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Smart Grid Laboratories Inventory 2018

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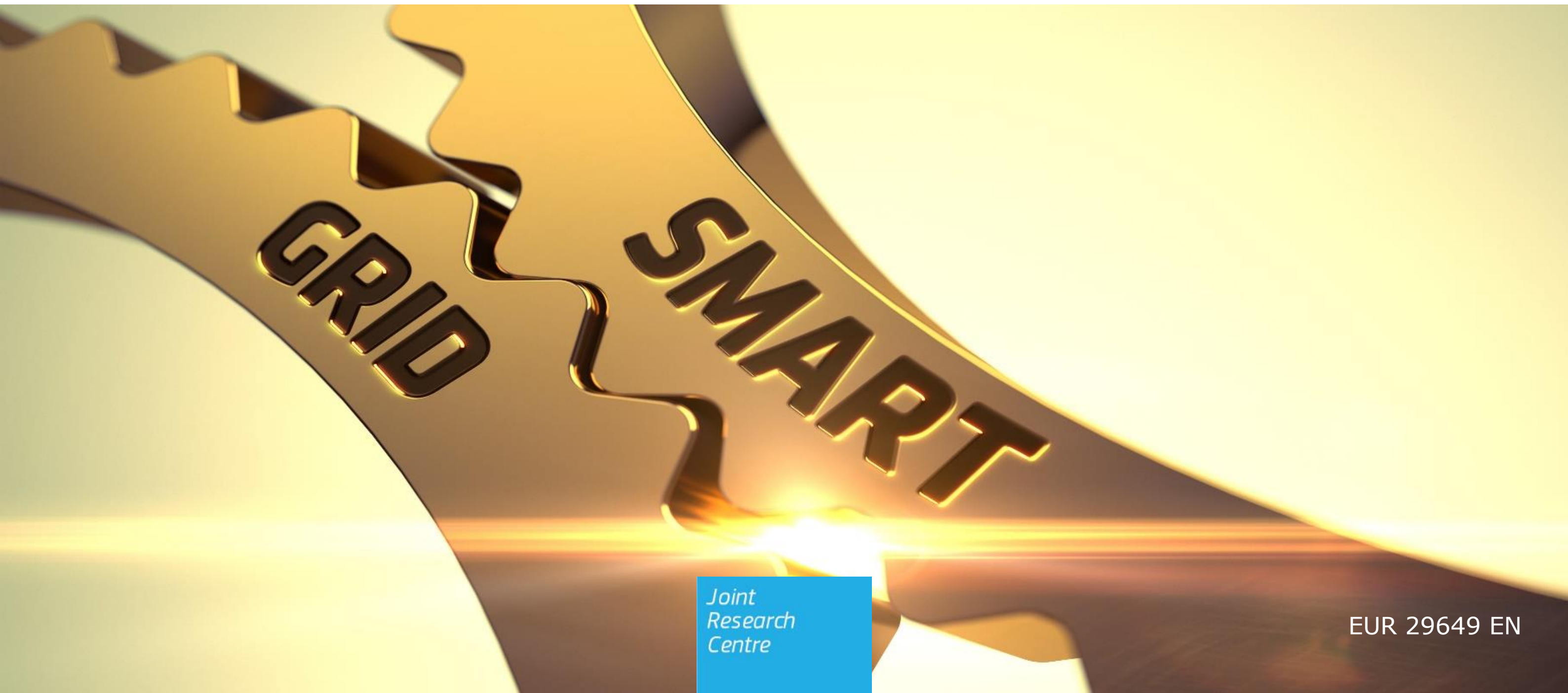

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Contents

1 Introduction 6
2 Survey Description 8
2.1 Previous Releases 8
2.1.1 First Release – 2015 8
2.1.2 Second Release – 2016 9
2.2 Current Release – 2018 11
2.3 Online Tool 12
3 Results 13
3.1 Overview – Smart Grid Laboratories Inventory Participants 13
3.2 General Information 15
3.3 Investments 19
3.3.1 Investments for the Lab Construction 19
3.3.2 Running Costs for Labs 19
3.3.3 Infrastructure Expansion Intentions 20
3.4 Analysis of Smart Grid Research Areas 21
3.4.1 Distribution Automation 21
3.4.2 Grid Management 23
3.4.3 Storage 24
3.4.4 Market 27
3.4.5 Generation and Distributed Energy Resources (DER) 29
3.4.6 Electromobility 31
3.4.7 Smart Home/Building 35
3.4.8 Smart Cities 37
3.4.9 Demand Response (DR) 38
3.4.10 ICT: Communication 38
3.4.11 Cyber Security 41
3.4.12 Advanced Metering Infrastructure (AMI) 43
3.5 Infrastructure Used 45
3.5.1 Power and Voltage Capability 45
3.5.2 Simulation Infrastructure 48
4 Conclusions and Future Perspective 51
4.1 Conclusive Remarks 51
4.2 Future Work 53
References 54
List of Abbreviations and Definitions 55
List of Figures 58

List of Tables 60
Annexes 61
Annex 1. List of Participating Labs 61

Abstract

This report is the third release of the Smart Grid Laboratories Inventory. It presents aggregated information about the smart grid topics of research, the technologies, the standards and the infrastructure used by top organisations that hold smart grid activities at a laboratory level. Several categories of smart grid research have been identified and information is provided with respect to standards and sub-topics of research. It is an update with respect to previous releases with the scope to present the state-of-the-art on smart grid research and increase the sample of participants.

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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.

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

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Executive summary

This report aims at giving an insight on the technologies and the infrastructure used by the scientific and industrial communities with respect to smart grid research.

In this third Smart Grid Laboratories Inventory report, we followed the same approach applied in the second release [1]. An online questionnaire has been developed and used in order to obtain information about the smart grid research carried out by identified laboratories/organisations. The questionnaire has a structure similar to the one used previously; apart from a few changes judged necessary after the feedback received from the participants. The questionnaire consists of three parts:

1. The first part refers to general questions, such as which sector the research focuses on (i.e. utilities, industry, academia, etc.), which fields of research are pursued (i.e. technology development, R&D (Research and Development) of equipment, standards development, etc.), whereas emphasis is also given on the investments planned by the research organisations;
2. The second part is dedicated to the specific categories of the smart grid research, with detailed information about the specific standards and technologies used for each category;
3. The third part refers to the infrastructure used by the laboratories.

It is worth mentioning that the online questionnaire appears in a dynamic way, meaning that specific fields appear only if relevant questions are answered positively. It has been addressed to everyone who runs or works in a smart grid lab.

The research activities have been divided in 12 categories, namely: Distribution Automation, Grid Management, Storage, Market, Generation and DER (Distributed Energy Resources), Electromobility, Smart Home/Buildings, Smart Cities, Demand Response (DR), ICT (Information and Communication Technologies), Cyber Security and AMI (Advanced Metering Infrastructure). Detailed information is gathered concerning the activities in each category, the standards/technologies used and objectives of the research activity.

Policy context

Many research organisations, key industry stakeholders and academia have designed and built their own smart grid laboratories with the aim to perform research activities that will allow the development of smart grid technologies and standards to facilitate their deployment at production scale.

In fact, 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) [2], DERlab [3], the European Network for cyber security (ENCS) [4] and Futured [5].

Laboratory activities try to follow several policies launched by the European Commission (EC) for making smart grids a reality (e.g. Electricity 2009/72/EC and Gas 2009/73/EC Directives, the Energy Union Strategy (COM[2015] final) and the Clean Energy for All Europeans Package (COM[2016]), the standardization Mandate M/490 on smart grid standardization; Calls in Horizon 2020 etc.).

The inventory reflects these efforts of the laboratories to follow the European policy in the smart gird field, thus constituting a valuable tool for identifying the technological gaps and guiding future funding programs.

An online website is expected to increase visibility for the participants. It will become a tool to track smart grid activities carried out in the laboratories thus fostering

collaborations between research organisations, policy making bodies and all relevant smart grid stakeholders.

Key conclusions – Main findings

The third release of the Smart Grid Laboratories Inventory has gathered feedback from 89 labs worldwide. The sample has been enlarged 1.3 times with respect to the previous release, resulting in 89 labs in total, with 20 of them comprising the new sample. Out of these 89 labs, 69 are located in Europe and 20 outside.

Some of the key conclusions from this third edition of the survey are:

- Generation and DER (85.2%), Demand Response (75%), Grid Management (75%) and Storage (70.5%) are the main interest of the lab activities.
- There is an increased interest in Generation and DER, ICT and Electromobility.
- The sector at which most of the work is addressed to, is utilities (70.5% of labs conduct research for them), with industry and academia to follow with 66% and 65% respectively.
- Technology development, R&D of equipment, standards development and prototype testing are fields on which more than 70% of the labs work on
- 90% of the labs have their research activities on the distribution grid, whereas the islanded grid and the transmission grid are the ones to follow with 60% and 57% respectively.
- Almost 1/3 of the labs have spent between EUR 100,000 and EUR 500,000 as initial lab investments. Almost 1 out of 10 labs (11%) has dedicated investments of up to EUR 4 – EUR 5 million for the lab setup. The period in which these investments are spanned varies; however, almost 4 out 10 labs (38.5%) have performed the investments throughout 2-3 years.

The labs were asked about the use of technical standards in their research. It appeared that standard IEC 61850 (International Electrotechnical Commission) is the most used one in 7 out of 12 smart grid categories, namely: Distribution Automation, Grid Management, Storage, Generation & DER, Electromobility (for communication purposes), ICT and AMI. This comes in accordance also to the results presented in the previous release of the report [1].

The Smart Grid Laboratories Inventory gives a good overview of the current research on the smart grids, highlights the main topics where focus is given, points out the standards used and gives feedback on the main infrastructure used by smart grid labs. The picture is given in a worldwide scale, which makes the results more valuable and facilitates in identifying the research trends.

Related and future JRC work

The European Commission is deeply involved in the policy-making process related to several activities in the energy sector, and in particular in the smart grids field. The Joint Research Centre (JRC) mission, as the in-house service of the EC, 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 [6].
- The Distribution System Operators (DSO) Observatory, giving information about the European DSOs (grid characteristics and smart grid dimension) [7].
- The assessment framework for the identification of Smart Grid Projects of Common Interest (PCI) [8].

The Smart Grid Laboratories Inventory completes the picture of the aforementioned work and gives a clear idea of the smart grid research trends worldwide. In addition, this

project does not focus only in Europe, but worldwide, which gives an increased added value to the overall outcome.

As future work, the following actions will be performed:

- This periodic exercise will continue to take place in the future in order to give aggregated information about the research performed in smart grid labs. A further increase of the sample size of Smart Grid research facilities will be sought.
- An online platform will be created to achieve one of the initial targets of the project, fostering information and knowledge sharing, which will be hosted in a European Commission web server. Visual aspects will be enhanced to facilitate the graphical representation of the information available in the repository.
- A workshop will be organized at JRC premises with a number of key stakeholders with the aim of gathering a more direct feedback about the needs in the domain of data collection in Smart Grids, including the research laboratories inventory.
- Further promotion activities of this inventory are already planned, through worldwide known scientific Newsletters.

Quick guide

Chapter 1 gives a short introduction to the subject. Chapter 2 presents the basis used for the survey questionnaire and presents the highlights from previous reports. Chapter 3 presents the results from the statistical analysis performed on the collected data. Initially, some general information is presented related to the number of labs participating and their location. Afterwards, analytic results are presented for each category. The Conclusions chapter summarises the main findings and insights and addresses future perspectives and work to be done.

1 Introduction

Electricity is a key commodity for the well-functioning of modern societies. The present power system has been initially designed to accommodate a unidirectional flow of energy and information, from the large centralized generation system, through the transmission and distribution systems to the centres of consumption. This traditional way of operation reached a high level of reliability and quality of service and for that reason it has persisted for a long time. In recent decades, assuring security of supply from sustainable sources and at an affordable price for all consumers has become one of the most ambitious goals worldwide.

The increasing amount of renewable energy sources (RES) reduces CO_2 emissions and improves the security of supply on one side, but on the other side, it introduces more uncertainty and unpredictability on transmission and distribution power grids. The impossibility of storing large quantity of energy at an economical price intensifies the challenging task of balancing generation supply with real-time customers' demand. Despite the fact that Distributed Generation (DG) reduces losses related to transport and transformation (to high voltages) of electricity, it introduces in the system more and more complexity which has to be efficiently managed at an operational level. From the demand side, the rapid growth in electricity demand over the last century is challenging both energy producers and system operators and it is only expected to increase even more in the future in part due to the electrification of the transport sector and of building heating systems. Coping with higher energy consumption demand represents a burden to traditional power stations. Practically, the power system infrastructure does not fully meet the needs and the increasing complexity implied by the novel emerging scenarios in the electricity system.

A major requirement for today's modern power grids is a two-way flow of electricity and information to create an automated and distributed energy delivery network. ICT is a core element of this concept in order to enable data gathering and processing in real time. All of these related issues form the basis to the smart grid concept.

Smart grids represent the evolution of the traditional electricity networks to integrate new actors and scenarios to make the provision of electricity more secure, sustainable and affordable and with high levels of quality and security of supply.

Some of the main capabilities of a smart grid system include the integration of DER and large-scale RES and the implementation of different systems and functions for demand response. System integration is crucial to enable these capabilities. Making the smart grid system work requires the cooperation and integration of multidisciplinary players with different business interests, and the adoption of new compatible business models and regulations.

A total of 950 smart grid projects according to [6], have been launched from 2002 up until today, amounting to €5 billion investment. This extensive research and development effort is complementary to the emergence of new activities for well-established laboratories or the appearance of new ones. For this reason, the infrastructure to be used in terms of the increasing smart grid research is of vital importance. This research infrastructure is needed for testing prototypes and systems, for checking the interoperability of these new systems, for assessing their performance and integration in the whole system and also for certificating their compliance with related standards and among relevant standards.

A large and wide set of research infrastructures for technology and solutions development is crucial for a consolidated roll out of Smart Grids. Only through accurate research programs and implementation exercises, able to replicate with a high level of accuracy real-life scenarios, can uncertainty be reduced to the bare minimum.

This report aims at collecting information about the smart grid topics of research, the technologies and the standards used by top organisations that hold smart grid activities at a laboratory level. For this purpose an online questionnaire has been created and

used. The report presents aggregated results that give an insight into the state-of-the-art regarding the smart grid laboratories activities.

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.

Although it might seem evident that having that kind of information would result in better understanding of the current state-of-the-art in Smart Grids and might facilitate their deployment and evolution, it is also clear that there is no easy way to get it, and if available, its interpretation and usefulness might not be straightforward.

2 Survey Description

This is the third release of the Smart Grid Laboratories Inventory. The scope has been to give an update of the situation with respect to the smart grid labs worldwide and give an overview of the topics in which research is conducted. In this Section we present the description of the survey, some highlights from previous releases and we also describe the online tool intended to be created as a complementary activity for this report.

2.1 Previous Releases

2.1.1 First Release – 2015

The project of creating an inventory of Smart Grid research facilities worldwide started in early 2013. The first attempt was made by searching information publicly available on the Internet about organisations owning a Smart Grid lab facility. Although it was a simple option that required less effort and cost, it was not an optimal solution. The main issues found were related to the completeness, accuracy and consistency of the information and triggered the need for using a focused survey to collect information in a structured way.

The elaboration of the survey took almost one year due to the number of stakeholders involved for consultation. The outcome was a survey with over 170 questions, covering 13 thematic areas in Smart Grids. Priority was given to single-choice or multiple-choice questions over open questions to facilitate the aggregation of information for statistical purposes. Questions were explained in detail through contextual help text to facilitate the selection of a given answer.

A dynamic filtering concept was introduced. At the beginning of the survey participants would be asked to specify in which areas they are working on at the research facility. Their answers would allow filtering out all questions related to areas where they were not carrying out any research activities. The objective was to simplify the completion of the survey and to adapt its size to each organisation depending on the activities.

Participation in the survey was open to any organisations, public or private, owning a Smart Grid lab facility. A prelisted set of organisations were explicitly invited to participate. Those organisations were selected as follows:

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

A personal survey link per participant was provided so they could log in to get automatically all data already entered. This brought two main advantages:

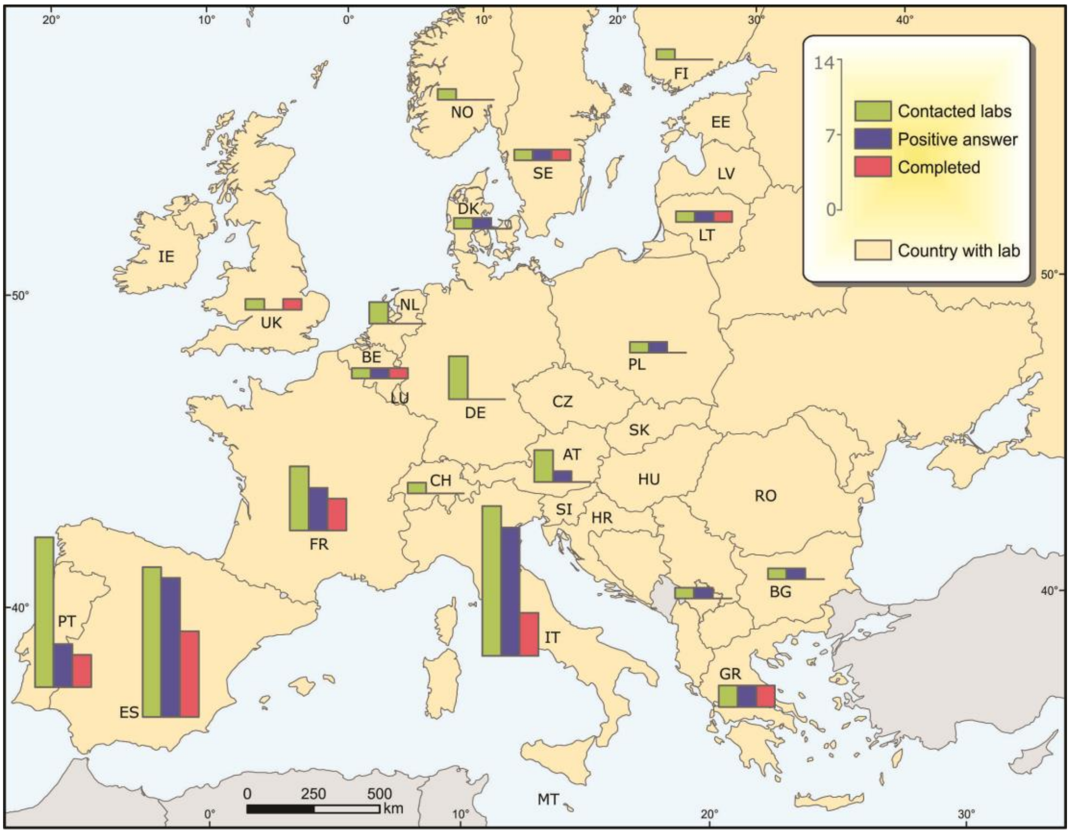
- Participants would be able to complete the survey in different sessions.
- Participants would be able to update details when needed.

Security measures were implemented as the database might contain sensitive information. For each lab a single point of contact was identified. This contact point was the main contact for the JRC during the data input phase. All contacts were provided with a personal survey link to access and complete the questionnaire. The survey was published on a European Commission online platform publicly available on the Internet (http://ses.jrc.ec.europa.eu/smart-grid-laboratories-survey) and it was completed directly by the participating organisations. Data provided through the online survey was stored in an online repository.

In the first release, 24 Smart Grid lab facilities participated in the survey and the information provided by them was processed in order to form a report which included an aggregated analysis, whereas sensitive information, like investment plans was not included in the report, published early 2015 [9]. The report was made such as it would have been impossible to identify the information provided by each participant separately. 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 [9].

Figure 1. 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), as extracted from [9].



2.1.2 Second Release – 2016

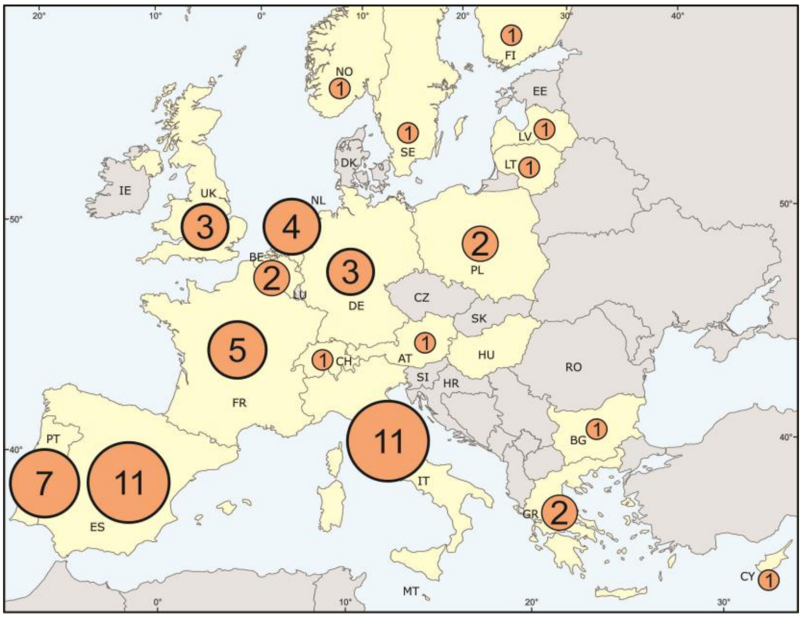
The second report [1] was published late 2016 and was an update of the 2015 release. From the beginning, the main objective was to regularly publish aggregated information in order to provide an overview of the current facilities, to highlight trends in research and investments and to identify existing gaps. Information provided has been anonymized so no individual organisation or facility could be individually identified by the information published. The target of the second release was set to expand the number of research facilities from the 24 available in the first phase to over 50, resulting in an increase of over 100% of the existing dataset. This target was deemed to be fundamental in order to have even more relevant results in terms of statistics and global visibility. One of the objectives has been to expand beyond Europe and include more geographical areas. World areas were expanded and further internet searches were carried out not only to increase the list of potential participants but also to gather data that could be aggregated and published, with the corresponding reservations of accuracy and consistency exposed previously, along with the data provided by the participating organisations.

For the second release a continuity approach was chosen. Heavy modifications of the survey structure would have had a negative impact in the expertise that the team acquired during the development of the first phase. It would have also required reengaging the organisations that completed the first release to provide the updates needed for the new version of the survey. However, in reality, updates of the lab activities or infrastructure would be minimal only one year after having provided the initial dataset, resulting in a less-than-efficient process.

