is observed that cellular technologies, like 5G, 4G, 3G, LTE, etc are very popular as the technologies used for research on the smart grid. It is noteworthy, that even 6G is used by a couple of labs for research purposes. On the other hand, solutions like LORA, LoraWan, NB-IOT, 6LoWPAN, representing low power wide area networks, also play their role in the smart grid research.

Table 27. Wireless technologies and percentage of labs that uses them.

Wireless Technologies	% of labs
WiFi	43%
5G	39%
3G	36%
LTE	32%
Bluetooth	29%
4G	29%
GSM	21%
ZigBee	21%
NB-IOT	11%
6LoWPAN	11%

Source: JRC analysis, 2022.

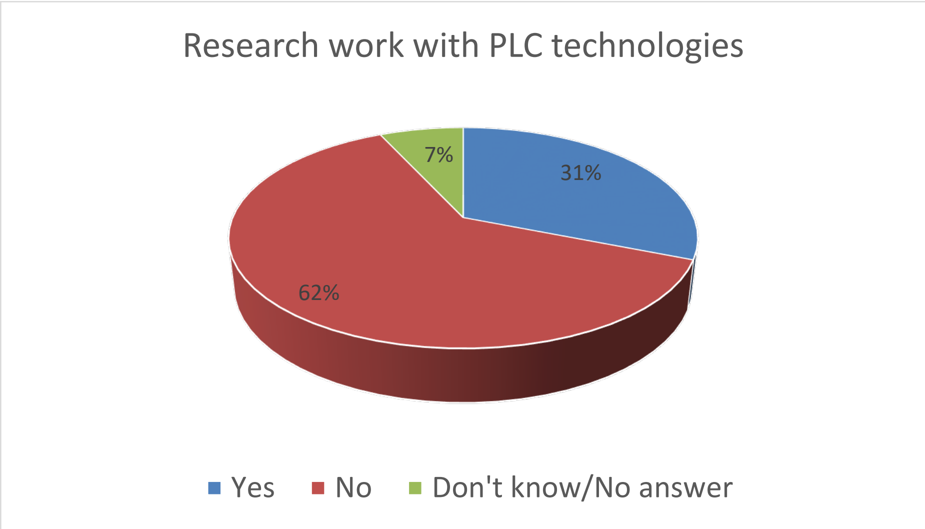
Table 28. Wireless technologies used at least by one or two labs.

Wireless technologies used at least by one or two labs	
LoraWan	6G
LORA	IEEE 802.15.4G
GPRS	WiMax
BLE	LTE M
RF-mesh	Wi-Sun

Source: JRC analysis, 2022.

After having examined the situation regarding wireless technologies, it is worth to see the research carried out with wired technologies. An important wired technology for smart grid communications is the power line communications (PLC) technology, which allows data communication through the power lines of the energy system. Figure 41 shows the percentage of active labs in the field that carry out research with PLC. It is noteworthy that only the 31% of the labs carry out such research. This may be explained due to the fact that, as it has been shown above, wireless communications play a key role in smart grid communications, especially for smart home and energy communities' solutions. Nevertheless, power line communications still remain a crucial part of smart grid communications, especially for specific applications, like smart meter data transferring, which also facilitates other programs, like demand response. When further asked which PLC technologies are used, the 69% of the active labs in the field replied to be using Narrowband PLC (NB-PLC), while 46% of them uses Broadband PLC (BPL).

Figure 41. Research work with PLC technologies.



Source: JRC analysis, 2022.

With respect to the standards / specifications used for communication purposes, Table 29 summarizes the situation. As it is clear, the IEC 61850 standard is used by the majority of the active labs in the field (83%), whereas IPv4 and IPv6 are also widely used (54% and 44% respectively). These three solutions were also ranked as first three in the 2018 Inventory, however, their percentages were significantly lower.

There are also other options mentioned to be used at least by one or two labs, which are not included in Table 29, since the percentages would have been very low. These options are presented in Table 30. It can be seen, that the IEC 60870 standard is used for communication purposes, whereas other PLC solutions are shown, either NB-PLC or BPL.

Table 29. Standards / protocols / specifications and percentage of labs.

Standards / protocols / specifications	**% of labs**
IEC 61850 - Communication networks and systems in substations	83%
IPv4 - IP version 4	54%
IPv6 - IP version 6	44%
Modbus	17%
MPLS - Multiprotocol Label Switching	15%
DLMS/COSEM – Device Language Message Specification	15%
PRIME	12%
G3-PLC	10%
DNP3	7%
DSL - Digital Subscriber Line (including ADSL, VDSL, HDSL, SHDSL…)	7%

Source: JRC analysis, 2022.

Table 30. Standards / protocols / specifications used at least by one or two labs.

Standards/specifications used by at least 2 labs	
IEC 60870-5-101	Meters and More
IEC 60870-5-104	IEEE 1901.2
IEC 60870-5-103	HomePlug
SONET	

Source: JRC analysis, 2022.

4.6.2 Cyber Security

Cyber security is a sub-category of research under the Digitalization, Communication and Data field, according to the ETIP SNET concept. The 58% of labs active in the field, carry out research on cyber security. The most important aspects of this research are presented in this Section.

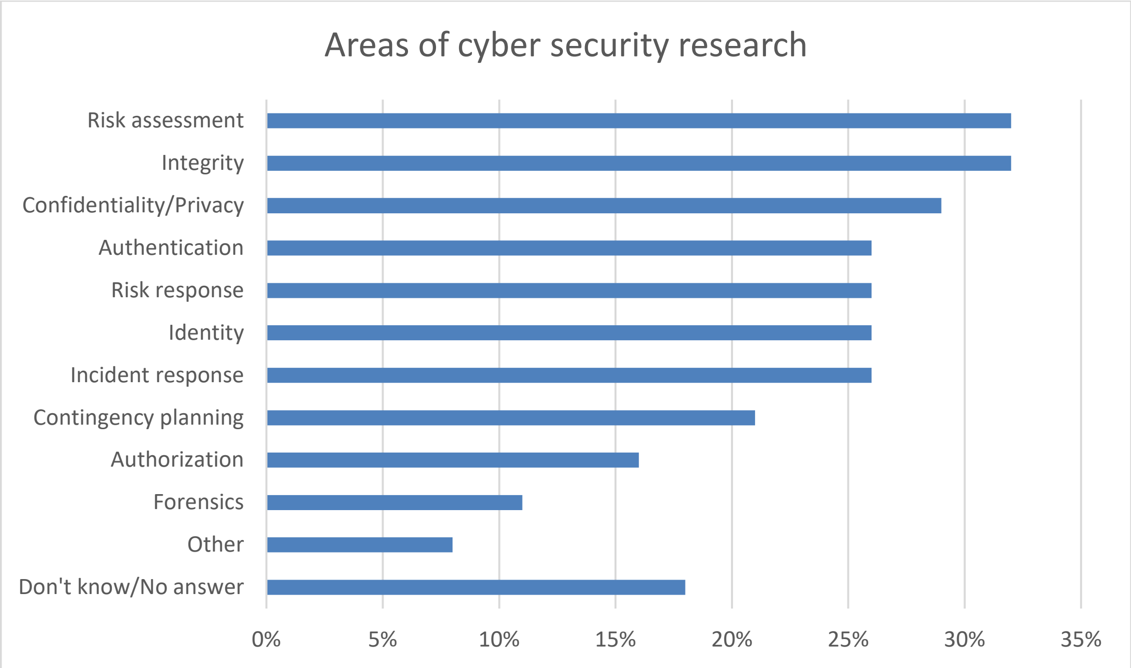
Figure 42 shows the protocols / technologies under investigation in the cyber security field. As it can be seen from Figure 42, the scientific interest is split among these technologies, with the first one ranked (Internet Protocol Security) to be gathering 32% of the active labs in the field. The ones to follow are the Public Key Infrastructure, Secure Shell, Secure Hash Algorithm, Advanced Encryption Standard with 26% for the former two and 24% for the latter two ones respectively. The situation was more or less the same for the 2018 Inventory results, with all protocols / technologies gathering moderate percentages of lab participants.

Figure 42. Protocols / Technologies for cyber security.

Source: JRC analysis, 2022.

It is interesting to see the areas of cyber security research, which are presented in Figure 43. Similarly to the protocols / technologies used for cyber security, also here the percentages gathered remain at moderate levels and it seems that the scientific interest is split among different cyber security areas of research. Risk assessment and Integrity come first with 32% of the active labs in the field, Confidentiality/ Privacy follows with 29%, whereas four areas are found in the third position with 26% of the active labs, namely the Authentication, Risk Response, Identity, Incident Response. Comparing with the results of the 2018 survey, the situation has remained more or less the same, with moderate percentages for all areas of research also back then. It is also noteworthy that the "Don't know / No answer" option has a relatively high percentage here. This can be explained mainly by other factors, like "human" factors, indicating that reaching the end of the survey, some participants did not reply to specific questions, and/ or also that this is about specific knowledge and perhaps the person most suitable from one organization to answer it, did not have the chance to complete the survey.

