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# Smart Grid Laboratories Inventory 2016

Andreadou N., Olariaga Guardiola M.,
Papaioannou I., Prettico G.

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**Contact information**
Name: Nikoleta Andreadou
Address: Joint Research Centre. Building 44 Office 114 Via Enrico Fermi 2749
Email: nikoleta.andreadou@ec.europa.eu
Tel.: +39 0332 78 3866

**JRC Science Hub**
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**Title**
*Smart Grid Laboratories Inventory 2016*

Abstract
*The smart grid implies that a vast amount of information needs to be handled and requires an effective energy management. Assessing the new technological solutions that would best accommodate the needs of a smart grid is of vital importance. This report aims at collecting information about the smart grid topics of research, the technologies and the standards used by top organizations that hold smart grid activities at a laboratory level. For this purpose an online questionnaire has been used. The report presents aggregated results that give an insight into the state-of-the-art regarding the smart grid field.*

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- Centre for Urban Energy, Ryerson University, Toronto (Schneider Electric Smart Grid Laboratory) – Canada
- EnerNex (Smart Grid Labs) – USA
- EDP Labelec (Laboratory of Smartgrids) – Portugal
- Institute of Physical Energetics – IPE (Smart Grid Research Centre) – Latvia
- Princeton University (Princeton Laboratory for Energy Systems Analysis) – USA
- L2EP (Laboratory of Electrical Engineering and power electronics) – France
- Durham University (Smart Grid Lab) – UK
- Florida State University (Center for Advanced Power Systems, CAPS) – USA
- Lawrence Berkeley National Laboratory – LBNL (FLEXLAB) – USA
- Imperial College of London (Smart Energy Laboratory) – UK
- Centro de Investigação em Energia, REN-StateGrid, S.A. (R&D Nester Real Time Power Systems Simulation Laboratory) – Portugal
- IMEC (Photovoltaics Department) – Belgium
- National Laboratory for Energy and Geology (LNEG) – Portugal
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- IMDEA (Smart Energy Integration Lab, SEIL) – Spain
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- Ricerca sul Sistema Energetico SpA (RSE Distributed Energy Resources Test Facility) – Italy
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- GAS NATURAL FENOSA (Interoperatibility Laboratory) – Spain
- WROCLAW UNIVERSITY OF TECHNOLOGY (Laboratory of Power Line Communications) – Poland
- Electricité de France (Concept Grid) – France
- University Mediterranea of Reggio Calabria (Measurement Laboratory) – Italy
- VTT Technical Research Centre Of Finland Ltd (VTT Multipower test environment) – Finland
- Lodz University of Technology (Institute of Electrical Power Engineering, Laboratory of Distributed Generation) – Poland
- CARTIF (ENERGY DEPARTMENT) – Spain

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

***Authors***

Nikoleta Andreadou, Miguel Olariaga Guardiola, Ioulia Papaioannou, Giuseppe Prettico

## Executive Summary

This is the second release of the Smart Grid Laboratories Inventory. The project was launched in November 2014, and the first report was issued in early 2015 [1]. The aim is to collect information about the smart grid laboratories in Europe and beyond. Furthermore, the Joint Research Centre (JRC) as a neutral data broker can guarantee data accuracy and confidentiality.

The electricity grid is undergoing significant changes and one can foresee its further evolution in order to adapt to the increasing regulatory, market and technological demands. Particularly, the development and growth of Renewable Energy Sources (RES) has implied a transformation in the way electricity is produced and managed. In addition, the necessity to reduce the total $CO_2$ emissions calls for a better and more efficient energy usage. Modern power grids are adapting to cope with this new scenario, with massive integration of control, power electronics and information and telecommunication technologies (ICT), new operational and planning strategies and emerging innovative service arrangements.

A smart grid implies that a vast amount of information needs to be properly handled. Efficient energy management requires a constant monitoring and control of the power grid, and flows of data among different actors. However, for the advances in ICT, power electronics and other technologies to have an effective impact on the modernization of the grid, they will have to be subject to a considerable effort in testing and trial in laboratory settings. These laboratory activities need to be devoted not just to the single technology, but more importantly to the integration of systems and to the collective features – most prominently the interoperability among components.

As it can be expected, evaluating these new technologies and deciding on the technological solutions that would be most suitable for each use case requires substantial research and experimental work in dedicated laboratories. 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. This complements the contribution of the JRC to the evaluation of ongoing Smart Grid developments. Other works have been carried out towards this direction, like the Smart Grid Projects Outlook [2] (since 2011), where the European smart grid projects are presented and described, the inventory of Distribution System Operators in Europe [3], the assessment framework for the identification of Smart Grid Projects of Common Interest (PCI) [4], and the Cost Benefit Analysis of Smart Grid Projects [5].

In this second Smart Grid Laboratories Inventory report, we followed the same approach applied in the first release. An online questionnaire has been used in order to obtain information about the smart grid research carried out by identified laboratories/organizations. The questionnaire has a structure similar to the one used in 2015; apart from a few changes judged necessary after the feedback received from the participants of the first release. The questionnaire consists of three parts:

- The first part refers to general questions, such as which sector the research focuses on, which fields of research are pursued, what kind of collaborations are held, whereas emphasis is also given on the investments planned by the research organizations;
- 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;

- 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.

The research activities have been divided in 13 categories, namely: Distribution Automation, Grid Management, Storage, Sustainability, Market, Generation and DER (Distributed Energy Resources), Electromobility, Smart Home/Buildings, Smart Cities, Demand Response, ICT (Information and Communication Technologies), Cybersecurity, AMI (Advanced Metering Infrastructure). Detailed information is gathered concerning the activities in each category, the standards/technologies used and objectives of the research activity.

One of the goals of this second release was to increase the sample of the participating labs in the survey, so as to obtain more accurate results about the smart grid research being carried out. In addition, one of our targets was getting feedback from labs outside Europe. For this purpose, focus was given to labs located in USA, as this would help enhancing the collaboration Europe-USA. Expanding to other territories is a future objective of this Inventory. Whereas the first report included information from 24 labs, 45 new contributions have been obtained for this release. This new report includes also the information obtained from the 24 former participants, since none of them objected in using their data for the 2016 report version. Therefore, in total the sample of this report results in 69 labs, meaning that it has been more than doubled with respect to the 2015 SGLI report.

Furthermore, in an attempt to obtain more information about the smart grid topics that are under investigation, a thorough internet search was carried out on further 31 labs, thus resulting in an extended sample of 100 labs/organizations. Although in depth information is still missing about the standards and technologies used by these 31 extra labs, mainly due to difficulties in finding such detailed information in their web sites, some conclusions can be drawn about the technological smart grid research trends.

Some general conclusions deducted from our survey sample and from the extended sample are summarized as follows:

- The main customers of the smart grid labs are utilities, the academia and industrial companies.
- The initial budget for setting up the lab is, on average, around 2 M€, but for large institutions it reaches up to 30 M€. On average, the estimated total annual running cost amounts to a median value of 135,000 €.
- IEC 61850 is the mostly used standard (in 7 out of the 13 categories) for: Distribution Automation, Grid Management, Storage, Generation & DER, Electromobility (for communication purposes), ICT and AMI activities. For the other categories, more specific standards are adopted.
- Our survey sample has shown that among the 13 categories identified, those that attract mostly the scientific interest are: Generation & DER, Demand Response, Grid Management and Storage. This comes in accordance with the conclusions drawn from the extended sample of 100 labs, where the top categories are proved to be again Generation & DER, Grid Management and Storage.
- A minimum of 40% of the total number of labs (100) uses a real-time simulator, whereas at least 47% of them perform research on microgrids.

JRC has the objectives of making the smart grid lab inventory a periodic exercise (ideally an annual activity). The goal is to obtain as much information as possible about the

smart grid activities carried out at a laboratory level, the technologies and standards used, so as to derive concrete conclusions about current and future trends in the smart grid field. The future tasks to be carried out can be summarized as follows:

- To revise the structure of the survey. Areas will be adapted to actual trends in Smart Grids and further collaboration with the main standardization organizations in the world is expected. Simplification of the overall structure will be also tackled.
- To create an online platform to achieve one of the initial targets of the project, this is fostering information and knowledge sharing. Visual aspects will be enhanced to facilitate the graphical representation of the information available in the repository.
- To organize a workshop at JRC premises with a number of key stakeholders with the aim of gathering a 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 will been planned along the year.
- To further extend of the number of Smart Grid research facilities that will take part in the inventory. The survey will be further customized to target the different world areas and the report will be divided accordingly.

Benefits for participating organisations are numerous, and will become more significant as the inventory grows:

- The report will contribute to analysing the trends in the smart grid field, thus constituting a valuable tool for identifying the technological gaps and guiding future funding programs.
- The online website is expected to increase visibility for the participants. It can result in an important means of identifying the appropriate partners for research in the smart grid field, thus enhancing collaborations between participants.

With the increase of the survey participants, which is the first objective for the future releases of this exercise, the value and significance of the results will increase. This will be the basis for the key message to all willing to contribute to the inventory: the usefulness of the collective effort facilitated by the JRC highly depends upon the quality of the information provided by the participants. Once this quality is guaranteed, the results of the inventory will have a positive impact on the stakeholders directly interested on smart grid research (industry, R&D organisations, academia), decision makers (R&D programmes, business, policy), and society at large.

# 1 INTRODUCTION

## 1.1 Smart Grid definition

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 CO2 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 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. Information and Communication Technologies (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 distributed energy resources (DER) and large-scale renewable sources (RES) and the implementation of different systems and functions for demand response (DR). 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.

## 1.2 Smart Grid interoperability

Interoperability is defined as the ability of two or more networks, systems, devices, applications, or components to interwork, to exchange and use information in order to perform required functions [6]. Interoperability is an important enabling aspect of technology deployments that Smart Grids are required to address.

Smart Grids are systems-of-systems with a broad scope, integrating electricity, information, communications, business process, and diverse appliances, in addition to interconnecting with other systems and enabling markets and transactions. The interoperability challenge derives from the integration of different components by different actors (industrial, end users) and constructed according to different standards. The lack of a common reference obstructs and delays the implementation of the smart

grids and the other systems that depend on them, mainly distributed renewable energy sources and electric vehicles.

In 2011, the European Commission issued the M/490 Standardization Mandate to European Standardization Organizations (ESOs) to support the European Smart Grid deployment. Consequently, CEN (European Committee for Standardization), CENELEC (European Committee for Electrotechnical Standardization), and ETSI (European Telecommunications Standards Institute) were requested to develop a framework to enable them to perform continuous standard enhancement and development in the field of Smart Grids, while maintaining transverse consistency and promoting continuous innovation. The CEN-CENELEC-ETSI Smart Grid Coordination Group recently finalized four reports: Extended Set of Standards to support Smart Grids deployment, Overview Methodology (which also includes as annexes the Architecture Model, Flexibility Management and Market Model Development), Smart Grid Interoperability and Smart Grid Information Security. Through those four reports it has been clearly pointed out the problematic of the high level of complexity related to the development of Smart Grids. As part of the technical reference architecture, a Smart Grids Architecture Model (SGAM) Framework is presented.

**Figure 1.** SGAM – Smart Grid Architectural Mode

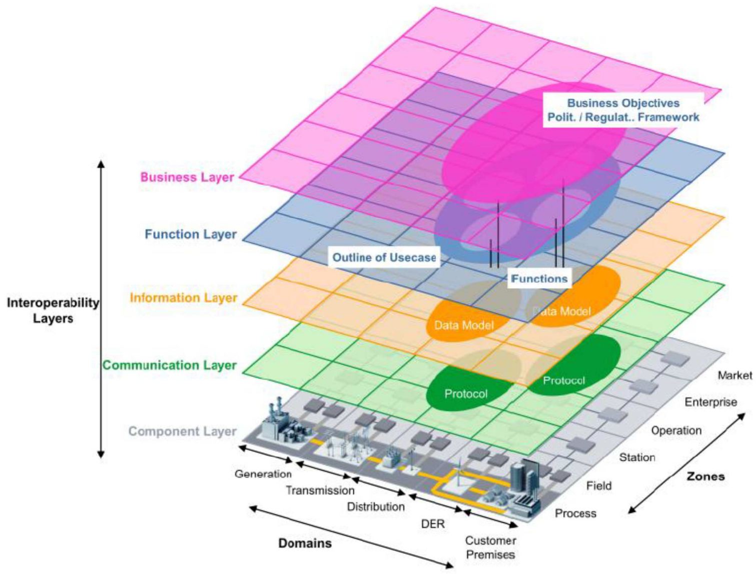



Figure 1 shows that the SGAM is a three-dimensional model that merges the dimension of the five interoperability layers (Business, Function, Information, Communication and Component) with the two dimensions of the Smart Grid Plane, i.e. zones (representing the hierarchical levels of power system management: Process, Field, Station, Operation, Enterprise and Market) and domains (covering the complete electrical energy conversion chain: Bulk Generation, Transmission, Distribution, DER and Customers Premises). One of the ideas that clearly emerge from this three-dimensional representation is that the number of actors involved and the relationships among them increases the already existing high level of complexity of the development of end-to-end Smart Grid solutions and applications.

From a technical point of view, interoperability requires exchange of information among actors. Smart Grid use cases detail that exchange of information and the required functions to achieve the use case expected result. Actors exchange information with other actors through interfaces and international standards, technologies and specifications are applicable. However, it is not sufficient that those actors conform to international standards for achieving interoperability. In fact, some standards have options resulting in incompatible implementations. In addition, regulatory issues might

restrict some of the functions that can be implemented in different countries in the different Smart Grid domains. Finally, before specifications or technologies are standardised they follow a development process that can result in incompatible implementations. Designing, developing and testing Smart Grid systems and components having an interoperability-by-design approach results crucial in order to increase the chances of achieving interoperability in the final products. For this, the existence of Smart Grid laboratory facilities, where design, development and testing can be carried out is fundamental.

In addition to the high number of actors and the complex relationships among them it is necessary to mention the existence of different world region practices that normally involve the use of different technologies and standards in some cases incompatible with each other. In vast homogeneous internal markets, this might have a lesser impact. However, in areas where different countries share common interconnection networks and might need to add redundancy mechanisms to ensure a higher resilience level, this point is never negligible. In fact, most power grid networks date back to a time when power and communication exchange needs were not as necessary as they are today and when global commerce was far from today's situation. As an example, electric vehicle manufacturers are compelled to reduce production costs if they are to compete in a globalized market. And that might only be achievable if standards are applied in as many levels as possible and it is important to ensure that little customization is required for the different world markets. Otherwise, production costs will necessarily increase. From such a complex example, it is obvious that interoperability issues should be addressed at the production process. In fact, interoperability is to play a key role in the ecosystem of the Smart Grids as different products from different manufacturers must be able to work together. And in a global economy, where manufacturers can target different world regions as part of their marketing process, the analysis of the standards, technologies, regulations and research areas worldwide is necessary.

## 1.3 Smart Grid laboratories

Achieving interoperability is a key aspect to support the need for Smart Grid research facilities, although it is not the only one reason. The current power grids have existed for many decades and for obvious reasons they cannot be rebuilt and replaced instantaneously. Alternatively, a new smart layer – the Smart Grids – can be designed and deployed for the existing grids.

Reference [2] shows that around 210 R&D projects with a total budget of about €830 million and around 250 demonstration projects with a total budget of about €2300 million have been developed in Europe in the last few years. 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.

In conclusion, 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.

Many research organizations, 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.

There is a wide variety of laboratories. Several are dedicated to pure research activities, technologies development, services or novel applications. Others are focused on factory,

performance and interoperability tests, through providing pre-configured test-beds available to manufacturers interested in guaranteeing compliance. There are also facilities primarily focused on accreditation and standardization activities. Generally, it is quite common to combine two or more types of activities.

In terms of activity areas, the range is even broader. Some facilities concentrate in only one area. However, most of them have the possibility to work on two or more areas in the same premises. Some large organizations have independent laboratory facilities under the same corporate umbrella, each of them covering a different area of activity, from generation to distribution, automation or power electronics. In that sense, one of the facilities becomes the client of another lab facility of the same organization in a coordinated effort to cover as many steps in the supply chain as required.

As a direct consequence of the type of activities carried out, it is possible to find laboratories that perform research work in a stand-alone fashion, since no external participation is needed to complete the research process. This is typical of large organizations that have the possibility to count with different facilities that cover different areas. On the contrary smaller organizations which primarily focus on specific areas usually tend to find partners to carry out their research activities. In that sense their facilities normally form part of a distributed network of research, where each resource plays a specific and independent role in the whole process.

Finally, the most popular form of facility is that of physical assets (imperative in the case of prototype development) where research activities are carried out with real hardware. However, it is also possible to find facilities with virtual equipment where most of the research activities are carried out in simulated environments. The availability of real time simulation systems has facilitated this possibility to organizations who do not count with large facilities or who are dedicated to small, specific components. It has also been a solution to those who wish to perform control-in-the-loop and/or hardware-in-the-loop tests by simulating the power grid on a real time system and connecting only the physical device under test.

Smart grids involve a significant number of actors, from energy providers and grid operators to telecom carriers, equipment manufacturers, standardization bodies, markets, the car industry, prosumers and consumers, severely increasing the difficulty to acquire an overview of what the current situation is at a given moment. In addition, investments to build smart grid lab facilities are considerable, increasing the dispersion of the lab capabilities and locations. In fact, consortiums 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. 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) [7], DERlab [8], the European Network for cyber security (ENCS) [9] and Futured [10] are just some concrete examples of these established partnerships with different technological and/or territorial scope.

As common in high-level technological sectors, laboratories face a number of difficult challenges which tend to jeopardize their long-term activity. As known, laboratory facilities require considerable investments in infrastructure. In some cases, i.e. communication technologies, capital recovery over the life of the investment can pose a serious problem, since these technologies evolve very fast. In other cases, particular problems have to be addressed by very specific facilities: as an example, a low number of yearly operational hours of the research infrastructure risks to challenge the economic sustainability of the investments that have been done. Apart from economic concerns, research infrastructures require a great deal of specialization, given the sophisticated technical tools and systems that have to be managed. A major problem can thus be the scarcity of experienced teams for setting up the facilities and carry out the experiments. Moreover as it is well known, the successful roll out of the different technologies depends

greatly on the standards harmonization over the regions. It is also necessary to assess to what extent and where, the different standards are being used.