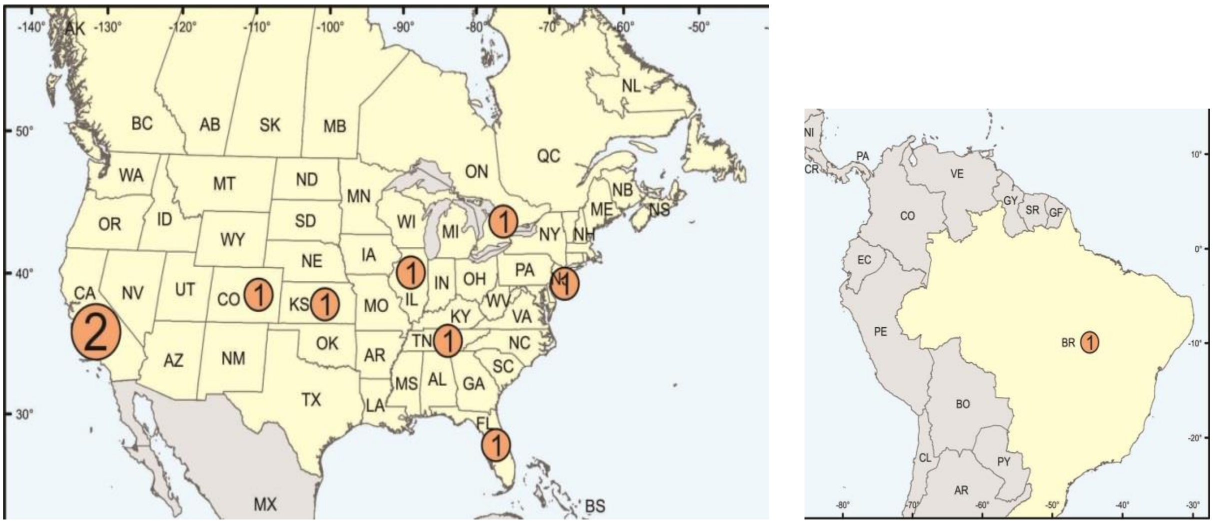
Even proposed changes were reduced to the minimum, some were still implemented. In addition, a simplified approach to data protection was implemented, ensuring that information would be treated homogenously while keeping the confidential data as such. Participants were provided with a clear scope of the activity, including a detailed explanation of the handling of the technical and personal data.

The concept of the second release was similar to the one of the first release, meaning that aggregated data was published. The total number of labs participating in this version was 69, which led to a sample of 2.87 times larger than the previous sample (69 labs). Figure 2 shows the distribution of the labs for the second release depending on their location.

Figure 2. Labs distribution according to the location in which they are based, a) In Europe, b) in America, as extracted from [1].



a)



b)

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, as extracted from [1].

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%

2.2 Current Release – 2018

The present report presents the results of the third release of the inventory of Smart Grid Labs. This year's objectives have been to:

- Provide an update of the situation with respect to smart grid labs and their fields of research.
- Extend the sample of labs so as to include more smart grid labs worldwide.
- To provide an aggregated analysis of the gathered information, highlighting the topics of research without disclosing sensitive data of the participants.

Feedback from the previous releases has been taken with respect to the questionnaire itself. For this version, we chose to have a simplified version of the questionnaire in order to make it more appealing for participants. This has been done, because it had been noticed that many participants with activities in numerous smart grid fields were reluctant to complete the questionnaire, due to its size. Information has been limited to the necessary for obtaining a high quality report. Some multiple choice questions were replaced with open text in order to make it simpler for participants to read and avoid providing them with unnecessary information. As a result, the structure of this report follows the same concept of the previous release; however, some fields have changed, and the information has shrunk only to the absolutely necessary one. The categories of research have remained the same, apart from "Sustainability", which is not included in this version. Feedback from the previous release has revealed that this category is somehow generic and can be implied also by other categories. Therefore, it has not been included in this version.

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. Personal data continues to be treated according to the current EC Regulation on the protection of individuals with regard to the processing of personal data by the Community institutions and bodies and on the free movement of such data.

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

2.3 Online Tool

Part of this project is to create an online tool which will give greater visibility to the participants of the survey. 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 Online Tool will be 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. For each facility, the main categories of research on which they work will be demonstrated. No sensitive information will be displayed on this website; only public available information will be shown, with the goal to increase visibility of the labs and promote their activities.

For future releases, it is intended that the report and the website will complement each other. The report will be used to reveal aggregated information and show trends in the smart grid research. On the other hand, the website will be used to enhance visibility of the already public information with respect to the smart grid labs.

3 Results

In this chapter, the aggregated analysis of the survey results is given. As a first step, statistical information is given about the participants. Some general information is shown, like the categories on which the labs perform their research and investment figures. Subsequently, the identified categories are analysed and the specific topics of research are shown. Finally, the infrastructure used in the smart grid labs is presented.

3.1 Overview – Smart Grid Laboratories Inventory Participants

The results presented in this chapter are derived from the replies we got from our online questionnaire. In this release, 20 new labs have been added in our database. Therefore, in total, 89 smart grid labs comprise our database, which in overall give a good idea of the trends with respect to the smart grid research. As a result, our sample has been increased regarding the previous releases; it is actually 1.3 times and 3.7 times larger than the sample used for the second and first release respectively.

For this version, approximately 150 labs have been contacted and invited to participate in our survey. The vast majority of them are located in Europe and North America, whereas we also spotted some labs in other regions, like China, Japan, Australia, South Africa, etc. It is worth noticing that all the previous participants have been contacted in order to get possible updates with respect to their research activities. It is worth noticing that none of these participants objected in using their data for this report.

The labs have been identified mainly through an extended internet search and through personal contacts from international conferences. On the other hand, some contacts given during the previous releases from the European National Contact Points for Horizon 2020 and the US Department of Energy have been used for this release as well.

There have been several problems with respect to obtaining the replies from the online survey. The main problem has been the lack of time, both from the participants' and the JRC's side. Increased workload gave little time for many participants to complete the survey, whereas there was little time also to identify and contact new labs. In addition, all participants have been contracted by email, which on many occasions does not help, since emails can end up in spam folders, email addresses can result problematic, etc. All the above factors, limited the new labs participating in our survey to 20. Nevertheless, the total number of 89 labs is considered a sufficiently high number to draw some conclusions on the smart grid research trends.

The majority of the labs are located in Europe (69 labs – 77.5%), covering a large number of countries. This is due to the fact that the JRC is mainly known in Europe and thus it has been easier for us to reach the European labs. However, 20 labs in total are outside Europe (22.5% of total number); this number is doubled since the last release when 10 labs from outside Europe had been included. With the online tool and the increased visibility of the labs, it is expected that more labs from other regions will be added in our database. It is worth noticing that this year we include two labs from Oceania, a geographical region which had not been covered in the previous releases. Unfortunately, there are still no participants from Asia or Africa, which is the target for the next release of the Smart Grid Laboratories Inventory.

Table 2 shows the percentages of labs participants for each country within Europe. The major part of labs is in Italy and Spain with Portugal to follow. This is mainly because of the location of our own lab (Italy) and the response of the equivalent National Contact Points for Horizon 2020. In Table 2 the countries with one lab have been summarized; these countries are: Bulgaria, Cyprus, Denmark, Finland, Ireland, Latvia, Lithuania, Norway, Russia, Sweden and Switzerland, with Ireland, Russia and Denmark the new entries for this release.

Table 2. Percentage of labs per country within Europe.

Country	**No of labs**	**%**
Spain	14	15.73
Italy	11	12.36
Portugal	7	7.87
Netherlands	5	5.62
France	5	5.62
UK	4	4.49
Germany	3	3.37
Greece	3	3.37
Belgium	2	2.25
Austria	2	2.25
Poland	2	2.25
Other	11	12.36
Total	**69**	**77.53**

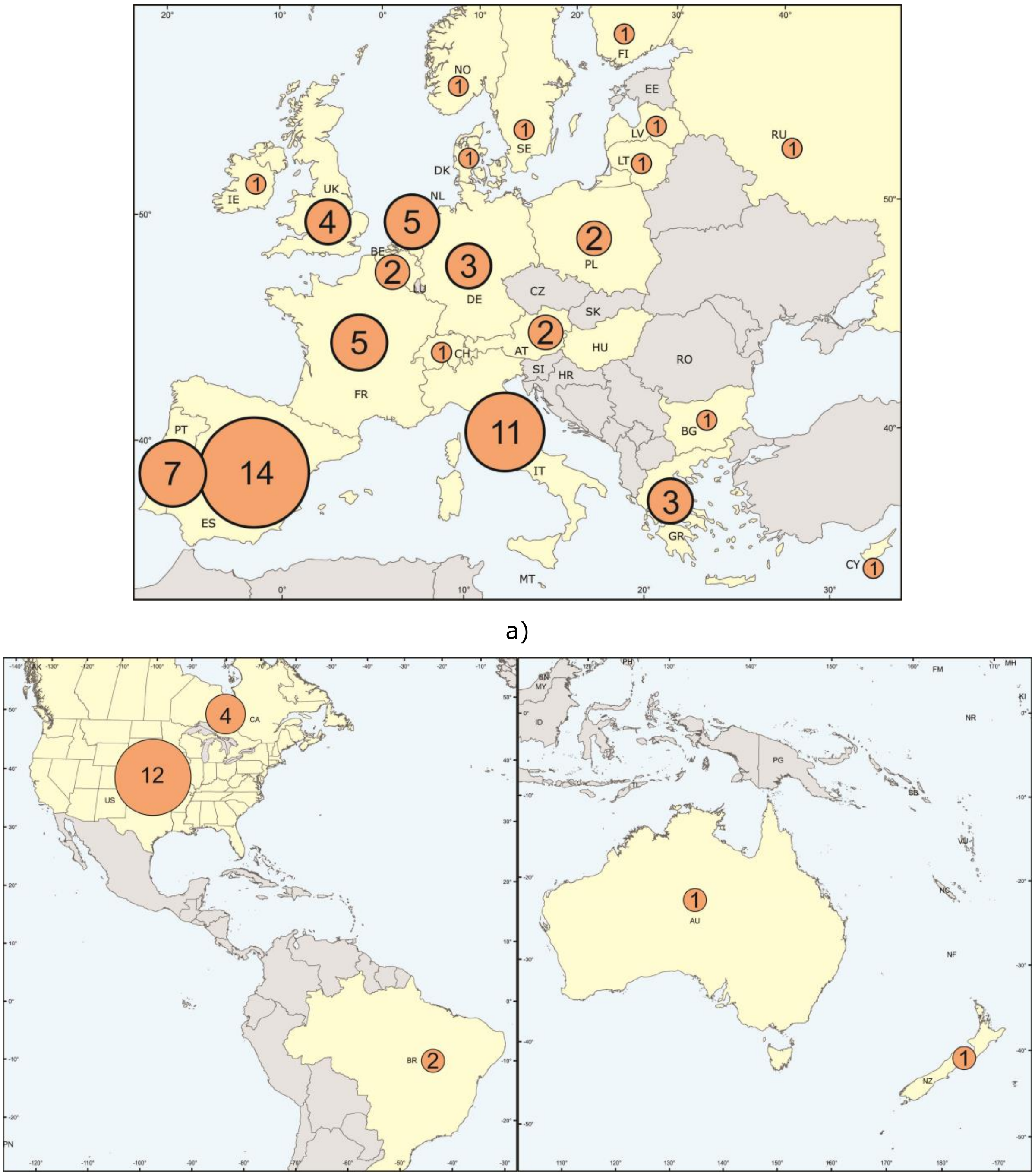
Table 3 shows the number of labs and the equivalent percentage (in total of 89) for each country outside Europe. The new entries for this year are Australia and New Zealand, whereas the participants from the rest of the countries have been increased with respect to the previous release. It is also worth noting that regarding the new sample added in this release, half of the labs are located in Europe and half outside.

Table 3. Percentage of labs per country outside Europe.

Country	**No of labs**	**%**
USA	12	13.48
Canada	4	4.49
Brazil	2	2.25
Australia	1	1.12
New Zealand	1	1.12
Total	**20**	**22.47**

Figure 3 shows the distribution of the labs according to their geographical location.

Figure 3. 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)

3.2 General Information

As a first step, it has been identified on which smart grid category the participant labs focus. In addition, other general information is collected like the sectors at which research is targeted, the specific fields of activity for each research category and the type of grid where research is targeted.

In this release, 12 categories of smart grid research have been addressed, namely: Distribution Automation, Grid Management, Storage, Market, Generation and DER, Electromobility, Smart Home/ Building, Smart Cities, Demand Response, ICT

Communication, Cyber Security and Advanced Metering Infrastructure. It should be noticed that most labs work on multiple categories. In addition, it is clear that many activities show overlap in multiple categories; for instance it is possible that activities on AMI will cover also aspects of Smart Home or Smart cities. Table 4 shows the percentages of labs that conduct research on these specific categories. As it is obvious from Table 4, the three most popular categories are Generation and DER, Demand Response and Grid Management, which were also the top categories noted in [1]. With respect to the shares of labs involved in research in the different categories, we observe that the share of labs within the samples in the previous [1] and this release only vary by one percentage point or less in the five categories: Demand Response, Storage, Smart City, AMI and Market. On the other hand, we notice an increase of more than 4% in three categories: Generation and DER, ICT and Electromobility, with respect to [1].

Table 4. 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

Figure 4 shows the percentage of labs that conducts research for specific sectors, like the industry, the academia, utilities, etc. It is obvious from the graph that utilities is at the top of the list, with 70.5% of the labs conducting research for them, whereas industry and academia follow with 66% and 65% respectively.

Figure 4. Sectors for which lab research is targeted.

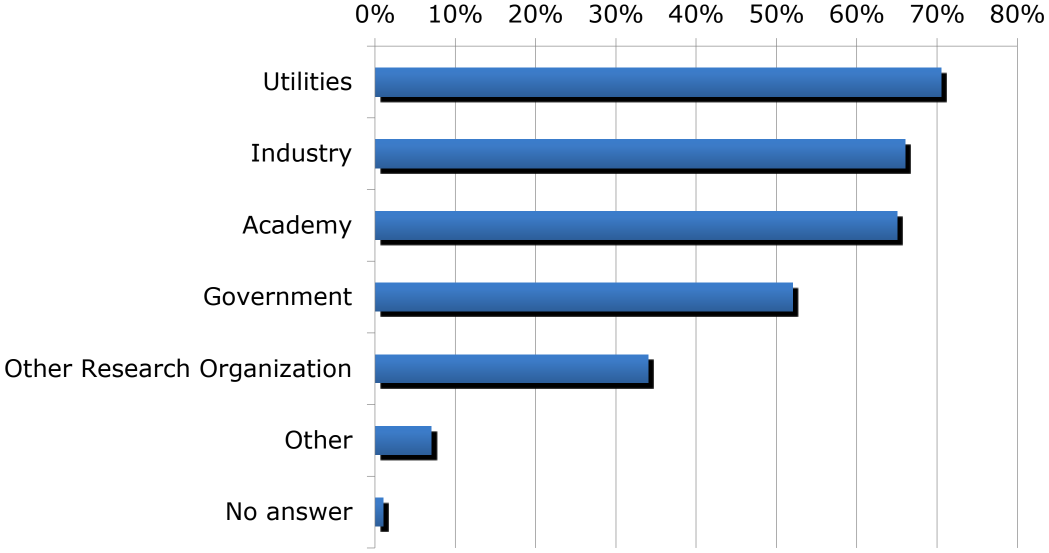


Figure 5 shows the fields of activities for the labs, like technology or standards development, prototype testing, etc. Figure 6 illustrates the percentage of labs that conduct research on a specific type of grid, like the transmission, distribution grid, isolated or islanded grid. It is observable from Figure 5 that more than 70% of the labs conduct research for technology development, R&D of equipment, Standards development and Prototype testing. Regarding the type of grid on which research is performed, 90% of the labs have their research activities on the distribution grid, whereas the islanded grid and the transmission grid are the ones to follow with 60% and 57% respectively.

Figure 5. Fields of activities for labs.

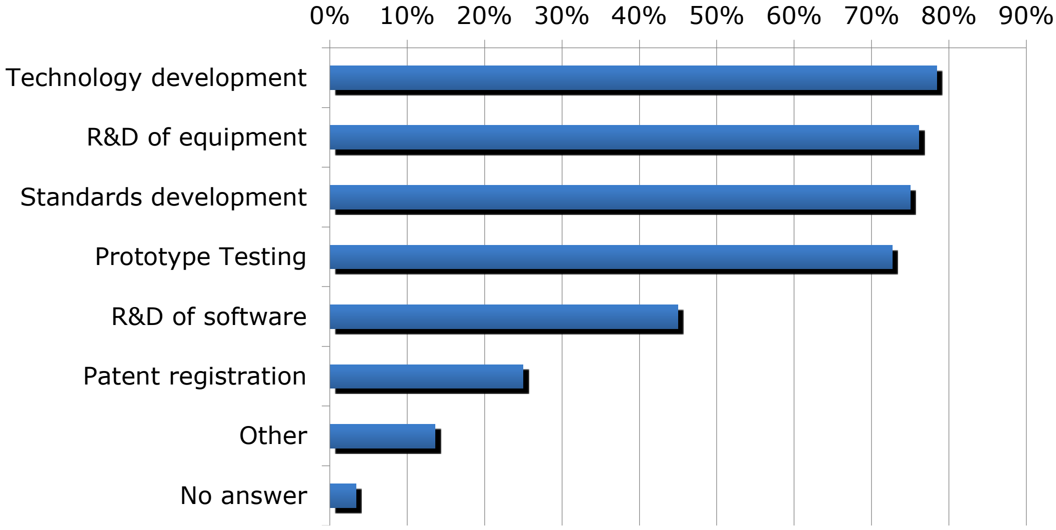
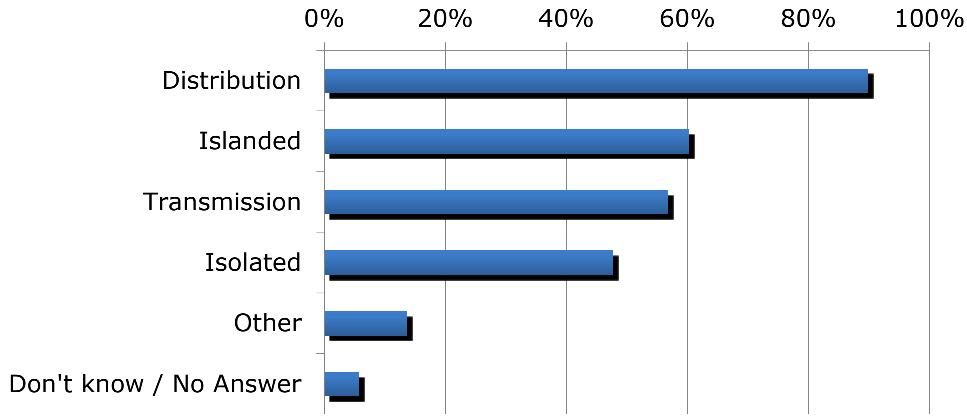
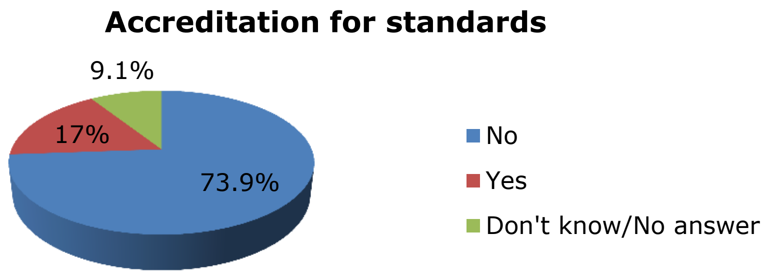


Figure 6. Types of grids for which lab research is aimed at.



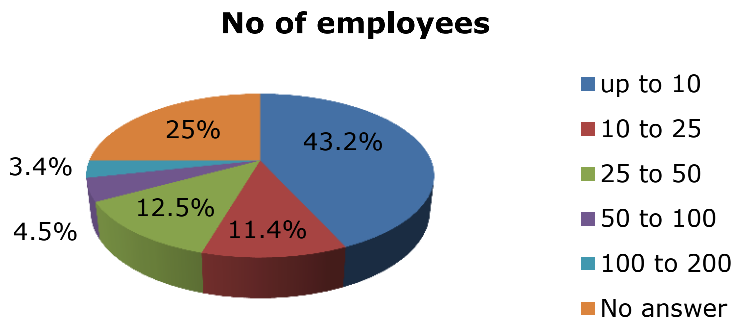
As general information, it is also interesting to see which percentage of labs holds accreditation for standards. Figure 7 shows this situation, where it is observed that the majority of the labs does not hold accreditation for standards (74%); only the 17% of the labs holds such accreditation.

Figure 7. Accreditation for standards held by labs.



Another interesting figure is the number of employees occupied in each lab. As it can be observed from the graph, most of the labs have a personnel of up to 10 people (43%); around 11-12% of them occupy from 10 to 25 or from 25 to 50 people; the labs that occupy a large number of people, namely from 50 to 100 or above 100 constitute a small percentage, 4.5% and 3.4% respectively.

Figure 8. Number of people working in the lab.



3.3 Investments

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

3.3.1 Investments for the Lab Construction

Only one third approximately of the labs (31%) has given information with respect to their investments for the lab construction. Although this number can be considered relatively low, the information provided can give a good feedback on the investments for smart grid labs. Figure 9 shows the percentage of labs with specific investments. Six categories have been used, which classify the labs according to the investments that have taken place for the lab construction. It should be noted that the percentages shown in Figure 9 are derived based on the total number of labs that have provided with feedback on their investments. It can be observed that a small percentage of the labs include an investment of lower than EUR 100,000. On the other hand, the percentage of large labs, including an investment of over EUR 4,000,000 is also low (11.5%). Most of the labs entail an investment between EUR 100,000 and EUR 500,000. It is also interesting to observe the duration in which these investments take place. The situation is variable, meaning that investments for the participant labs take place in various duration periods, from 1 up to 12 years. Figure 10 illustrates this matter. It can be observed that most of the labs (38.5%) have implemented their investments within 2 to 3 years. On the other hand, a considerable percentage of labs, around 20%, implement the investments throughout 6 to 7 years.