Figure 43. Areas of cyber security research.



Source: JRC analysis, 2022.

5 Results: Infrastructure Used and Services Offered

In this Section, information is provided about the infrastructure used by the survey participants. Similarly to the general information questions, many of the questions in this Section have remained the same with previous releases of the Inventory. However, there have been some additions this year, after feedback received in the past. In all results presented, we explicitly show the sample of labs used for their extraction.

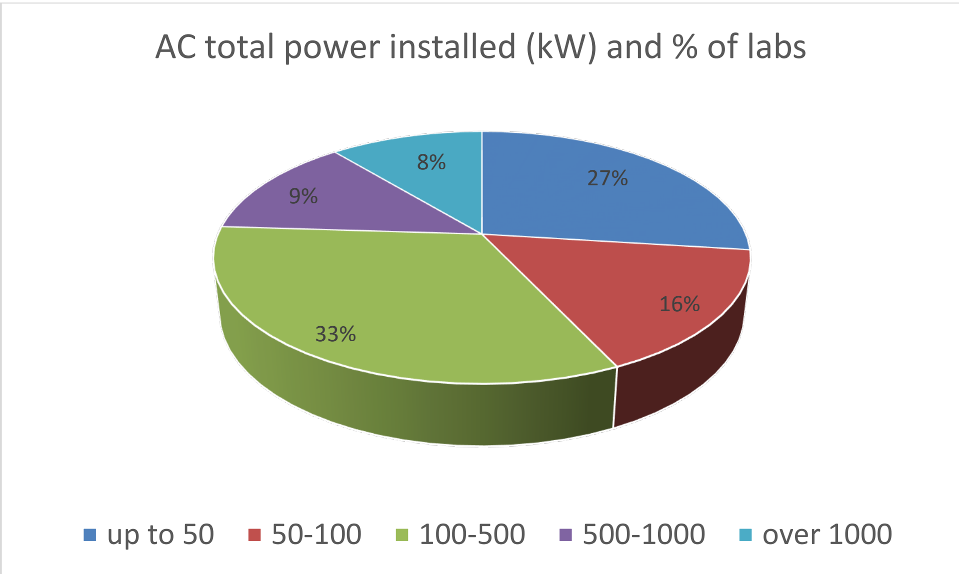
Initially, information about the power and voltage capabilities of the labs is presented, like the total power installed (AC and DC), the peak power of the infrastructure (AC and DC) and the voltage level (AC and DC). Afterwards, information about the labs' microgrids is collected, like what type of microgrid they have and which are its components. In addition, we present information about Hardware or Software – in-the-Loop activities as well as the percentage of laboratories working with an RTDS.

We also present information about other major equipment that the labs may possess and their main simulation/ optimization tools they use for research purposes. Finally, we show some information about testing services offered by the labs, which completes the picture of the smart grid research and what can be found out there with respect to labs facilities.

5.1 Power and Voltage Capability

In this Section, we present 6 figures, showing the total AC and DC power installed, the peak AC and DC power and the AC and DC voltage level of the labs. Figure 44 and Figure 45 show the AC and DC total power installed respectively and the percentage of labs. For the total AC installation, 63 labs have provided feedback with this respect, whereas for the DC installation, only 40 labs have replied (out of the extended sample of 86 labs). The reason behind this may be that some labs may have only AC installations.

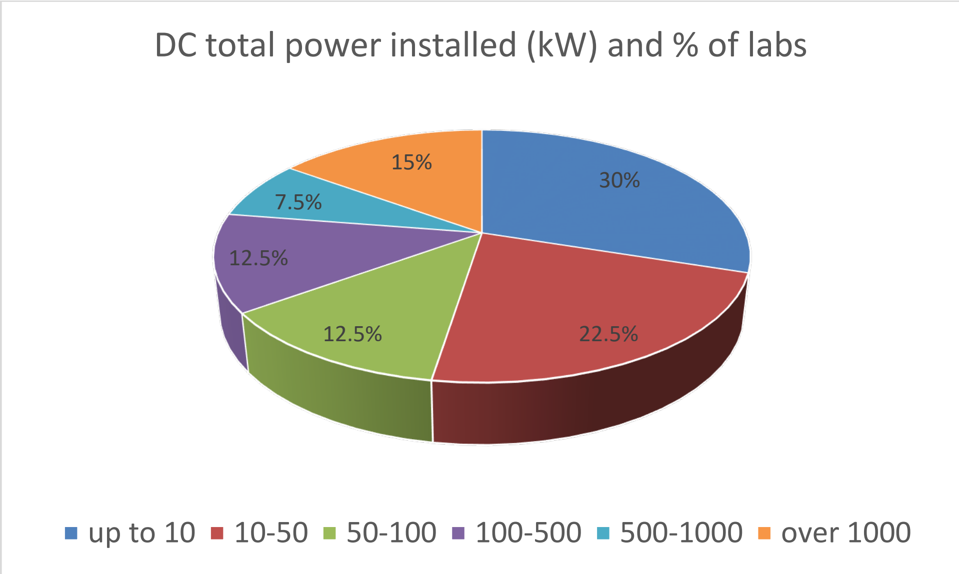
Figure 44. AC total power installed in kW and percentage of labs.



Source: JRC analysis, 2022.

As it can be deducted from Figure 44, most of the labs have an AC installed power between 100 and 500 kW (33%). A relatively big number of labs (27%) has an installation of up to 50 kW. However, there is also a considerable amount of labs that has an AC installation of over 500 kW, in total, 17% (9 labs). The situation was similar with the 2018 results, although on that occasion, the percentages of labs with lower installations were slightly lower (24% and 11% respectively for installations up to 50 kW and between 50-100 kW).

Figure 45. DC total power installed in kW and percentage of labs.



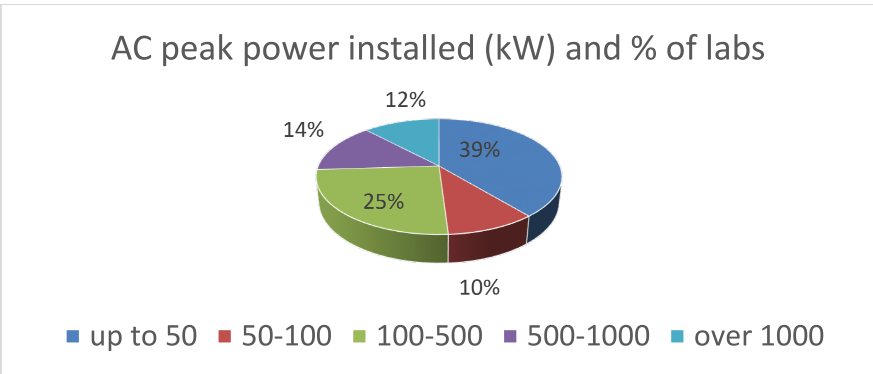
Source: JRC analysis, 2022.

As it can be seen from Figure 45, a little more than half of the labs has a DC total power installed up to 50 kW. The higher the number of DC power installed, the lower the number of labs. However, it is noticeable that 15% of the labs has a DC installation of over 1000 kW. The situation was slightly different in the 2018 results, where the 56% of the labs had a DC installation of up to 50 kW and around 12% of labs had an installation of over 1000 kW.

Figure 46 and Figure 47 show the peak AC and DC power installed respectively. For the extraction of these graphs, we got 51 and 28 replies respectively (from the extended sample of 86 labs). Again, the number of labs is lower with respect to the DC peak power installed. As explained above, a possible reason may be that many labs may not have a DC installation. Although the number of labs can be considered relatively low, especially for the DC case, the figures do show a trend in the smart grid research area.

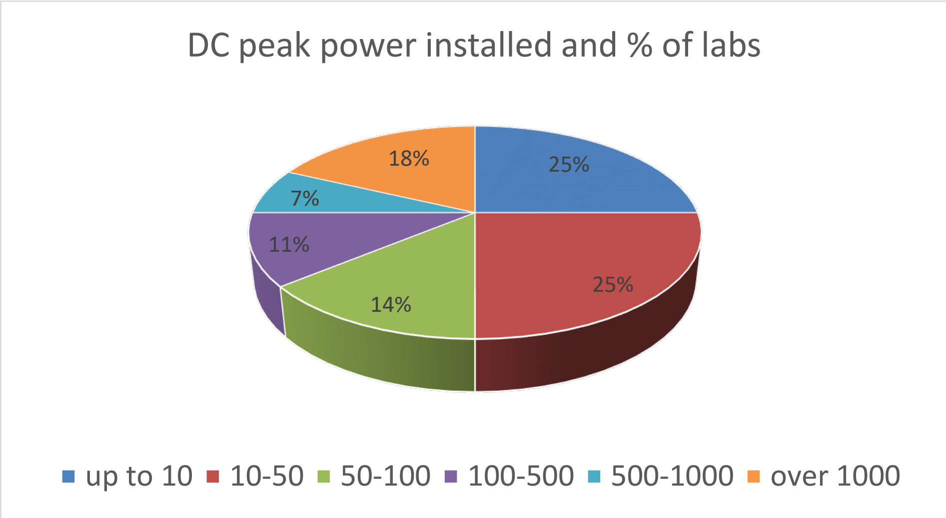
As it can be deducted from Figure 46, almost half of the labs have an AC peak power installed up to 100 kW, whereas the other half of the labs are divided between a peak power of 100-500 kW and over 500 kW. The situation was slightly different for the 2018 results, where the 44% of the labs had declared to have a peak power up to 100 kW. From Figure 47, it can be seen that one quarter of the labs has a peak power installed of up to 10 kW, another quarter of labs has a DC peak power between 10-50 kW. The other half labs have a peak power of more than 50 kW. Especially for labs with a very high DC peak installation (over 1000 kW), they accumulate a percentage of 18%. Again, the picture a bit different for the 2018 Inventory, where 54% of labs had a DC peak power up to 50 kW, whereas 12% of labs had a very high DC peak power installed (over 1000 kW).