## 1.4 Expected benefits

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 organizations, 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.

Despite the wide range of smart grid research areas and the intrinsic confidentiality and secrecy needs inherent to some research activities, there is a clear added value in the idea of having a general overview of the existing smart grid research facilities, their locations, their areas of activity and the standards and technologies in use. In some cases not only is it an added value but also a fundamental component. For instance, as already pointed out, smaller lab facilities are based on partnerships to be able to carry out research activities in larger projects. Nevertheless, finding partners represents sometimes a hard task. Additionally, there is the need for accreditation as well as, amongst other, to advertise more broadly the services offered (independent testing organizations). Web sites are certainly used by organizations as a platform to explain and offer their services. Indexing those sites might thus be the key element to bring higher visibility to their portfolios. A global overview of lab facilities might also play a key role in assessing market needs and identifying gaps in technological research, so that new programs with public or private funding can be developed and tailored to cover rising needs.

It is clear that the availability of information regarding smart grid research lab facilities, their activities, locations and connections can represent a key component to contribute to the development of Smart Grids in a more coordinated and harmonized way. This will ultimately result in improved chances of reaching the main targets of reducing energy related production costs, improving the efficiency of energy utilization and contributing to a more sustainable generation and consumption of electricity. However, even if it is commonly accepted that information and knowledge is the key to development, finding detailed information about ongoing smart grid research activities is not an easy task. Moreover, trying to put all the information together in order to identify common patterns and draw conclusions that can be of scientific value and use, might also be problematic. Many reasons lie behind this concept.

Smart Grid facilities can work on a large number of research areas, from renewable energy sources to electric vehicles or ICT. They can also involve a significant number of actors, from energy providers to telecom carriers, equipment manufacturers, standardization bodies, markets, the car industry, prosumers and consumers. Such a variety severely increases the difficulty to acquire an overview of what the current situation is at any given moment.

Research laboratory facilities can also present fairly complex setups and interconnections with other facilities, most likely as a consequence of the increasing complexity due to the variety of actors and relationships.

In addition, the wide range of activities that can be carried out can have very specific and only locally significant scopes. Although there are concepts globally accepted, each organization might see the situation from a different perspective, have different perceptions of things and can use its own organizational nomenclature to express its activities. This in turn adds an additional complication to the tasks of harmonizing information and comparing facilities or competencies.

Last but not least, there is a continuous development of new technologies and standards that make it difficult to keep track of all the different evolutions at all times. Online

information becomes soon obsolete, especially if it involves Information and Communication Technologies that evolve at a really high pace.

Moreover, investments to build smart grid lab facilities are considerable, increasing the dispersion of the lab capabilities and locations; in fact, consortiums and collaboration efforts are sought among lab facilities in order to gain leverage in shared infrastructure and knowledge and reduce the load of having a single facility covering all areas. This normally results in difficulties to physically locate the facilities, which, in turn, brings up another issue, which is that different world areas work with different technologies and standards, some of them comparable but some not. This obviously adds substantial complexity to the effort of gathering information and processing data.

Finally, industrial secrets and confidentiality issues are always present and limit the information made available to the research organizations.

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.

## 1.5 Report structure

After having shortly introduced the need for Smart Grid research facilities, Chapter 2 presents the basis used for the survey questionnaire. 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 summarizes the main findings and insights and addresses future perspectives and work to be done.

# 2 SURVEY

## 2.1 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 Internet about organizations owning a Smart Grid lab facility. Although it was a simple option that required less effort and cost, it was very soon proved not to be 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 completion and to simplify the aggregation of information for statistical purposes. Questions were explained in detail through contextual help text to facilitate the selection of a given answer. Sections in the survey were carefully drafted and organized to facilitate understanding.

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 organization depending on the activities.

Participation in the survey was open to any organizations, public or private, owning a Smart Grid lab facility. A prelisted set of organizations were explicitly invited to participate. Those organizations 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. In addition, new releases of the survey are expected to be regularly launched. By having a personal account, participating organizations would be able to reuse all previously entered information without having to re-type everything all over again, allowing them to focus only on new aspects.

Security measures were implemented as the database might contain sensitive information.

For each lab a single Point of Contact (POC) was identified. The POC was the main contact for the JRC during the data input phase. All POCs 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 Internet (http://ses.jrc.ec.europa.eu/smart-grid-laboratories-survey) and it was completed directly by the participating organizations.

Data provided through the online survey was stored in an online repository. POC(s) had access to the provided information at all times, which allowed for updates and or cancellations at any moment. However, only the information available on the repository on the 26th of November 2014 was processed and analysed to elaborate the report. Contributions received after that deadline remained in the system but were not

processed and aggregated for the 2014 report. Instead, they have been taken into account for the 2015 exercise.

The information provided by a total of 24 Smart Grid research facilities was processed and the results were included in the first report released in early 2015 [1]. The inventory and subsequent science and policy report was mentioned in the JRC Annual Report 2015 [11], page 13.

A complete description of the survey, sections and questions can be found on the aforementioned report.

## 2.2 Second release – 2016

The present report presents the results of the second release of the inventory of Smart Gird laboratories.

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 is anonymised so no individual organization or facility can be individually identified by the information published. Additionally, it was envisaged to create an online platform with open access to share the information collected supported by different visualization tools. In addition, participants might have a restricted access to a different area of the platform in order to have the possibility to collaborate with other research organizations based on the information provided, supporting the objective of information and knowledge sharing.

With those ideas in mind, a new consultation process was launched in early 2016 in order to define the strategy of the second release and beyond. Feedback provided by participants through the online survey during the completion of the first release was analysed and incorporated into the new survey version. In addition, feedback from main European Commission stakeholders was sought and also incorporated.

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 organizations 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. Finally, it would have meant a longer process, required to redesign the structure, readapt the survey and repository and harmonize the existing information. JRC was approached by different organizations right after the publication of the first release in order to be included in the second one. Delaying this second released would have meant losing the momentum created, and potentially the number of facilities that could be incorporated into the second release. This would go against the initial aim of providing the most complete state-of-the-art, evolution and trends in Smart Grids research facilities.

Even proposed changes were reduced to the minimum, some were still implemented. The main ones had to do with the financial aspects, which were now split into investments and running costs, being the former ones targeted by year in order to be able to aggregate them properly.

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. Personal data continues to be treated according to the Regulation (EC) 45/2001, of the European Parliament and of the Council of 18 December 2000 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.

Finally, 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. World areas were expanded and representatives of India, through the India Smart Grid Forum (ISGF), Japan, Canada, Brazil and China were approached. In addition, 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 organizations.

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

## 2.3 Link with the JRC work

The European Commission (EC) 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, including the survey on Smart Grid projects in Europe (since 2011), the inventory of Distribution System Operators in Europe [3], the assessment framework for the identification of Smart Grid Projects of Common Interest (PCI) [4] and the Cost Benefit Analysis of Smart Grid Projects [5]. In order to obtain a clear picture of the ongoing Smart Grid developments the JRC has identified the need to count with a repository of smart grid lab facilities.

The rapid evolution of the smart grid technologies and standards are dictating that the availability of a repository is a necessity. Any attempts to build such inventory might only bring significant benefits if carried out at present time, when there is still a lack of maturity and the need for general and specific information is at its peak.

# 3 RESULTS

## 3.1 Overview

The results presented in this chapter are correlated to the ones presented in the first release of the project carried out in 2015, [1]. The main scope has been to increase the sample of the labs included in the previous report, so as to give a more complete picture of the situation regarding the smart grid facilities; the categories on which research is focused and the infrastructure used. The previous report included data taken from 24 laboratories/organizations, located mainly in Europe, while extra 2 laboratories had completed the survey right after the deadline for the submission.

In this release, approximately 170 organizations have been contacted and invited to participate in our survey. The vast majority of them are located in Europe and North America, where focus has been given during this second version of the project. Due to time limitations, other geographical regions have not been thoroughly examined, which would be one of the objectives for potential future releases. The organizations have been identified through several sources, mainly through a detailed internet search carried out by our team, but also with the aid of the US Department of Energy and the European National Contact Points for Horizon 2020. In general, our survey received positive feedback from the organizations we contacted. Particularly, 51 organizations (58 laboratories) were interested in our project. It is worth mentioning that 2 organizations own different smart grid labs. This number was limited due to various reasons, among others:

- problematic email addresses found during our internet search;
- lack of identifying if an organization owns indeed a lab facility for smart grid research or if the research is carried out through different means (simulations, involvement only in past smart grid activities);
- Problems in identifying the correct laboratory director/leader;
- Lack of time on behalf of the contacted organizations;
- Problems in actual communication with the organization contact points due to spam folders or accidental email deletions;

Apart from the difficulties encountered in identifying the labs and communicating the information to the equivalent contact points, the lack of time on behalf of the potential participants and time restrictions for the project's realization, limited the final number of new submitted questionnaires to 43 for this second release. The new data collected have been elaborated together with the data gathered during the first release of the project, since none of those 26 participants in total objected in using their data for this report.

Therefore, the total number of labs included in this project release has reached 69, almost 2.9 times bigger than the sample of the first report. This indicates that the results can give a better picture of the situation with respect to the smart grid facilities and smart grid research in Europe and beyond, and that the conclusions drawn can give a hint about the current trends in the smart grid field.

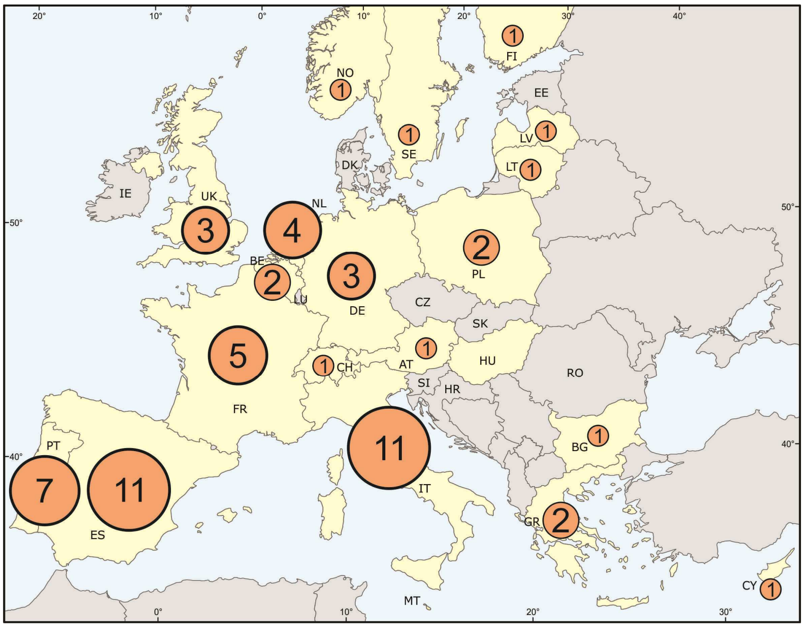
## 3.2 Location of the Laboratories

The majority of the participant laboratories are located in Europe (85.5%), covering a large number of countries. The major part of labs is in Italy and Spain (16%) with Portugal to follow (10%). This is mainly because by the location of our own lab (Italy) and the response of the equivalent National Contact Points for Horizon 2020. French, Dutch and British labs comprise the 7.2%, 6% and 4.3% respectively, whereas Belgium, Greece and Poland are represented by 2 participants (3%) each. Finally, we had one lab participant from Austria, Bulgaria, Cyprus, Finland, Latvia, Lithuania, Norway, Sweden

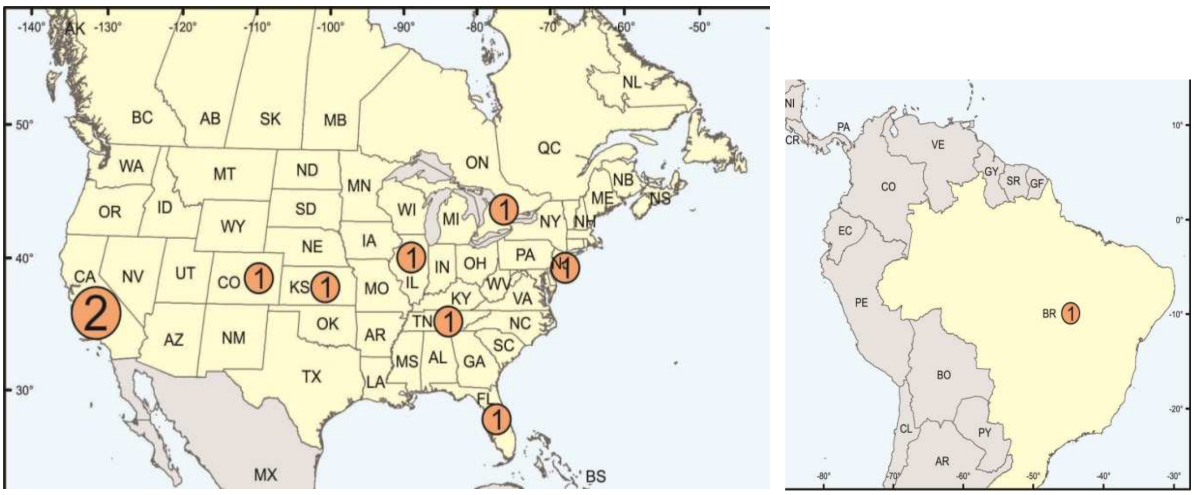
and Switzerland respectively. It is noteworthy that the number of the European labs reached more than the double of its value in the first release of the inventory, increasing from 25 to 59 labs.

One of the goals of the 2016 edition of the inventory was to include more labs outside Europe, since in the previous report 23 out of 24 labs were located in Europe. The percentage of non-European labs this time is 14.5% - 10 labs, out of which 8 are located in the USA, 1 in Canada and 1 in Brazil. This is expected to increase in future versions of this exercise, since it is intended to expand the inventory at a worldwide level. The small number of participants is partly explained by the fact that our inventory has been more advertised within Europe, as it is anticipated. Figure 2 shows the distribution of the labs that have completed our survey depending on their location.

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




a)




b)

In the following, we present the survey results, concluded from the completed and submitted questionnaires.

## 3.3 General Information

The information collected in this release is structured in a similar way to the one gathered for the 2015 Inventory. First of all it has been identified on which smart grid category the participant laboratories 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, the geographical area of interest, the way the results are disseminated, the type of collaborations held and the type of grid where research is targeted.

With respect to the smart grid research activities, 13 categories have been identified. Table 1 shows these categories and the percentage of the laboratories that work on each one of them. More detailed information about each one of these categories can be found in Section 3.6, with specific information on the standards/technologies used and the sub-topics of interest. As it can be observed from Table 1, the three most popular categories are Generation and DER (81%), Demand Response (76%) and Grid Management (73%), which were also the top three categories noticed in [1]. With respect to [1], it is noticed that 7 categories experience a similar percentage with a deviation of not more than 5%, namely the: Distribution automation, Market, Generation and DER, Electromobility, Demand Response, Cyber Security and AMI.

**Table 1.** Percentage of laboratories per activity

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

Figure 3 shows the sectors at which smart activities are targeted. As it can be easily observed, utilities, academy and industry are the sectors at which research is targeted the most with percentages 24%, 22% and 21% respectively. An 18% of the labs also perform research under governmental guidance. Regarding the specific fields of activities, Figure 4 shows information related to which extent laboratories work on R&D of software or equipment, standards or technology development, prototype testing or

patent registration. As the results show, R&D of software comes first in the list, with technology development and prototype testing to follow. R&D of equipment is also high in the list with a difference of 3-4%. It should be noted here that the percentages illustrated are derived by aggregating the percentages of each field normalized by the activities as a whole.

**Figure 3.** Sectors at which Lab research is targeted

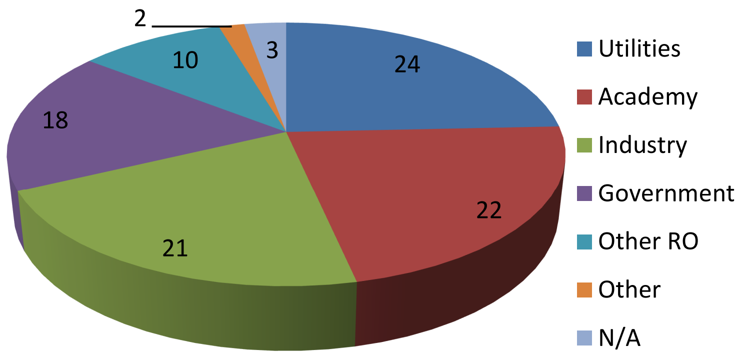
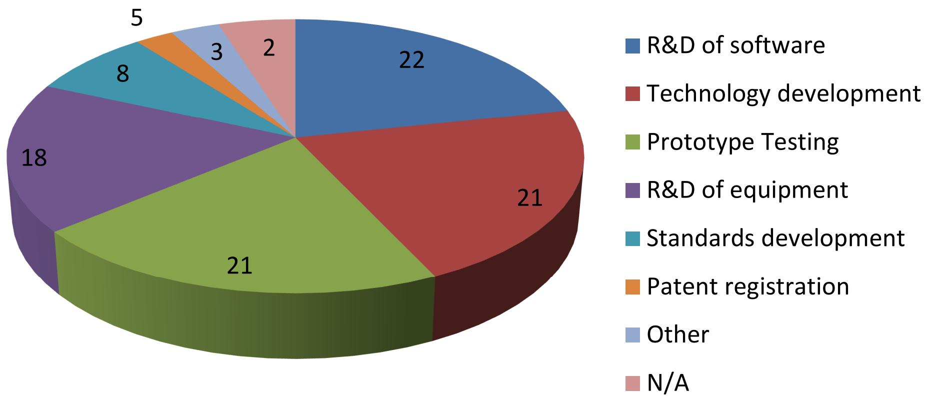



**Figure 4.** Fields of activity




In Figure 5 the different ways of results dissemination is presented. As it can be observed conference and scientific journals are the most popular options, gathering a percentage of 31% and 23% respectively of the participant labs. Web sites, white papers, use cases and books are alternative ways of publishing scientific results, but they attract much less the interest of the participants with respect to the former options. It is also worth noting that each lab can have more than one way of publishing results.