Figure 9. Percentage of labs with specific investments.

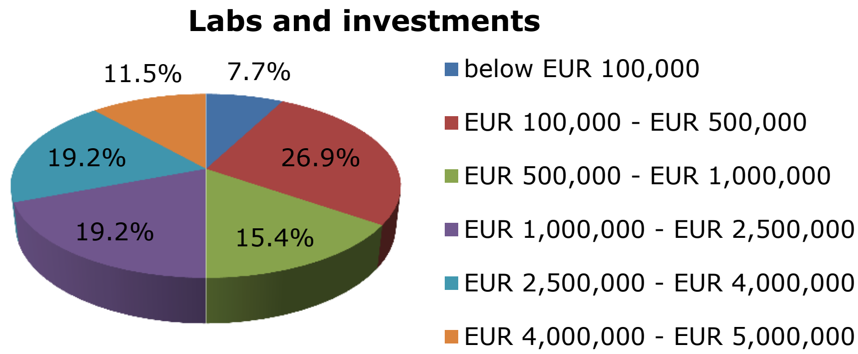
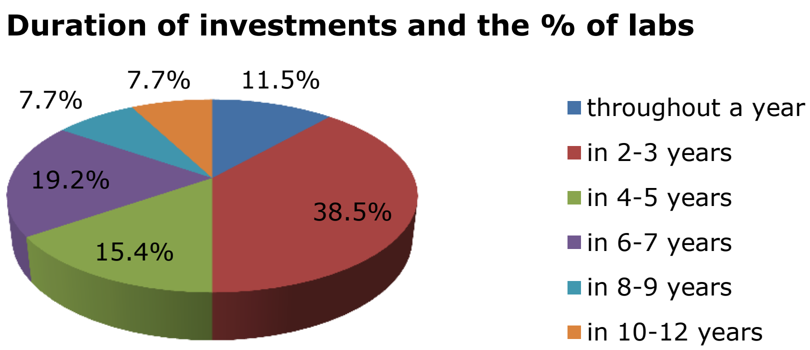


Figure 10. Percentage of labs with specific investments.

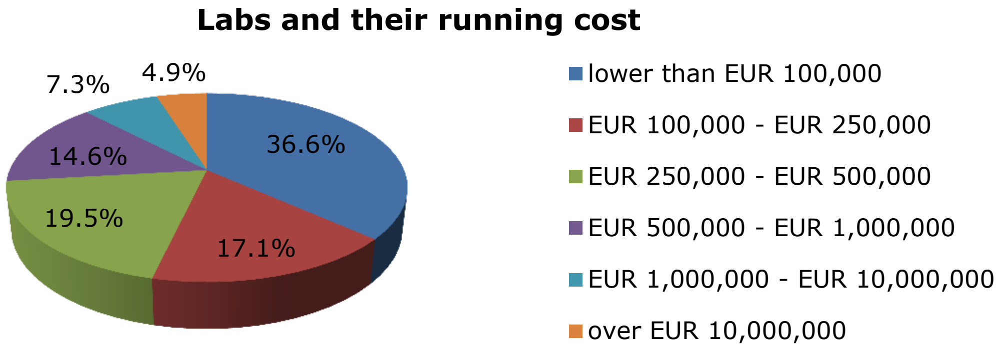


3.3.2 Running Costs for Labs

Regarding the running cost of the lab, including personnel costs, feedback has been obtained from 60% of the participating labs. Figure 11 shows the percentage of labs with

specific running costs. It can be observed that most of the labs (36.6%) have a running cost lower than EUR 100,000. The distribution of labs with running costs between EUR 100,000 and EUR 250,000, between EUR 250,000 and EUR 500,000 and between EUR 500,000 and EUR 1,000,000 is more or less the same with percentages of 17%, 19.5% and 14.6% respectively. Only a small percentage of labs (5%) has huge running costs, over EUR 10,000,000. It is noted that the percentages refer to the number of labs providing feedback on this question.

Figure 11. Percentage of labs with specific running costs.



3.3.3 Infrastructure Expansion Intentions

With respect to the planned investments, the majority of the labs have provided with feedback, namely the 77% of the questioned participants. 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 12 to Figure 14 show the infrastructure expansion intentions of the participant labs. It is noteworthy that none of the participants replied that there are intentions to decrease the infrastructure used in their lab. The majority of the labs replied positively for infrastructure expansion, which is more obvious for the short term period (over 80%). For the long term perspective, the situation is not very clear for many labs (42%). In addition, a relatively low percentage replied that they intend to leave the infrastructure as it is, 13%, 9% and 7% for the short, the medium and long term period respectively.

Figure 12. Short term infrastructure intentions and percentage of labs.

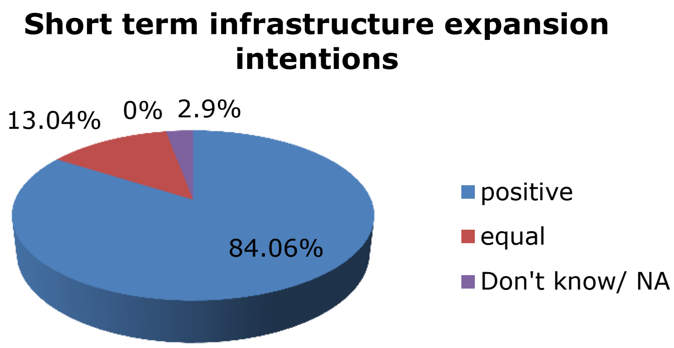


Figure 13. Medium term infrastructure intentions and percentage of labs.

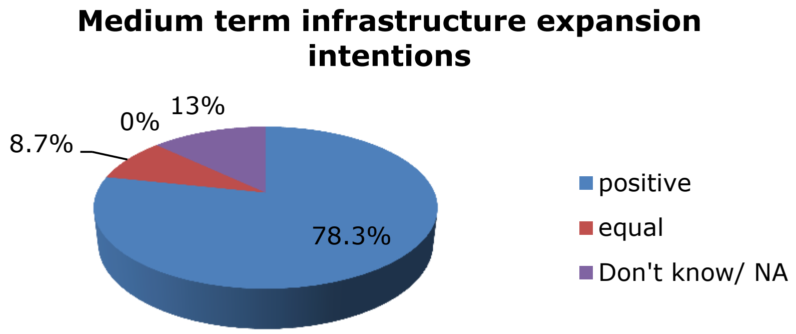
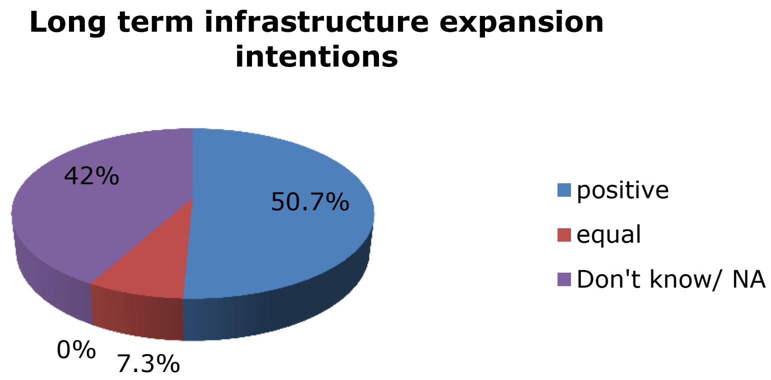


Figure 14. Long term infrastructure intentions and percentage of labs.



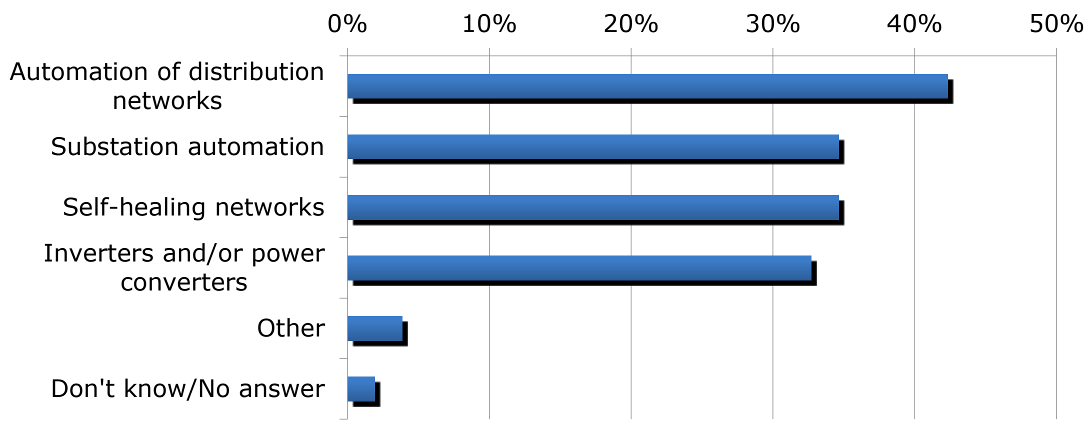
3.4 Analysis of Smart Grid Research Areas

In this section we present analytical information for each one of the identified categories individually.

3.4.1 Distribution Automation

For the labs that are working in the area of Distribution Automation (59% of total), the specific topics of investigation cover various fields, like Substation Automation, Automation of Distribution Networks, Inverters and Power Converters, Self-healing networks, etc., as shown in Figure 15.

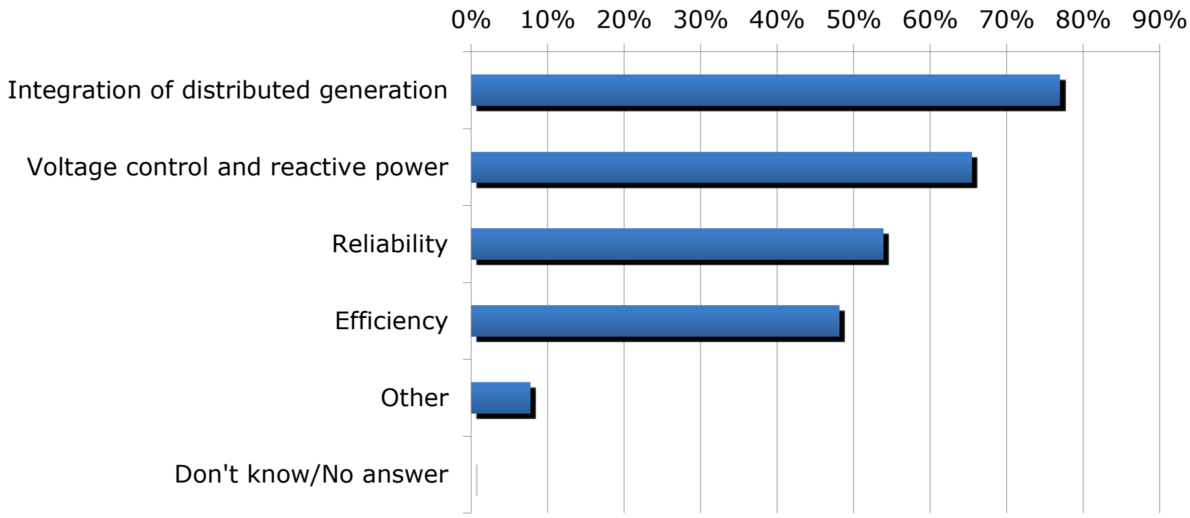
Figure 15. Percentage of labs that investigate specific Distribution Automation topics.



As it can be seen, in our survey the topic of Automation of distribution networks is ranked first among the labs involved in distribution automation, with a percentage of 42%, up from 34% and the second position in the last survey of 2016. Substation Automation and Self-healing networks come in the second position, both with a percentage of 35%, while inverters and power converters follow close behind with 33%.

The main objective of the research work performed in the above labs, which are active in the field of Distribution Automation (see Figure 16), is the integration of distributed generation that is identified as an objective by more than 75% of them. Voltage control and reactive power, as well as reliability, follow behind as the next most popular objectives.

Figure 16. Objectives of research work in distribution automation.



Regarding the standards used in distribution automation research activities, the IEC 61850 – Communication networks and systems in substations – is the most popular one, used in 60% of the laboratories involved in the field. A percentage of 27% of the active labs use the standard IEC 61968 – Common Information Model/Distribution Management, whereas 25% use the IEC 61970 – Common Information Model/Energy Management. The IEC 60870 - Telecontrol equipment and systems is used by 21% of the Distribution Automation laboratories. Table 5 gives a complete picture of the situation. Comparing with the results from the previous survey in 2016, there is an increase in the use of other than IEC standards (e.g. IEEE (Institute of Electrical and Electronics Engineers), CSA (Canadian Standards Association), AUS/NZ (Joint Australian and New Zealand Standards)), that is partially attributed to the fact that more labs outside Europe took part in the current survey.

Table 5. Standards used in Distribution Automation activities.

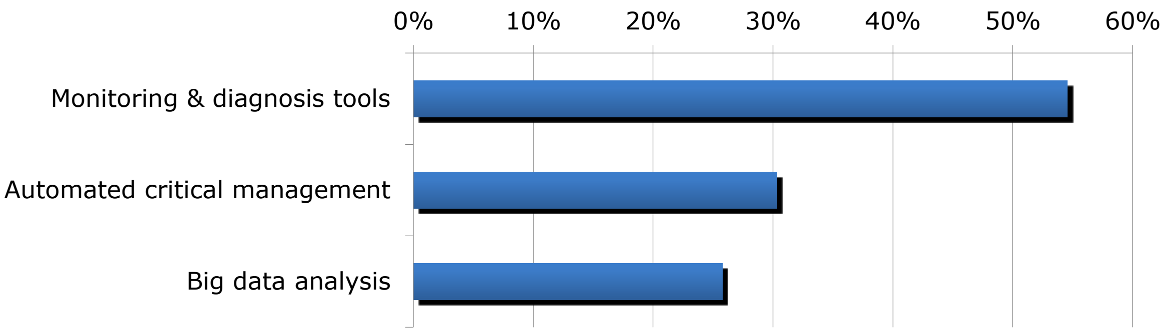
Standard	%
IEC 61850 – Communication networks and systems in substations	60%
IEC 61968 - Common Information Model / Distribution Management	27%
IEC 61970 - Common Information Model / Energy Management	25%
IEC 60870 - Telecontrol equipment and systems	21%
IEC 61869 – Instrument transformers	19%

IEC 62351 - Power systems management and associated information exchange - Data and communications security	17%
IEC 60255-24 - Electrical relays - COMTRADE	10%
IEC 62439 - Highly Available Automation Networks	4%
Other	19%

3.4.2 Grid Management

Grid Management is one of the most popular areas, on which Smart Grid labs around the world are working; in total 75% of those who participated in our survey. The main research topic is Monitoring & Diagnosis Tools (55% of the Grid Management labs), followed by Automated critical management and Big data analysis, as shown in Figure 17.

Figure 17. Main research topics of Grid Management labs.



From the labs, the large majority (75%) is also working in the topic of Microgrids, while almost half of them work with Phasor Measurements Units (PMU), see Figure 18 and Figure 19.

Figure 18. Percentage of Grid Management labs that conduct Microgrids related research.

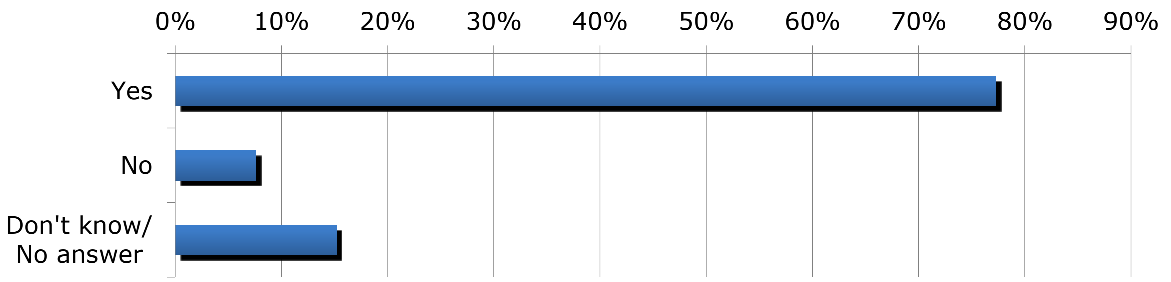
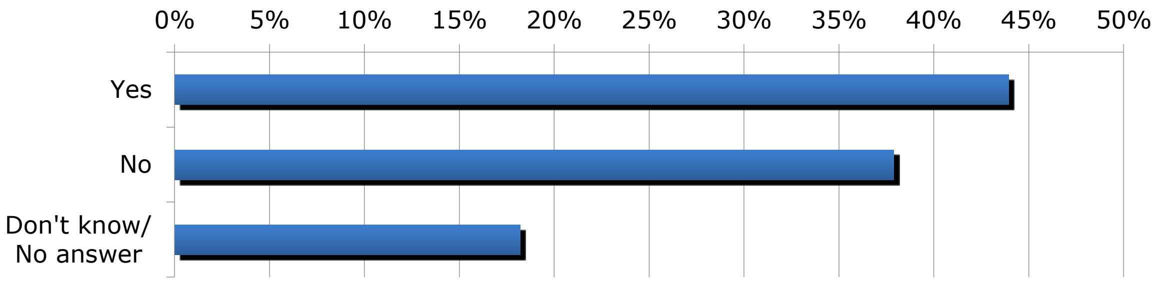


Figure 19. Percentage of Grid Management labs that work with PMUs.



With respect to standards used in these labs, the most used standard is again the IEC 61850, but also other standards present remarkable use, such as IEC 61968, IEC 61970 and IEC 60870. For more details check Table 6.

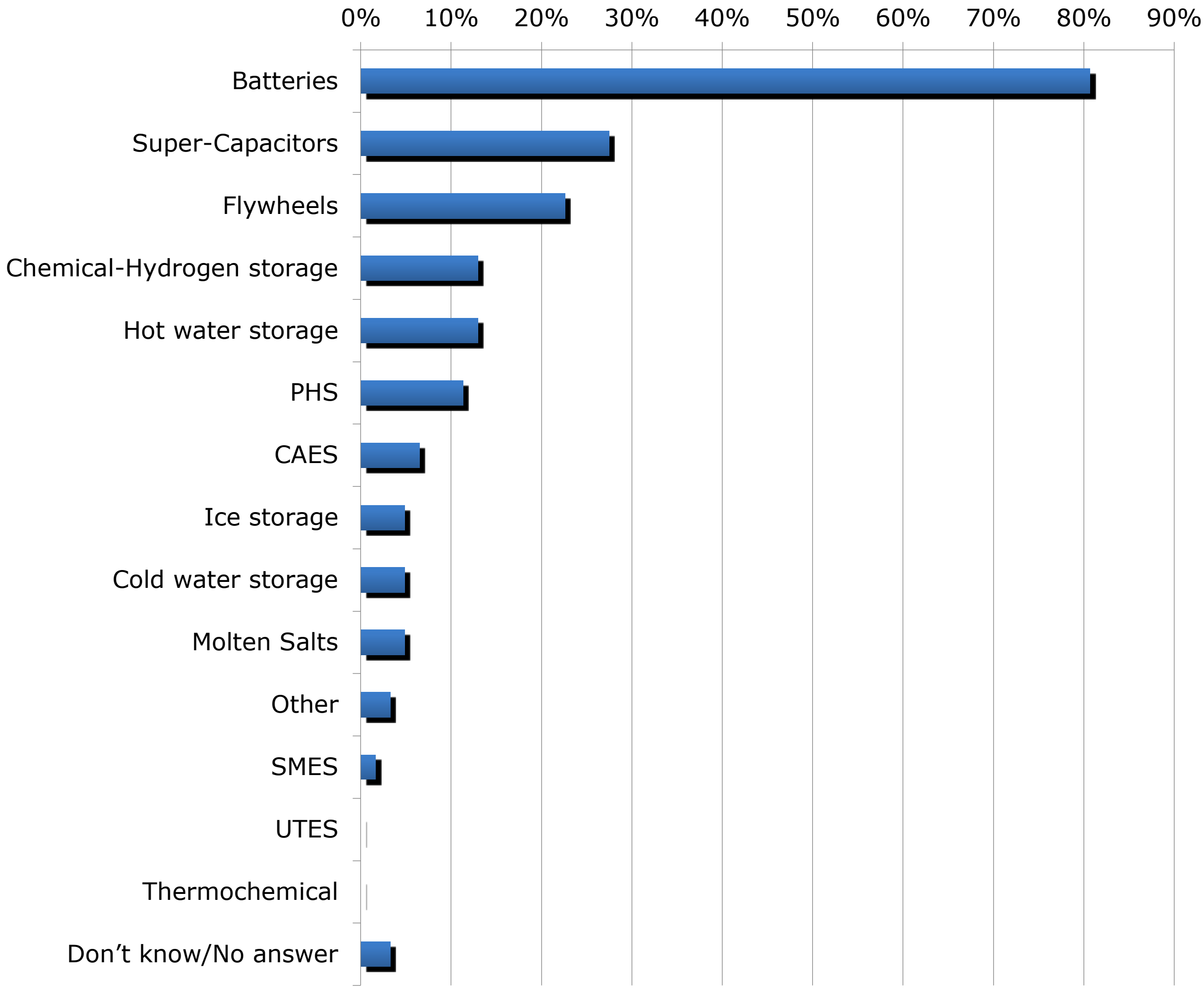
Table 6. Standards used in Grid Management activities.