Figure 46. AC peak power installed in kW and the percentage of labs.



Source: JRC analysis, 2022.

Figure 47. DC peak power installed in kW and the percentage of labs.

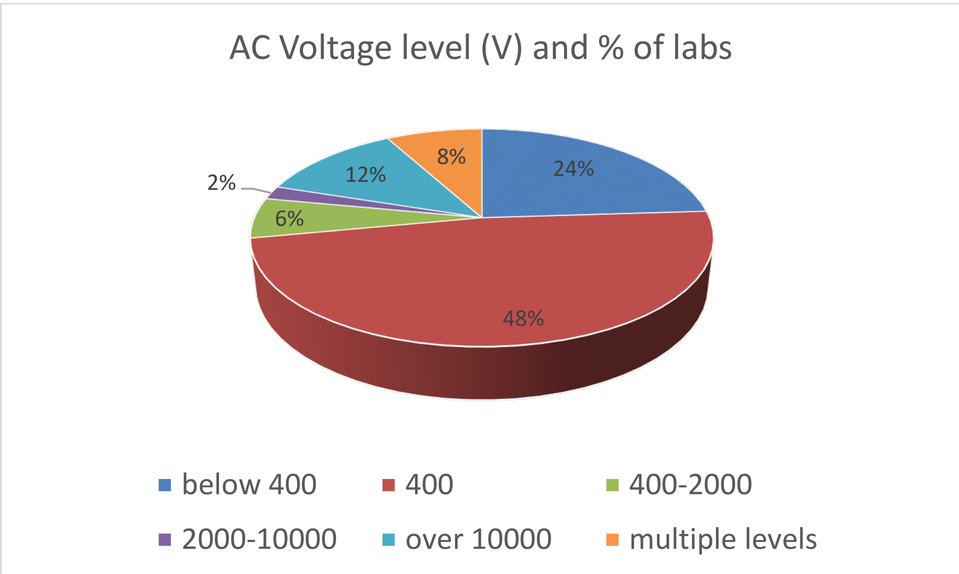


Source: JRC analysis, 2022.

Figure 48 and Figure 49 show the AC and DC voltage level and the percentage of labs respectively. The labs from which we have got a reply were 63 and 39 respectively from the extended sample of 86 labs. As it can be observe from Figure 48, most of the labs have an AC voltage level of exactly 400 V (48%), with another 24% having a level below 400 V. Only 20% of labs has a voltage level between 400-10000, which is huge range. On the other hand, 8% of labs support multiple levels, both high and low. The situation was similar in 2018, where the 76% of labs had a voltage level up to 400 V and a 6% of labs would support multiple levels.

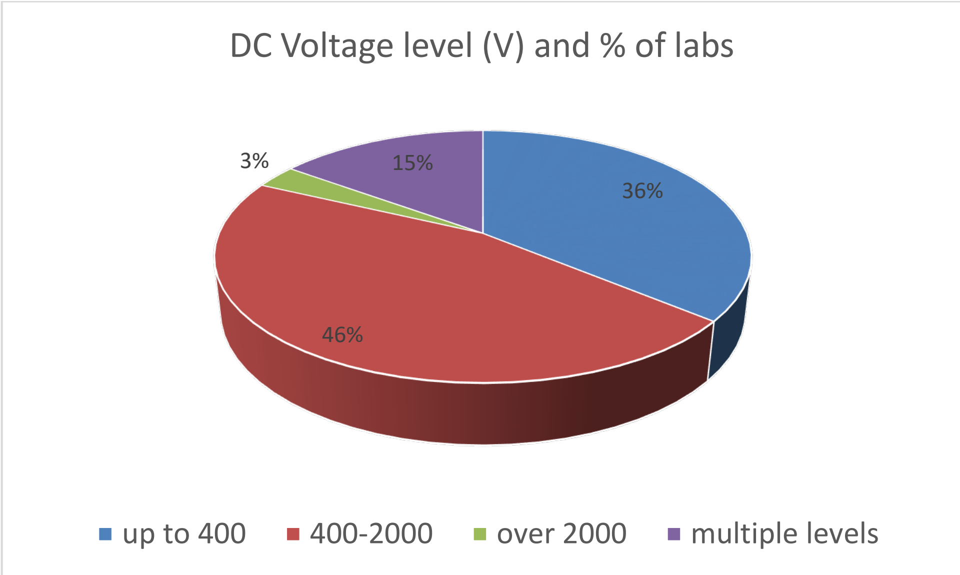
The value of 400 V has not been so critical for the DC voltage level. It is observed by Figure 49 that the labs are kind of divided between two groups: those with low voltage level, up to 400 V (36%) and those with higher voltage level, from 400-2000 V (46%). Few labs have an even higher level, above 2000 V, whereas, again, there is a number of labs (15%) that supports multiple levels of voltage, low and high. In the 2018 results, the two groups of levels (up to 400 and between 400-2000) were perfectly equal, collecting 46%, whereas the remaining percentage of labs supported multiple levels.

Figure 48. AC voltage level and the percnetage of labs.



Source: JRC analysis, 2022.

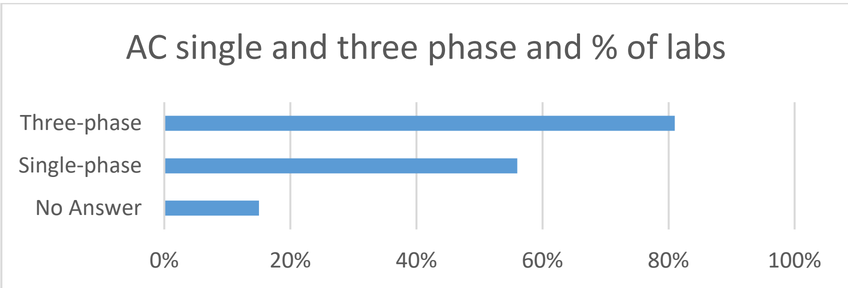
Figure 49. DC voltage level and the percentage of labs.



Source: JRC analysis, 2022.

Further on, we collected information about single and three-phase AC systems with which labs are working. The sample used here is the 86 labs, whereas only a small percentage of labs did not give feedback to this question. Figure 50 shows the percentages of labs working with such systems. It should be noticed that working with a single phase system does not exclude working also with a three-phase one. Therefore, many labs have replied that they use both systems. Three-phase systems are more popular, gathering the 81% of the labs, whereas 56% of labs works with a single AC system.

Figure 50. AC single and three-phase systems usage and percentage of labs.



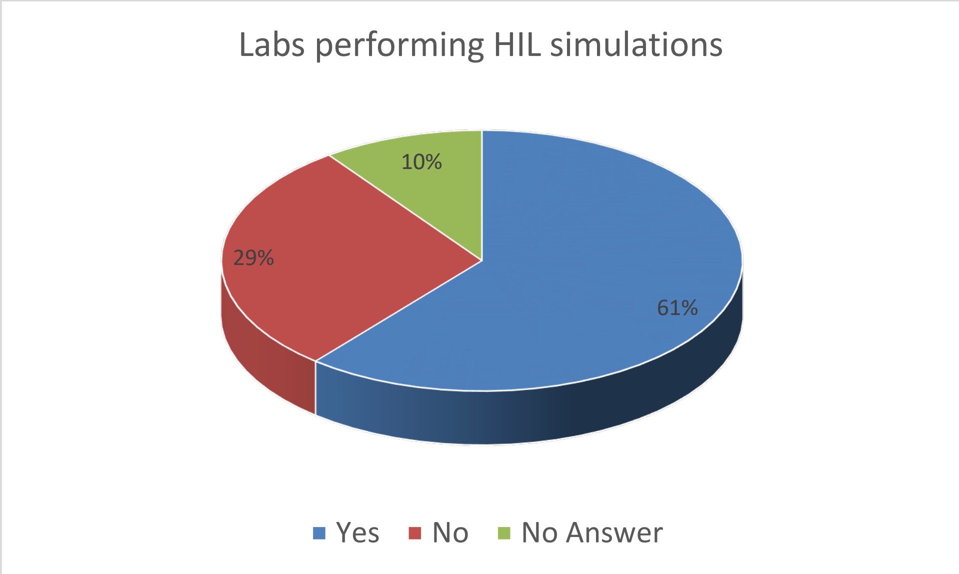
Source: JRC analysis, 2022.