Smart grid research can be the outcome of a stand-alone or collaborative activity. In an effort to obtain a picture of how the activities are performed, we gathered information about the research on each category and the nature of these research activities. Figure 6 shows the amount of work based on each type of collaborations expressed in percentages with respect to the activities as a whole. It is clear that most labs hold sporadic collaborations for specific projects (40%), whereas permanent collaborations are less popular (28%). Stand-alone activities are performed by a 25% of the participant labs.

**Figure 5.** Results dissemination

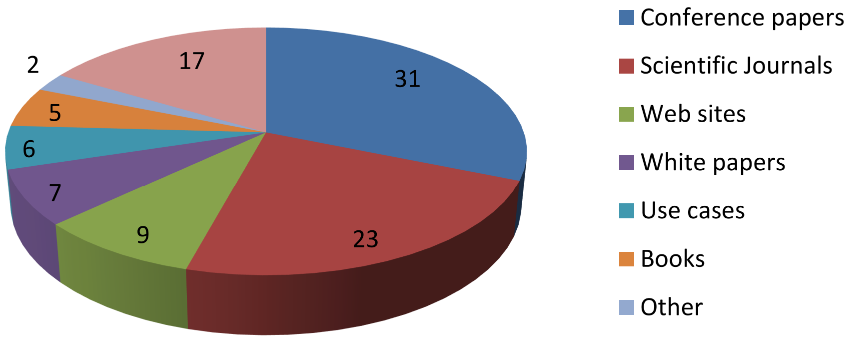
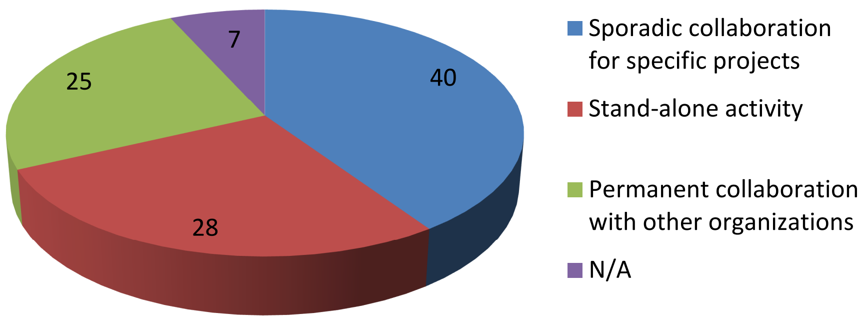
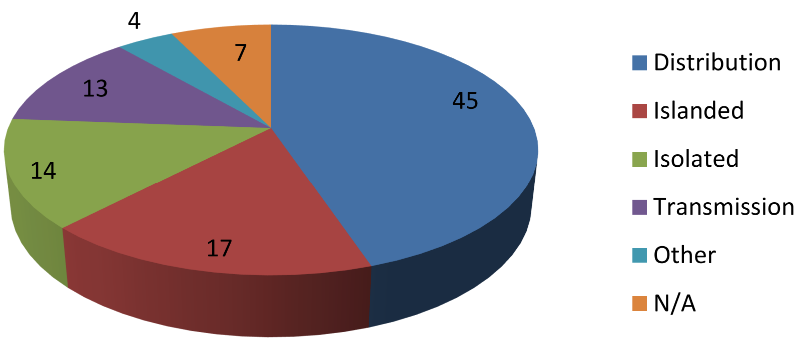



**Figure 6.** Types of collaborations




In Figure 7 the types of grid to which research is dedicated is showed. As it can be observed 45% of the total activities are dedicated to the distribution grid, as opposed to only 13% that is devoted to the transmission grid. The equivalent percentages for the isolated and islanded grid are 14% and 17% respectively.

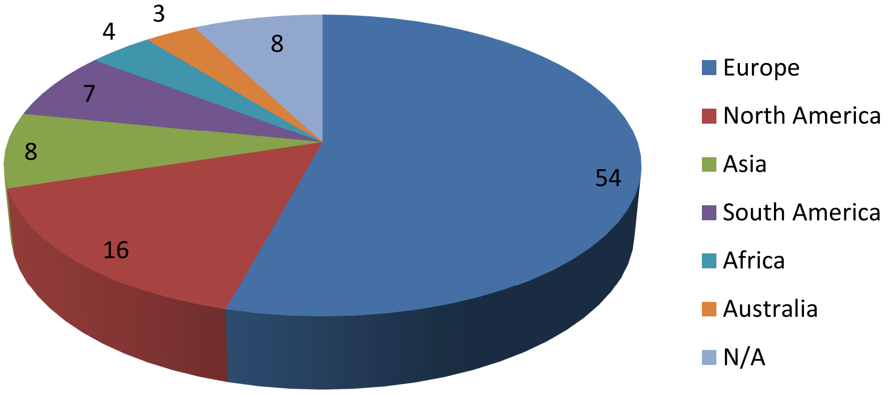
**Figure 7.** Types of grid to which research is dedicated



Finally, Figure 8 gives information on the geographical area where research is carried out. As it can be observed, the majority of the labs focus on Europe, which is anticipated since the participants are mainly located in Europe. Based on the location of the participating labs, as it is expected, North America comes second in the list, with Australia gathering the least of smart grid activities.

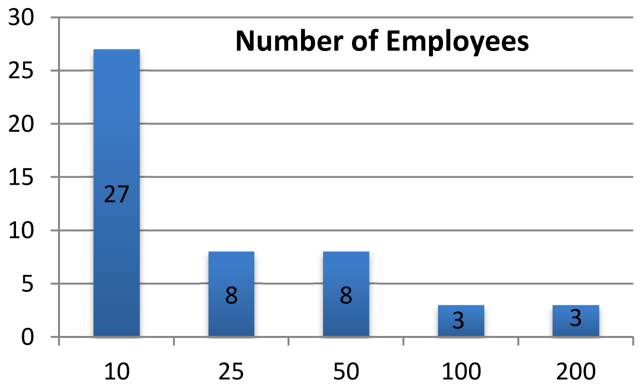
When comparing to the results obtained in [1], it can be observed that the conclusions derived from Figure 3 to Figure 8 remain more or less the same, with respect to the most popular sectors at which lab research is targeted, the fields of activity, the results dissemination, the type of collaborations held and the type of grid to which research is dedicated. This shows that although the sample is almost 2.9 bigger than the previous one, the preferred options have more or less remained unchanged, which indicates that the results presented can be representative of the worldwide situation.

**Figure 8.** Geographical area of interest for smart grid research




With respect to the number of people involved in the smart grid labs that we have surveyed the histogram in Figure 9 shows how heterogeneous these numbers are. The total number of replies in this case amounts to 71% of the total (69 Labs).

**Figure 9.** Number of employees involved in smart grid labs

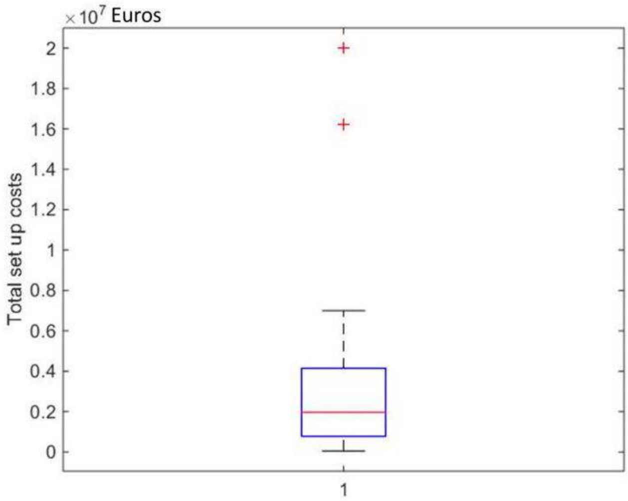



From Figure 9 it is immediately seen that while the majority of labs relies on the effort of less than 10 people, there are extreme cases in which up to 200 people are involved. This figure is indeed related to the annual running cost of the lab once personnel costs are taken into account.

## 3.4 Investments figures

In the following a boxplot of the budget spent to set up the smart grid labs (taking part to the survey) is given. To this aim Figure 10 reports a standardized way of displaying the distribution of data based on a five number summary: minimum, first quartile, median, third quartile, and maximum. The central rectangle spans the first quartile to the third quartile (the interquartile range or IQR). A segment inside the rectangle shows the median and "whiskers" above and below the box show the locations of the minimum and maximum.

**Figure 10.** Box plot of the cost to set up a smart grid lab




The three main values of interest in the previous figure are the first quartile (Q1) the median and the third quartile (Q3). In the sample analyzed these values correspond respectively to euros.

**Table 2.** Quartile values for set-up costs

| | Q1 | Median | Q3 |
|---|---|---|---|
| Total set up costs (€) | 775000 | 1975000 | 4147500 |

Two of these three values are used in the following to separate the labs into three main groups as a function of the spent budget to set up: those with set-up costs above Q3 (big size), those between Q1 and Q3 (medium size) and those below Q1 (small size).

Figure 11 shows how and when the labs (with a set-up budget above Q3) have spent their budget. The values are represented as a percentage of the total, for instance Lab 6 has spent 100% of its declared budget in 2011 and since it belongs to the group with budget above Q3, it means that this values falls between Q3 and the maximum shown in the boxplot in Figure 10. This method is used for preserving the confidentiality of the data provided by the labs taking part to our survey.

Figure 12 shows how and when the labs (with a set-up budget between Q1 and Q3) have spent their budget. The values are represented as a percentage of the total.

For instance Lab 13 has spent 90% of its available budget on 2012 and 10% on 2013. In this case the budget falls in the range between 775k€ and 4M€.

Figure 13 shows the last group of labs, those with a set-up budget below Q1. As already done the percentage of the total budget and the year in which this has been spent have been reported.

**Figure 11.** Cost to set up labs with a budget above Q3: more than 4 million euros

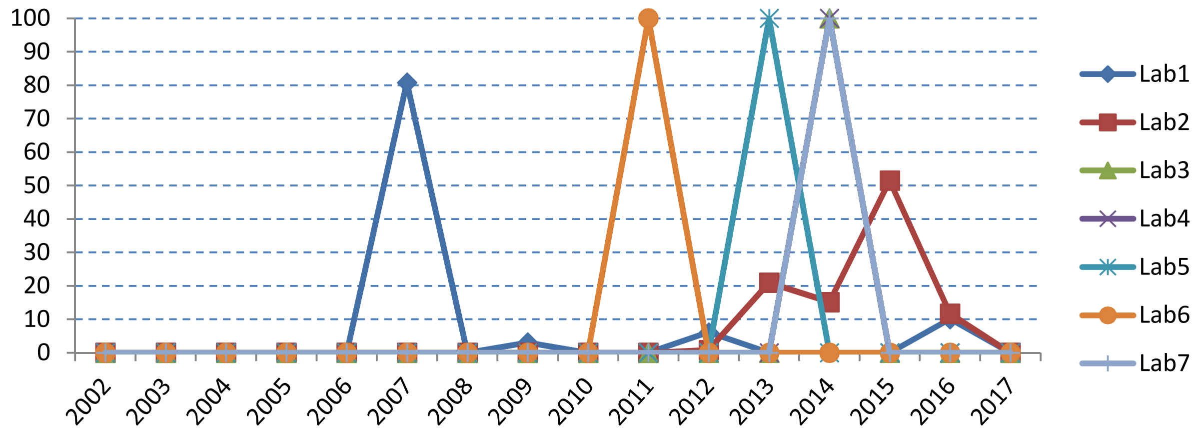



**Figure 12.** Cost to set up labs with a budget between Q1 and Q3

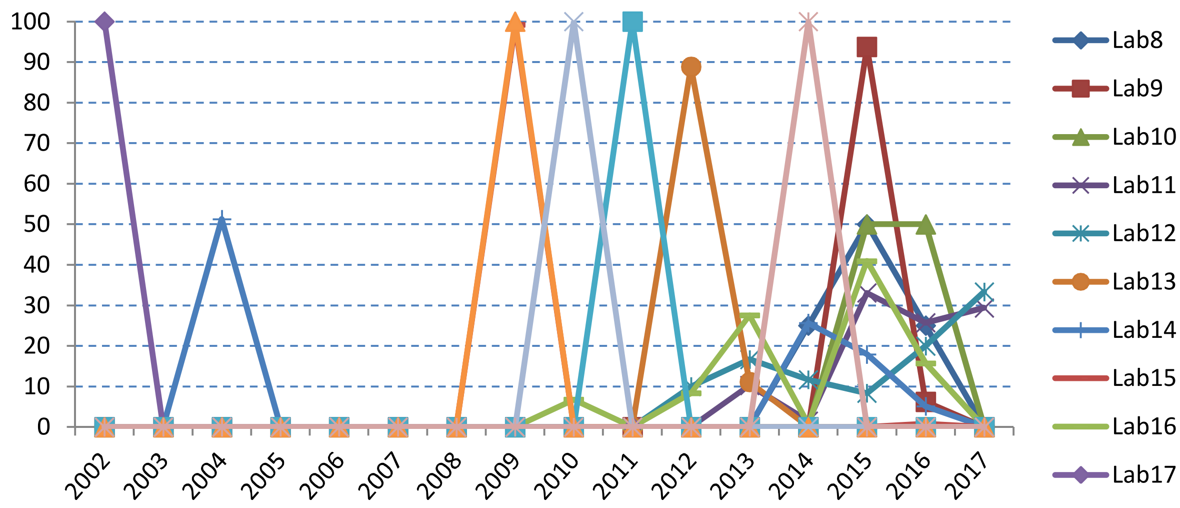
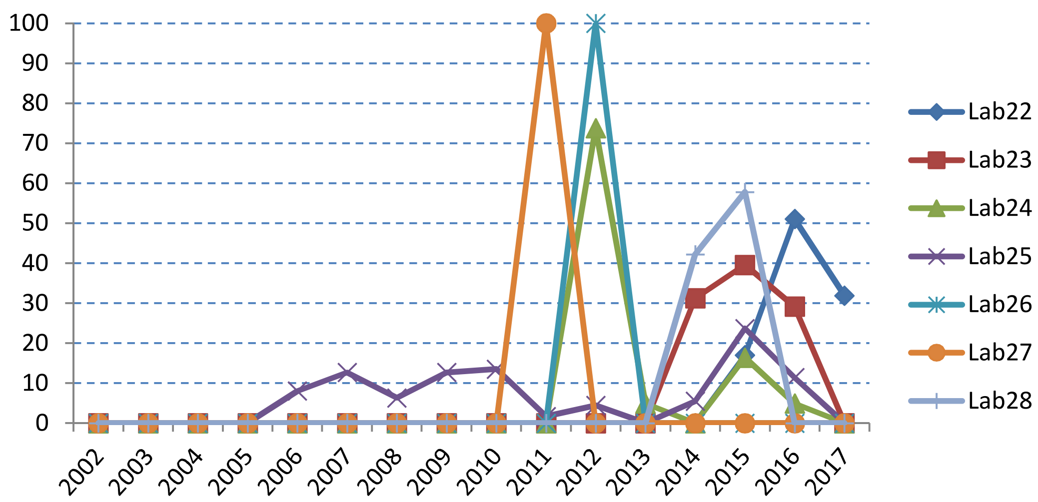



**Figure 13.** Cost to set up labs with a budget below Q1



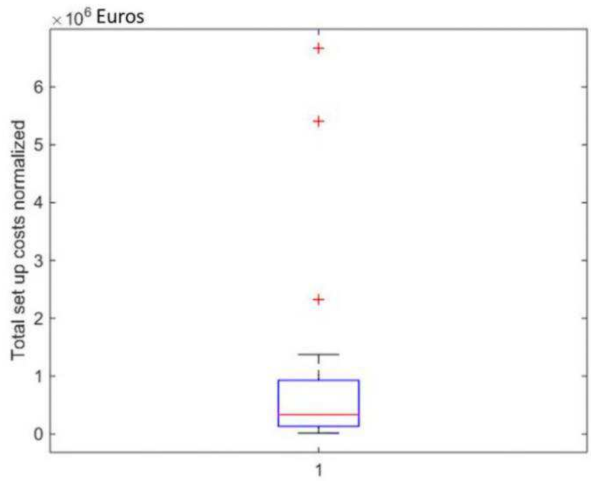
Another figure of interest (Figure 14) is reported in the following which takes into account the set up costs normalized by the years of activity of the labs. Figure 14 shows a boxplot of these values.

The three values of interest are now the ones shown in Table 3.

**Table 3.** Quartile values for set-up costs taking into account the years of activity of the labs

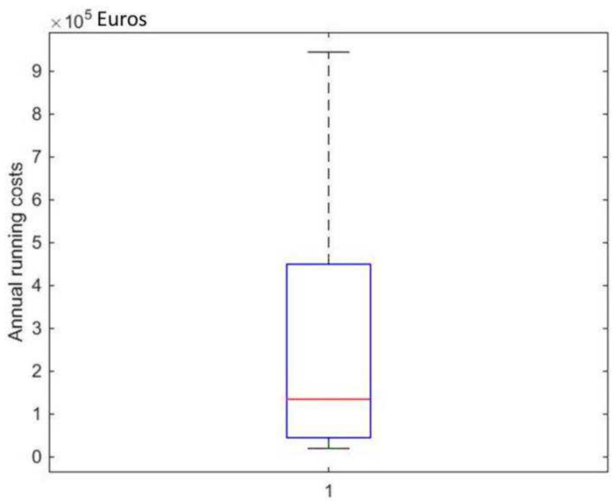
| | Q1 | Median | Q3 |
|---|---|---|---|
| Total set up costs normalized (€) | 132500 | 338000 | 929500 |

**Figure 14.** Boxplot of set costs normalized with respect to the year of activity of each lab




These values provide a more clear idea on the costs to be undertaken to set up a smart grid lab. But the picture cannot be complete without another important value that labs taking part to the survey recognize as a key one: the annual running cost of the lab. Note that this value comprehends: software licenses, maintenance of the infrastructure but also the personnel involved and actively working into the lab. In certain cases these value can be even higher than that of setting-up the lab. Figure 15 shows a box plot of the annual running costs of smart grid labs based on 33% of the replying labs.

**Figure 15.** Boxplot of the annual running costs of the smart grid labs



The three values of reference in this case are shown in Table 4.