Standard	**%**
IEC 61850 - Communication networks and systems in substations	42%
IEC 61968 - Common Information Model / Distribution Management	23%
IEC 61970 - Common Information Model / Energy Management	17%
IEC 60870 - Telecontrol equipment and systems	15%
IEC 62351 - Power systems management and associated information exchange	12%
IEC 61499 - International Standard for Distributed Systems	9%
IEC 61131 - Programmable controllers	8%
IEC 62357 - Power system control and associated communications	8%
IEC 62325 - Common Information Model (CIM) for Energy Markets	6%
IEC 61158 - Digital data communications for measurement and control	5%
IEEE 1344 - Standards for synchrophasors for power systems	5%
IEC 62361 - Power systems management and associated information exchange	3%
Other	14%

3.4.3 Storage

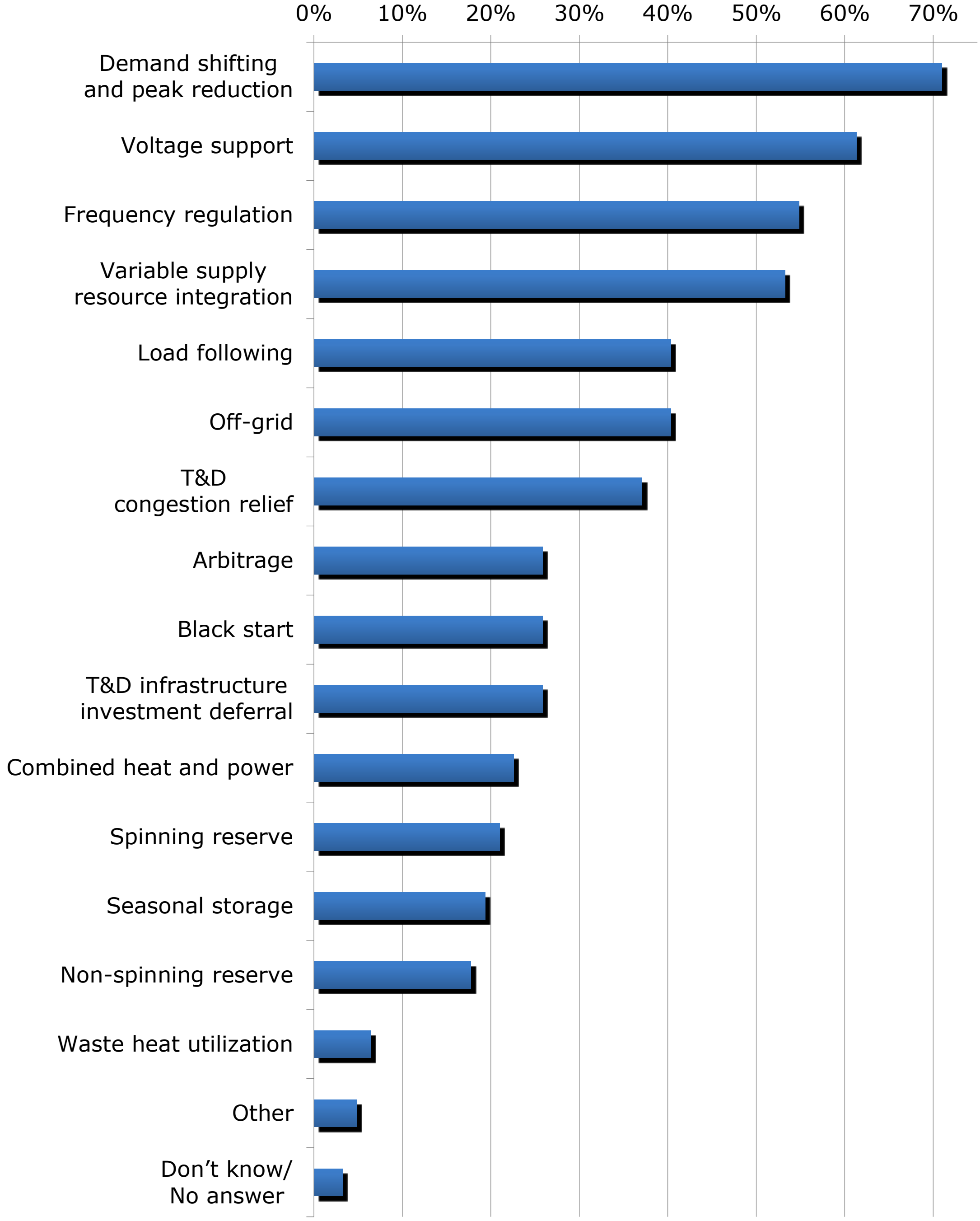
From the Smart Grid labs that participated in our survey almost 60% answered that they work in the area of Energy Storage. However, Energy Storage is a broader field of research that includes many different technologies, thus we wanted to identify the type of storage technology in which the labs were involved. The large majority of the storage research labs, more than 80%, conducted research related with battery energy storage. Super-capacitors and flywheels follow with much less shares, 27% and 23% respectively, whereas the rest of the technologies are being present only in a few of the labs. A detailed overview is shown in Figure 20.

Figure 20. Percentage of Storage labs involving different type of Energy Storage Technologies. The technologies are: Batteries, Super-Capacitors, Flywheels, Chemical-Hydrogen storage, Pumped-storage hydroelectricity (PHS), Compressed air energy storage (CAES), Ice storage, Cold water storage, Molten Salts, Superconducting Magnetic Energy Storage (SMES), Underground Thermal Energy Storage (UTES), Thermochemical and other.



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 more than 60%, while voltage support follows behind with 62%. Frequency regulation and variable supply resource integration attract also more than half of the active labs in the field. Other areas covered in a large number of labs are load following, off-grid and transmission and distribution (T&D) congestion relief. The details of the topics and the equivalent percentages are shown in Figure 21.

Figure 21. Percentage of Storage labs conducting research on different applications.



Concerning the standards used for storage in smart grids, almost 15% of the storage-related research labs use the IEC 61850 – Communication networks and systems in substations standard. Analytically, the standards used with their equivalent percentages are shown in Table 7. Some participants have noted that their work with storage is technology neutral, involving for example proper management of storage and integration as a distribution system asset, thus they do not research on specific technologies or communication standards.

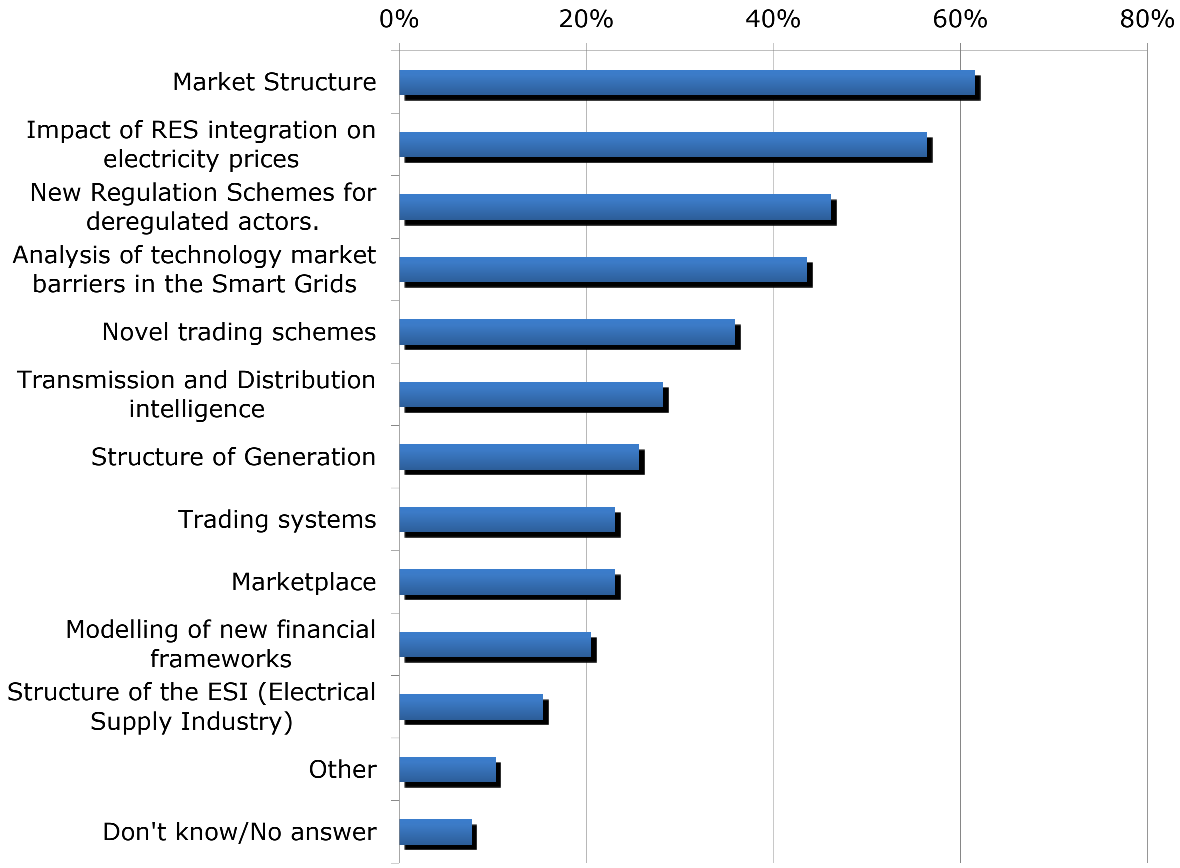
Table 7. Standards used in Storage activities.

Standard	**%**
IEC 61850 - Communication networks and systems in substations	15%
IEC 61970 - Common Information Model / Energy Management	5%
IEC 62351 - Power systems management and associated information exchange	2%
IEC 60870-5-104 Transmission Protocols - Network access for IEC 60870-5-101 using standard transport profiles	2%
Other	2%

3.4.4 Market

Almost half of the smart grid labs that participated in the survey are involved in research activities relevant to markets. Figure 22 reveals that there is a variety of topics under investigation regarding markets for the involved laboratories. The most popular topic is market structure, which is investigated in more than 60% of the active labs, while the impact of RES integration on electricity prices is ranked second with more than 55%. New regulation schemes for deregulated actors, analysis of technology market barriers in the smart grids, novel trading schemes and transmission and distribution intelligence follow with percentages between 46% and 28%. The topics of structure of generation, trading systems and marketplace attract between 25% and 30% of the involved laboratories, whereas modelling of new financial frameworks and structure of the electrical supply industry are the least popular topics with 20% and 15%, respectively. Modelling of new financial frameworks has presented the greatest increase in popularity, from 13% in the previous survey to 20% in the current one, while the rest of the topics have only slight changes of less than 2%.

Figure 22. Percentage of labs conducting research on different market topics.



Although market activities might not be strictly characterized as technical, some of the laboratories have reported that they use technical standards for their research. The main standard, used by almost a quarter of the labs that are involved in market research activities, is IEC 61970 - Common Information Model / Energy Management. The standards IEC 61968 - Common Information Model / Distribution Management and IEC 62325 - Common Information Model (CIM) for Energy Markets are both used by 18% of the active labs, while 8% have answered that they use IEC 60870 - Telecontrol equipment and systems, and IEC 62351 - Power systems management and associated information exchange (Table 8). Finally, some of the labs have reported that they do not use specific standards, but they follow guidelines and practices of the market regarding Power Exchanges.

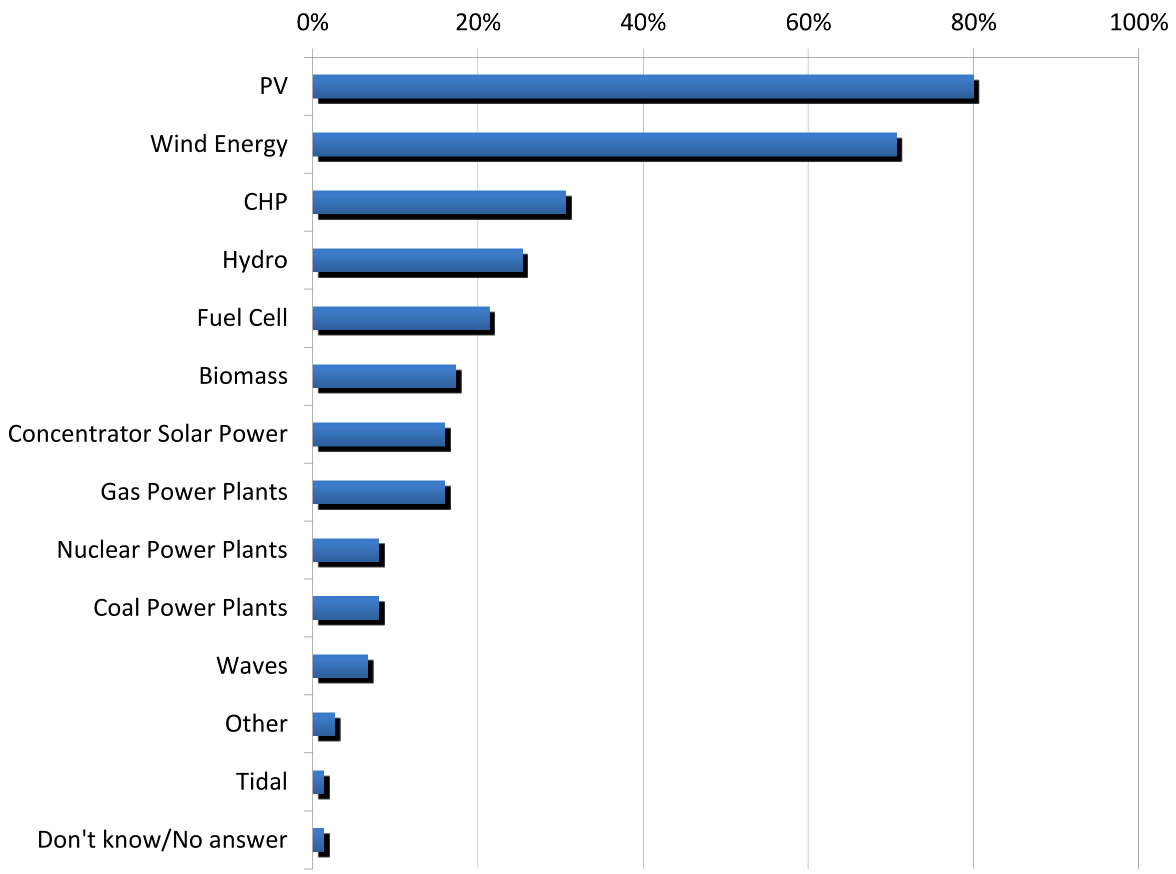
Table 8. Standards used in market activities.

Standard	**%**
IEC 61970 - Common Information Model / Energy Management	23%
IEC 61968 - Common Information Model / Distribution Management	18%
IEC 62325 - Common Information Model (CIM) for Energy Markets	18%
IEC 60870 - Telecontrol equipment and systems	8%
IEC 62351 - Power systems management and associated information exchange	8%
Other	5%

3.4.5 Generation and Distributed Energy Resources (DER)

More the 85% of the questioned laboratories are involved in activities concerning generation and Distributed Energy Resources (DER), an increase from 80% in the previous survey. Figure 23 shows on which technologies the laboratories work. Comparing with the results from the previous survey, the dominant technologies are still PV (photovoltaics) and wind energy, with similar percentages of about 80% and 70%, respectively, followed by combined heat and power (CHP) with 31%. In general, most of the technologies have retained their percentage with a slight increase or reduction of +/- 1-2%, except Biomass, which has further reduced to 17% down from 20% in the previous survey. It may be notable that both Coal and Nuclear Power Plants have slightly increased by 1% and 2%, respectively, although they are still among the least popular.

Figure 23. Percentage of generation and DER labs working on different technologies.



With respect to the use of standards in the generation and DER sector, the one that is mostly used is still the IEC 61850 (Communication Networks and Systems in Substations). However, it’s worth mentioning also the IEC 61400 (Wind Turbines) and the European Standard EN 50438 (Requirements for the connection of micro-generators in parallel with public LV distribution networks). More information can be found in Table 9, where comparing with the results from the previous survey there is a significant increase in the number of different standards used (from 16 to 28). In addition, some of the labs haven't reported the use of any standard, saying that they may use many different ones depending of their activity.

Table 9. Standards used in generation and DER activities.

Standard	**%**
IEC 61850 - Communication networks and systems in substations	35%
IEC 61400 – Wind Turbines	19%
EN 50438 - Requirements for the connection of micro-generators in parallel with public low-voltage distribution networks	17%
IEC 60904 - Photovoltaic devices	13%
IEC 61724 - Photovoltaic system performance monitoring	12%
IEC 61968 - Application integration at electric utilities - System interfaces for distribution management	11%
IEC 62351 - Power systems management and associated information exchange	11%
IEC 61970 - Common Information Model / Energy Management	9%
IEC 61194 - Characteristic parameters of stand-alone photovoltaic (PV) systems	8%
IEC 61727 - Photovoltaic (PV) systems. Utility interface	8%
IEC 61499 - International Standard for Distributed Systems	8%
IEEE Std 1547-2003 (R2008) - IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems	7%
IEC 61730 - Photovoltaic (PV) module safety qualification	4%
IEC/TS 62257 Recommendations for small renewable energy and hybrid systems for rural electrification	4%
IEC 61869 - Instrument transformers	4%
IEC 61215: Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval	4%
IEC 61000 – Electromagnetic compatibility	4%
IEEE Std C50 - IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator-Motors for Hydraulic Turbine Applications Rated 5 MVA and Above	3%
EN 50160 – Voltage characteristics of electricity supplied by public electricity networks	3%
IEC 60044-1 – Instruments Transformers. Part 1 : Current transformers	3%
IEC 60071 - Insulation co-ordination	3%
IEC 62559 - IntelliGrid methodology for developing requirements for energy systems	3%

IEEE Std 115 - Test Procedures for Synchronous Machines	3%
IEEE Std 286 - IEEE Recommended Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation	3%
IEEE Std 451 - IEEE Standard Definitions for Excitation Systems for Synchronous Machines	3%
IEEE Std C37.96-2012-IEEE Guide for AC (Alternating Current) Motor Protection	3%
IEEE Std C37.102_Guide for AC Generator Protection	3%
Other	11%

3.4.6 Electromobility

From the laboratories that participated in this third version of the survey, 61% have answered that they conduct research related with electromobility, a percentage slightly lower than in the previous report. There are several topics in which research work is conducted regarding Electric Vehicles, either full electric and/or plug-in hybrids. Vehicle-to-grid (V2G) remains the most popular field of research among the electromobility labs, although with a slight decrease to 56% from 59% in the previous report. Energy Storage, on the other hand, has increased its percentage from 52% to 56%, now occupying the first position along with V2G. A similar increase is observed in Charging Technologies, which have reached to 52%, from 48% previously, surpassing the Grid load impact, which is now in the fourth place with 50%, also slightly increased from 48% previously. Demand response, Energy efficiency, Power quality and Interoperability follow as subjects of research interest with similar percentages as in the last survey. The aforementioned information, along with some more research subjects, is summarized in Figure 24.

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. More than 40% of the laboratories conducting EV/PHEV (Plug-in Hybrid Electric Vehicles) research work with the IEC 61851 Mode 3 (AC slow or fast charging using a specific EVs multi-pin socket with control and protection functions), while 37% conducts research on the IEC 61851 Mode 2 (AC low charging from a regular socket equipped with specific EVs protection mechanism). 35% of the electromobility laboratories use the IEC 61851 Mode 4 (DC (Direct Current) fast charging using special charger technology), which comparing with the previous survey has slightly surpassed the use of IEC 61851 Mode 1 (AC slow charging from a regular electrical socket), used by 31%. In addition to IEC 61851, the SAE (Society of Automotive Engineers) AC or DC mode is also used but at a lower extent. In Table 10 this situation is presented analytically. An important note here is the increase in use of other charging topologies, although by few labs only, which include superfast charging and wireless charging (IEC 61980).

Figure 24. Percentage of electromobility labs conducting research on different research topics.

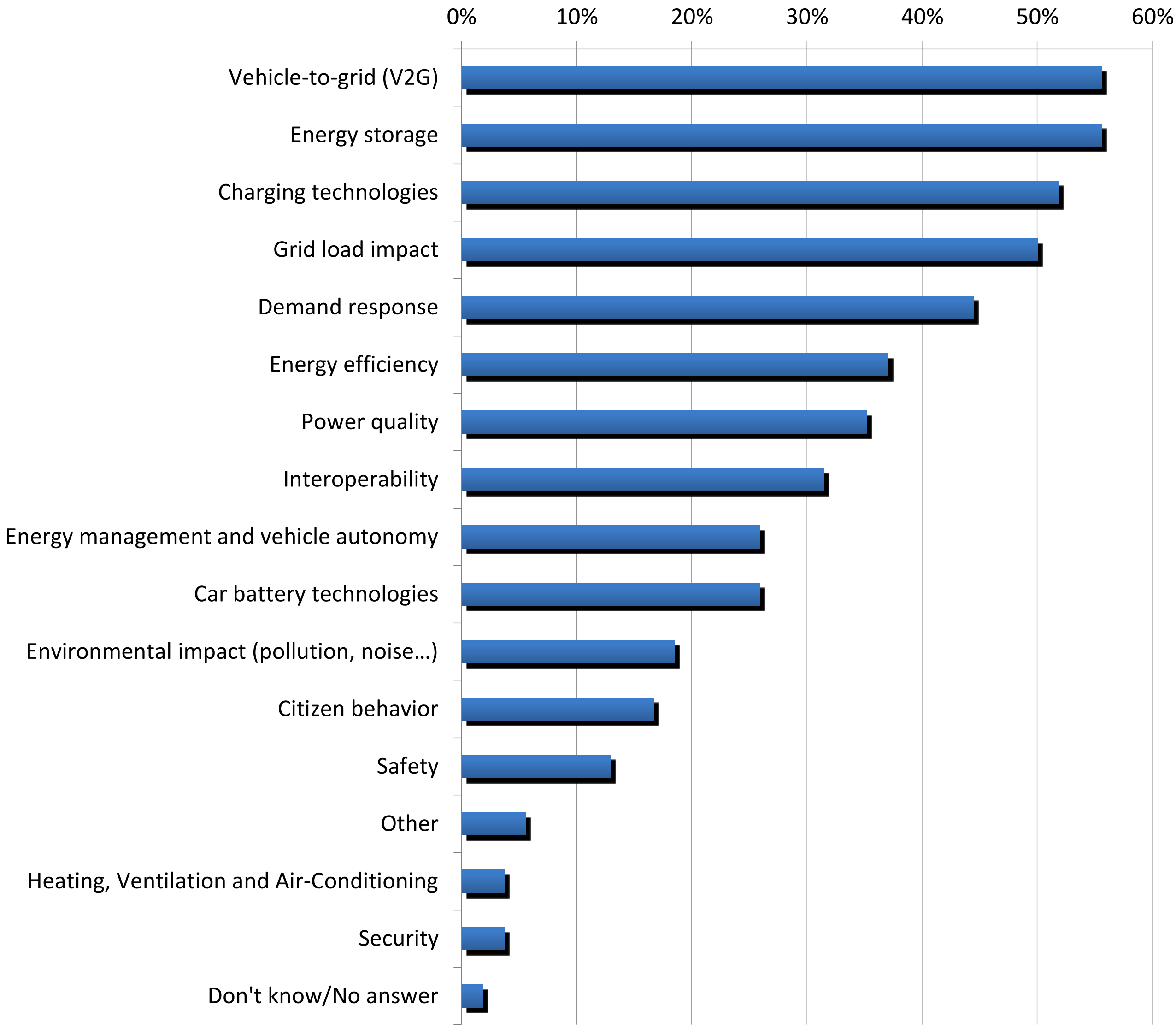


Table 10. Utilisation percentage of the different charging topologies for EV and PHEV.