Comparing to the previous Inventory results, there is a noticeable change, since in 2018, only 47% and 35% of labs had declared to work with a three-phase and a single phase AC system respectively. We notice an increase in this release, which reveals current trends in the smart grid research.

5.2 Simulation Infrastructure

An interesting point is whether or not the labs perform Hardware in the Loop (HIL) simulations and in such a case, the areas in which they work, i.e. control hardware in the loop, power hardware in the loop, etc. In Figure 51, it is shown the percentage of labs performing hardware-in-the-loop (HIL) simulations. The sample has been the 86 labs. It is seen that 61% of labs replied positively to this question, whereas the 29% negatively. Comparing to the 2018 results, we would observe a significant increase in the percentage of labs performing HIL simulations, since only 47% had replied positively back then. This shows that HIL gains importance in the scientific community.

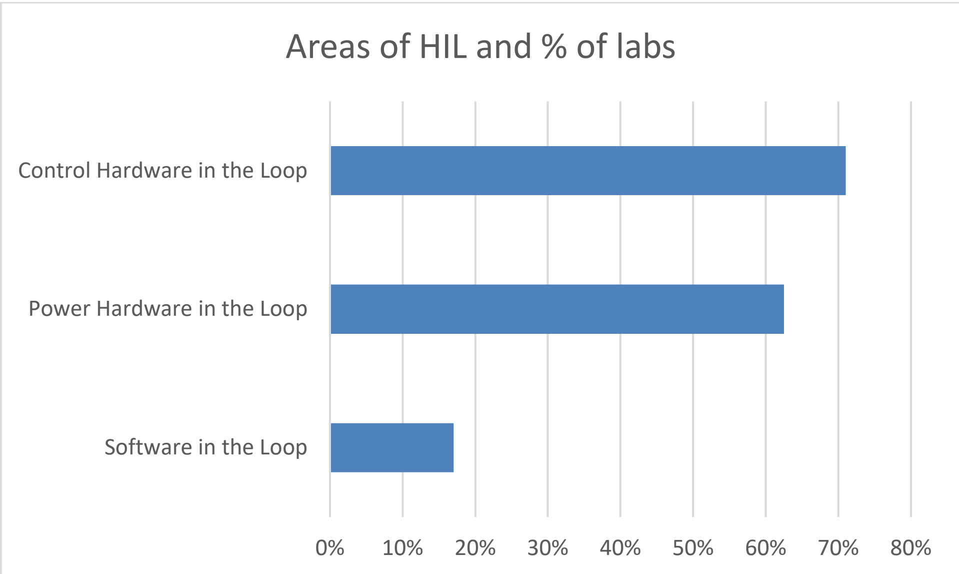
Figure 51. Percentage of labs performing Hardware-in-the-Loop simulations.



Source: JRC analysis, 2022.

With respect to what kind of HIL work is being done, Figure 52 gives relevant information. The percentages refer, of course, only to the labs that replied positively in the previous question. It can be observed that 71% of the labs with HIL, perform control hardware in the loop, whereas a 63% performs power HIL. On the other hand a 17% performs software in the loop work. As it is anticipated, working with one kind of HIL does not exclude working also with another, thus the cumulative percentages are not 100%.

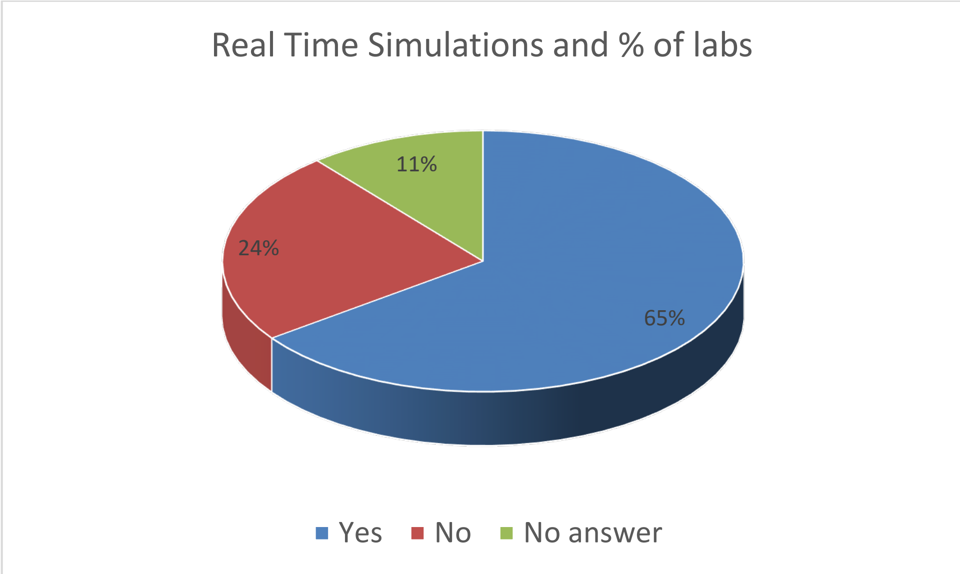
Figure 52. Areas of HIL and percentage of labs.



Source: JRC analysis, 2022.

It is also interesting to see at this point, the percentage of labs that uses a Real Time Simulator (RTS). Figure 53 shows this information (sample 86 labs). It is observed that 65% of the labs do use a RTS, whereas the 24% of labs doesn't. In the 2018 release of the Inventory, it was observed that the 50% used an RTS and the 21% did not. Again, we notice an increase in the number of labs using real time simulations, which reveals a growing interest towards this form of research as well.

Figure 53. Real Time simulations and the percentage of labs.



Source: JRC analysis, 2022.

5.3 Microgrids and Major Infrastructure

Microgrids have been the topic of research for many labs and therefore, we collect information with this respect, meaning that the labs have been asked to describe their microgrids, in case they work with such. This question has been introduced in this release of the Inventory and the participants have replied in a form of free text. We collected 27 replies out of the 50 labs that gave feedback this year. Information was collected mainly about the components comprising the microgrids. The replies varied a lot, since there have been noted various compositions of microgrids not only with respect to their size but also regarding their components. In Table 31 we show the main components comprising the microgrids of the labs participating in our survey. The percentages shown refer to the 27 labs replying they have an operating microgrid.

Table 31. Components of microgrids and percentage of labs.

Components of microgrids	% of labs
Photovoltaics and/or PV systems	52%
Batteries	44%
Wind turbines	33%
Controllable loads	30%
Power converter	18%
Inverters	15%
Generators	11%
Charging points	7%

Source: JRC analysis, 2022.

It is worth mentioning at this point, that many of the microgrids described by the participant labs can operate in connected or islanded mode. In addition, 30% of the labs that work on microgrids have declared that their microgrid is flexible for tests and can be adjusted according to the needs.

Another question introduced this year has to do with other major equipment owned by the labs. Thus, the participating labs had the opportunity to mention particular equipment they possess. Also this question was in the form of free text, giving the chance to the labs to describe their equipment. We collected 31 replies out of the 50 labs and the answers varied a lot, since the research focus of the labs varies a lot. In Table 32 we group the equipment listed by the labs and present the number of labs in possession of such equipment.

Table 32. Major equipment and percentage of labs.

Equipment	**% of labs**
Power amplifier	19%
Battery energy storage system	19%
Grid emulator	13%
Network and communication equipment (network test equipment, mobile power quality testing equipment, communication network simulator)	10%
Climatic chamber	6%
PV simulator and / or emulator	6%
Rotating machines	6%
Measurement equipment	6%
Other	10%

Source: JRC analysis, 2022.

Other equipment mentioned are: flexibility management platform software tools, antennas, anechoic chamber. It should be noted here, that equipment like a Real Time Simulator are not included in this list, since there has been a dedicated question for this scope.

5.4 Simulation / Optimization tools and services offered by the labs

In this Section we present the simulation or optimization tools used by the labs and we also refer to the services they are able to offer. This is information that is based on new questions in the questionnaire, therefore, only the feedback from the 2021 participants has been used.

With respect to the simulation/ optimization tools, the labs had the opportunity to present what they use in order to carry out smart grid research. It was a free text question and the replies we got varied a lot. As a general result, it can be concluded that the tools used for simulations vary as much as the labs can vary among them and their objectives. Therefore, a plethora of simulation tools has been noted down, whereas few of them have been in common. It should be also noted however, that although the simulation tools vary, their objectives are more or less similar. For example, many labs carry out grid simulations, but they use a plethora of tools for this scope. Especially for grid simulation, we received much feedback regarding the simulation tools. Table 33 shows these simulation tools and the percentage of labs that uses them. 27 labs replied to this question, so, this was the basis of our calculations.