**Table 4.** Quartile values for annual running costs

| | **Q1** | **Median** | **Q3** |
|---|---|---|---|
| Annual running costs (€) | 45000 | 135000 | 450000 |

It is worth mentioning here that a Q1 close to 45,000 euros seems to suggest that participants in the survey could have not taken into account the cost of personnel. To avoid this kind of misunderstandings in future versions of the questionnaire we plan to separate the annual running cost record into personnel cost and other costs (licenses, maintenance, software, etc.).

## 3.5 Planned Investments

In the following a current picture of the estimated investments that the interviewed labs are planning to do (or expected to undertake) is given. Three main periods are considered: *short term* (0-5 years), *medium* (5-10 years) and *long term* (+10 years). A first figure gives a first hint of how the uncertainty on future investments is perceived by the smart grid laboratories taking part in the study: the median for each period (short, medium, long) of the obtained replies for the whole 13 categories.

**Table 5.** Number of answers for planned investments

| **Median Answers Short Period** | **Median Answers Medium Period** | **Median Answers Long Period** |
|---|---|---|
| 47% | 36.7% | 32.3% |

As shown on average only less than 33% of labs has already a strategy or just an idea of the investments to be done (or not to be done) in the long term while almost one out of two has a clear idea in the short period. From this percentage the number of 'don't know' answers needs to be subtracted. In fact for each category in which the smart grids labs have an active role (in terms of research activity, projects involvement, etc.) we have asked them to indicate if they plan to: i) increase their investments (increase option), ii) decrease their investments (decrease option), iii) undertake the same amount of investments (equal option) or iv) they simply don't know (don't know option).

In the figures that follow a considerable amount of information on this subject is reported. For sake of clarity the following facts need to be taken into account:

1. The three columns refer to the planned investments for the short, medium and long term.
2. For each period (short, medium, long) the percentage of labs (in the subset of labs working in the given category) is shown, distinguishing between those which plan to increase, to decrease, to maintain the same investments or that just admit that don't know what they will do.
3. As already mentioned, due to the fact that the number of replies decreases from one period to the next one the short term replies are used as reference. This method allows to better understand the trends of the foreseen investments as a function of time.
4. The percentage of labs which have replied to the question with respect to the total (69 labs) is reported below each period.

5. Labs which have replied only on the short term period are considered as indicating a 'no answer' for the following periods (medium, long) not a 'don't know'.

For the category *Distribution Automation* while in the short term more than half of the sample (46% of total) considers to increase its own investments with respect to current levels only 25% of it plans to do it in the long term period. It is worth also mentioning that the number of those which will maintain an unchanged level of investments (~20%) seems almost constant during the three periods. Only a very limited amount of labs plans to decrease its investments in the short and medium term period (Figure 16).

In the *Grid Management* category 60% of the sample (50% of the total) plans to increase its investments in the short term period and around 30% plans to keep them equal, as shown in Figure 17. These numbers decrease by 13% and 4% respectively in the medium term and halve in the long term (if compared with the short term). For the decreasing option it is quite small and it seems again quite constant in the three periods of interest.

**Figure 16.** Planned investments for Distribution Automation

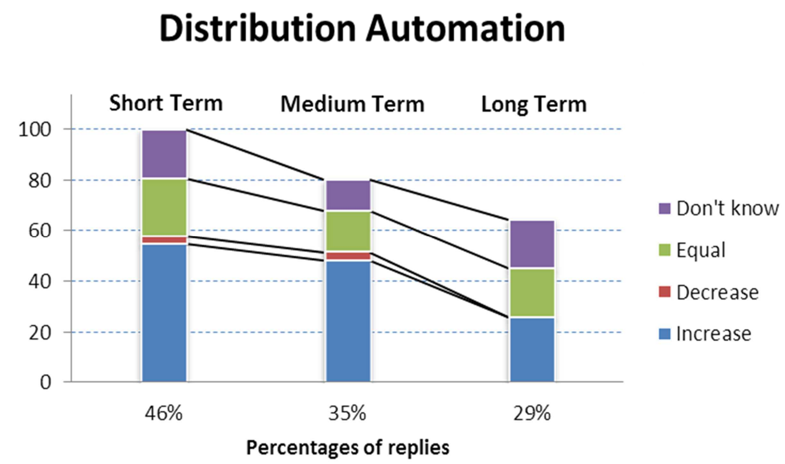
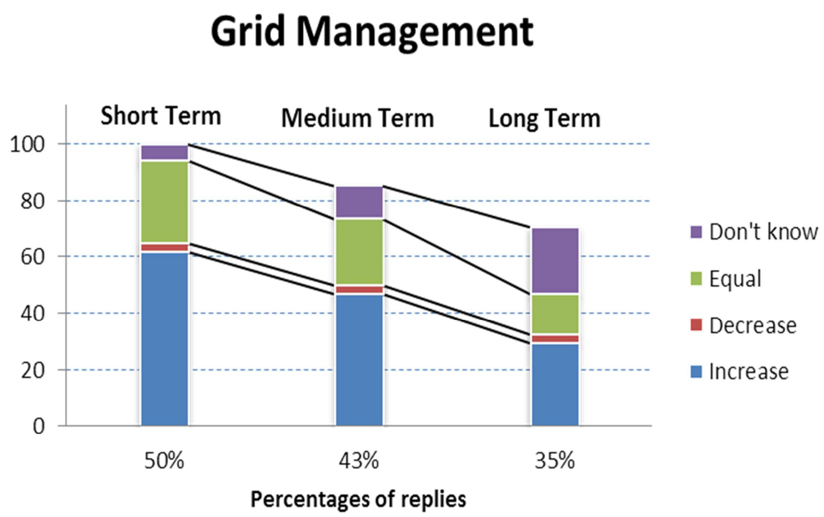



**Figure 17.** Planned investments for Grid Management




With respect to *Storage* activities almost 64% of smart grid labs in the sample (53% of total) plans to increase short term investments and 28% of it plans to keep them equal.

Note that also in the medium term (that is up to ten years from now) the number of labs willing to increase their investments touches the 55%. No decreases intentions are observed for this category (Figure 18).

In the *Sustainability* area a different situation is observed, as shown in Figure 19. Only 36% of the sample (28% of total) is willing to increase its investments in the next five years and this value falls to 10% after ten years. Comparing the three periods the trend seems to suggest that the only diminishing part is that of increasing investments, the other (equal, decrease and don't know) seem to remain quite constant with a 40%, 5% and 15% respectively.

**Figure 18.** Planned investments for Storage

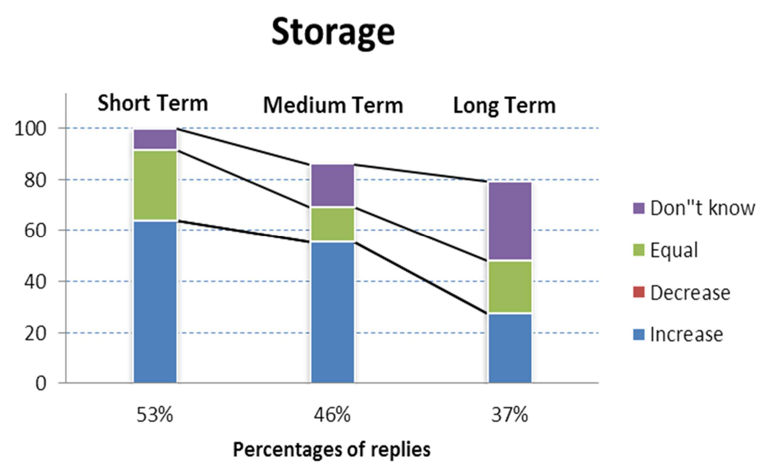
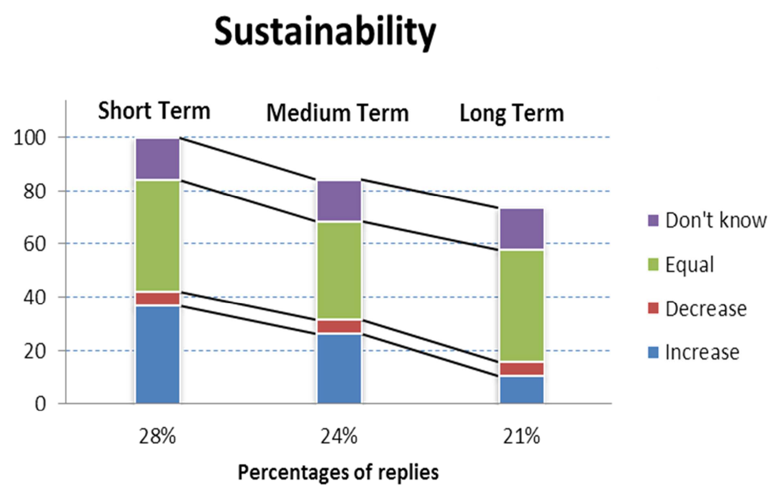



**Figure 19.** Planned investments for Sustainability




With respect to *Market* activities almost 40% of the sample (34% of total) plans to increase its investments in the short run and a 44% of it plans to keep them invariant. An inversion of this trend is observed in the medium term with a 44% willing to increase and a 40% willing to maintain the same level. In the long term instead a considerable part of those willing to invest in the short and medium run seems to not knowing how their strategy on market activities could change within ten years (Figure 20).

Among those labs working on integration of Generation and Distributed Energy Resources 67% of the sample (54% of total) plan to increase their investments in the

next five years (Figure 21). This number decreases to 35% in the long term but still remains quite high when compared with other categories. A 5% of the sample indicates its willingness to reduce investments in this sector suggesting an interest for other areas of the smart grid sector.

**Figure 20.** Planned investments for Market

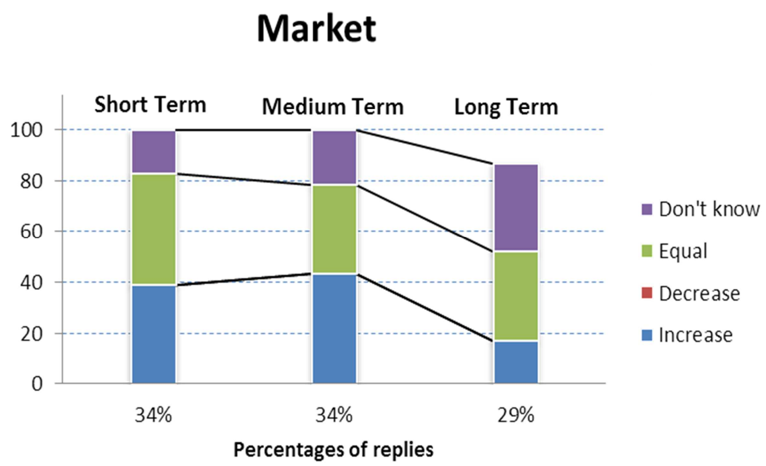
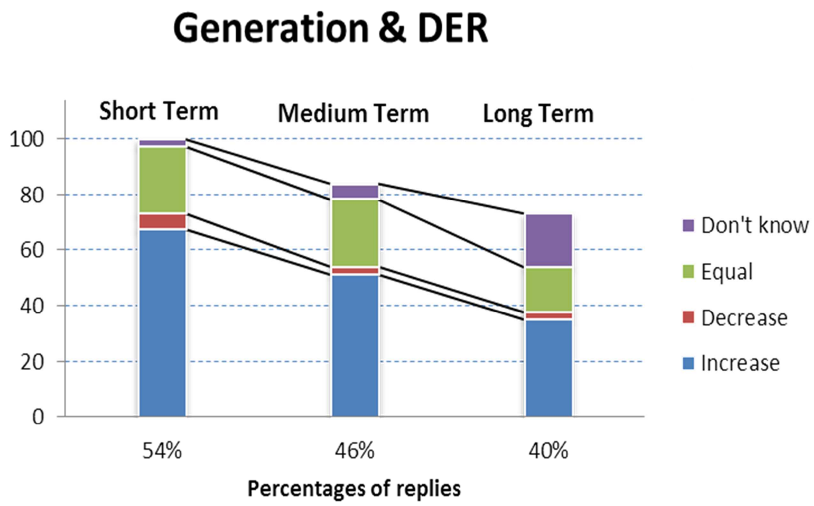



**Figure 21.** Planned investments for Generation & DER




In the *Electromobility* area, in the short term run a bigger part (43% of the sample, which amounts to 51% of the total) is planning to keep constant the level of investments while a slightly smaller part, (34%) is considering an increase. This trend seem to change in the medium part where the bigger part (43%) seems to be willing to increase its investments compared with the 23% which plans to maintain the current level. When looking at the 'decrease' part an 8.5% is observed which seems higher when compared with the previous categories. A deeper analysis or a direct interview with those labs planning to decrease their investments could help shedding some light on the reasons behind this number (Figure 22).

With respect to *Smart Home* activities almost 64% of smart grid labs in the sample (49% of total) plans to increase short term investments and 24% of it plans to keep them equal. Note that also in the medium term (that is up to ten years from now) the number of labs willing to increase still touches the 55% that seems to label this area as

a key one also in the medium run. This fact is also stressed by the fact that no decreases intentions are observed for this category. From a different perspective this could also mean that not enough investments were done so far by the labs on this topic and a raising interest on it is pushing toward this trend (Figure 23).

**Figure 22.** Planned investments for Electromobility

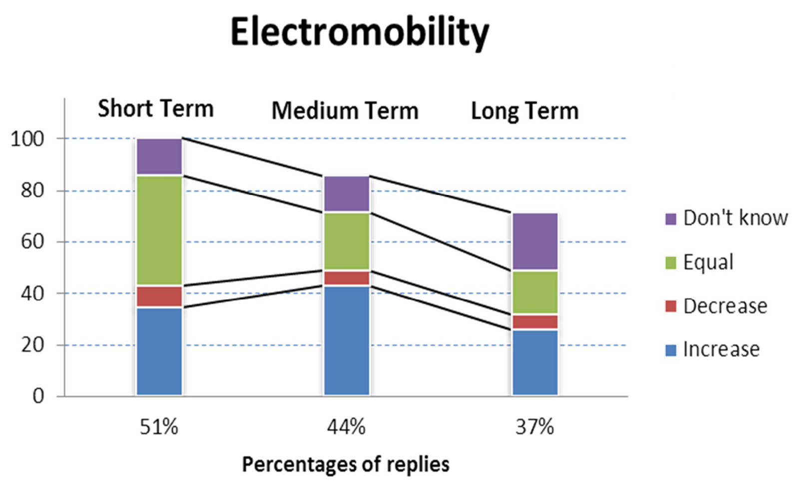
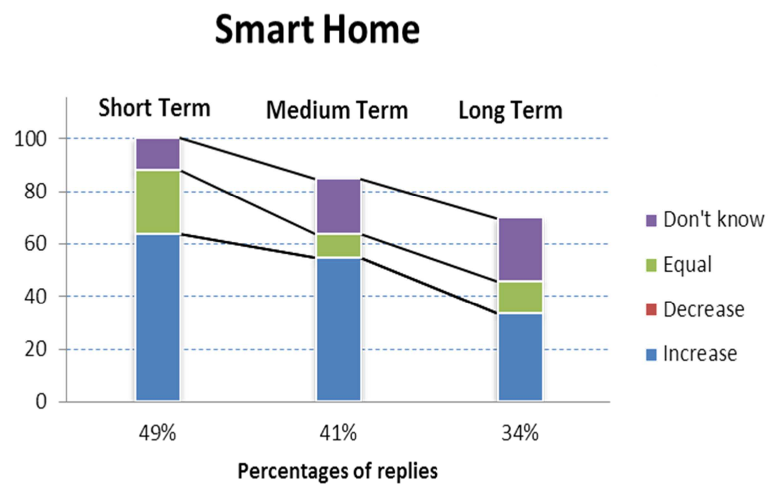



**Figure 23.** Planned investments for Smart Home




The Smart Cities label is becoming more and more important in the Smart Grid sector given its potential to intersect several layers of technologies which indeed requires a more holistic approach. Almost 67% of smart grid labs in the sample (40% of total) plans to increase short term investments and 15% of it plans to keep them equal. Note that also in the long term the number of labs willing to increase is only slightly above the 40% that seems to label also this area as a key one also in the medium and long run. No decrease options have been mentioned at all by labs active in this area (Figure 24).

In the *Demand Response* category 62.5% of the sample (47% of the total) plans to increase its investments in the short term period and around 28% plans to keep them equal, as shown in Figure 25. These numbers decrease by 12% and 13% respectively in the medium term and becoming 28% and 18% in the long therm. The decreasing option is quite small (3%) hence negligible in the short term.

Information and Communication technologies are at the core of the smart grid transition and this fact is clearly highlighted by the intention on investments, which is depicted in Figure 26. Out of the 50% of the total labs, 70% of them plan to increase investments on ICT and a 24% plans to keep them at the current levels. This figure is decreased to 56% and 44% in the medium and long run respectively.

Cybersecurity is another key topic in smart grid and in fact an 80% of the sample (37% of total) considers the option of increasing the investments or to keep them at current levels (52% and 32%) respectively. An interesting trend is observed for this category as happened for the electromobility and market ones. In the medium term labs which intend to increase their investments grow of 4% (to 56%). This seems to suggest that cybersecurity in smart grids could develop further within five to ten years perhaps after that other technologies become more widely used (Figure 27).

In the short term the forecasted investments for AMI seems quite balanced: 48% of the labs in the sample (40% of total) are willing to increase their investments and 37% plan to keep them equal. For the medium and long term an almost specular situation is given with 26% vs 22% willing to increase and a 30% willing to keep them invariant. Also a small part (4%) shows the intention to decrease them (Figure 28).