Charging topology	**%**
IEC 61851 Mode 3 – AC slow or fast charging using a specific EVs multi-pin socket with control and protection functions	41%
IEC 61851 Mode 2 – AC low charging from a regular socket equipped with specific EVs protection mechanism	37%
IEC 61851 Mode 4 – DC fast charging using special charger technology	35%
IEC 61851 Mode 1 – AC slow charging from a regular electrical socket	33%
SAE AC level 1	9%
SAE AC level 2	9%

SAE AC level 3	9%
SAE DC level 1	6%
SAE DC level 2	6%
Other	11%

Since the charging connectors for EVs and PHEV are a critical part of the whole structure, it is important to acknowledge the type of connectors or relative standards used in current research work. Comparing with the previous survey, CHAdeMO is now the most popular connector type, used in 28% of the labs. IEC 62196-2 "Type 2" - single and three phase vehicle coupler and IEC 62196-2 "Type 1" - single phase vehicle coupler follow with 26% and 22%, respectively. Mennekes and SCHUKO are the next most popular standards, and the rest are shown in Table 11, where in the category other wireless and CEEplus are included.

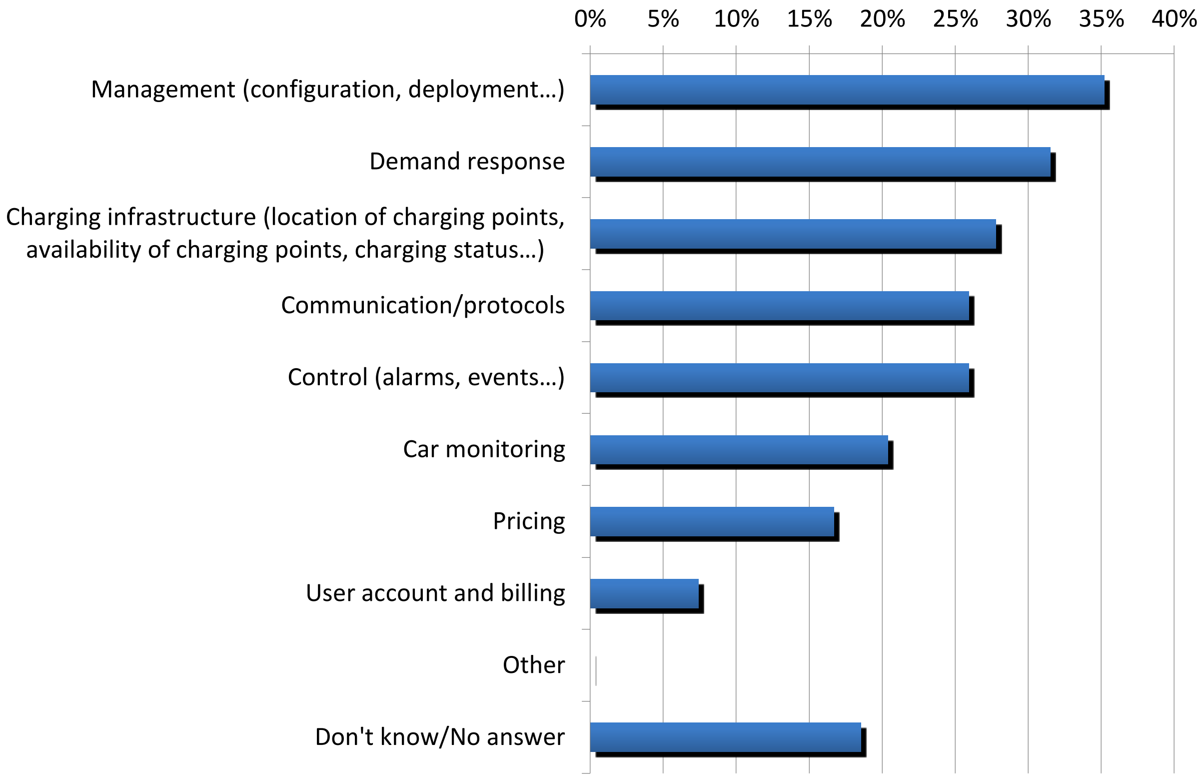
Table 11. Percentage of utilization of the different standards for charging connectors.

Standard for charging connectors	**%**
CHAdeMO	28%
IEC 62196-2 "Type 2" - single and three phase vehicle coupler	26%
IEC 62196-2 "Type 1" - single phase vehicle coupler	22%
Mennekes (VDE-AR-E 2623-2-2)	22%
SCHUKO	20%
IEC 62196-1 - Conductive charging of electric vehicles - Part 1: General requirements	19%
IEC 62196-2 "Type 3" - single and three phase vehicle coupler with shutters	19%
IEC 62196-3 - Dimensional compatibility and interchangeability requirements for DC and AC/DC. pin and contact-tube vehicle couplers	11%
SAE J1772 - EVs and PHEV Conductive Charge Coupler	11%
Combined charging system (DC)	9%
EVs Plug Alliance	6%
Yazaki	6%
SCAME	6%
Other	6%

The labs that are involved in electromobility activities were also asked if they develop some kind of software application, and in that case to which areas is this software addressed. More than a third of the active laboratories (35%) perform research on software applications for Management (configuration, deployment). Software applications for Demand Response have increased to more than 31%, up from 27% in the previous

survey. Charging infrastructure (location of charging points, availability of charging points, charging status, etc.) has also increased to 28% from 25% in the previous survey, whereas Communications/protocols with 26% have dropped to the fourth position, from 27% and second position previously. The highest increase, however, is for Control, which has climbed to 26%, up from 18% in the previous study. Car monitoring, Pricing, and User account and billing follow behind. Figure 25 depicts the aforementioned situation.

Figure 25. Different type of software applications for electromobility.



Finally, regarding the communication standards that are used mostly by electromobility labs, IEC 61850 comes at first position followed by IEC 61851 and IEC 15118. All the standards/protocols that are used for communication purposes in electromobility activities, along with the percentage of the EV/PHEV laboratories that uses them, are shown in Table 12. It is noted that OCPP (Open Charging Point Protocol) is a new addition to the list, since the previous survey.

Table 12. Communication protocols applied for electromobility activities.

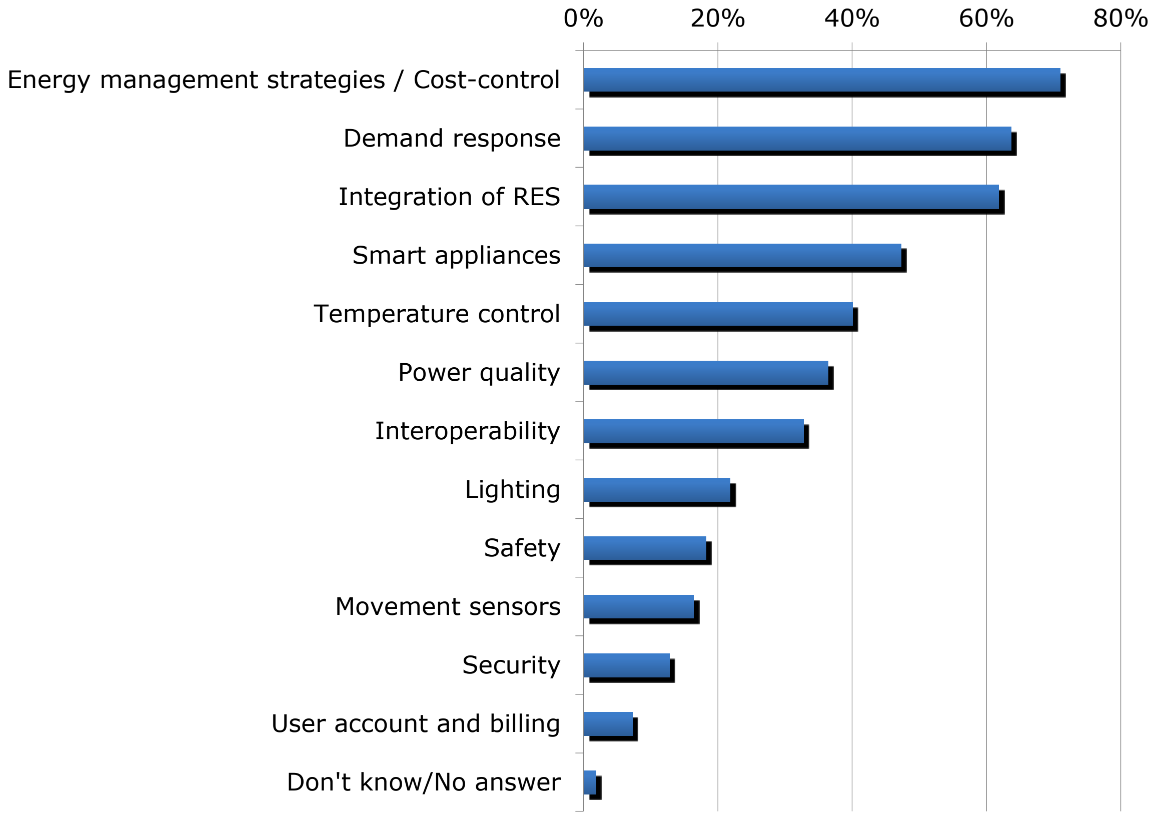
Communication protocol	**%**
IEC 61850 - Communication networks and systems in substations	30%
IEC 61851 - Electric vehicle conductive charging system	26%
ISO/ IEC 15118 - Vehicle to grid communication interface	17%
IEC 62351 - Power systems management and associated information exchange	7%
IEEE 80211P - Wireless access in vehicular environment	4%
SAE J2847 - Communication between Plug-in Vehicles and the Utility Grid	4%

SAE J2931 - Digital Communication for Plug-in Electric Vehicles	4%
OICP – Open Interchange Protocol (Hubject)	4%
OCPP: Open Charging Point Protocol	4%
Other	7%

3.4.7 Smart Home/Building

Among the 89 laboratories that participated in the survey, more than 60% are active in the research area of smart homes and smart buildings. Within this broad topic there are multiple sub-categories, thus most respondents engage in multiple of these categories. Energy management strategies and cost-control is the most widely studied area with 71% of those labs that engage in smart home research, followed by the topic demand response (64%) and integration of RES (62%). Furthermore, the topics smart appliances, temperature control, power quality and interoperability respectively are in the focus of more than a third of labs engaging in smart homes. The extensive lists of research topics with respect to smart homes and the shares of labs, which work in this areas can be viewed in Figure 26.

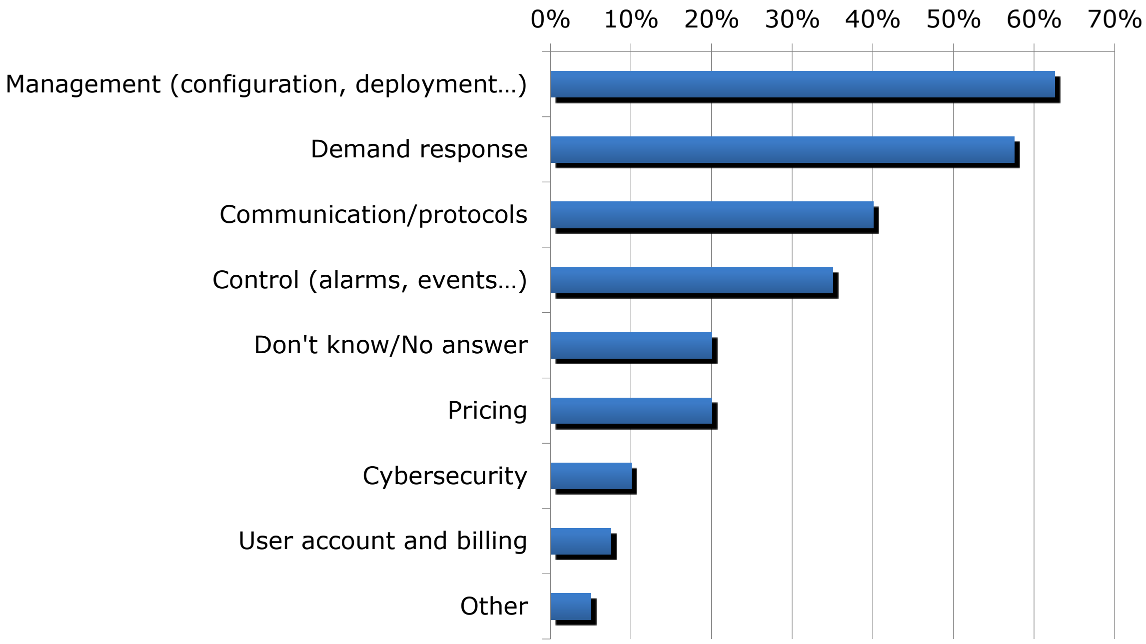
Figure 26. Activities regarding smart home research. Share of the total number of labs that are active in smart home research.



More than 70% of the labs that are active in the area of smart homes also engage in the development of software applications for smart home purposes. The issue most commonly addressed through applications is management (configuration, deployment,…) with 63% of researching smart home labs, followed by demand response, in which 58% of the labs active in smart homes and buildings engage. Besides that, communication/protocols, control and pricing are applications for which 40%, 35% and 20% of labs develop software respectively; it is notable that cyber security thus gaining

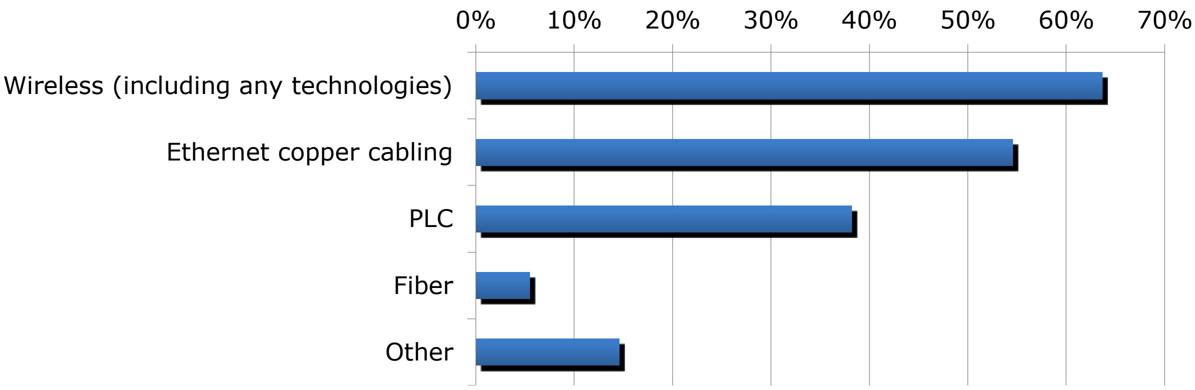
more interest is still only investigated by 10% of the respondents. A full list of the topics addressed through application developments including the shares of labs that do so can be viewed in Figure 27.

Figure 27. Software development for smart home application. Share of labs that are active in smart home and software applications.



In terms of telecommunication technologies the ones most widely used by the interviewed labs are Wireless, which are employed by 64% of the labs and Ethernet cabling used by 55%, while Power Line Communication (PLC) is also an accepted option utilized by 38%. The full picture of the respondents' answers to the question of utilized telecommunication technology is displayed in Figure 28.

Figure 28. Telecommunication technologies used in the laboratories for smart home activities. Share of the total number of labs that are active in smart home research.

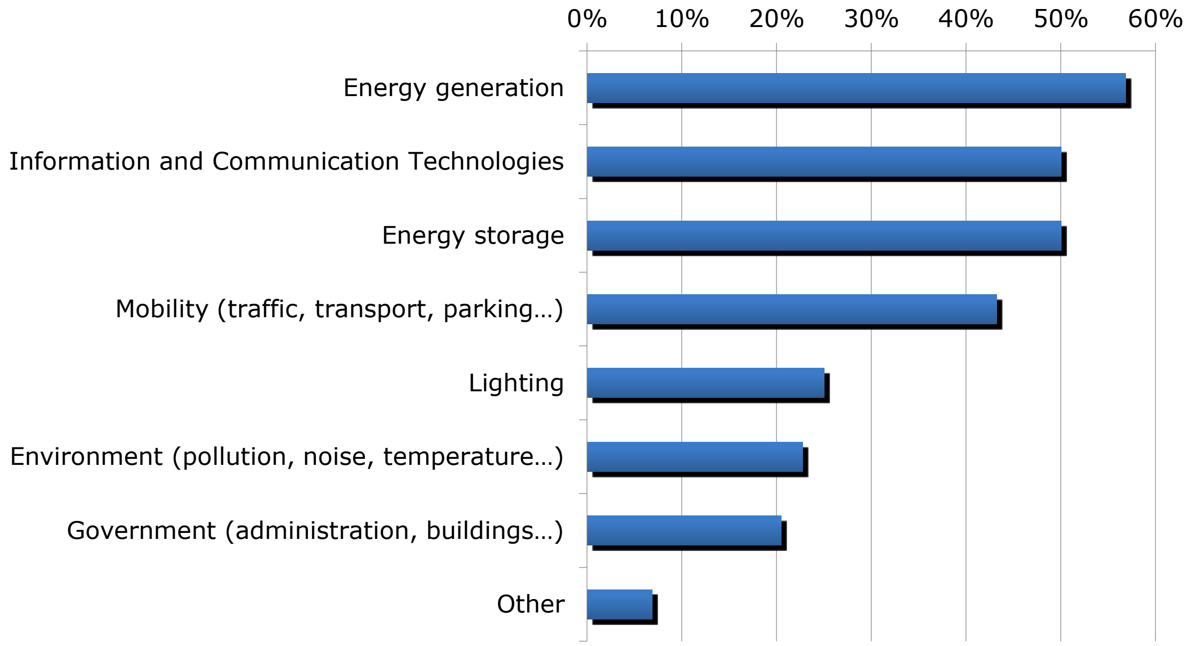


Among the laboratories active in smart homes only 24% conduct their research according to standards, according to the lack of responses from the remaining labs. However, some of the standards that have been mentioned are e.g. EN 13321 - Open data communication in building automation, controls and building management, EN 50491 - General requirements for Home and Building Electronic Systems (HBES), Building Automation and Control Systems (BACS), IEC 62351 - Power systems and ISO/IEC 14543 - Information technology - Home Electronic Systems (HES).

3.4.8 Smart Cities

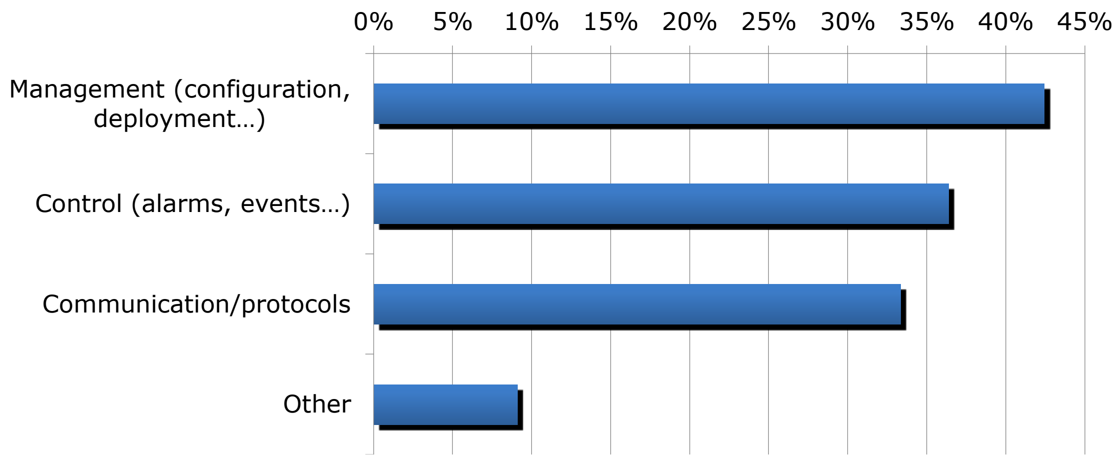
The topic of smart cities is in the focus of half of the laboratories that participated in the survey. Among these positive respondents the most popular areas of research regarding smart cities are energy generation with 57% of labs conducting research in that area and ICT with 50% of labs. Notably, energy storage and mobility with 50% and 43% respective shares of labs that are engaging in research are areas that are enjoying increasing interest in comparison to the results obtained from the smart grid lab inventory 2016. A full account of the areas of research in smart cities and the respective shares of laboratories can be viewed in Figure 29.

Figure 29. Activities regarding smart city research. Share of the total number of labs that are active in smart city research.



As opposed to the large interest of smart home applications, merely 45% of the labs that are active in smart city research are also developing software for smart city applications. However, those that do develop applications do so in the areas of management (42%), control (36%) and communication (33%). These responses are displayed in Figure 30.

Figure 30. Software development for smart city application. Share of labs that are active in smart cities and software applications.