Table 33. Grid simulation tools and percentage of labs.

Grid simulation Tools	%
Matlab - grid simulation	44%
PowerFactory - grid simulation	15%
Pandapower - grid simulation	11%
RTDS	8%
DigSilent	8%

Open DSS	8%
PSCAD	8%
SimPLECS	8%
PSS/E	8%

Source: JRC analysis, 2022.

According to Table 33, Matlab has been the most popular tool used by the labs to carry out grid simulations, whereas PowerFactory follows and Pandapower. Apart from the aforementioned tools, others that have been mentioned by at least one lab, for the purpose of grid simulations are shown in Table 34.

Table 34. Other tools used by at least one lab for grid simulation.

Tools for grid simulation	
SinapGrid	Modelica
OPAL	eMEGASIM
ETAP	ePHASORSIM
CeMOS	HYPERSIM
PSAT	Gridcal
EMTP	Typhoon

Source: JRC analysis, 2022.

Apart from grid simulations, which has proved to be a pvery popular activity among labs, there are other tools used for other purposes. Table 35 shows such tools and the purpose they serve.

Table 35. Other tools used at least by one or two labs and the purpose they serve.

Other tools and their scope
Python - energy market modelling
PSIM - electronical simulation
Labview
Microgrid Optimization toolkit
Julia - market optimization
Octave - energy market modelling
Data analytics toolbox
HOMER - power systems economics analysis
NREL SAM - RES system modelling
Keysight CDS - for EV and EVSE
Apros - heat and energy system modelling

Source: JRC analysis, 2022.

As Table 35 reveals, the number of tools found to be used can result as many as the labs interrogated. Some examples of tools used for specific purposes, are, as seen from Table 35: Python for energy market modelling, PSIM for simulating electronic circuits, whereas there are also tools for very specific functionalities, like heat and energy system modelling and simulation of RES systems. It should be noted at this point, that the scope of listing these tools is exclusively informative and it is reminded that the list is not exhaustive. There are many tools outside this list that can be efficient for simulation purposes. The scope of this Inventory is only to identify some of the tools used and not to act in favour of their utilization.

In order to depict the services offered by the labs, another free text question has been added in our questionnaire and the participants had the chance to list the services they offer. We received 24 replies out of the 50 labs that gave feedback this year (it has been a newly added question to the survey). The situation is proved to vary a lot with respect to these services offered. Table 36 summarizes these services and presents the percentage of the labs that offer them, whereas Table 37 lists the services offered by at least one lab of the participant ones.

Table 36. Services offered and the percentage of labs.

Services Offered	**% of labs**
Integration and testing of devices (hardware testing, meter, relay testing, high voltage products tests, etc)	33%
Research and Development support	29%
Performance tests of photovoltaic systems and PVs	21%
PHIL	17%
Storage Energy System Testing	12.5%
EV testing	12.5%
Development of prototypes	12.5%
Protection testing	8%
Cyber-security/ fault assessment	8%
Plant monitoring, visualization and control systems	8%

Source: JRC analysis, 2022.

As it can be seen from Table 36, a popular service is testing of several devices. The activities of testing varied a lot as well as the devices that could be tested. Under this category we grouped the testing of different devices, like meters, relays, high voltage products and hardware in general used for the smart grids. In addition, another popular service is support for research and development, which is the natural result of the experience obtained by the labs. Performance tests of PVs and photovoltaic systems in general come next along with Power hardware in the loop services. Apart from the services listed in Table 36, there have been more services found, declared to be offered by at least one lab out of the questioned ones. These services are displayed in Table 37.

Table 37. Services offered by at least one lab.

Services offered by at least one lab
IOP testing
Certification tests
Blockchain development
Microgrid design

Source: JRC analysis, 2022.

It is worth noticing, that interoperability testing is only declared to be offered by one lab. Since interoperability becomes a popular topic in the power system sector, with many elements needed to communicate correctly with each other and many diverse systems needed to work together and exchange data for the automatization of the grid and its upgrade to the smart grid, it may be implied that there is a potential gap in this field and that labs offering interoperability services may be increased in the future. Similar conclusions can be derived for blockchain development, which seems to be an upcoming topic in the area of smart grids, yet there is only one lab that offers such service out of 50 labs of our questionnaire. On the other hand, it should be mentioned at this point, that there may be more labs offering such services, which have not participated in this exercise, or even that participated but did not declare to offer such services, due to various reasons, i.e. the correct person did not have the opportunity to fill in the questionnaire. Therefore, the numbers are indicative, but still give a hint of the work being done and the services that can be supported by smart grid labs.

6 Conclusions and Future Perspective

6.1 Conclusive Remarks

The Smart Grid Lab Inventory is a periodical exercise, taking place roughly every couple of years and aiming at depicting the situation of smart grid research at laboratory level. This report is the fourth release and provides up-to-date information about smart grid research. The Smart Grid Lab Inventory gathers general information about the smart grid lab participants and their infrastructure and also information about the research carried out on specific categories. This year the ETIP SNET concept has been adopted. This means that the categories of research and their sub-categories are coherent with the ETIP SNET initiative and the EIRIE platform.

EIRIE, the European Interconnection for Research Innovation & Entrepreneurship is a living dynamic multi-functional platform for all the energy system stakeholders and for all citizens to benefit of a series of services. European Technology & Innovation Platforms (ETIPs) have been created by the European Commission as an outcome of the new Integrated Roadmap Strategic Energy Technology Plan (SET Plan) and have united numerous stakeholders and experts from the energy sector. The ETIP Smart Networks for Energy Transition (SNET) are responsible for guiding the scientific community towards the energy transition era. One of the outcomes of ETIP SNET has been to define the technologies and systems in support of the functionalities in the area of smart grids. Thus, every activity in the smart grid field can be categorised in a broader group of technologies. Particularly, there are 5 groups of technologies, which have been taken into consideration here, namely: Integrated Grid; Customers and Market; Storage; Generation; Digitalization, Communication and Data.

In this work, the information collected is in accordance to the ETIP SNET concept. Feedback from 86 labs has been collected. Fifty of these labs have provided with updated information during Autumn 2021. The rest of the labs had provided information in the previous releases of the Inventory, however, no information dating more than 5 years has been used for this report.

6.1.1 In numbers – General Information

For this report, information has been collected from 65 labs located in Europe and 21 labs outside Europe. The general information collected has been:

1. Labs' operating date:

   48% of labs operated / opened from 2015 and afterwards

2. Area of surface the labs cover:

   44% of labs cover an area up to 250 m^2

3. Number of employees:

   43% of labs have up to 10 employees, revealing that many of the labs work with a relatively low number of personnel.

4. If accreditation for standards is held:

   The 20% of labs holds accreditation for standards

5. Intentions for infrastructure expansion:

   Infrastructure expansion is intended by 70%, 62% and 51% of labs respectively for the short term, medium term and long term perspective.

6. Fields of activities for labs:

   The 86% of labs perform R&D on hardware and software research activities

7. Types of grids for which research is carried out:

   The 91% of labs carries out research on the distribution grid

8. Investments and funding information
   - Investments duration: The 50% of labs has had their investments for a period of up to 4-5 years.

- Amount of investments: 50% of labs has had investments of up to 1,000,000 euros.
- Running costs of labs: 56% of labs have a running cost of up to 250,000 euros
- Funding sources for labs: 34.38% of funding for labs comes from own sources, 31.25% comes from national funding, whereas 34.38% comes from EU funding.

6.1.2 In numbers – Categories of research

For the five categories of research it can be summarized:

- The 84% of labs works on the Integrated Grid
- The 79% of labs works on Generation
- The 77% of labs works on Digitalization, Communication and Data
- The 76% of labs works on Customers and Market
- The 70% of labs works on Storage

For the results summarized for each category, all percentages refer to labs active in the specific category.