**Figure 24.** Planned investments for Smart Cities

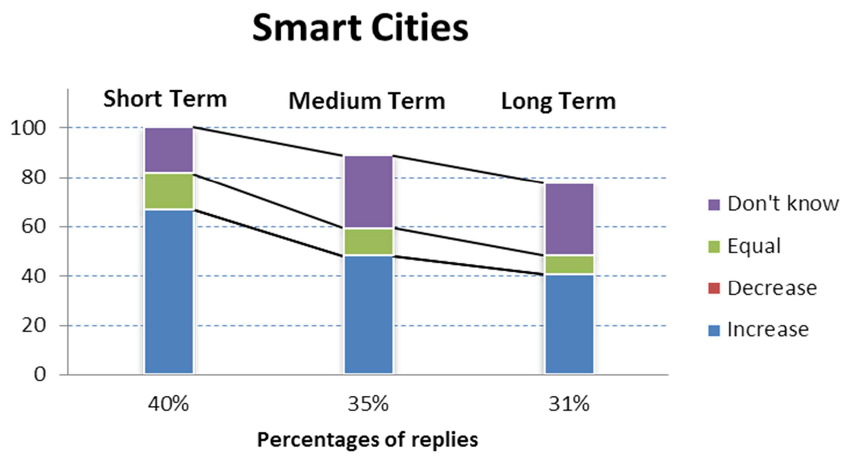



**Figure 25.** Planned investments for Demand Response

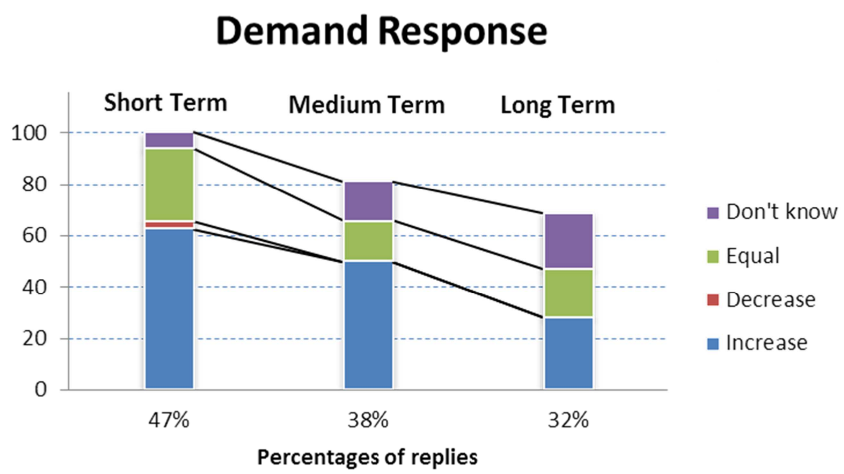


**Figure 26.** Planned investments for ICT

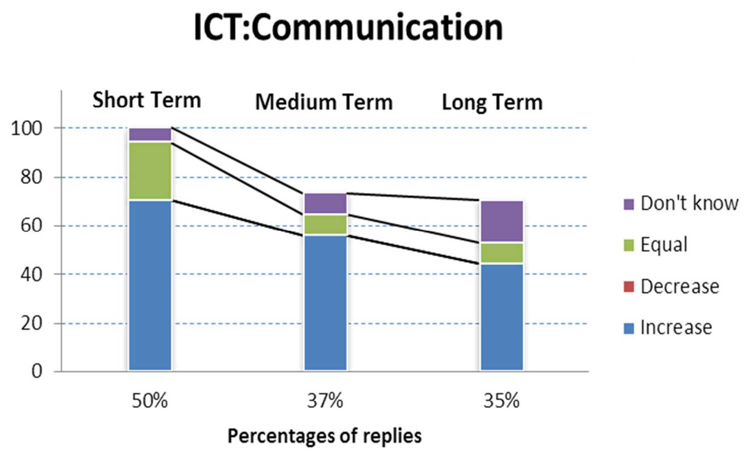



**Figure 27.** Planned investments for Cybersecurity

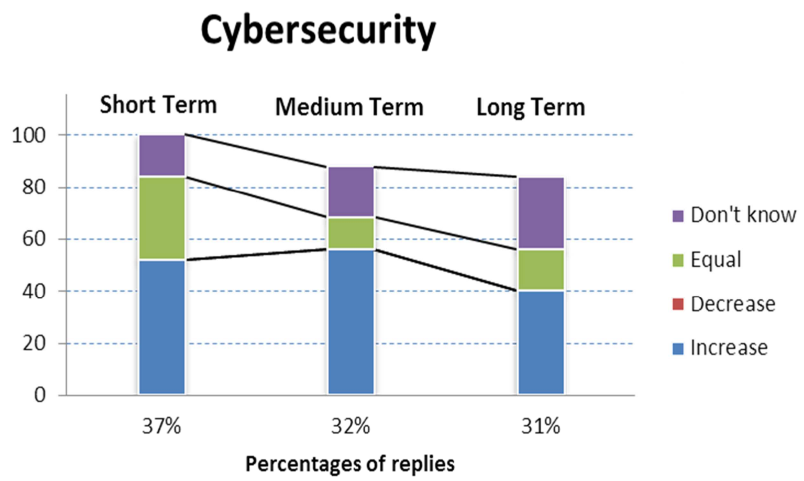
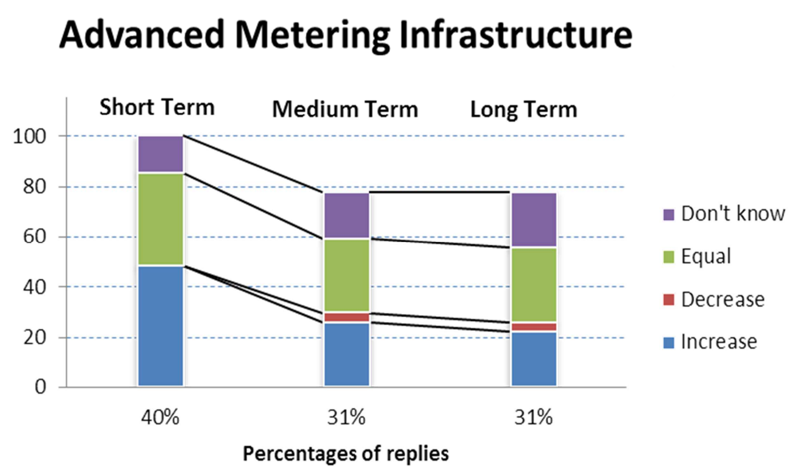



**Figure 28.** Planned investments for AMI



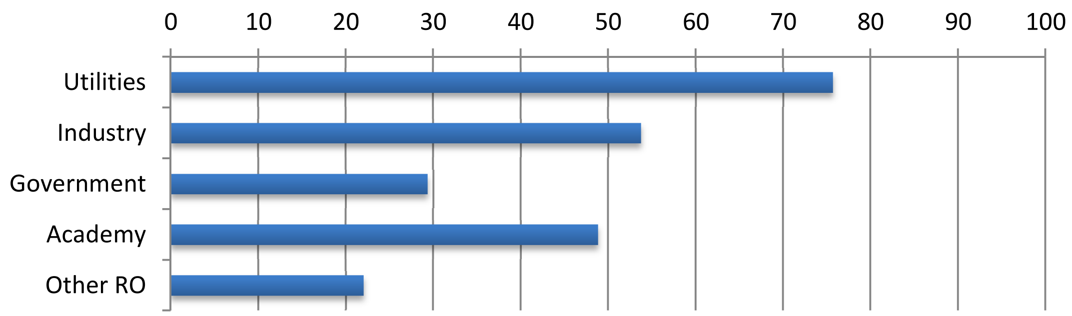
## 3.6 Analysis of Smart Grid Areas

In this Section we present more detailed information about the categories of smart grid activities. The specific areas of interest are presented with focus on the standards, protocols and technologies used by the laboratories for smart grid research. In addition, further emphasis is given on particular sub-topics of some categories in order to identify the technological trends on topics that greatly attract the scientific research. For reasons of completeness, we initially present for each category relative information to the one presented in Section 3.3 in an aggregated way about the sectors at which research is targeted, the fields of activities, the way of results dissemination, the nature of collaborations, the type of grid on which research is conducted, etc. It should be noted here that the percentages shown refer to the labs that perform a specific activity among the actively involved labs in the equivalent category.

### 3.6.1 Distribution Automation

The activities in this area are mainly targeted for the utilities, with the sector gathering approximately 75% of the actively involved labs in the sector. Activities focused on industry and academic subjects also gather high percentages of 53% and 48% respectively. The situation is depicted in Figure 29.

**Figure 29.** Sectors at which research is targeted in Distribution Automation




The vast majority of the Distribution Automation involved laboratories are focusing on Technology development and prototype testing (73% and 68%), followed by the R&D equipment and R&D software, as shown in Figure 30. Regarding the dissemination of the scientific results, it can be observed from Figure 31 that this is done predominantly through conference or journal papers. Web sites, white papers, books and use cases are lower in the list, gathering less than 20% of the labs in Distribution Automation.

**Figure 30.** Fields of activity for the Distribution Automation smart grid category

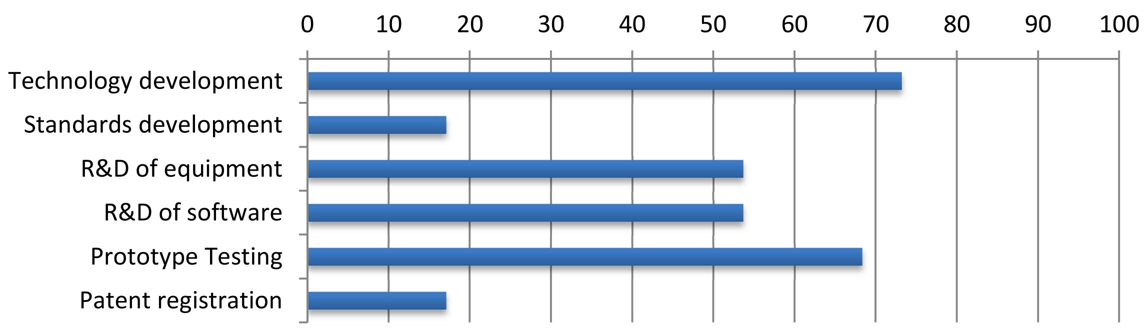
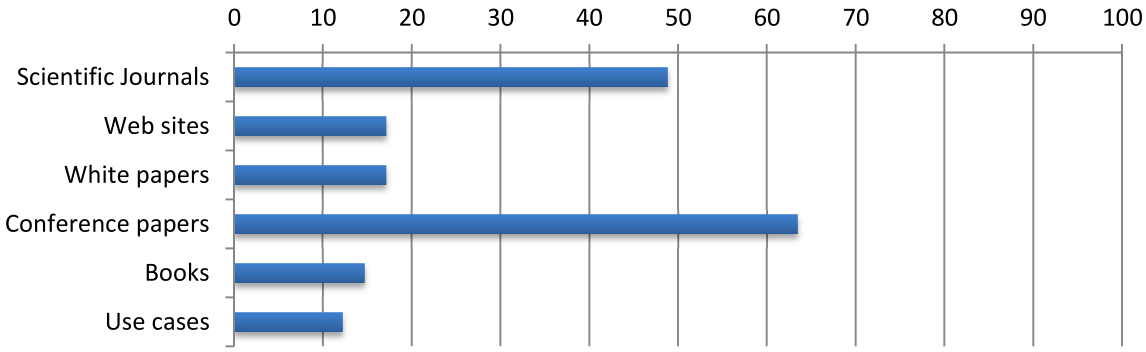


**Figure 31.** Results dissemination in Distribution Automation




The activities vary from stand alone to collaborative ones, either sporadic or permanent with other organizations. It is worth noticing that the three different concepts of activities experience similar probabilities with a very small difference as depicted in Figure 32. Figure 33 shows that the 82% of the activities on Distribution Automation are carried out in Europe, which is easily explained, since the majority of the labs are located in Europe. However, all the other continents gather a small percentage of the research activities, with almost 30% in North America. According to Figure 34 the distribution network is the main asset on which Distribution Automation research activities are focused. However, the islanded, isolated and transmission networks are important fields of research, since more 34%, 17% and 12% of the actively involved labs in the sector conduct research on them respectively.

**Figure 32.** Nature of activities in the Distribution Automation

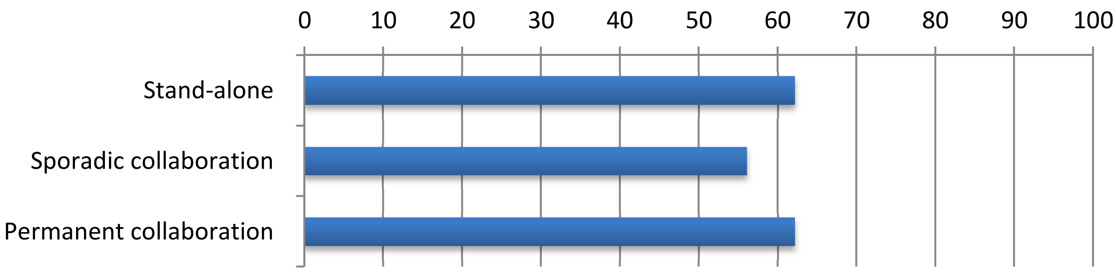
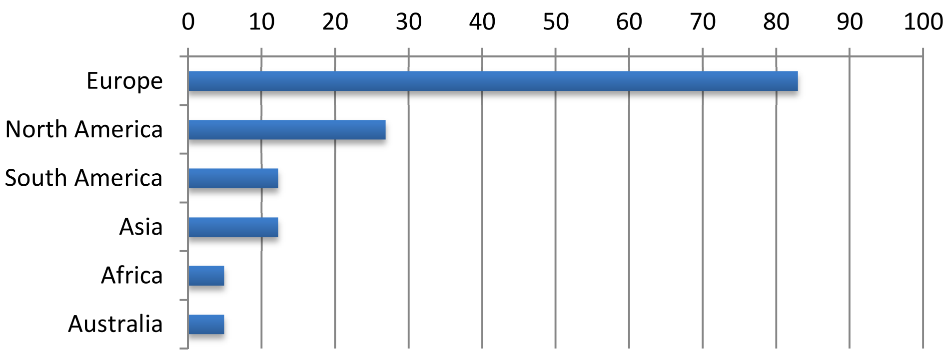



**Figure 33.** Geographical area where research activities are focused in Distribution Automation




Specifically for Distribution Automation, the topics for investigation cover various fields, like substation automation, automation of distribution networks, self-healing networks, inverters/power converters etc, as Table 6 indicates.

**Figure 34.** Networks on which research in Distribution Automation is carried out

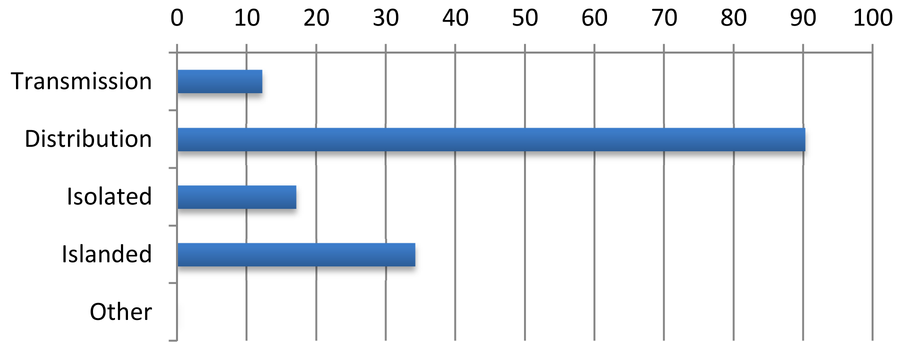



**Table 6.** Percentages of Distribution Automation topics per laboratory

| **Topic** | **%** |
|---|---|
| Substation automation | 37% |
| Automation of distribution networks | 34% |
| Self-healing networks | 32% |
| Inverters and/or power converters | 27% |
| Other | 2% |

In our survey, substation automation is ranked first among the activities of the labs involved in distribution automation with a percentage of 37%. The topic of automation of distribution networks and power converters/inverters follow close behind with 34% and 32% of the active labs in the field. This is depicted in Table 6. The main objective is the integration of distributed generation which attracts more than 75% of the labs active in this field. Voltage control and reactive power as well as reliability follow, being the next most popular objectives of the active labs (Table 7).

**Table 7.** Objectives of research work in distribution automation

| **Objective** | **%** |
|---|---|
| Integration of distributed generation | 78% |
| Voltage control and reactive power | 66% |
| Reliability | 54% |
| Efficiency | 46% |
| Other | 5% |

Regarding the standards used for distribution automation issues, the IEC 61850 – Communication networks and systems in substations – is the most popular one, gathering in total the percentage of almost 70% of the activities of the laboratories involved in the field. A percentage of 34% of the active labs uses the standard IEC 61968 – Common Information Model/Distribution Management as well as the IEC 61970 – Common Information Model/Energy Management. The IEC 60870 - Telecontrol equipment and systems are used by a 27% of the DA laboratories. The IEC 61869

Instrument transformers and the IEC 62351 - Power systems management and associated information exchange - Data and communications security follow with 24% and 22% respectively. Table 8 gives a complete picture of the situation.

**Table 8.** Standards used for Distribution Automation activities

| **Standard** | **%** |
|---|---|
| IEC 61850 – Communication networks and systems in substations | 68% |
| IEC 61968 - Common Information Model / Distribution Management | 34% |
| IEC 61970 - Common Information Model / Energy Management | 32% |
| IEC 60870 - Telecontrol equipment and systems | 27% |
| IEC 61869 – Instrument transformers | 24% |
| IEC 62351 - Power systems management and associated information exchange - Data and communications security | 22% |
| IEC 60255-24 - Electrical relays - COMTRADE | 12% |
| IEC 62439 - Highly Available Automation Networks | 5% |
| Other | 5% |

### 3.6.2 Grid Management

With respect to the sectors at which Grid Management activities are targeted, Figure 35 reveals the situation. Utilities, but also the academy and the industry are interested in grid management research activities, with the former two sectors attracting 67% and 57% respectively of the questioned labs. Similarly to the distribution automation field, the results are presented in conference and journal papers, whereas other ways of dissemination like books, white papers and web sites are far lower as a preference, with differences at the range of 40%, as Figure 36 illustrates.

Figure 37 displays that R&D of software and technology development are the main topics of investigation, since more than 55% of the actively involved labs in the sector occupy themselves with such topics. Sporadic collaborations are more popular as a nature of activities for 65% of the active lab, permanent collaborations and stand – alone activities follow with 38% and 36% respectively as illustrated in Figure 38. The vast majority of the activities are carried out in Europe. However, Figure 39 shows that there is a percentage of around 15-20% of research activities that are focused also in North, South America and Asia.

Regarding the part of the network that the Grid Management research activities are focused on, according to Figure 40, the distribution network comes first on the list, gathering almost the 90% of the actively involved labs in the sector. Other types of network, like the transmission and islanded network, also attract the scientific interest, since they gather approximately the 42% of the questioned labs.