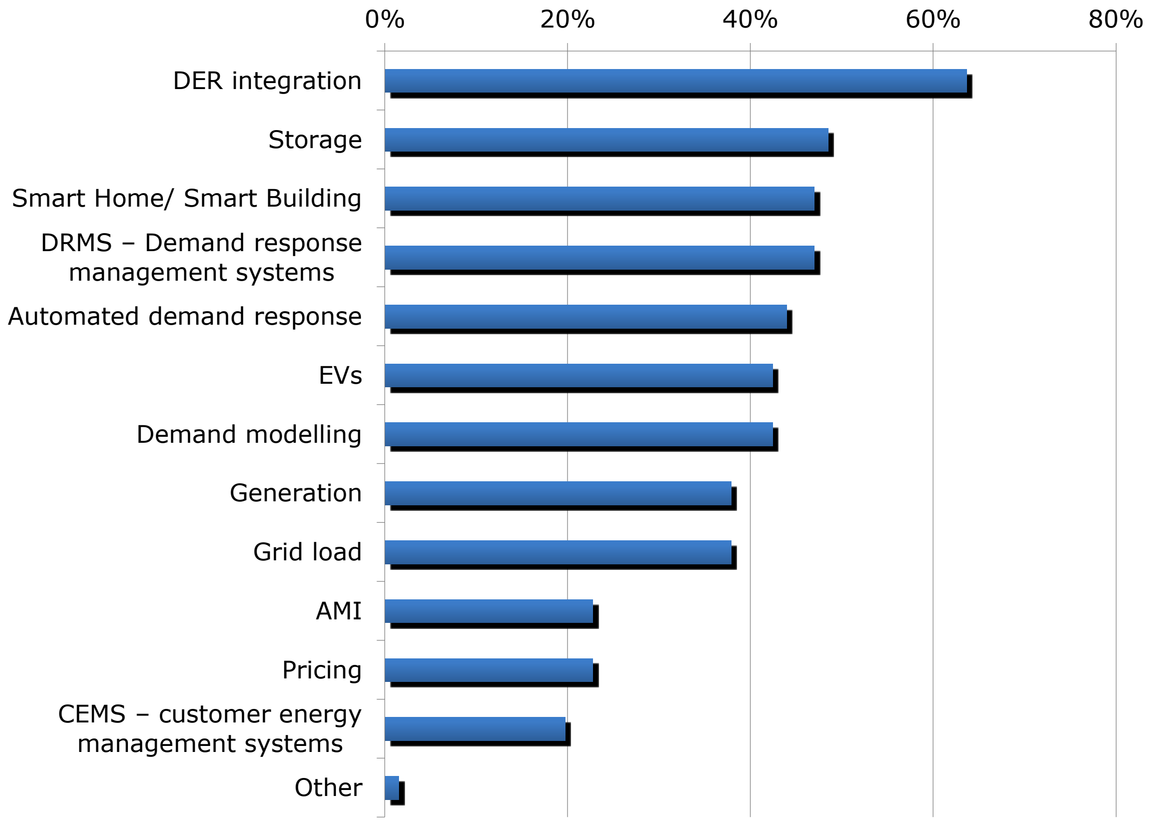


3.4.9 Demand Response (DR)

Demand response is a topic that attracts great attention by various stakeholders in the area of smart grid research and applications and is thus in the focus of 75% of the labs that are listed in the inventory. The most common area of research is DER integration as declared by 64% of those labs active in demand response; other important areas of research are storage, smart home/smart building and demand response management systems (DRMS) amongst others. The exhaustive list of topics of interest regarding demand response and the percentage of labs active in the areas with respect to those that are investigating demand response is provided in Figure 31.

In terms of standards, 30% of the respondents declared what standards they apply. The most commonly used among them is the Open Automated Demand Response Alliance (OpenADR), mentioned by 15% of the demand response labs. Further standards that are used by 13% and 11% of the labs respectively are the IEC 61970 - Energy management system application program interface and the IEC 62351 - Power systems management and associated information exchange.

Figure 31. Activities regarding demand response research. Share of the total number of labs that are active in demand response research.



3.4.10 ICT: Communication

There are 62.5% of the labs that participated in JRC's survey that are active in the field of ICT. The networks, which are in the focus of their research are LAN (Local Area Network) being investigated by 47% of those labs active in ICT, followed by WAN (Wide Area Network) with 42%, FAN (Field Area Network) and HAN (Home Area Network) both with 29% of labs working on them. The list of networks is completed by NAN (Neighbourhood Area Network) and PAN (Personal Area Network) and can be viewed in its entirety in Figure 32.

There are a multitude of protocols, specifications and technologies applied in ICT communication, amongst which the most popular is the IEC 61850 – Communication

networks and systems in substations, which is utilized by 58% of labs that are active in ICT. Further, there are IPv4, which is used increasingly by 38% of labs, followed by IPv6, which is utilized by 29%. Among the other protocols are e.g. MPLS (Multiprotocol Label Switching) or DSL (Digital Subscriber Line) and SDH (Synchronous Digital Hierarchy). An extensive list of protocols used by ICT labs with the corresponding percentages of labs is displayed in Table 13.

Figure 32. Telecommunication network research in ICT activities. Shares of labs that are active in ICT.

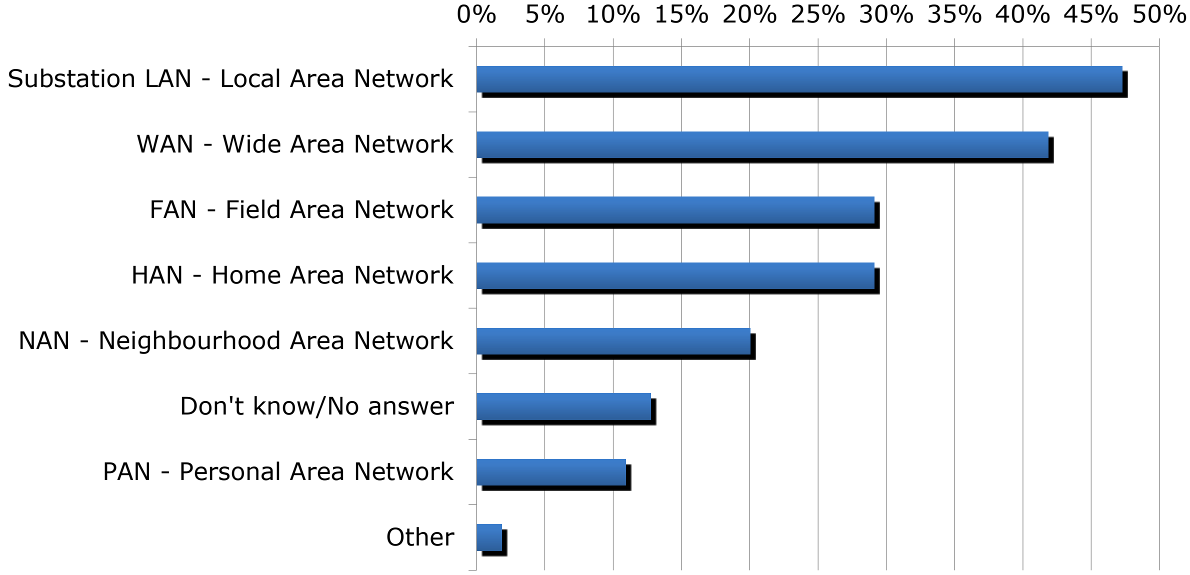
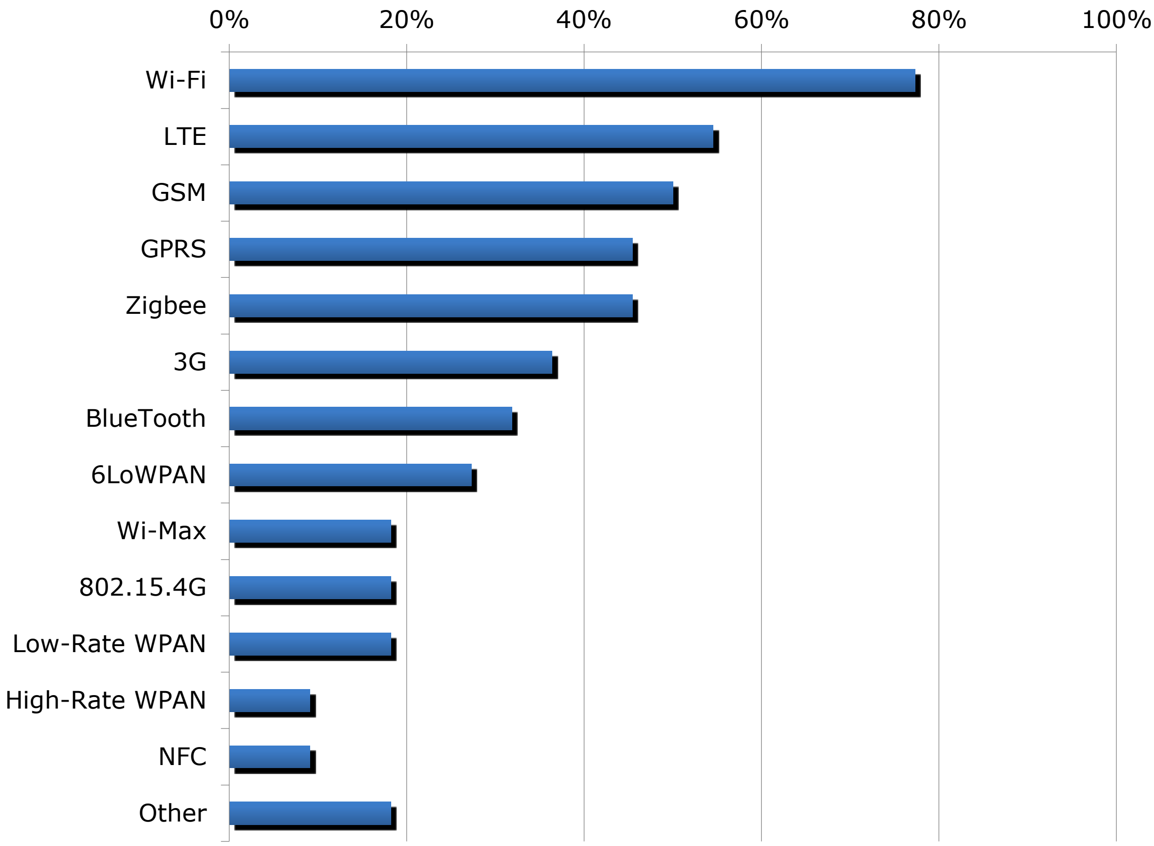


Table 13. ICT communication protocols and usage in shares of labs that are active in ICT.

Standard	**%**
IEC 61850 – Communication networks and systems in substations	58%
IPv4 – IP version 4	38%
IPv6 – IP version 6	29%
MPLS – Multiprotocol Label Switching,	11%
DSL – Digital Subscriber Line (including ADSL, VDSL, HDSL, SHDSL…)	5%
SDH - Synchronous Digital Hierarchy	5%
SONET - Synchronous Optical Network	4%
MPLS – Multiprotocol Label Switching	4%
IEC 60870-5-104	4%
OSGP – Open Smart Grid Protocol	4%
Webservices	4%
Others	25%

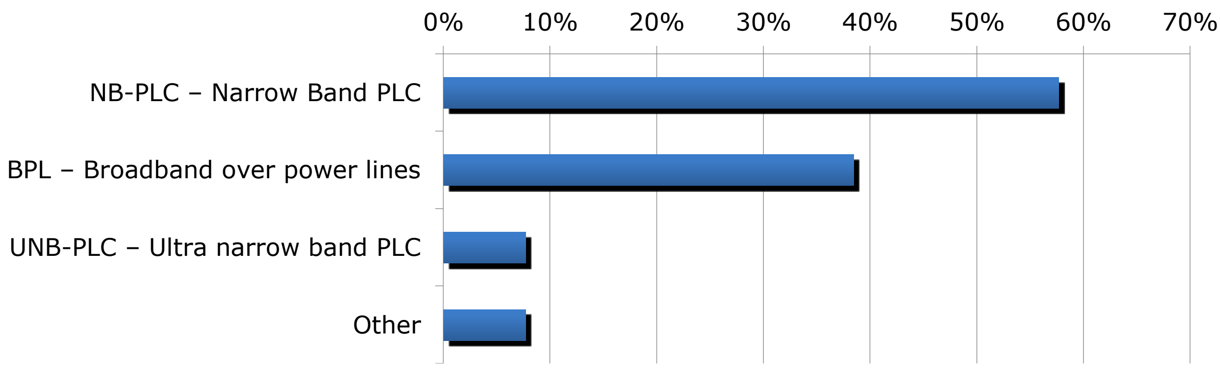
Within the area of ICT almost half of the labs also conduct research in wireless technologies. There is a large variety of technologies available and utilized, which can be seen in Figure 33, where also the shares of labs that use them is indicated with respect to the total number of labs active in wireless technology research in general. The most commonly investigated ones are Wi-Fi (Wireless Fidelity) (77%), LTE (Long Term Evolution) (55%), GSM (Global System for Mobile (Communication)) (50%), GPRS (Global Packet Radio Service) (45%) and Zigbee (45%). Amongst the technologies mentioned by the responding labs under "other" is the upcoming 5G wireless, which is expected to receive increasing attention in the future.

Figure 33. Research in the different wireless technologies and shares of labs that are active in wireless technologies.



Almost half of the ICT labs investigate Power Line Technologies (PLC). The most attention is received by NB-PLC – Narrow Band PLC, where 58% of the PLC research is conducted, followed by BPL – Broadband over power lines with 38% of labs that research in the area, see Figure 34.

Figure 34. Research in the different PLC technologies and shares of labs that are active in PLC.



Within PLC research there are a variety of standards and technologies that being used by PLC labs. The most popular one is PRIME Alliance (PoweRline Intelligent Metering Evolution), where 35% of the PLC labs are active. Further, 19% of labs conduct research on HomePlug, 15% on G3-PLC Alliance and 8% on IEEE 1901.2 - Low-Frequency (less than 500 kHz) Narrowband Power Line Communications for Smart Grid Applications. The full account of standards and technologies within PLC research and the respective percentages of PLC labs that are active in the area can be viewed in Table 14.

Table 14. Standards and technologies used in PLC research and shares of labs that are active in PLC.

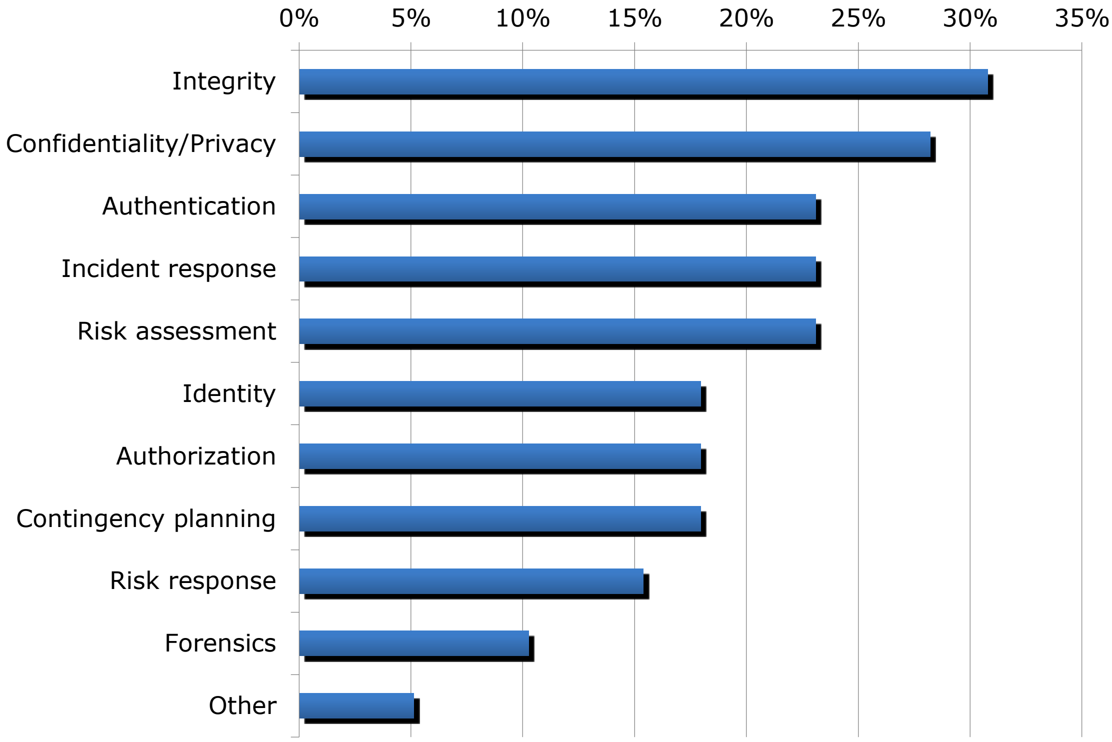
Standard	**%**
PRIME Alliance	35%
HomePlug	19%
G3-PLC	15%
IEEE 1901.2 - Low-Frequency (less than 500 kHz) Narrowband Power Line Communications for Smart Grid Applications	12%
IEEE 1901 – Broadband over power line networks	8%
IEC 61334 – Distribution automation using distribution line carrier systems	8%
ITU-T G.hnem – Narrowband OFDM power line communications transceivers	8%
Other	4%

Lastly, among the 55 laboratories, which are active in the ICT sector 55% conduct research in the area of monitoring and control of the communication infrastructure.

3.4.11 Cyber Security

The topic of cyber security in the context of smart grids is receiving increasing attention and is being investigate by 44% of the labs that participated in the survey. In their research the labs target different areas among which integrity is the most popular one with 31% of cyber security labs conducting research in it. Further fields, in which the labs are active, include confidentiality/privacy (28%), authentication (23%), incident response (23%) and risk assessment (23%). The full account of areas of activity including the respective shares of cyber security labs that dedicate their research to the topics can be viewed in Figure 35.

Figure 35. Activities regarding cyber security research and shares of labs that are active in cyber security.



The protocols and standards applied by the cyber security labs are displayed in Table 15. The most widely used one with 33% is IPSec – Internet Protocol Security, followed by PKI – Public Key Infrastructure (28%) and AES – Advanced Encryption Standard (26%). Other examples of technologies are SHA – Secure Hash Algorithm and SSH – Secure Shell, which are each utilized by 18% of the cyber security labs, see Table 15.

Table 15. Cyber security protocols and standards and usage in shares of labs that are active in cyber security.

Standard	**%**
IPSec – Internet Protocol Security	33%
PKI – Public Key Infrastructure	28%
AES – Advanced Encryption Standard	26%
SHA – Secure Hash Algorithm	18%
SSH – Secure Shell	18%
RSA - Ron Rivest, Adi Shamir and Leonard Adleman (crypto system)	15%
AAA – Authentication, Authorization and Accounting	15%
DES – Data Encryption Standard	13%
3DES – Triple DES	13%
MD5 – Message Digest algorithm 5	10%

RADIUS - Remote Authentication Dial-In User Service	10%
EAP - Extensible Authentication Protocol	8%
Oauth – Open secure authorization protocol	8%
Other	8%

3.4.12 Advanced Metering Infrastructure (AMI)

There are 45% of responding labs carrying out research activities in Advanced Metering Infrastructure (AMI). The key area of interest for the labs is monitoring with 53% of active research facilities in this field, followed by demand response with 43%. Another crucial aspect of AMI is communication being in the focus of 43% of labs. In terms of communication around half of the labs employ wireless solutions and half employ PLC (Power Line Communication) technologies, while also wired (copper, fibre …) communication technologies are used by 38% of respondents. Other areas of research in AMI include interoperability (40%), management (35%) and customer information (30%). A full account of research topics related to AMI and the shares of researching labs can be found in Figure 36.

Lastly, in terms of standards 23% of labs mention IEC 61850 - Communication networks and systems in substations as technology they use, further standards with a utilization of 13% each are IEC 61970 - Energy management system application program interface, IEC 62056 - Electricity metering - Data exchange for meter reading, tariff and load control and IEC 61968 - Application integration at electric utilities. A more extensive list of standards and shares of usage can be viewed in Table 16.

Figure 36. Activities regarding AMI research and shares of labs that are active in AMI.

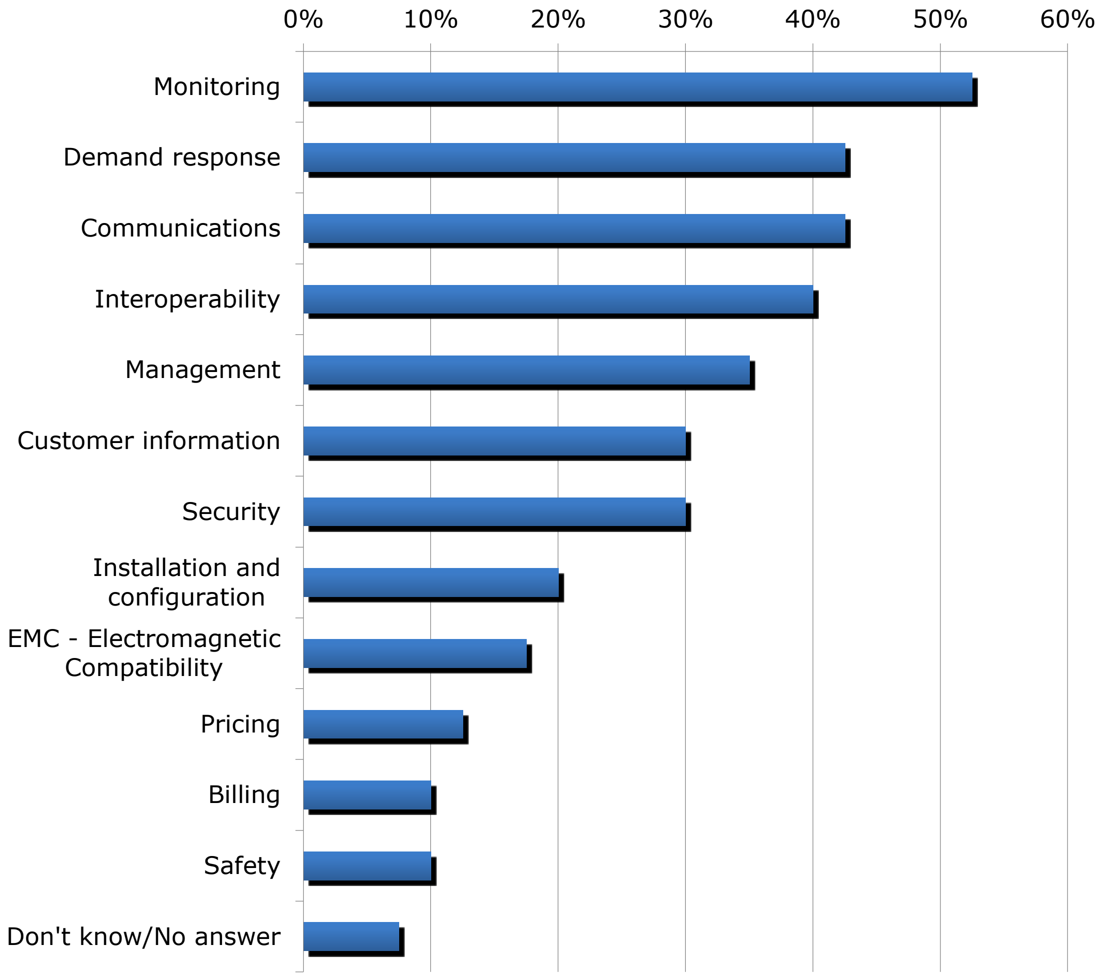


Table 16. AMI standards and usage in shares of labs that are active in AMI.