Integrated Grid:

- The first 3 ranked technologies are:
  - Equipment sensing, monitoring, measuring for analysis, solutions and control (75%)
  - Equipment and apparatus of the integrated grid (64%)
  - Models, Tools, Systems for the operation analysis, control and the development of the integrated grid including cost elements (63%)
- The 40% of labs works with PMUs, whereas the 70% works on microgrids
- The most popular objective of research in this field is: Integration of distributed generation
- The most popular standard used is: IEC 61850 - Communication networks and systems in substations (77%).
- The 47% works on AMI
  - Most popular topics: Monitoring (65%), Demand Response (65%), Interoperability (54%)
  - 57% of labs on AMI use wireless technologies

Customers and Market:

The areas of research for customers and market are ranked as follows:

- Distributed flexibility, load, forecast, management and control and demand response including end devices, communication infrastructure and systems (86%)
  - The most popular area of research is: DER integration (64%)
  - The most popular standard / specification is: OpenADR (64%)
- Building control, automation and energy management systems (68%)
  - The most popular area of research is: Energy Management strategies (91%)
  - The most popular technology used is: Wireless (82%)
- Electric vehicles (68%)
  - The most popular area of research is: Vehicle-to-Grid (75%)
  - The most popular standard for charging modes is the IEC 61851 (50%), whereas the most popular standard for connectors is CHADemo (40%)
- Energy communities (58%)
  - The top 3 ranked areas of work are: Information and Communication technologies (63%), Power generation (63%) and Energy storage (61%).
- Electricity market (52%)
  - The top 3 ranked areas of research are: Market Structure, Transmission and Distribution Intelligence, Impact of RES integration on electricity prices, all with 44%.
- Smart appliances (51%)
- Lighting (22%)

Storage:

- The most popular energy storage technology is: Storage electric (87%)

- The most popular energy storage applications are: Demand Shifting and peak reduction (70%), Voltage support (63%), Frequency regulation (55%)

Generation:

- The top 3 ranked areas of research here are: Solar including PV and CSP (81%), Flexible generation (78%), Wind generation (62%)
- The most popular standards for this category are: IEC 61850 and IEC 61400, both with 30%

Digitalization, Communication and Data:

The areas of research for Digitalization, Communication and Data are ranked as follows:

- Communication networks including devices and systems for signals and data connectivity and solutions (85%)
  - The most popular network under research is the Substation LAN (64%)
  - The 67% of the labs active in the field does monitoring and control of communication infrastructure
  - The 58% of labs active in the field performs research on wireless technologies, with WiFi the most popular one (43%)
  - The 31% of the active labs in the filed carry out research on Power Line Communications
  - The most popular standard used is the IEC 61850 (83%)
- Digital twins (61%)
- Data and Cyber security including repositories (58%)
  - The most popular protocol / technology used is the IPSec, Internet Protocol Security (32%)
  - The most popular area of research is the Risk Assessment and Integrity (32%)
- Artificial intelligence (54%)

6.1.3 In numbers – Infrastructure and services offered

The last part of the survey is dedicated to collecting information regarding the infrastructure used, the simulations performed, the services offered. The information collected has been:

1. AC total power installed:

   The 43% of labs has a total AC power installed up to 100 kW

2. DC total power installed:

   The 52.5% of labs has a total DC power installed of up to 50 kW

3. Usage of 3-phase and single-phase systems:

   The 81% of labs uses three-phase systems, whereas the 56% uses single-phase systems

4. Simulations performed:

   The 61% of labs performs Hardware-in-the-Loop simulations

   The 65% of labs performs Real-Time simulations

5. Microgrids and their components:

   The first 3 ranked components of microgrids are: photovoltaics and/or PV systems (52% of labs with microgrids), batteries (44% of labs with microgrids), wind turbines (33% of labs with microgrids).

6. Major equipment:

   The top 3 ranked major equipment are: power amplifier, battery energy storage system, grid emulator

7. Simulation / optimization tools by labs:

   The most popular tool is Matlab

8. Services offered by labs:

The first two ranked services listed by labs are: Integration and testing of devices (hardware testing, meter, relay testing, high voltage products tests, etc), (33%) and Research and Development support (29%)

6.1.4 Summing-up

As it can be observed, the smart grid has been and is attracting the scientific interest. It is noteworthy that all 5 categories of research are collecting more than 70% of the labs participating in the survey. The standard mostly used is the IEC 61850, which is in accordance with previous releases of this exercise. Equipment sensing is the most interesting topic for the integrated grid, whereas for digitalization, communication and data, the topic of interest is data connectivity issues. On the other hand, energy management strategies are the most popular topic for customers and market category, whereas electric storage is the dominant field for storage category, as its name implies. Solar, wind and flexible generation are the main topics for research related to generation, as also the name implies. In terms of infrastructure, power amplifiers, battery energy storage systems and grid emulators are the most popular ones for smart grid labs. It is also worth mentioning that the majority of the labs intends to increase the investments in the field, highlighting the importance of smart grid research and the fact that this field is anticipated to continue attracting the interest of the scientific community.

To sum up, it can be said that the Inventory gives in-depth information for many aspects of the smart grid research. The reader is directed to the respective Sections of this report in order to retrieve information about smart grid research carried out by the labs. It is obvious that smart grid is a rich topic for research and this justifies the big amounts of investments and number of scientists working on it.

6.2 Future Work

The Smart Grid Laboratories Inventory has been proven to be an important exercise that gives insight into the research performed in the field and reveals specific trends. It will continue to take place periodically giving the state-of-the-art in the smart grid field. A further increase of the participant labs will be sought, combined of course with obtaining updated information of the existing labs in our database.

In addition, the website where information is found about the Smart Grid lab Inventory will be updated and it is intended to facilitate finding the information by the users in a straightforward way. Only basic information about the labs will be included as a first step, displaying information about the categories of research they carry out. Visual aspects will be enhanced to facilitate the graphical representation of the information available in the repository. In addition, and as it has been advertised from the beginning, it is envisaged that information will be displayed through the EIRIE platform, acting as a hub for researchers wishing to find any information on smart grid research.

For future releases of the Inventory, it is also intended to let the participant labs decide if they wish to have more information about their lab displayed on the website for promoting their activities and advertising their work. Finally, and through different means, further promotion activities of this inventory are already planned, like promoting the inventory through worldwide known scientific Newsletters.

References

1. DIRECTIVE 2009/72/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC, available online at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0072.
2. DIRECTIVE 2009/73/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC. Available online at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009L0073.
3. DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources, Official Journal of the European Union, 21/12/2018, available online at: https://ec.europa.eu/energy/topics/renewable-energy/directive-targets-and-rules/renewable-energy-directive_en.
4. 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, Official Journal of the European Union, 14/06/2019, available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0944&qid=1638267506488&from=EN .
5. Energy Union Strategy, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK, A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2015:80:FIN.
6. Clean Energy for all Europeans package, online at: https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en.
7. Smart Grid Mandate Standardization Mandate to European Standardisation Organisations (ESOs) to support European Smart Grid deployment, available online at: https://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.detail&id=475#
8. ISGAN, “ISGAN. International Smart Grid Action Network,” 2018. Available online at: http://www.iea-isgan.org/?c=2/27/61.
9. DERlab, “DERlab. European Distributed Energy Resources Laboratories,” 2018, available online at: http://www.der-lab.net/.
10. ENCS, “ENCS. European Network for Cyber Security,” 2018, available online at: https://www.encs.eu/.
11. FutuRed, “FutuRed. The Spanish Electrical Grid Platform,” 2018, available online at: http://www.futured.es/.
12. F. Gangale, J. Vasiljevska, F. Covrig, A. Mengolini, and G. Fulli, “Smart grid projects outlook 2017: facts, figures and trends in Europe,” EUR 28614 EN, DOI: 10.2760/15583, Luxembourg, 2017.
13. Prettico, G., Marinopoulos, A. and Vitiello, S., Distribution System Operator Observatory 2020, EUR 30561 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-28431-4, doi:10.2760/791730, JRC123249.
14. V. Giordano, S. Vitiello, and J. Vasiljevska, “Definition of an Assessment Framework for Projects of Common Interest in the Field of Smart Grids,” EUR 25828 EN, DOI: 10.2790/83888, Luxembourg, 2014.
15. M. Poncela, G. Prettico, N. Andreadou, M. Olariaga, G. Fulli, and C.-F. Covrig, “Smart Grid Laboratories Inventory 2015,” EUR 27155 EN, DOI: 10.2790/451423, Luxembourg, 2015.
16. N. Andreadou, M. Olariaga Guardiola, I. Papaioannou, and G. Prettico, “Smart Grid Laboratories Inventory 2016,” EUR 28319 EN, DOI: 10.2790/946498, Luxembourg, 2016
17. N. Andreadou, L.L. Jansen, A. Marinopoulos, I. Papaioannou, Smart Grid Laboratories Inventory 2018, EUR 29649 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-99673-3, doi:10.2760/983805, JRC114966.
18. L. L. Jansen, N. Andreadou, I. Papaioannou, A. Marinopoulos, "Smart Grid Lab Research in Europe and Beyond", International Journal of Energy Research, Wiley, 2019, DOI: https://doi.org/10.1002/er.4818.
19. EIRIE Platform, Available online at: https://ses.jrc.ec.europa.eu/eirie/en.
20. ETIP SNET description, Available online at: https://www.etip-snet.eu/about/etip-snet/.
21. PANTHERA project description, available online at: https://pantera-platform.eu/.
22. Deliverable D3.1: Report on current status and progress in R&I activities: Technology, Work Package WP3 "The state of R&I, standardisation and regulation", PANTERA - Pan European Technology Energy Research Approach, 08/07/2020. Available online at: https://pantera-platform.eu/wp-

content/uploads/2020/07/D3.1-Report-on-current-status-and-progress-in-RI-activities-Technology.pdf.
23. DERlab. Database of DER and smart grid research infrastructure. Available online at: https://infrastructure.der-lab.net/.