The main topics of interest are technical feasibility studies, design, interconnection and integration of DERs and real time simulations.  Considerable focus is also given to the grid design, Pre-Deployment validation of MicroGrids, dynamical analysis, protection and control relays (the exact percentages are shown Table 9).

**Figure 35.** Sectors at which Grid Management research is targeted

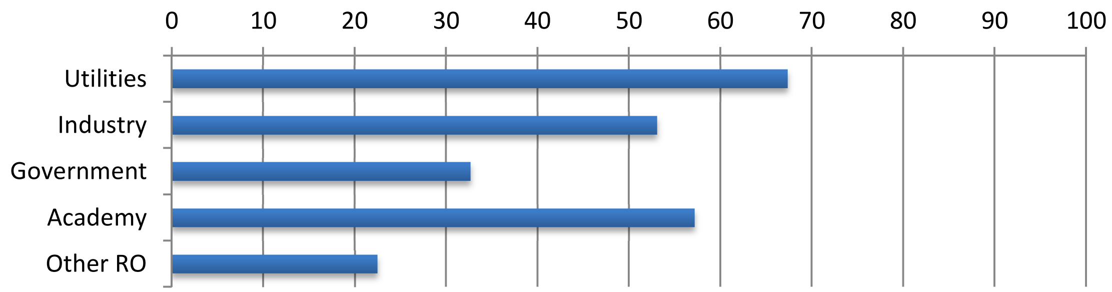



**Figure 36.** Results dissemination in Grid Management

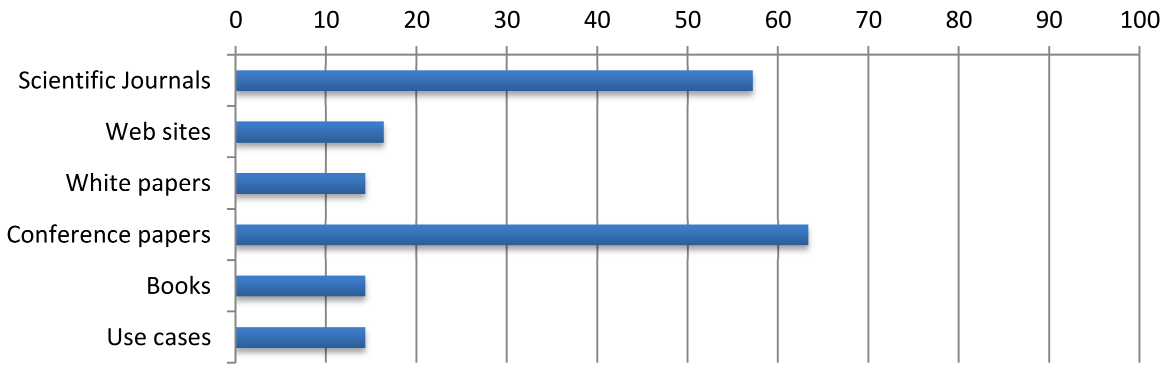



**Figure 37.** Fields of activity for the Grid Management category

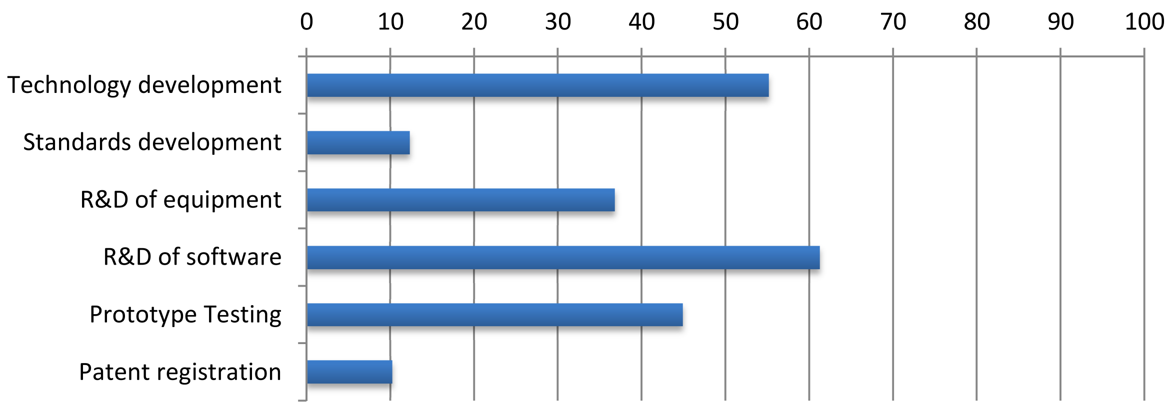



**Figure 38.** Nature of activities in Grid Management

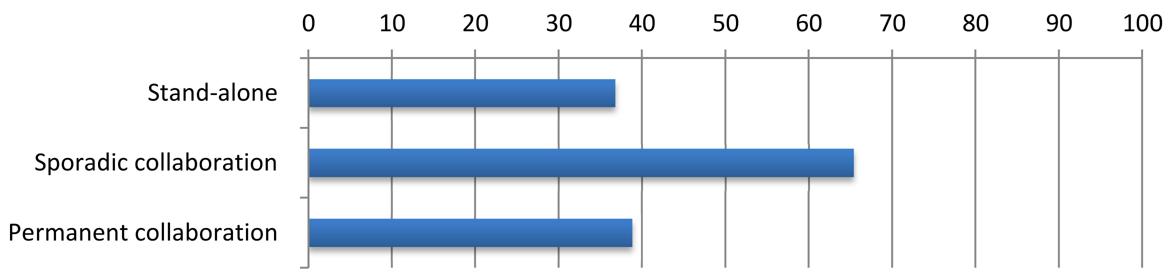


**Figure 39.** Geographical area on which Grid Management activities are focused

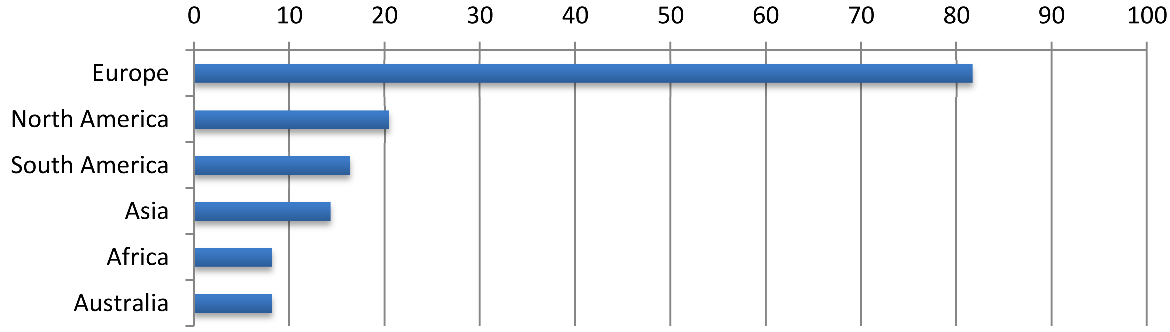



**Figure 40.** Networks on which Grid Management research is carried out

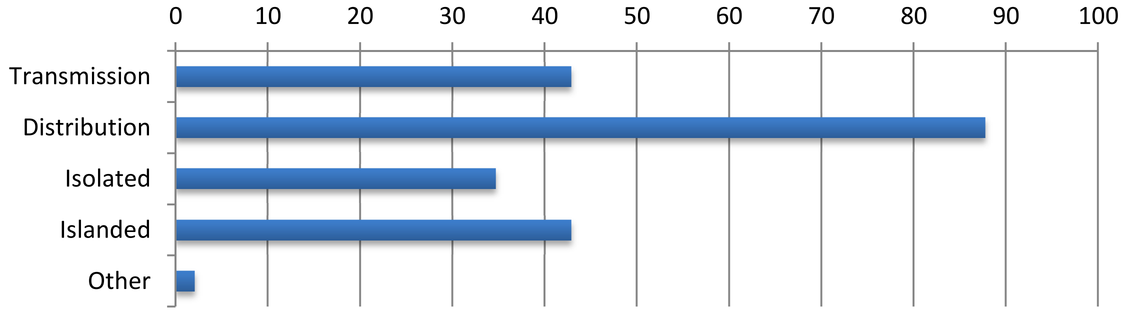



**Table 9.** Percentages of Grid Management topics per laboratory

| **Topic** | **%** |
|---|---|
| Technical feasibility studies | 51% |
| Design | 47% |
| Interconnection and Integration of Distributed Energy Resources (DER) | 31% |
| Real time simulation | 29% |
| Dynamical Analysis | 23% |
| Power Quality studies | 18% |
| Protection and control relays | 14% |
| Pre-Deployment Validation | 10% |
| Other | 2% |

Almost one third of the participants are testing Phasor Measurements Units (PMUs). More than 25% of the active lab implement post-disturbance analyses through PMUs and GPS synchronization and integrate PMUs in advanced control through remote feedback. The majority of the labs involved in Grid Management activities are coping with Microgrids (78%).

Another important fact is that more than 30% of the participant labs are dedicated in activities related to automated critical management. In particular intense research is being carried out on outages and short-circuits analyses.

Almost 80% of the participants are also involved in monitoring and network diagnosis, notably on automatic fault detection and predictive maintenance. The concept of Big Data Analysis and Management is also attracting the scientific interest in the field: a bit more than 30% of the labs is carrying out activities which require this kind of knowledge. With respect to standards the most used one is the IEC 61850, but also other standards are remarkable (for details check Table 10).

**Table 10.** Standards used for Grid Management activities

| **Standard** | **%** |
|---|---|
| IEC 61850 - Communication networks and systems in substations | 63% |
| IEC 61968 - Common Information Model / Distribution Management | 34% |
| IEC 60870 - Telecontrol equipment and systems | 24% |
| IEC 61970 - Common Information Model / Energy Management | 24% |
| IEC 62351 - Power systems management and associated information exchange | 20% |
| IEC 61499 - International Standard for Distributed Systems | 15% |
| IEC 61131 - Programmable controllers | 12% |
| IEC 62357 - Power system control and associated communications | 12% |
| IEC 62325 - Common Information Model (CIM) for Energy Markets | 10% |
| IEC 61158 - Digital data communications for measurement and control | 7% |
| IEEE 1344 – Standards for synchrophasors for power systems | 7% |
| IEC 62361 - Power systems management and associated information exchange | 5% |
| IEC 61784 - Digital data communications for measurement and control | 2% |
| Other | 7% |

### 3.6.3 Storage

Storage activities are primarily dedicated to academia and industry, and secondarily to utilities and governmental organizations, since the 57%, 55%, 48% and 36% respectively of the active laboratories in this category are working for the aforementioned sectors, as Figure 41 depicts. R&D software and Technology development are the main goals for storage smart grid activities, while each field attracts a percentage of 61% and 55 % of the active laboratories. Prototype testing and R&D equipment follow closely with 45% and 37%. Figure 42 describes the situation.

**Figure 41.** Sectors at which Storage smart grid activities are targeted

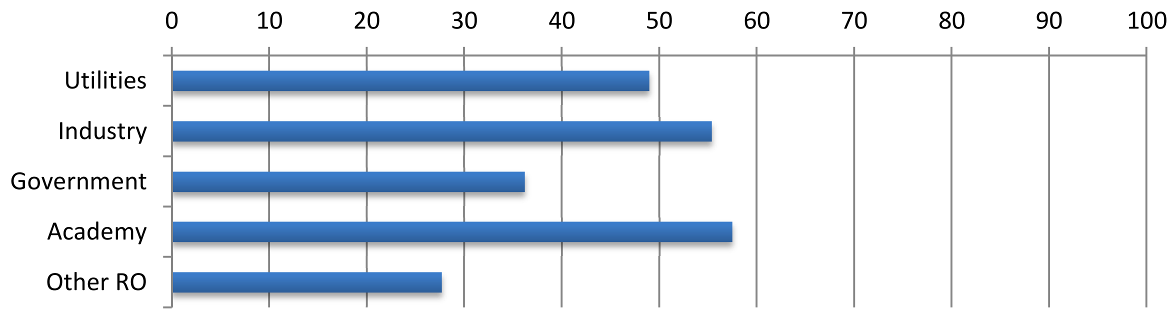



**Figure 42.** Fields of activities for Storage

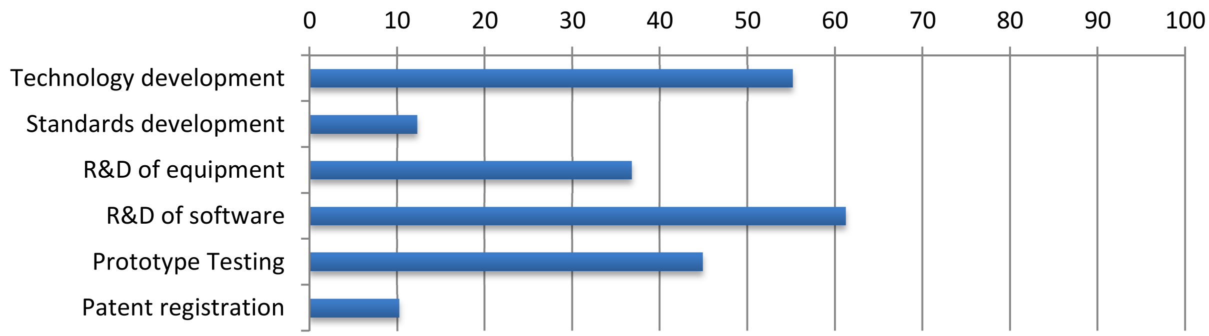
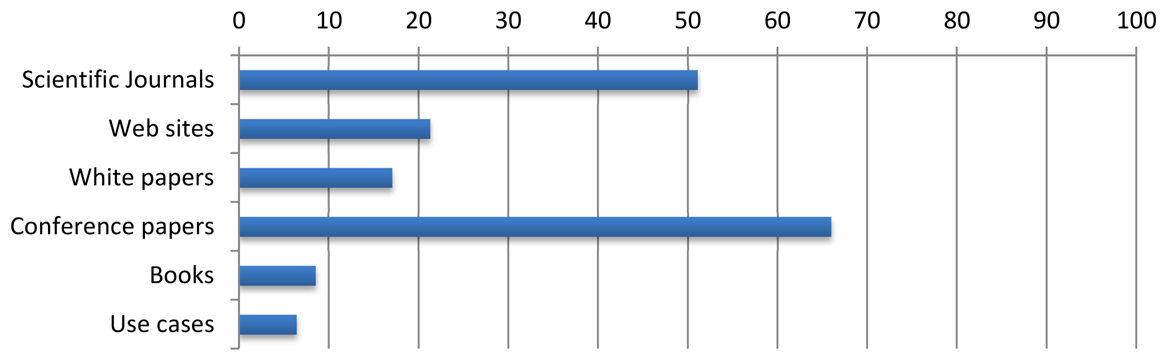



**Figure 43.** Results dissemination for Storage




Conference papers and scientific journals are ranked as top options for the results dissemination, whereas web sites follow with 21% and white papers with 17% of the active labs. As it can be observed from Figure 43, conferences are the preferred way of results dissemination for more than the 65% of the actively involved labs.

Figure 44 illustrates that the major part of the activities is sporadic collaborations in contrary with last year's survey where stand alone activities had the highest percentage. With respect to the geographical area on which research activities are focused, it is worth noticing that all of the active labs in storage have on-going activities in Europe, whereas only 14% and 21% of them in Asia and North America, as shown in Figure 45.

The distribution network is the asset that attracts mostly the scientific interest, whereas islanded and isolated networks play also an important role in storage issues, as it can be observed in Figure 46. The transmission network comes lower in the list, since it gathers the interest of less than 30% of the questioned labs.

**Figure 44.** Nature of Storage smart grid activities

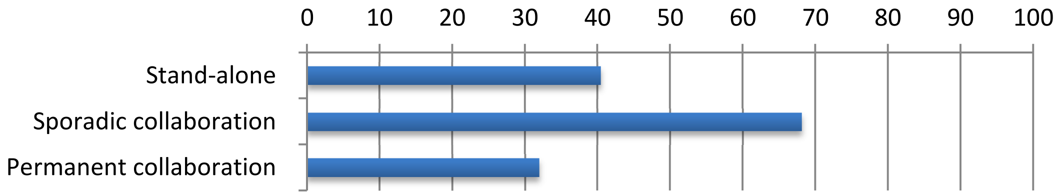



**Figure 45.** Geographical area of interest for Storage smart grid activities

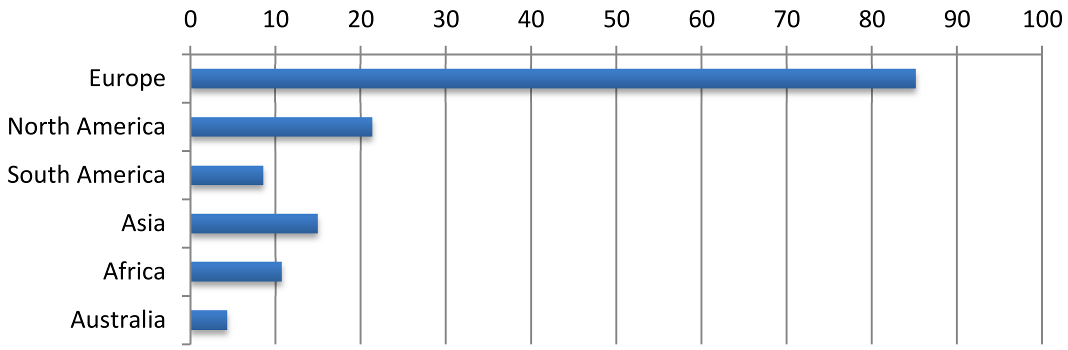
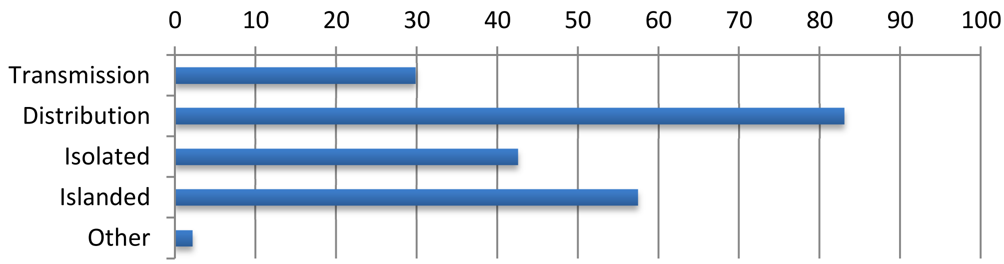



**Figure 46.** Networks on which Storage smart grid activities are focused




Storage is a greater field of research that can involve many subtopics. Batteries are the topic of investigation that is predominantly used among active laboratories, gathering a percentage of 77% among them. Super-capacitors are a topic of interest that comes next with a noticeable difference of 30% with respect to batteries for active research in the field. Flywheels and PSH are other two topics of research with a percentage of 26% and 15% respectively. Other possible topics under Storage smart grid related fields are the Hot water storage, CAES, Chemical-Hydrogen Storage, ice storage and cold water storage. More analytically, the described situation is depicted in Table 11.