Standard	**%**
IEC 61850 - Communication networks and systems in substation	23%
IEC 62056 - Electricity metering - Data exchange for meter reading, tariff and load control	13%
IEC 61968 - Application integration at electric utilities	13%
IEC 61970 - Energy management system application program interface	13%
IEC 62052 - Electric Metering Equipment – Generic requirements	8%
IEC 62351 - Power systems management and associated information exchange	8%
IEEE 1377 - Utility Industry Metering Communication Protocol Application Layer	5%
IEC 62054 - Electricity metering (a.c.) - Tariff and load control, IEC 62056 - Electricity metering - Data exchange for meter reading, tariff and load control	5%

IEC 62058 - Electricity metering equipment (AC) - Acceptance inspection	5%
IEC 62059 - Electricity metering equipment - Dependability	5%
IEC 62053 - Electric Metering Equipment – Particular requirements	5%
Other	13%

3.5 Infrastructure Used

In this Section, information is provided about the infrastructure used by the survey participants. As a first step, information about the power and voltage capabilities of the facility is given, like the total power installed (AC and DC), the peak power of the infrastructure (AC and DC) and the voltage level (AC and DC).

3.5.1 Power and Voltage Capability

With respect to the total and peak AC power installed, 62.5% of the labs shared such information. The percentage is lower for the total and peak DC power installed, namely 42%. The situation is similar regarding the voltage level, meaning that 60% and 37.5% of the labs respectively shared such information. A reason for the difference between the percentages with respect to AC and DC power and voltage can be due to the fact that some labs may only have AC installations. Figure 37 and Figure 38 show the percentage of labs having a specific AC and DC power installed. It should be noted that only the labs that have given feedback on this question have been considered for the percentage extraction. Regarding the AC installed power, most of the labs (34%) have a power capability between 100 and 500 kW. Only a small percentage (11%) has power capability of over 1000 kW. It is also noteworthy that in total 35.8% of the labs have installed power capability of up to 100 kW. With respect to the DC power installed, most of the labs have a power between 10 and 50 kW (30%), whereas a significant amount (27%) has a smaller installed power capability of up to 10 kW. The situation is similar to the AC installed power case when it comes to labs with high power installed, over 1000 kW, meaning that only a small percentage has large DC power (12%).

Figure 37. Total AC power installed (kW) and percentage of labs with such power.

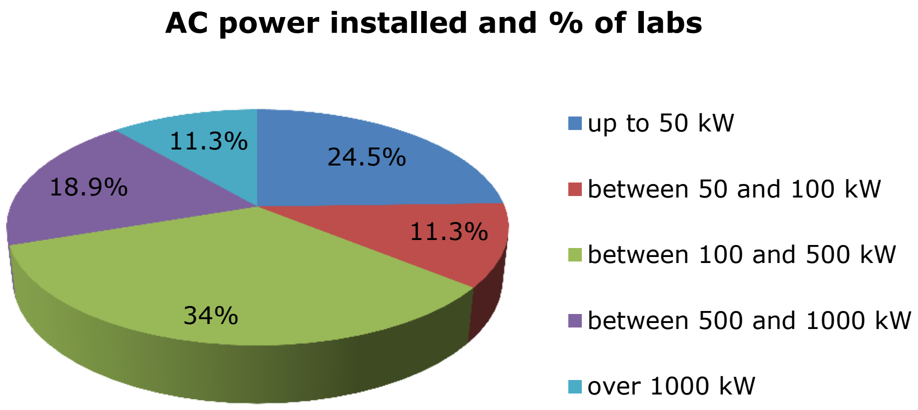


Figure 38. Total DC power installed (kW) and percentage of labs with such power.

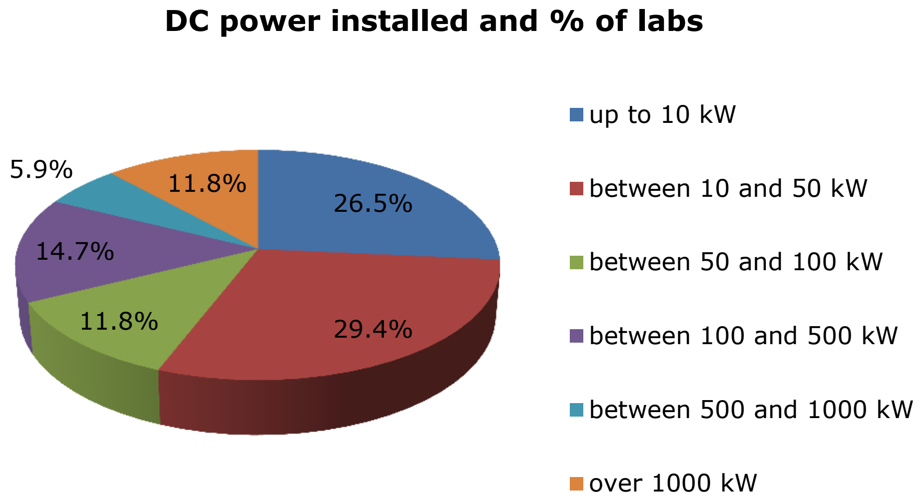


Figure 39 and Figure 40 show the peak AC and DC power of the installed equipment. It can be observed that a higher percentage of labs (30.6%) use a lower AC peak power (up to 50kW) for the installed equipment with respect to total number of labs that have this power installed. On the other hand, again for the AC case, a lower percentage of labs (25%) use a power between 100 and 500 kW in comparison to the equivalent percentage that has this installed power (Figure 37). As for the DC peak power of the installed equipment, the percentages of the labs using a specific power is similar to the ones that have this power capability level installed in their lab (Figure 38 and Figure 40).

Figure 39. Peak AC power (kW) of the installed equipment (kW) and percentage of labs with this power.

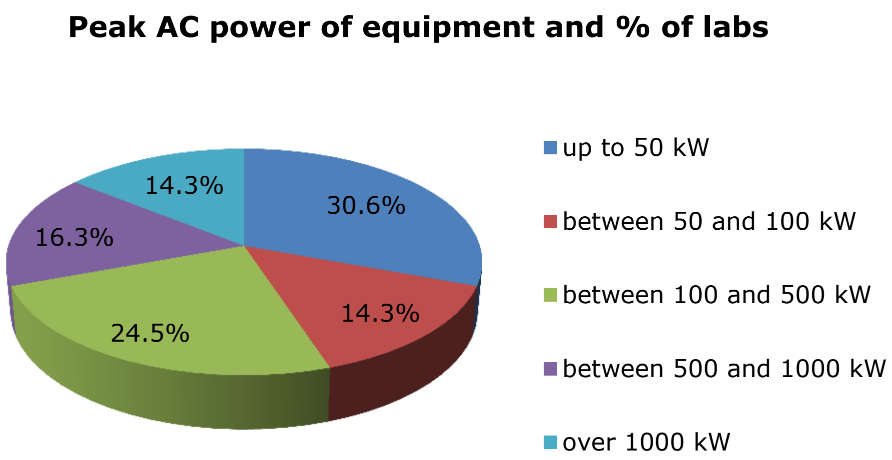


Figure 40. Peak DC power (kW) of the installed equipment and percentage of labs with this power.

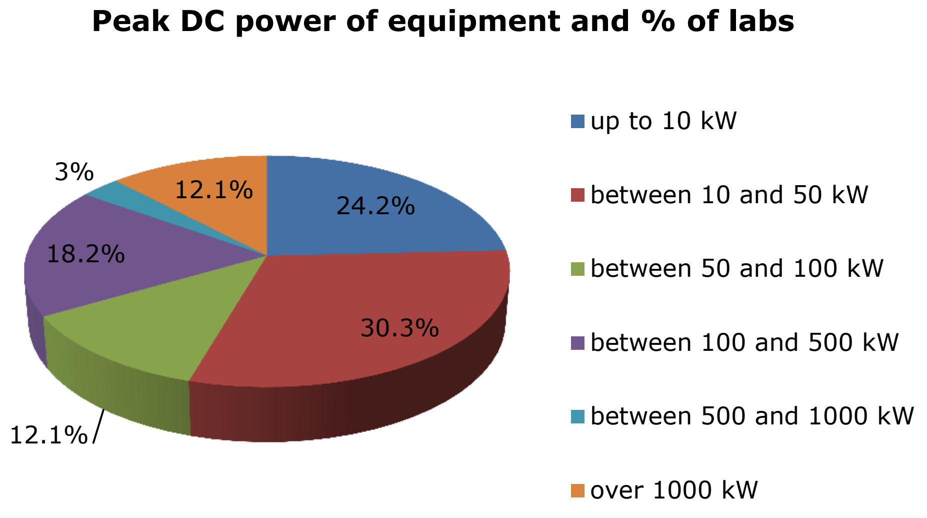


Figure 41 and Figure 42 show the percentage of labs that have a specific AC and DC voltage level respectively. It should be noted that only the labs that have given feedback on this question are considered for extracting these figures. It can be observed that the majority of the labs use a voltage up to 400 V for the AC case (76.5%). On the other hand, for the DC case, the same amount of labs use a voltage of up to 400 V and between 400 and 2000 V (46.7%). In addition, there are some labs that have defined to be using multiple levels of voltage; these levels can highly vary, like from 400 V to 20 kV.

Figure 41. AC Voltage level and % of labs with this voltage.

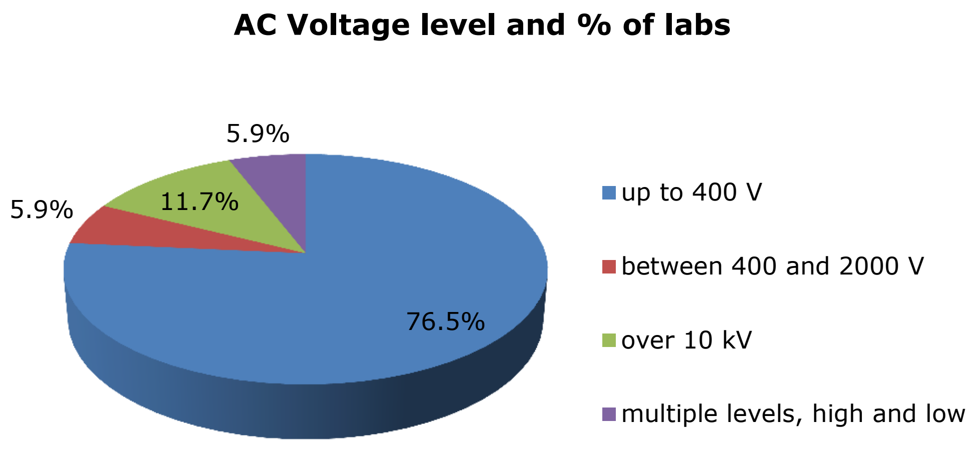
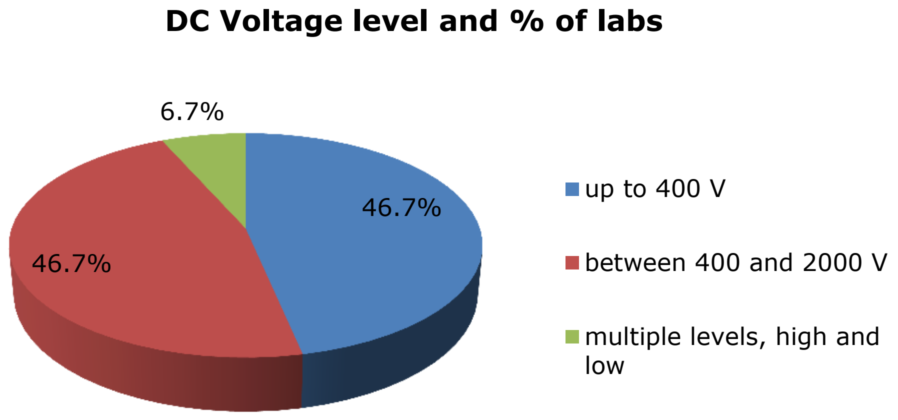


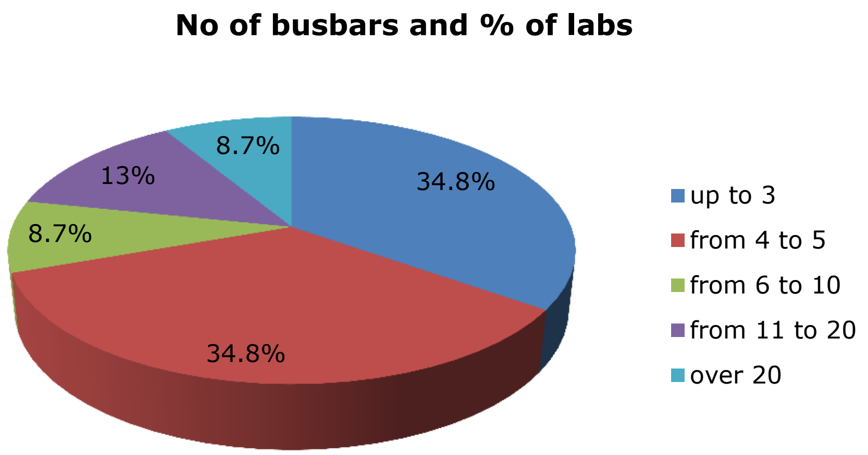
Figure 42. DC Voltage level and % of labs with this voltage.



Finally, with respect to single-phase and three-phase systems, the 46.6% of all participants stated that they use a three-phase system, whereas 35.2% of them declared of working with a single-phase system.

Regarding the operation of microgrids, the 28% of the labs participating in the survey have declared that they use a microgrid. The number of busbars for such a microgrid varies from 1 to 25. Figure 43 shows the percentage of labs that use a specific number of busbars. For the derivation of this figure, only the labs that work on microgrids have been taken into account. It is obvious that the majority of the labs (69.6%) use up to 5 busbars. A small number of labs (8.7%) uses a large number of busbars, namely over 20.

Figure 43. No of busbars and percentage of labs with these busbars.



3.5.2 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. Figure 44 shows the percentage of labs that perform HIL. As it can be observed, almost half of the labs declare that they perform such simulations, whereas only 20% approximately states that they do not perform any HIL simulations.

Figure 44. Labs performing HIL simulations.

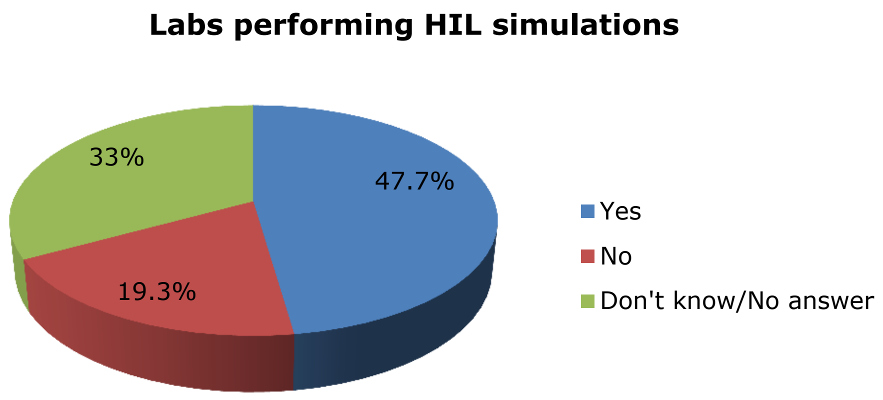
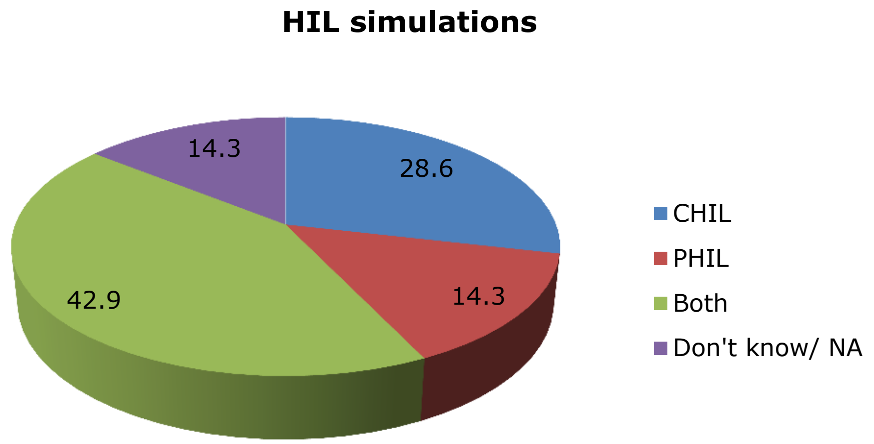


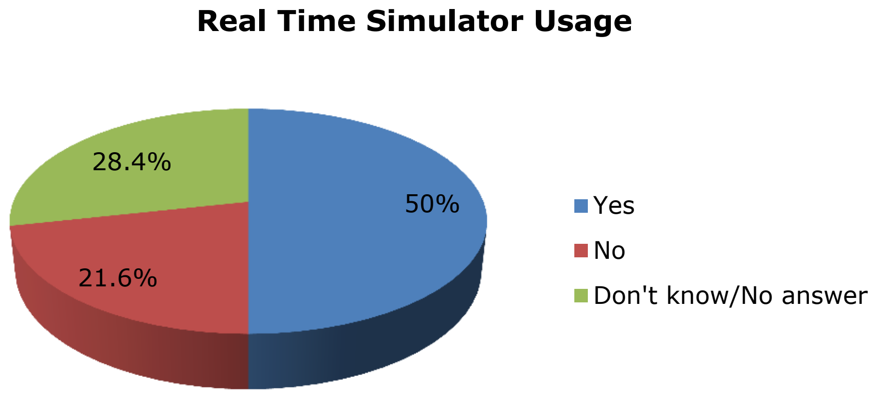
Figure 45 shows that most of the labs that perform hardware in the loop simulations, perform both control and power hardware in the loop (42.9%). On the other hand, there are many labs that perform only either control or power hardware in the loop simulations (in total 42.9%).

Figure 45. Specific topics for HIL simulations and percentage of labs working on them. The two options are control hardware in the loop (CHIL) and power hardware in the loop (PHIL).



Finally, we address the issue of the usage of a real time simulator or not. Figure 46 shows the situation, where it is obvious that half of the labs do use a real time simulator for their research work. On the other hand, approximately one fifth of the labs declares that they do not work with a real time simulator.

Figure 46. Labs using a real time simulator.



4 Conclusions and Future Perspective

4.1 Conclusive Remarks

The report is the third release of the Smart Grid Laboratories Inventory, which aims at providing up-to-date information regarding the research performed in smart grid labs worldwide. The Smart Grid Laboratories Inventory gives information about the topics of research, the standards and the infrastructure used, thus providing an important insight for the smart grid trends. The project initiated with focus on Europe, containing 24 labs. Later on, the sample expanded within and beyond Europe, to reach the number of 89 labs in this release, meaning that the number of labs has become 3.7 times larger than the one in the first release. Out of these, 69 are located in Europe, 18 in America and 2 in Oceania.

After elaborating on the survey results, several conclusions can be drawn with respect to the trends of the smart grid scientific community.

First of all, the categories on which more than 70% of the labs have research activities are: Generation and DER (85.2%), Demand Response (75%), Grid Management (75%) and Storage (70.5%). These categories were also listed first in the previous report [1]. Compared to the numbers in [1], it is observed that the new sample gives very small variation (less or equal to 1%) with respect to five categories: Demand Response, Storage, Smart City, AMI and Market. On the other hand, we notice an increase of more than 4% in three categories: Generation and DER, ICT and Electromobility, with respect to [1].

As general information, it can be concluded that the sector at which most of the work is addressed to, is utilities (70.5% of labs conduct research for them), with industry and academia to follow with 66% and 65% respectively. This can be explained by the fact that these sectors are expected to reap more immediate benefits from a technological evolvement in the smart grid field. Technology development, R&D of equipment, standards development and prototype testing are fields on which more than 70% of the labs work on. In addition, 90% of the labs have their research activities on the distribution grid, whereas the islanded grid and the transmission grid are the ones to follow with 60% and 57% respectively. This can be explained by the fact that the distribution grid features a higher level of complexity, since it has to perform tasks - like monitoring of end-client consumptions, renewable resources integration and substation automation – with very different characteristics and a large number of entities to interact with.

With respect to investments for the initial setup of the lab, something more than one fourth of the labs (27%) has spent between EUR 100,000 and EUR 500,000 as initial lab investments. Almost 1 out of 10 labs (11%) has dedicated investments of up to EUR 4 – EUR 5 million for the lab setup. The period in which these investments are spanned varies; however, almost 4 out 10 labs (38.5%) have performed the investments throughout 2-3 years. Regarding the lab running cost, more than one third of the labs (36.6%) have a running cost lower than EUR 100,000, whereas only a 5% of them has a large running cost of over EUR 10,000,000. It is interesting that when it comes to future expansion intentions, no lab has given respective negative feedback. The majority of the labs has positive intention for expansion, especially for the short term period (84% of labs replying positively) and the medium term period (almost 80%). This percentage drops for the long term perspective to 50%, which is reasonable, since it is difficult to have a clear idea of the expansion plans long term (over than 10 years).

In our aggregated analysis, special attention has been given to the categories of research. Specifically, sub-topics of interest have been identified and information about the standards used can be derived. The information on the categories of research can be summarized as follows, where the percentages refer to the active labs on a specific category:

Distribution automation:

- Most labs working on distribution automation focus on automation of distributed networks (42.3%) and secondarily on substation automation (35%) and self-healing networks (35%).

Grid Management:

- The subtopic of interest that comes first on the list is monitoring and diagnosis tool (55%).
- Half of the labs working on grid management work on microgrids, whereas PMUs also attract the interest of half of the labs active on this category.
- The majority of labs working with storage focus on batteries (80.7%).
- Regarding energy storage applications, demand shifting and peak reduction is the number one on the list.

Storage:

- The majority of labs working with storage focus on batteries (80.7%).
- Regarding energy storage applications, demand shifting and peak reduction is the number one on the list.

Market:

- Market structure is the number one sub topic when it comes to research on market (62%).

Generation and DER:

- The main technologies on which the labs work are photovoltaics and wind energy, with percentages 80% and 70% respectively.

Electromobility:

- The top topics under investigation are: vehicle to grid (55.6%), energy storage (56%) and charging technologies (52%).

Smart Home/ building:

- Areas of research most smart home labs are active in descending order: energy management strategies/cost-control (71%), demand response (64%), integration of RES (62%).
- More than 70% of the labs active in smart homes also do software applications.
- The most widely used telecommunication technologies are: wireless (64%), Ethernet copper cabling (55%).