List of Abbreviations and Definitions

3DES	Triple DES
6LoWPAN	IPv6 over Low-Power Wireless Personal Area Networks
AAA	Authentication, Authorization and Accounting
AC	Alternating Current
ADMS	Advanced Distribution Management Systems
AES	Advanced Encryption Standard
AMI	Advanced Metering Infrastructure
AUS/NZ	Joint Australian and New Zealand Standards
BPL	Broadband over Power Lines
BLE	Bluetooth Low Energy
CAES	Compressed air energy storage
CCS	Combined Charging System
CDS	Charging Discovery System
CEE	Centre for Energy Epidemiology
CEMS	Customer Energy Management System
CHIP	Control Hardware in the Loop
CHP	Combined Heat and Power
CIM	Common Information Model
CSP	Concentrated Solar Power
DC	Direct Current
DER	Distributed Energy Resources
DES	Data Encryption Standard
DG	Distributed Generation
DLMS	Device Language Message Specification
DNP3	Distributed Network Protocol 3
DR	Demand Respond
DRMS	Demand Respond Management System
DSL	Digital Subscriber Line

DSO	Distribution System Operator
DSS	Distribution System Simulator
EAP	Extensible Authentication Protocol
EIRIE	European Interconnection for Research Innovation & Entrepreneurship
EMC	Electromagnetic Compatibility
ENCS	European Network for cyber security
VETIP SNET	European Technology and Innovation Platforms Smart Networks for Energy Transition
EU	European Union
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FACTS	Flexible ac transmission systems
FAN	Field Area Network
GPRS	General Packet Radio Service
GSM	Global System for Mobile (communications)
HAN	Home Area Network
HIL	Hardware in the Loop
HVAC	Heating Ventilation and Air Conditioning
HVDC	High Voltage Direct Current
IEA	International Energy Agency
ICT	Information and Communication Technologies
IOP	Interoperability
IPSec	Internet Protocol Security
ISGAN	Implementing Agreement for a Co-operative Programme on Smart Grids
JRC	Joint Research Centre
KNX	Konnex
LAN	Local Area Network
LPWAN	Low Power Wide Area Network
LTE	Long Term Evolution
LTE M	Long Term Evolution – Category M

M2M	Machine to machine
MD5	Message Digest algorithm 5
MDMS	Meter and Data Management System
MPLS	Multiprotocol Label Switching
MQTT	Message Queueing Telemetry Transport
NB-IOT	Narrow Band Internet of Things
NB-PLC	Narrow Band Power Line Communication
NAN	Neighborhood Area Network
Oauth	Open secure authorization protocol
OCCP	Open Charge Point Protocol
OCPI	Open Charge Point Interface
OPC DA	Open Platform Communications Data Access
OpenADR	Open Automated Demand Response
OSGP	Open Smart Grid Protocol
PAN	Personal Area Network
PANTHERA	PAN European Technology Energy Research Approach
PDC	Phasor Data Concentrators
PCI	Projects of Common Interest
PHEV	Plug-in Hybrid Electric Vehicle
PHIL	Power Hardware in the Loop
PKI	Public Key Infrastructure
PLC	Power Line Communication
PMU	Phasor Measurements Unit
PRIME	PoweRline Intelligent Metering Evolution
PSIM	Physical security information management
PSS	Power System Simulator
PV	Photovoltaics
RADIUS	Remote Authentication Dial-In User Service
RES	Renewable Energy Sources

RICAP	R&I status and Continuous gAP analysis
RSA	Ron Rivest, Adi Shamir and Leonard Adleman (crypto system)
RTDS	Real Time Digital Simulator
RTS	Real Time Simulator
R&I	Research and Innovation
R&D	Research and Development
SAREF	Smart Appliances Reference
SET	Strategic Energy Technology
SHA	Secure Hash Algorithm
SIRFN	Smart Grid International Research Facility Network
SGAM	Smart Grid Architecture Model
SSH	Secure Shell
T&D	Transmission and Distribution
USEF	Universal Smart Energy System
V2G	Vehicle to Grid
WAN	Wide Area Network
WI-FI	Wireless Fidelity
WiMax	Worldwide Interoperability for Microwave Access

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Annex 1. List of Participating Labs

In the following the list of participating labs is presented.

Table 38. List of participating labs in Europe sorted by country with feedback in Autumn 2021.

No.	Name of the Organization	Name of Lab	Acronym of Lab	Country	Website
1	AIT Austrian Institute of Technology	Smart Electricity Systems and Technologies Laboratory	SmartEST	Austria	https://www.ait.ac.at/en/solutions/power-system-technologies-development-validation/smartest-lab
2	cyberGRID Gmbh & Co KG	cyberGRID Smart Grids LAB	cyberLAB	Austria	www.cyber-grid.com
3	Technical University of Sofia	Power Electronics Laboratory of Technical University of Sofia	PELTUS	Bulgaria	www.tu-sofia.bg
4	University of Cyprus, FOSS Research Centre for Sustainable Energy	DER-GRID Smart Facility	FOSS-DGSF	Cyprus	www.foss.ucy.ac.cy
5	Aalborg University	Smart Energy Systems	SES Lab	Denmark	https://www.energy.aau.dk/laboratories/ power-systems-laboratories/smart-energy-systems/
6	L2EP	L2EP		France	https://www.epmlab.eu/
7	EDF	Concept Grid	CG	FRANCE	https://www.edf.fr/NetworksLab
8	VTT Technical Research Centre of Finland	Technology Platform Smart Energy	TP Smart Energy	Finland	https://www.vttresearch.com/en/vtt-world/
9	University of Vaasa	FREESI		Finland	https://www.uwasa.fi/en/research/research-platforms/vebic/vebic-laboratories
10	TU Munich	Center for Combined Smart Energy Systems	CoSES	Germany	www.vedranperic.de
11	National Technical University of Athens	Electric Energy Systems Laboratory	EESL	Greece	https://www.smartrue.gr
12	Centre for Renewable Energy Sources and Saving	Experimental Microgrid	DG Lab	Greece	www.cres.gr

13	Center for Research and Technology Hellas / Information Technologies Institute	Digital Energy Lab of Varlab		Greece	https://varlab.iti.gr
14	RSE- Ricerca sul Sistema Energetico SpA	RSE Distributed Energy Resources Test Facility	RSE DER-TF	ITALY	http://www.rse-web.it/home.page
15	University Mediterranea of Reggio Calabria	Electric and Electronic Measurements Laboratory		Italy	http://www.misure.unirc.it/
16	ABB S.p.A.	Smart Lab		Italy	www.abb.com
17	Polytechnic University of Bari	Electrical Energy Systems	Prince	Italy	www.princelab.it
18	ENERGY SECURITY, DISTRIBUTION AND MARKETS	Smart Grids Interoperability Laboratory	SGILab	ITALY	http://ses.jrc.ec.europa.eu
19	European Commission, Joint Research centre	Electric and Hybrid Vehicles Testing Facility	VeLA8	Italy	https://ec.europa.eu/jrc/en/research-facility/ vehicle-emissions-laboratory-vela
20	European Commission, Joint Research Centre	Semi-Anechoic Chamber for Electromagnetic Compatibility Testing	VeLA 9	Italy	https://ec.europa.eu/jrc/en
21	European Commission, Joint Research Centre	EPIC		Italy	https://ses.jrc.ec.europa.eu/epic-hub
22	ABB S.p.A.	Open Lab		Italy	www.abb.com
23	TU Delft	Electrical Sustainable Power Laboratory	ESP Lab	The Netherlands	www.tudelft.nl/esplab
24	DNV Netherlands B.V.	Protocol test lab	PCTC	Netherlands	https://www.dnv.com/power-renewables/services/testing/ communication-protocols.html
25	European Commission, Joint Research Centre	Smart Grid Interoperability Centre - Petten		The Netherlands	http://ses.jrc.ec.europa.eu/
26	Norwegian University of Science and Technology	National Smart Grid Laboratory	NSGL	Norway	https://www.ntnu.edu/smartgrid
27	The Department of Electrical Power Engineering of the Wroclaw University of	Power Line Communication	KE-PLC	Poland	https://ke.pwr.edu.pl/dydaktyka/ laboratoria-dydaktyczne