**Table 11.** Percentage of activity regarding Energy Storage Technologies

| Energy Storage Technology | % |
|---|---|
| Batteries | 77% |
| Super-Capacitors | 30% |
| Flywheels | 26% |
| PHS | 15% |

| | |
|---|---|
| Hot water storage | 15% |
| CAES | 9% |
| Chemical-Hydrogen storage | 9% |
| Ice storage | 9% |
| Cold water storage | 9% |
| Molten Salts | 4% |
| SMES | 2% |
| Other | 2% |
| UTES | 0% |
| Thermochemical | 0% |

In general, it is noted that many of the research organizations questioned, perform investigation on many of the storage subtopics simultaneously. The most popular topics are demand shifting and peak reduction and voltage support with more than 60%. Variable supply resource integration and frequency regulation attract also more than half of the active labs in the field. Other areas covered are the load following, transmission and distribution congestion relief and off-grid for more than one third of the labs. The details of the topics and the equivalent percentages are shown in Table 12.

**Table 12.** Percentage of activity regarding Energy Storage applications

| **Energy Storage Application** | **%** |
|---|---|
| Demand shifting and peak reduction | 70% |
| Voltage support | 64% |
| Variable supply resource integration. | 55% |
| Frequency regulation | 53% |
| Load following | 38% |
| Transmission and Distribution (T&D) congestion relief | 38% |
| Off-grid | 38% |
| T&D infrastructure investment deferral | 26% |
| Seasonal storage | 23% |
| Combined heat and power | 23% |
| Arbitrage | 21% |
| Black start | 21% |

| | |
|---|---|
| Spinning reserve | 19% |
| Non-spinning reserve | 15% |
| Waste heat utilization | 6% |
| Other | 6% |

The survey reveals that 53% of the researchers on the field perform practical tests/measurements. On the other hand, only the 25% performs reliability tests.

Concerning the standards used for storage in smart grids, almost 20% of the storage-related researchers uses the IEC 61850 – Communication networks and systems in substations standard. Analytically, the standards used with their equivalent percentages are shown in Table 13.

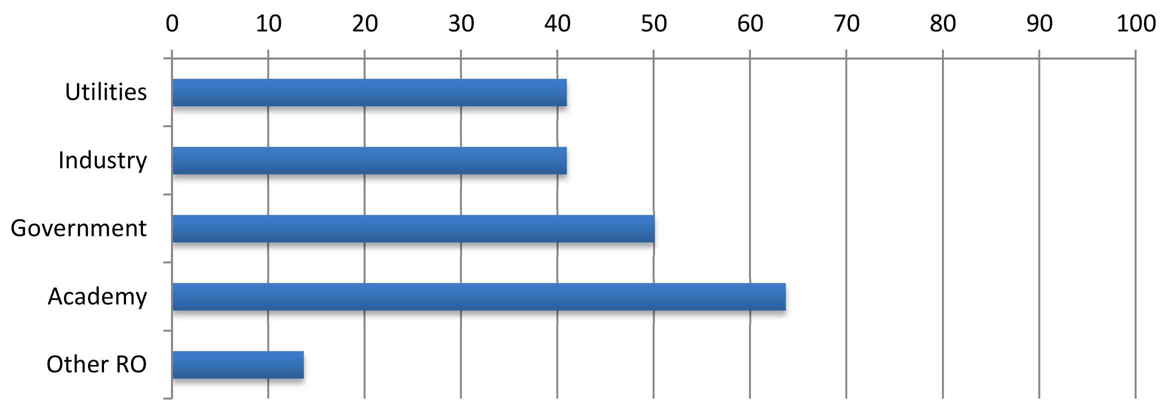
**Table 13.** Standards used for Storage activities

| Standard | % |
|---|---|
| IEC 61850 - Communication networks and systems in substations | 19% |
| IEC 61970 - Common Information Model / Energy Management | 6% |
| IEC 62351 - Power systems management and associated information exchange | 2% |
| Other | 2% |

### 3.6.4 Sustainability

Almost 33% of the laboratories are working in the area of sustainability. Academic and governmental interests are ranked at the first places when it comes to sustainability tasks since they gather the interest of 64% and 50% respectively of the actively involved labs in the field. Utilities and industry are the sectors that follow equally, with percentage of approximately 40%. Figure 47 illustrates the above situation.

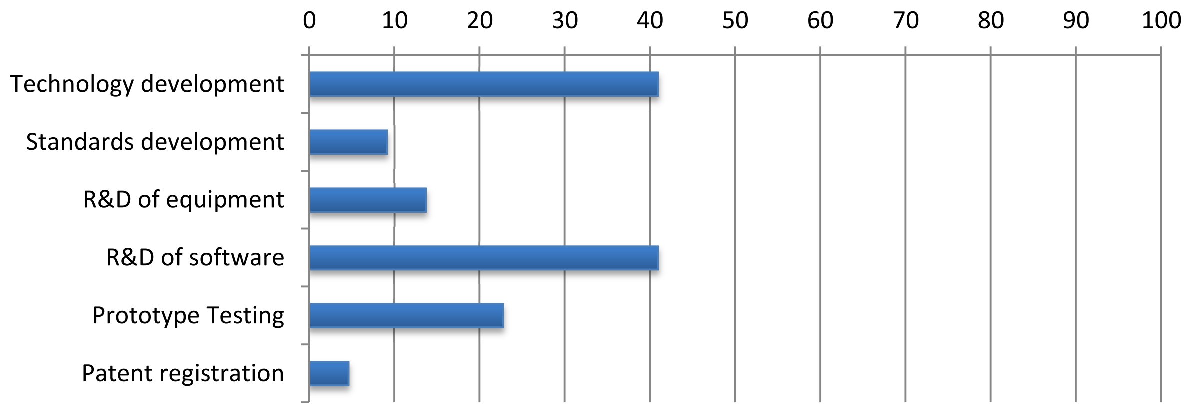
**Figure 47.** Sectors at which research for smart grid Sustainability is focused




Regarding the fields of activities for Sustainability, similarly to the other smart grid categories, Technology development comes first, along with R&D of software, attracting almost the 40% of the actively involved labs. Prototype testing follows with more than

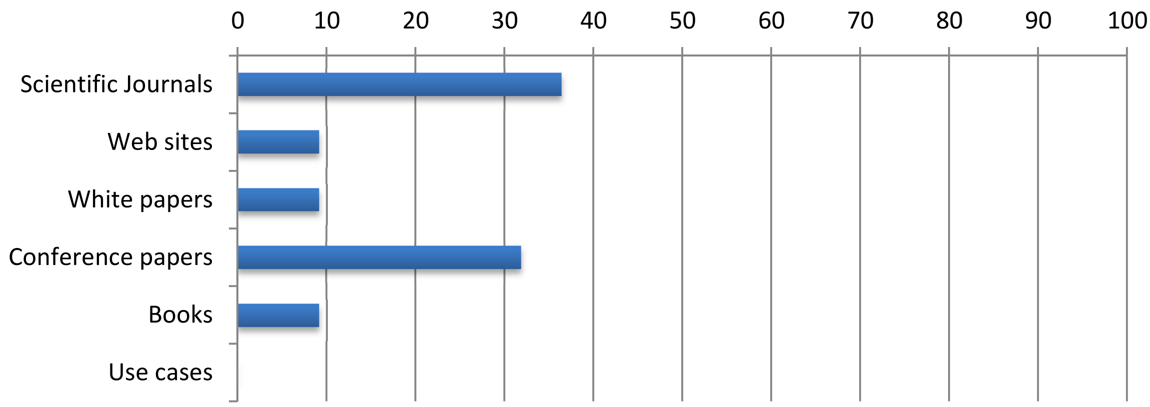
20% and R&D of equipment with 14%. The other identified fields show a smaller preference among the Sustainability focused participants with a percentage around 10%, as shown in Figure 48.

**Figure 48.** Fields of activities on which sustainability research is focused




When it comes to results dissemination, conference and scientific papers are most popular choices for the labs performing research on Sustainability. Other ways of results dissemination, like white papers and books are lower in the list, with a percentage of nearly 10% among the Sustainability labs (Figure 49).

**Figure 49.** Results dissemination for Sustainability




Half of the labs work on this topic in a stand-alone fashion and in sporadic collaborations. Permanent collaborations are less popular with a gradual percentage decrease at the range of 32%, as it can be observed by Figure 50. With respect to the countries in which these activities are carried out, the figures are similar to the previous categories: Europe is the main area of interest. It is also noteworthy that a percentage of nearly 30% of the actively involved labs conducts research in North America and 14% in the South America. Figure 51 shows analytically the situation.

The preference with regard to the networks on which Sustainability is carried out converges to that observed for the other smart grid categories, meaning that the distribution network is the dominant part of the network, whereas the other parts follow with a relatively high difference, as observed in Figure 52.

Among the labs which are contributing to sustainability issues, close to half of them are involved in life cycle analysis in Smart Grids but also on Green House Gas (GHG) development of reduction strategies and GHG analysis (the percentages are 45%, 27%,

22% respectively). Only a 9% is studying the recycling processes for new Smart Grid equipment.

**Figure 50.** Nature of Sustainability activities

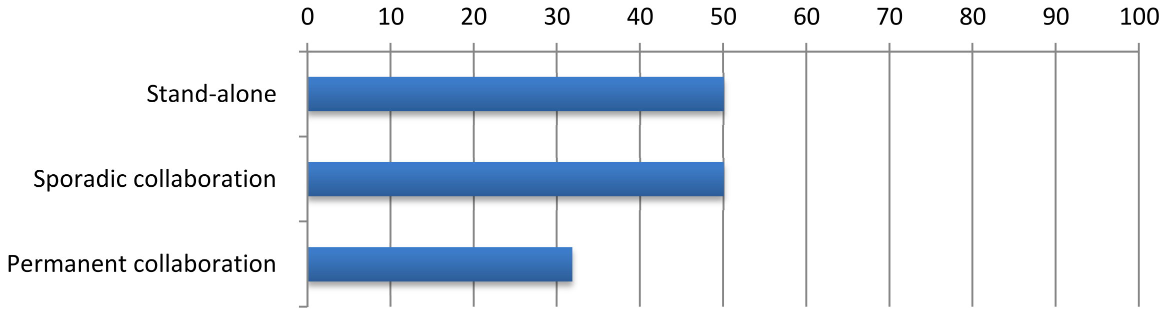



**Figure 51.** Geographical area on which research for Sustainability is focused

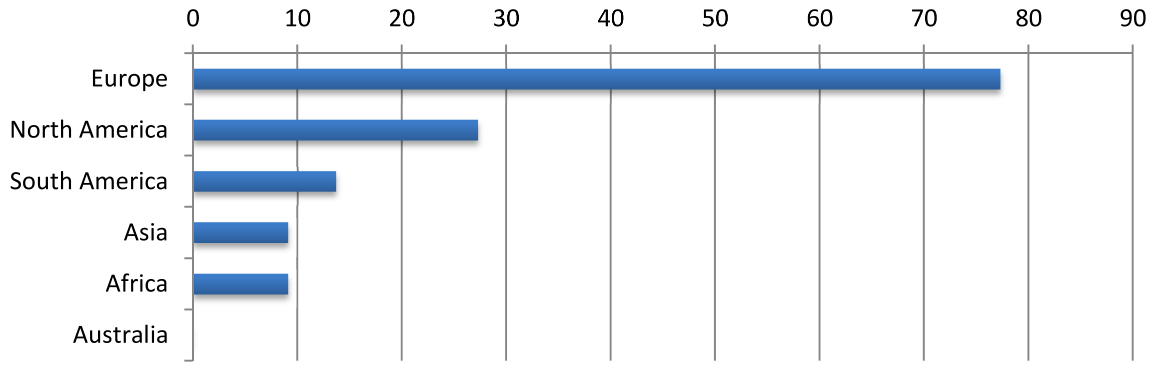
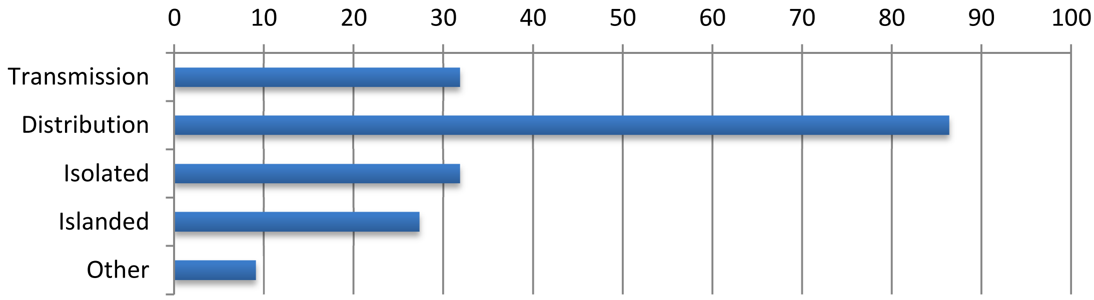



**Figure 52.** Networks on which Sustainability research focuses




### 3.6.5 Market

Almost 45% of the laboratories are involved in market related activities in the smart grid. Among them, the majority (60%) is supported by utilities and secondarily by the government with almost 55%, following by the academy and the industry, as shown in Figure 53.

Regarding the fields of smart grid Market activities, as revealed by Figure 54, R&D of software is the first choice among the actively involved labs, since more than half of the participant laboratories are occupied with such tasks. Technology development follows and then Standards development. Likewise the other smart grid categories, conference and journal papers are the preferred way for results dissemination, whereas use cases

also attract a small percentage for results presentation, nearly to 15% of the actively involved labs, as depicted in Figure 55.

**Figure 53.** Sectors at which Market smart grid activities are targeted

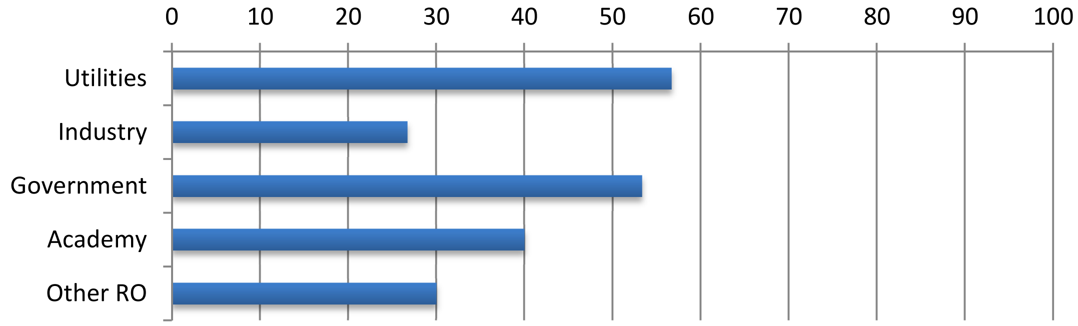



**Figure 54.** Fields of activities for smart grid Market

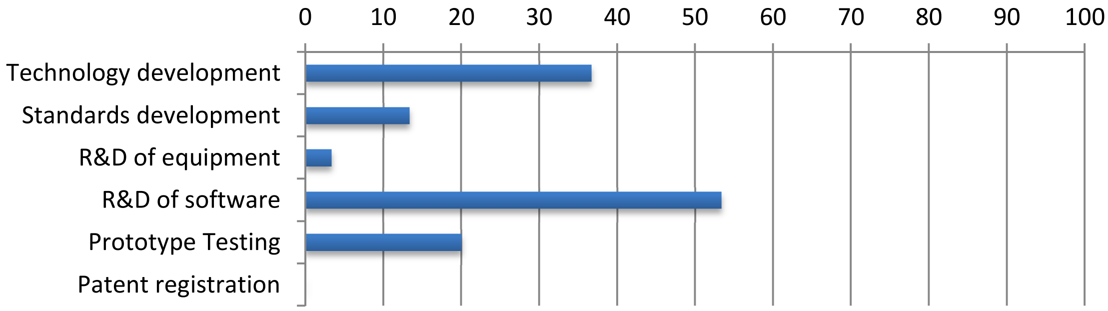
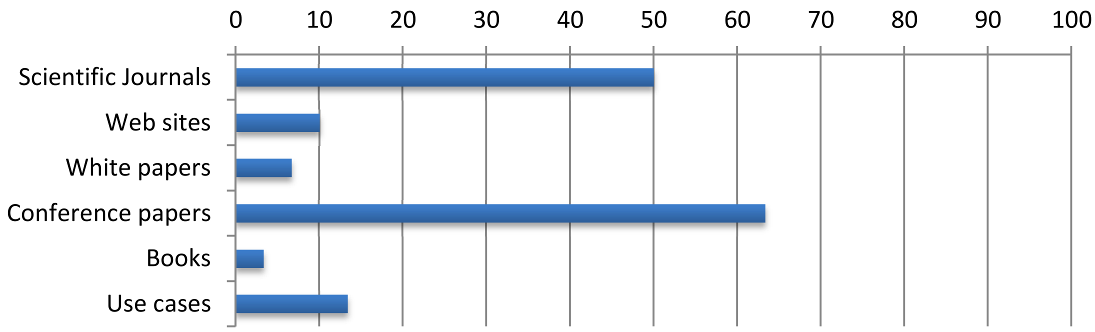



**Figure 55.** Results dissemination for Market




A great majority of the labs actively involved in the markets have sporadic collaborations, following by stand-alone activities and permanent collaborations (Figure 56). With respect to the network on which Market related smart grid research is performed, the major part of the activities focuses on the distribution network, which attracts the interest of 70% of the labs actively involved in the sector. It is noteworthy that half of these labs also target the transmission system. This situation is illustrated in Figure 57. As for the geographical region on which research is focused, Europe remains the continent on which the biggest part of the activities is carried out. It is worth noticing that, apart from Europe and America, in this year's survey a small percentage of activity is also presented in Asia as shown in Figure 58.