Smart Cities:

- Most common areas of research are: Energy generation (57%), ICT (50%), Energy storage and Mobility (43%).
- The following topics are the most popular in software development for smart cities: management (42%), control (36%) and communication/protocol (33%).

Demand Response:

- Areas of research most popular within demand response: DER integration (64%), Storage (48%), Smart Home/Smart Building (47%), DRMS (47%).
- The most widely applied standards are: OpenADR Alliance (15%), IEC 61970 - Energy management system application program interface (13%).

ICT Communication:

- Networks in which labs conduct research: LAN (47%), WAN (42%), FAN (29%), HAN (29%).
- Wireless technologies that most labs conduct research on: Wi-Fi (77%), LTE (55%), GSM (50%), GPRS (45%) and Zigbee (45%).

- PLC technologies are investigated by 47% of the labs in ICT, with mostly used technologies: NB-PLC – (58%), BPL (38%).
- Of the ICT labs 55% perform research in monitoring and control.

Cyber Security:

- Top ranked areas of research in cyber security: integrity (31%), confidentiality/privacy (28%).

Advanced Metering Infrastructure:

- Key activities carried out by the labs: Monitoring (53%), demand response (43%), communication (43%) and interoperability (40%).
- Data communication channel technologies used by the labs: Wireless (53%), PLC (48%) and Wired (38%).

It is also noteworthy that one standard stands out in 7 out of the 13 smart grid categories, which is the IEC 61850. Actually, it is ranked as the first standard to be used in these 7 categories, namely: Distribution Automation, Grid Management, Storage, Generation & DER, Electromobility (for communication purposes), ICT and AMI. This comes in accordance also to the results presented in the previous release of the report [1].

With respect to the infrastructure used by the questioned labs, the following conclusions can be drawn:

- Half of the labs declare that they perform HIL simulations, with around 86% of them declaring that they perform control or power hardware in the loop.
- Half of the labs use a real time simulator.

4.2 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. This periodic exercise will continue to take place in the future in order to give aggregated information about the research performed in smart grid labs. A further increase of the number of Smart Grid research facilities will be sought.

In addition, an online platform will be created to achieve one of the initial targets of the project, fostering information and knowledge sharing. This platform will be hosted on a European Commission web server and will present different areas and levels of access, from open to restricted for interested parties. Visual aspects will be enhanced to facilitate the graphical representation of the information available in the repository.

As a future task, a workshop will be organized at JRC premises with a number of key stakeholders with the aim of gathering a more direct feedback about the needs in the domain of data collection in Smart Grids, including the research laboratories inventory. In addition, and through different means, further promotion activities of this inventory are already planned, like promoting the inventory through worldwide known scientific Newsletters.

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List of Abbreviations and Definitions

AAA	Authentication, Authorization and Accounting
AC	Alternating Current
AES	Advanced Encryption Standard
AMI	Advanced Metering Infrastructure
AUS/NZ	Joint Australian and New Zealand Standards
BPL	Broadband over Power Lines
CAES	Compressed air energy storage
CEMS	Customer Energy Management System
CHIP	Control Hardware in the Loop
CHP	Combined Heat and Power
CIM	Common Information Model
CSA	Canadian Standard Association
DC	Direct Current
DER	Distributed Energy Resources
DES	Data Encryption Standard
DG	Distributed Generation
DR	Demand Respond
DRMS	Demand Respond Management System
DSL	Digital Subscriber Line
DSO	Distribution System Operator
EAP	Extensible Authentication Protocol
EC	European Commission
EN	European Standards
ESO	European Standardization Organisation
EUR	Euro
EV	Electric Vehicle
FAN	Field Area Network
GPRS	General Packet Radio Service

GSM	Global System for Mobile (communications)
HAN	Home Area Network
HIL	Hardware in the Loop
ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IPSec	Internet Protocol Security
JRC	Joint Research Centre
LAN	Local Area Network
LTE	Long Term Evolution
MD5	Message Digest algorithm 5
MPLS	Multiprotocol Label Switching
NB-PLC	Narrow Band Power Line Communication
NAN	Neighborhood Area Network
Oauth	Open secure authorization protocol
OpenADR	Open Automated Demand Response
OSGP	Open Smart Grid Protocol
PAN	Personal Area Network
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
PSH	Pumped-storage hydroelectricity
PV	Photovoltaics
RADIUS	Remote Authentication Dial-In User Service

RES	Renewable Energy Sources
RSA	Ron Rivest, Adi Shamir and Leonard Adleman (crypto system)
R&D	Research and Development
SAE	Society of Automotive Engineers
SDH	Synchronous Digital Hierarchy
SHA	Secure Hash Algorithm
SMES	Superconducting Magnetic Energy Storage
SONET	Synchronous Optical Network
SSH	Secure Shell
T&D	Transmission and Distribution
UTES	Underground Thermal Energy Storage
V2G	Vehicle to Grid
WAN	Wide Area Network
WI-FI	Wireless Fidelity
3DES	Triple DES

List of Figures

Figure 1. 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), as extracted from [9].. 9

Figure 2. Labs distribution according to the location in which they are based, a) In Europe, b) in America, as extracted from [1]. 10

Figure 3. Labs distribution according to the location in which they are based in a) Europe, b) the Americas and c) Australia and Oceania........15

Figure 4. Sectors for which lab research is targeted........17

Figure 5. Fields of activities for labs........17

Figure 6. Types of grids for which lab research is aimed at........18

Figure 7. Accreditation for standards held by labs. 18

Figure 8. Number of people working in the lab........18

Figure 9. Percentage of labs with specific investments. 19

Figure 10. Percentage of labs with specific investments. 19

Figure 11. Percentage of labs with specific running costs. 20

Figure 12. Short term infrastructure intentions and percentage of labs. 20

Figure 13. Medium term infrastructure intentions and percentage of labs........21

Figure 14. Long term infrastructure intentions and percentage of labs. 21

Figure 15. Percentage of labs that investigate specific Distribution Automation topics. .21

Figure 16. Objectives of research work in distribution automation. 22

Figure 17. Main research topics of Grid Management labs. 23

Figure 18. Percentage of Grid Management labs that conduct Microgrids related research........23

Figure 19. Percentage of Grid Management labs that work with PMUs........23

Figure 20. Percentage of Storage labs involving different type of Energy Storage Technologies. The technologies are: Batteries, Super-Capacitors, Flywheels, Chemical-Hydrogen storage, Pumped-storage hydroelectricity (PHS), Compressed air energy storage (CAES), Ice storage, Cold water storage, Molten Salts, Superconducting Magnetic Energy Storage (SMES), Underground Thermal Energy Storage (UTES), Thermochemical and other. 25

Figure 21. Percentage of Storage labs conducting research on different applications....26

Figure 22. Percentage of labs conducting research on different market topics. 28

Figure 23. Percentage of generation and DER labs working on different technologies. ..29

Figure 24. Percentage of electromobility labs conducting research on different research topics........32

Figure 25. Different type of software applications for electromobility. 34

Figure 26. Activities regarding smart home research. Share of the total number of labs that are active in smart home research. 35

Figure 27. Software development for smart home application. Share of labs that are active in smart home and software applications........36

Figure 28. Telecommunication technologies used in the laboratories for smart home activities. Share of the total number of labs that are active in smart home research. 36

Figure 29. Activities regarding smart city research. Share of the total number of labs that are active in smart city research. 37

Figure 30. Software development for smart city application. Share of labs that are active in smart cities and software applications. 37

Figure 31. Activities regarding demand response research. Share of the total number of labs that are active in demand response research. 38

Figure 32. Telecommunication network research in ICT activities. Shares of labs that are active in ICT. 39

Figure 33. Research in the different wireless technologies and shares of labs that are active in wireless technologies. 40

Figure 34. Research in the different PLC technologies and shares of labs that are active in PLC. 40

Figure 35. Activities regarding cyber security research and shares of labs that are active in cyber security. 42

Figure 36. Activities regarding AMI research and shares of labs that are active in AMI. 44

Figure 37. Total AC power installed (kW) and percentage of labs with such power. 45

Figure 38. Total DC power installed (kW) and percentage of labs with such power. 46

Figure 39. Peak AC power (kW) of the installed equipment (kW) and percentage of labs with this power. 46

Figure 40. Peak DC power (kW) of the installed equipment and percentage of labs with this power. 47

Figure 41. AC Voltage level and % of labs with this voltage. 47

Figure 42. DC Voltage level and % of labs with this voltage. 48

Figure 43. No of busbars and percentage of labs with these busbars. 48

Figure 44. Labs performing HIL simulations. 49

Figure 45. Specific topics for HIL simulations and percentage of labs working on them. The two options are control hardware in the loop (CHIL) and power hardware in the loop (PHIL). 49

Figure 46. Labs using a real time simulator. 50

List of Tables

Table 1. Percentage of laboratories per activity, as extracted from [1]. 11
Table 2. Percentage of labs per country within Europe. 14
Table 3. Percentage of labs per country outside Europe. 14
Table 4. Percentage of labs per activity. 16
Table 5. Standards used in Distribution Automation activities. 22
Table 6. Standards used in Grid Management activities. 24
Table 7. Standards used in Storage activities. 27
Table 8. Standards used in market activities. 28
Table 9. Standards used in generation and DER activities. 30
Table 10. Utilisation percentage of the different charging topologies for EV and PHEV. .32
Table 11. Percentage of utilization of the different standards for charging connectors. .33
Table 12. Communication protocols applied for electromobility activities. 34
Table 13. ICT communication protocols and usage in shares of labs that are active in ICT. 39
Table 14. Standards and technologies used in PLC research and shares of labs that are active in PLC. 41
Table 15. Cyber security protocols and standards and usage in shares of labs that are active in cyber security. 42
Table 16. AMI standards and usage in shares of labs that are active in AMI. 44
Table 17. List of participating labs sorted by country. 61

Annexes

Annex 1. List of Participating Labs

In the following the list of participating labs is presented.

Table 17. List of participating labs sorted by country.

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	CYBERGRID GMBH	cyberGRID Smart Grids LAB	cyberLAB	Austria	www.cyber-grid.com
3	AIT Austrian Institute of Technology	Smart Energy Systems and Technologies Laboratory	SmartEST	Austria	https://www.ait.ac.at/themen/smart-grids/power-system-technologies-development-validation/smart-electricity-systems-and-technology-services/
4	VITO (as part of EnergyVille)	EnergyVille Technology lab		Belgium	www.vito.be
5	IMEC	Photovoltaics Department		Belgium	www.imec.be
6	University of São Paulo	Research Center in Smart Energy Grids	NAPREI	Brazil	http://143.107.255.134/enerq/contato.html
7	School of Electrical and Computer Engineering - University of Campinas (FEEC-UNICAMP)	Smart Grids Laboratory	LabREI	Brazil	https://www.fee.unicamp.br/lab-rei/smart-grid-laboratory-labrei?language=en

8	Technical University of Sofia	Power Electronics Laboratory	PEL	Bulgaria	www.tu-sofia.bg
9	UOIT	Energy Systems and Nuclear Science Research Centre	ESNS	Canada	https://faculty.uoit.ca/gaber/
10	Kinectrics	GRIDSIM Power Lab	GRIDSIM	Canada	www.kinectrics.com
11	Polytechnique Montreal	Optimization for Smart Grids	OSG	Canada	http://osg.polymtl.ca/
12	Centre for Urban Energy, Ryerson University, Toronto, Canada	Schneider Electric Smart Grid Laboratory	SESG Lab	Canada	www.ryerson.ca/cue
13	University of Cyprus	Research Centre for Sustainable Energy (FOSS)	FOSS	Cyprus	www.foss.ucy.ac.cy
14	Aalborg University	Smart Energy Systems	SES-Lab	Denmark	https://www.et.aau.dk/laboratories/power-systems-laboratories/smart-energy-systems/
15	VTT Technical Research Centre Of Finland Ltd	VTT Multipower test environment	Multipower	Finland	www.vtt.fi
16	Electricité de France	Concept Grid		France	http://networks-lab.edf.com
17	L2EP	Laboratory of Electrical Engineering and power electronics	L2EP	France	http://l2ep.univ-lille1.fr/?lang=en
18	Grenoble Electrical Engineering Laboratory	PREDIS	PREDIS	France	http://www.g2elab.grenoble-inp.fr/

19	CNRS	Procédés-Matériaux-Energie Solaire	PROMES	France	www.promes.cnrs.fr
20	TELECOM Bretagne / Institut MINES-TELECOM	Smart Grid Competence Center	SGCC	France	
21	RWTH Aachen University - Institute for Automation of Complex Power systems	ACS Real Time Laboratory		Germany	www.acs.eonerc.rwth-aachen.de
22	TU Berlin	Energiewende Laboratory		Germany	
23	TU Dortmund University	Smart Grid Technology Lab	SGTL	Germany	www.smartgrid-tec-lab.com
24	Centre for Research and Technology Hellas – Information Technologies Institute	CERTH/ITI nZEB SmartHouse (DIH)	nZEB SmartHouse	Greece	https://smarthome.iti.gr
25	National Technical University of Athens	Electric Energy Systems lab	EES-lab	Greece	www.ece.ntua.gr
26	Centre for Renewable Energy Sources and Saving	Microgrid and Distributed Energy Resources Laboratory		Greece	www.cres.gr
27	University College Dublin	Integrated Energy Lab	IE Lab	Ireland	https://energyinstitute.ucd.ie/work-with-us/ie-lab/
28	INSIEL s.p.a.	Divisione	Energy Saving	Italy	www.insiel.it

		Telecomunicazioni	for Building		
29	European Commission, Joint Research Centre	Electric and Hybrid Testing Facility	VeLA8	Italy	
30	European Commission, Joint Research Centre	EPIC		Italy	
31	University Mediterranea of Reggio Calabria	Measurement Laboratory		Italy	
32	Politecnico di Bari	PrInCE Microgrid - Electric Power System Laboratory	MG-Lab PrInCE	Italy	
33	Ricerca sul Sistema Energetico SpA	RSE Distributed Energy Resources Test Facility	RSE DER-TF	Italy	www.rse-web.it
34	Selta S.p.A.	Selta Smart Grid Lab	Selta_SGL	Italy	www.selta.com
35	European Commission, Joint Research Centre	Semi-Anechoic Chamber for Electromagnetic Compatibility Testing	VELA9	Italy	
36	European Commission	Smart Grid Interoperability Centre - Ispra		Italy	
37	ABB Italy	Smart Lab	Smart Lab	Italy	www.abb.com
38	University of Pisa	SmartGrid Lab	SGL	Italy	
39	Institute of Physical	Smart Grid Research	SGRC;	Latvia	http://fei-web.lv/

	Energetics (IPE)	Centre	SmartHomeLab; PMULab		
40	Kaunas University of Technology	Laboratory of Smart Electric Energy Technologies & Electric Power Networks		Lithuania	
41	DNV GL	Battery lab		Netherlands	https://www.dnvgl.com/services/battery-laboratory-arnhem-59065
42	DNV GL	Flex Power Grid Lab	FPGL	Netherlands	
43	DNV GL	Protocol test lab		Netherlands	https://www.dnvgl.com/services/protocol-standardization-and-testing-6828
44	European Commission, Joint Research Centre	Smart Grid Interoperability Centre - Petten		Netherlands	
45	University of Auckland	Power Systems Group	PSG	New Zealand	https://www.auckland.ac.nz/en/engineering/our-research/discover/research-areas-and-facilities/power-systems.html
46	NTNU and SINTEF	National Smart Grid Laboratory	NSGL	Norway	http://www.ntnu.edu/smartgrid
47	Lodz University of Technology	Institute of Electrical Power Engineering, Laboratory of Distributed Generation	DGLab	Poland	www.i15.p.lodz.pl/en
48	WROCLAW UNIVERSITY OF TECHNOLOGY	Laboratory of Power Line Communications		Poland	

49	Universidade do Minho	Group of Energy and Power Electronics - Centro ALGORITMI	GEPE	Portugal	https://www.gepe.dei.uminho.pt/
50	ISA Energy Efficiency, S.A.	Innovation & Product		Portugal	www.isasensing.com
51	EDP Labelec	Laboratory of Smartgrids	SMARTLAB	Portugal	http://www.edplabelec.com
52	INOV INESC INOVAÇÃO	N/A	INOV	Portugal	www.inov.pt
53	National Laboratory for Energy and Geology (LNEG)	National Laboratory for Energy and Geology (LNEG)	LNEG	Portugal	www.lneg.pt
54	Centro de Investigação em Energia, REN-StateGrid, S.A.	R&D Nester Real Time Power Systems Simulation Laboratory	R&D Nester Lab	Portugal	http://rdnester.com/en-GB/lab/
55	INESC TEC - INESC Technology and Science	Smart Grid and Electric Vehicle Laboratory	SGEVL	Portugal	http://reive.inescporto.pt/en
56	Skolkovo Institute of Science and Technology	Smartgrids lab		Russian Federation	https://crei.skoltech.ru/energysystems/facilities/
57	DNV GL Services Spain S.L.	DNV GL Smart Grid Lab Madrid		Spain	
58	CENTRO NACIONAL DE ENERGIAS RENOVABLES - CENER	CENER Atenea Microgrid	ATENEA	Spain	http://www.cener.com/es/areas-de-investigacion/departamento-de-integracion-en-red-de-energias-renovables/infraestructuras-y-recursos-

					tecnicos/microrred-atenea/
59	Universitat Politècnica de Catalunya - BarcelonaTech	CITCEA-Lab	CITCEA-Lab	Spain	www.citcea.upc.edu
60	ORMAZABAL Corporate Technology	Demonstration & Experimentation Unit	UDEX	Spain	http://www.ormazabal.com/en/about-us/our-own-technology/technological-innovation-center
61	CARTIF	ENERGY DEPARTMENT		Spain	www.cartif.com
62	Tecnalia	InGRID. Smart Grids Testing and Research Infrastructure	InGRID	Spain	http://www.tecnalia.com/en/energy-environment/index.htm
63	GAS NATURAL FENOSA	Interoperatibility Laboratory	LINTER	Spain	http://www.unionfenosadistribucion.com/es/redes+inteligentes/1297137260045/conozca+nuestro+laboratorio.html
64	Catalonia Institute for Energy Research (IREC)	IREC Energy SmartLab		Spain	www.irec.cat
65	IK4-CEIT (Centre of Studies and Technical Research) / JEMA ENERGY	iSare Microgrid Gipuzkoa	iSare	Spain	www.i-sare.net
66	Universidad Politécnica de Madrid	Net-Positive Energy Building: "Magic Box"	MagicBox	Spain	http://www.ies.upm.es/
67	Instituto Tecnológico de la Energía (ITE)	Renewable energy integration and demand side management	ITE	Spain	www.ite.es

		laboratory			
68	IREC - Catalonia Institute for Energy Research	Semi-virtual Energy Integration Laboratory (SEILAB)	SEILAB	Spain	www.irec.cat
69	IMDEA	Smart Energy Integration Lab	SEIL	Spain	http://www.energy.imdea.org/scientific-facilities/smart-energy-integration-lab
70	CIRCE	SMART GRIDS LABORATORY	RESEARCH CENTRE FOR ENERGY RESOURCES AND CONSUMPTION	Spain	www.fcirce.es
71	STRI	STRI Smart Grid Research, Development and Demonstration Platform	STRI RD&D	Sweden	www.stri.se
72	École Polytechnique Fédérale de Lausanne	Distributed Electrical Systems Laboratory	DESL	Switzerland	http://smartgrid.epfl.ch
73	Delft University of Technology	Electrical Sustainable Power Laboratory	ESP Laboratory	The Netherlands	https://www.tudelft.nl/en/eemcs/the-faculty/departments/electrical-sustainable-energy/dc-systems-energy-conversion-storage/electrical-sustainable-power-lab/
74	University of Strathclyde	Power Networks Demonstration Centre	PNDC	United Kingdom	www.strath.ac.uk/pndc
75	Imperial College of London	Smart Energy Laboratory		United Kingdom	http://www.imperial.ac.uk/electrical-engineering/research/control-and-power/

76	Durham University	Smart Grid Lab		United Kingdom	https://www.dur.ac.uk/ecs/smart.grid/
77	Newcastle University	Smart Grid Laboratory and Energy Storage Test Bed		United Kingdom (UK)	https://www.ncl.ac.uk/engineering/about/facilities/electricalelectronicengineering/smart-grid/#overview
78	NC State University	FREEDM Systems Center	FREEDM (Future Renewable Electric Energy Delivery and Management)	United States	freedm.ncsu.edu
79	Colorado State University	Advanced Power Engineering Laboratory	APEL	United States of America	https://sites.google.com/rams.colostate.edu/ssuryana/apel
80	Florida State University	Center for Advanced Power Systems	CAPS	United States of America	www.caps.fsu.edu
81	National Renewable Energy Laboratory (NREL)	Energy Systems Integration Facility	ESIF	United States of America	http://www.nrel.gov/esif/
82	Lawrence Berkeley National Laboratory (LBNL)	FLEXLAB		United States of America	flexlab.lbl.gov
83	Princeton University	Princeton Laboratory for Energy Systems Analysis	PENSA	United States of America	http://energysystems.princeton.edu
84	Colorado School of Mines	Research Group Advanced Control of Energy and Power Systems	ACEPS	United States of America	http://aceps.mines.edu/

85	Kansas State University	Smart Grid Lab		United States of America	http://www.ece.k-state.edu/research/powerandenergy/sgl/index.html
86	EnerNex	Smart Grid Labs	SGL	United States of America	
87	UCI Microgrid Testbed	University of California, Irvine Advanced Power and Energy Program	UCI APEP	United States of America	www.apep.uci.edu
88	Microgrid Systems Laboratory	New Mexico SMART Grid Center		USA	http://microgridsystemslab.com
89	Washington State University	Smart Grid Demonstration and Research Investigation Lab	SGDRIL	USA	sgdril.eecs.wsu.edu
Labs who's survey responses were received after the deadline and which will be included in the following release of the inventory:					
90	CNRS	Laboratory of Analysis and Architecture of Systems	LAAS-CNRS	France	https://www.laas.fr/
91	Schneider Electric Spain	Laboratorio de Ensayos alta Tensión Griñón	LEATG	Spain	https://www.schneider-electric.es/es/
92	Technical University of Catalonia	MCIA Innovation Electronics	MCIA	Spain	www.mcia.upc.edu

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