	Science and Technology				
28	INESCTEC	Smart Grids and Electric Vehicles Laboratory	SGEVL	Portugal	https://sgevlab.inesctec.pt/en
29	National Laboratory for Energy and Geology (LNEG)	Renewable Energy Integration Laboratory	RESILab	Portugal	https://www.lneg.pt/area/energia/integracao-e-sustentabilidade-de-sistemas-de-energia/
30	Centro de Investigação em Energia REN – State Grid, S.A.	R&D Nester laboratory	n/a	Portugal	https://www.rdnester.com/en-GB/lab/
31	EDP Labelec	SmartLab		Portugal	https://labelec.edp.com
32	Skolkovo Institute of Science and Technology	Smart grid laboratory		Russia	https://crei.skoltech.ru/cest/facilities/smart-grid-laboratory/
33	Tecnalia	Smart Grids Testing and Research Infrastructure	INGRID	Spain	www.tecnalia.com
34	Catalonia Institute for Energy Research (IREC)	IREC Energy SmartLab		Spain	https://www.irec.cat/
35	IMDEA Energy Institute	Smart Energy Integration Lab	SEIL	Spain	https://www.energy.imdea.org/events/2020/ seil-platform-smart-grid-laboratories-inventory
36	CIRCE	SMART GRIDS LABORATORY		Spain	www.fcirce.es
37	ORMAZABAL Corporate Technology	Demonstration & Experimentation Unit	UDEX	SPAIN	https://www.futured.es/en/capability/ ?prettyUrl=ormazabal-corporate-technology-aie
38	i-Sare	i-Sare Microgrid Gipuzkoa	i-Sare	Spain	http://www2.i-sare.net/
39	SPANISH NATIONAL RENEWABLE ENERGY CENTER	ATENEA MICROGRID	ATENEA	SPAIN	https://www.cener.com/microrred-atenea/
40	Universitat de Girona	Energy Hub Living-Lab	NA	Spain	https://exit.udg.edu/
41	SICA S.A.	ENERGY LAB SICA	ELS	SPAIN	https://sica.es
42	UNIVERSIDAD DE LEÓN	LABORATORY OF POWER SYSTEMS AND SMART GRIDS	ERESMAGrid	SPAIN	https://eresma.unileon.es/

43	KTH - Royal Institute of Technology	Sustainable Power Lab	SPL	Sweden	https://www.kth.se/ee/epe/research/labs/ the-sustainable-power-laboratory-1.771349
44	Durham University	Durham Smart Grid Laboratory	DSGL	UK	https://www.dur.ac.uk/smart.grid/

Source: JRC analysis, 2022.

Table 39. List of participating labs outside Europe sorted by country with feedback in Autumn 2021.

No	Name of the organisation	Name of the laboratory	Acronym of the lab	Country	Website
1	University of São Paulo	Research Center in Smart Energy Grids	NAPREI	Brazil	http://www.naprei.prp.usp.br/#contato
2	University of Campinas - Unicamp	Smart Grid Laboratory - Laboratório de Redes Elétricas Inteligentes	LabREI	Brazil	https://www.fee.unicamp.br/lab-rei/smart-grid-laboratory-labrei?language=en
3	University of Pretoria	SANEDI Smart Grid Labs	SGL	South Africa	www.pwrup.info
4	Kinectrics Inc.	GRIDSIM Power Lab		Canada	https://www.kinectrics.com/Solutions/Pages/GRIDSIM-Lab.aspx
5	University of California Riverside	College of Engineering Center for Environmental Research and Technology	CE-CERT	United States of America	https://www.cert.ucr.edu/
6	Florida State University	Center for Advanced Power Systems - Power Hardware in the Loop Lab		USA	https://www.caps.fsu.edu/

Source: JRC analysis, 2022.

Table 40. List of participating labs in Europe sorted by country with feedback in previous releases.

No	Name of the organisation	Name of the laboratory	Acronym of the lab	Country	Website
1	EnergyVille	EnergyVille: Battery Lab; Thin Film Photovoltaic Lab; Thermo Technical Lab; Low Voltage Grid Lab; Digital		Belgium	www.energyVille.be/en/labs

		Grid Emulation Lab; Power Electronics Lab; Photovoltaic Reliability Lab; Medium-Voltage Lab; PV Module Lab; Outdoor Metrology Lab for (Building-Integrated) PV; Home Lab; Bipolar DC Lab; Battery Testing Lab			
2	CNRS	Laboratory of Analysis and Architecture of Systems	CNRS - LAAS	France	https://www.laas.fr/
3	Grenoble Electrical Engineering Laboratory	PREDIS	PREDIS	France	http://www.g2elab.grenoble-inp.fr/
4	TU Dortmund University	Smart Grid Technology Lab	SGTL	Germany	www.smartgrid-tec-lab.com
5	TU Berlin	Energiewende Laboratory		Germany	https://www.sense.tu-berlin.de/ menue/laboratory/ smart_grid_lab/parameter/en/
6	RWTH Aachen University - Institute for Automation of Complex Power systems	ACS Real Time Laboratory		Germany	www.acs.eonerc.rwth-aachen.de
7	University College Dublin	Integrated Energy Lab	IE Lab	Ireland	https://energyinstitute.ucd.ie/work-with-us/ie-lab/
8	Selta S.p.A.	Selta Smart Grid Lab	Selta_SGL	Italy	www.selta.com
9	Institute of Physical Energetics (IPE)	Smart Grid Research Centre	SGRC; SmartHomeLab; PMULab	Latvia	http://fei-web.lv/
10	DNV GL	Flex Power Grid Lab	FPGL	Netherlands	https://www.dnv.com/research/power-and-renewables/pr-fpgl.html
11	Universidade do Minho	Group of Energy and Power Electronics - Centro ALGORITMI	GEPE	Portugal	https://www.gepe.dei.uminho.pt/

12	Universitat Politècnica de Catalunya - BarcelonaTech	CITCEA-Lab	CITCEA-Lab	Spain	www.citcea.upc.edu
13	Instituto Tecnológico de la Energía (ITE)	Renewable energy integration and demand side management laboratory	ITE	Spain	www.ite.es
14	Universidad Politécnica de Madrid	Net-Positive Energy Building: "Magic Box"	MagicBox	Spain	http://www.ies.upm.es/
15	CARTIF	ENERGY DEPARTMENT		Spain	www.cartif.com
16	SCHNEIDER ELECTRIC ESPAÑA S.A.	LABORATORIO DE ENSAYOS ALTA TENSIÓN GRIÑÓN	LEATG	Spain	https://www.schneider-electric.es/es/
17	Technical University of Catalonia	MCIA Innovation Electronics		Spain	www.mcia.upc.edu
18	École Polytechnique Fédérale de Lausanne	Distributed Electrical Systems Laboratory	DESL	Switzerland	http://smartgrid.epfl.ch
19	Imperial College of London	Smart Energy Laboratory		United Kingdom	http://www.imperial.ac.uk/electrical-engineering/research/control-and-power/
20	Newcastle University	Smart Grid Laboratory and Energy Storage Test Bed		United Kingdom	https://www.ncl.ac.uk/engineering/about/facilities/electricalelectronicengineering/smart-grid/#overview
21	University of Strathclyde	Power Networks Demonstration Centre	PNDC	United Kingdom	www.strath.ac.uk/pndc

Source: JRC analysis, 2022.

Table 41. List of participating labs outside Europe sorted by country with feedback in previous releases.

No	Name of the organisation	Name of the laboratory	Acronym of the lab	Country	Website
1	The University of Melbourne	Smart Grid Lab	SGL	Australia	https://electrical.eng.unimelb.edu.au/power-energy/smart-grid/
2	University of Auckland	Power Systems Group	PSG	New Zealand	https://www.auckland.ac.nz/en/engineering/our-research/discover/research-areas-and-facilities/powersystems. html
3	Centre for Urban Energy, Ryerson University, Toronto, Canada	Schneider Electric Smart Grid Laboratory	SESG Lab	Canada	www.ryerson.ca/cue

4	UOIT	Energy Systems and Nuclear Science Research Centre	ESNS	Canada	https://faculty.uoit.ca/gaber/
5	Princeton University	Princeton Laboratory for Energy Systems Analysis	PENSA	United States of America	http://energysystems.princeton.edu
6	Kansas State University	Smart Grid Lab		United States of America	http://www.ece.k-state.edu/research/powerandenergy/sgl/index.html
7	Enernex	Smart Grid Labs	SGL	United States of America	https://www.enernex.com/podcast/virtual-power-plants-and-the-smart-grid-test-lab/
8	UCI Microgrid Testbed	University of California, Irvine Advanced Power and Energy Program	UCI APEP	United States of America	www.apep.uci.edu
9	Lawrence Berkeley National Laboratory (LBNL)	FLEXLAB		United States of America	flexlab.lbl.gov
10	Colorado School of Mines	Research Group Advanced Control of Energy and Power Systems	ACEPS	United States of America	http://aceps.mines.edu/
11	Washington State University	Smart Grid Demonstration and Research Investigation Lab	SGDRIL	United States of America	sgdril.eecs.wsu.edu
12	Microgrid Systems Laboratory	New Mexico SMART Grid Center		United States of America	http://microgridsystemslab.com
13	Colorado State University	Advanced Power Engineering Laboratory	APEL	United States of America	https://sites.google.com/rams.colostate.edu/ssuryana/apel
14	NC State University	FREEDM Systems Center	FREEDM (Future Renewable Electric Energy Delivery and Management)	United States of America	freedm.ncsu.edu
15	National Renewable Energy Laboratory (NREL)	Energy Systems Integration Facility	ESIF	United States of America	http://www.nrel.gov/esif/

Source: JRC analysis, 2022.

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