Table 14 reveals that there is a variety of topics under investigation regarding market for each of the involved laboratory. The most popular one is Market structure that occupies

60% of the active researchers in the field, while Impact of RES integration on electricity prices is ranked at the second place with 53%. 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 47-30%. The topics of Structure of Generation, Marketplace and Trading Systems and Marketplace attract 20-30% of the involved laboratories. On the other hand, Structure of the ESI (Electrical Supply Industry) and Modeling of new financial frameworks are the least popular topics – for the time being – gathering the interest of less than 15% of the active laboratories.

**Figure 56.** Nature of Market smart grid activities

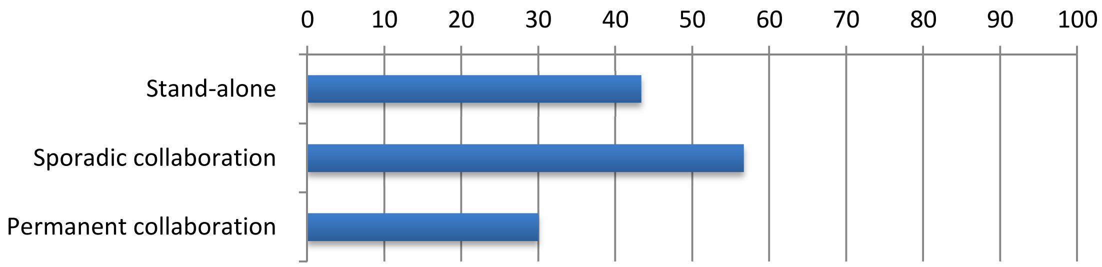



**Figure 57.** Networks on which Market research is focused

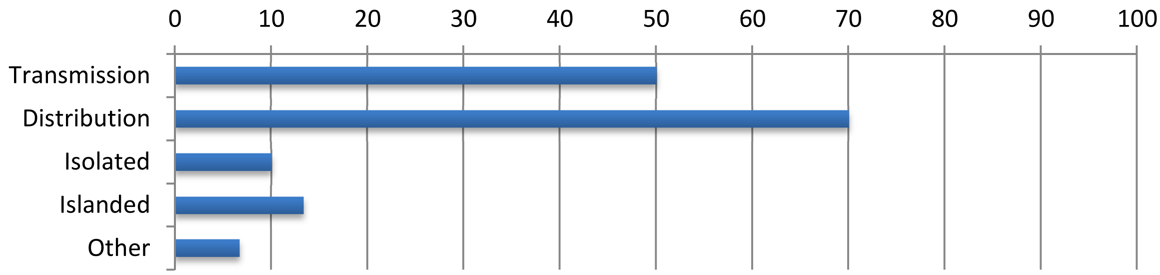
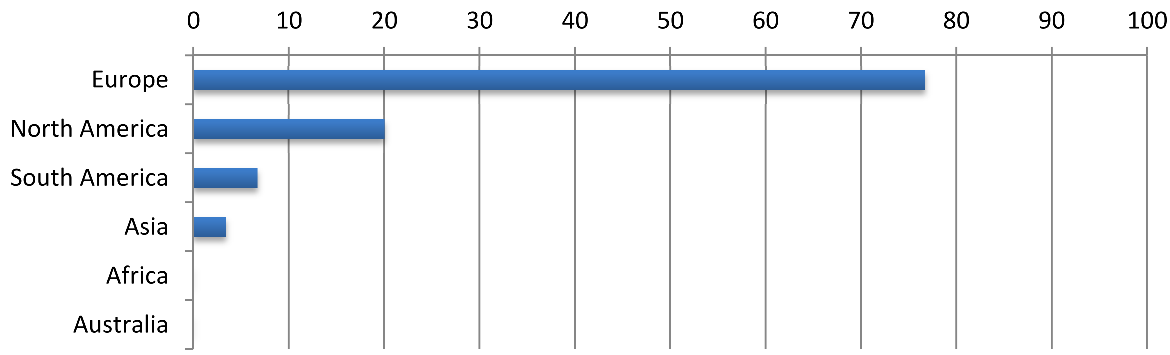



**Figure 58.** Geographical areas on which Market smart grid activities are targeted




The 30% of the participants performing research work on the field of Market use the standard 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 with a percentage of 23%. The standards IEC 60870 - Telecontrol equipment and systems, and IEC 62351 - Power systems management and associated information exchange follow both with 10% (Table 15).

**Table 14.** Percentage of activity regarding Market topics

| **Activity** | **%** |
|---|---|
| Market Structure | 60% |
| Impact of RES integration on electricity prices | 53% |
| New Regulation Schemes for deregulated actors | 47% |
| Analysis of technology market barriers in the Smart Grids | 43% |
| Novel trading schemes | 37% |
| Transmission and Distribution intelligence | 30% |
| Structure of Generation | 27% |
| Marketplace | 27% |
| Trading systems | 20% |
| Structure of the ESI (Electrical Supply Industry) | 13% |
| Modelling of new financial frameworks | 13% |
| Other | 13% |

**Table 15.** Standards used for Market activities

| **Standard** | **%** |
|---|---|
| IEC 61970 - Common Information Model / Energy Management | 30% |
| IEC 61968 - Common Information Model / Distribution Management | 23% |
| IEC 62325 - Common Information Model (CIM) for Energy Markets | 23% |
| IEC 60870 - Telecontrol equipment and systems | 10% |
| IEC 62351 - Power systems management and associated information exchange Integration of Retail Market | 10% |
| Other | 3% |

### 3.6.6 Generation and DER

More the 80% of the questioned laboratories are involved in activities concerning Generation and Distributed Energy Resources (DER). These activities are mainly targeted to the academic sector and the utilities. Industry follows with almost 50% and Government and Other research organizations proceed with less than 40% (Figure 59). According to Figure 60, the objectives of such activities are primarily prototype testing, technology development and R&D software for more than 50% of the participant laboratories, followed by the R&D equipment with almost 45%. The means of results dissemination are conference and journal papers with a percentage of 74% and 57% of

the active laboratories using these solutions, whereas books and white papers attract the 20% of them, as it can be observed in Figure 61.

**Figure 59.** Sectors at which Generation & DER research is targeted

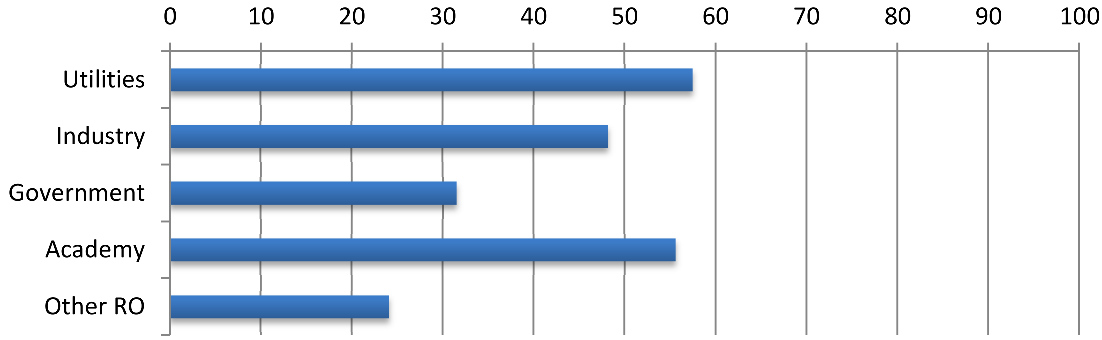



**Figure 60.** Fields of activities for Generation and DER

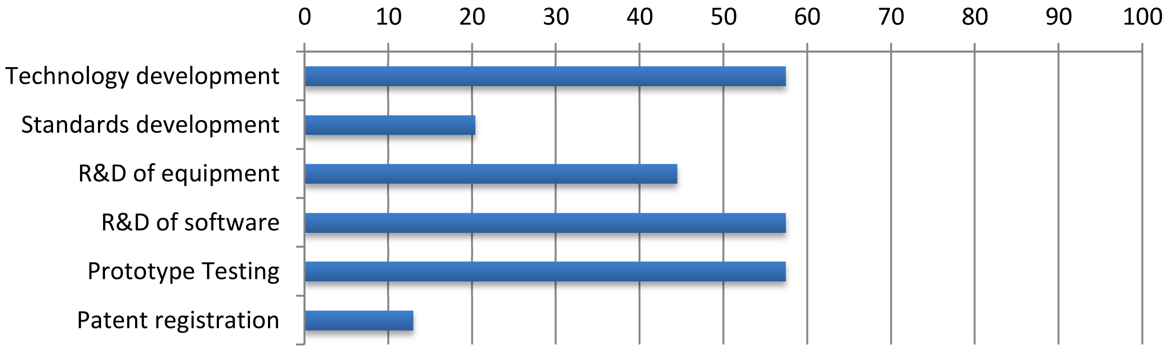
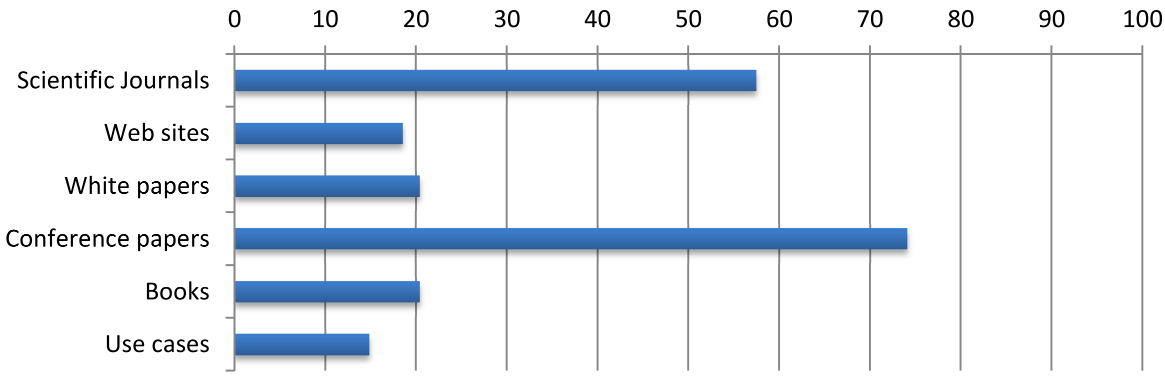



**Figure 61.** Results dissemination for Generation & DER




Regarding the nature of the activities in the Generation & DER field (see Figure 62) sporadic collaborations are more favorable with more than 60% followed by stand-alone activities with approximately 40% and permanent collaborations with 35%. Figure 63 shows that the vast majority of the activities are led in Europe, with more than 80% of the actively involved labs performing research in Europe. North America attracts the interest of 25% of these labs. It is noticeable that this year's results show that the interest is moving to the rest of the world. As shown in Figure 64, most activities are implemented on the distribution network, whereas it is also noted that a relatively high percentage of the active laboratories takes part in activities involving the islanded (56%)

and isolated (41%) networks. The transmission network comes lower in the list, likewise the other smart grid categories.

**Figure 62.** Nature of the Generation & DER activities

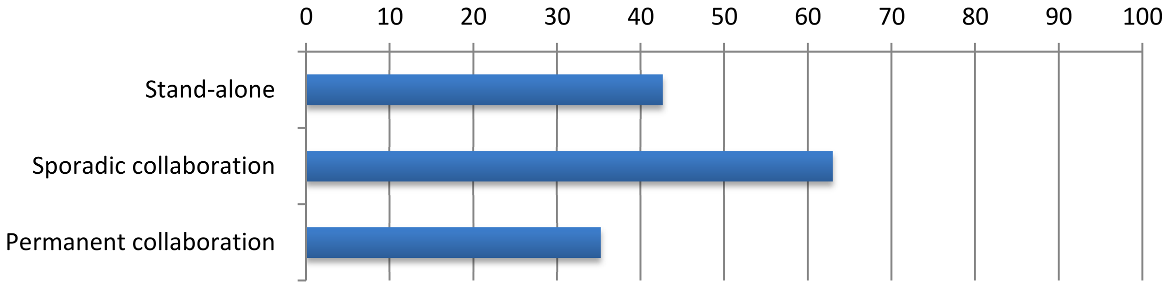



**Figure 63.** Geographical area on which Generation & DER activities are focused

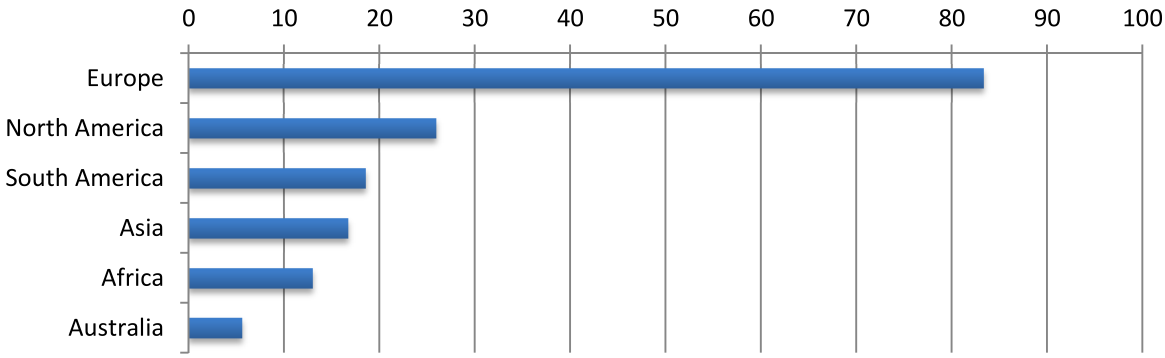



**Figure 64.** Networks on which Generation & DER activities are focused

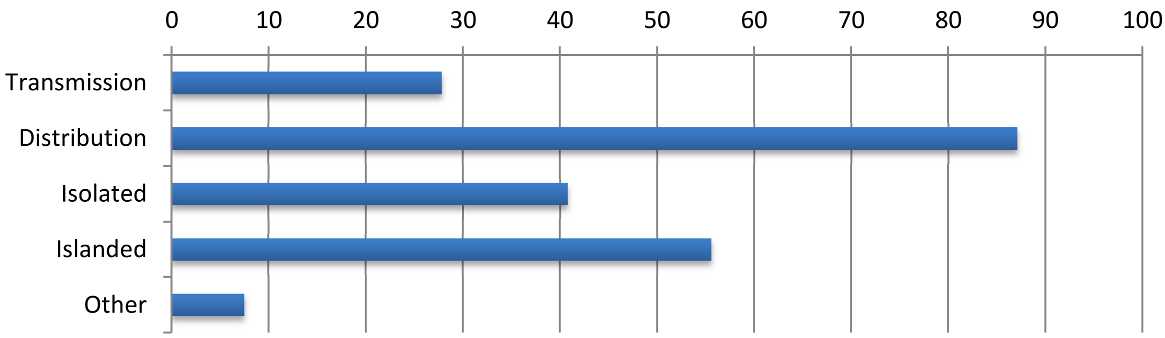



Table 16 shows on which technologies the laboratories work. It is interesting to see the change between the two surveys. Thus the dominant technologies are still PV and Wind Energy, with the solar energy to come first in this year's results. Biomass, Hydro and Fuel Cell follow. It is noticeable to see that there is a drop for CHP and Ocean energy. The research activities mainly focus on RES integration, forecasting analysis and advanced control.

With respect to standards usage in the generation and DER sector, the one that is mostly used is the IEC 61850 (Communication Networks and Systems in Substations). However, it’s worth mentioning also the IEC 61400 (Wind Turbines) and the EN 50438 (Requirements for the connection of micro-generators in parallel with public LV distribution networks). More information can be found in Table 17.

**Table 16.** Percentage of work on the different Generation and DER technologies

| Technology | Old survey | New survey |
|---|---|---|
| PV | 89% | 78% |
| Wind Energy | 89% | 69% |
| CHP | 45% | 31% |
| Hydro | 39% | 24% |
| Biomass | 39% | 20% |
| Fuel Cell | 34% | 19% |
| Gas Power Plants | 25% | 17% |
| Concentrator Solar Power | 30% | 15% |
| Waves | 15% | 7% |
| Coal Power Plants | 15% | 7% |
| Nuclear Power Plants | 9% | 6% |
| Tidal | 6% | 2% |

**Table 17.** Percentage of Standards usage in the Generation and DER activities

| Standard | % |
|---|---|
| IEC 61850 - Communication networks and systems in substations | 41% |
| IEC 61400 – Wind Turbines | 24% |
| EN 50438 - Requirements for the connection of micro-generators in parallel with public low-voltage distribution networks | 22% |
| IEC 60904 - Photovoltaic devices | 17% |
| IEC 61724 - Photovoltaic system performance monitoring. | 17% |
| IEC 61968 - Application integration at electric utilities - System interfaces for distribution management | 13% |
| IEC 61970 - Common Information Model / Energy Management | 13% |
| IEC 61194 - Characteristic parameters of stand-alone photovoltaic (PV) systems | 11% |
| IEC 61727 - Photovoltaic (PV) systems. Utility interface | 11% |
| IEC 62351 - Power systems management and associated information | 11% |

| | |
|---|---|
| exchange | |
| IEC 61499 - International Standard for Distributed Systems | 9% |
| IEC 61730 - Photovoltaic (PV) module safety qualification | 6% |
| IEC/TS 62257 Recommendations for small renewable energy and hybrid systems for rural electrification | 6% |
| IEC 61869 - Instrument transformers | 4% |
| IEC/TS 61836 Solar photovoltaic energy systems - Terms definitions and symbols | 2% |
| Other | 9% |

### 3.6.7 Electromobility

For electromobility issues, utilities, industry, government and academia are all high in the list with percentages higher than 45%, whereas the 29% of the active laboratories in the field work for other research organizations, as shown in Figure 65. According to Figure 66, Prototype testing, R&D equipment and software are the main goals of the active laboratories, with technology development in general coming up next. In addition, standards development attracts the 27% of the active laboratories, which is considered to be relatively high in relation to the other research activities. When it comes to results dissemination, conference papers are the number one choice for the participant laboratories, with scientific journals to follow, as depicted in Figure 67.

**Figure 65.** Sectors at which Electromobility research is targeted

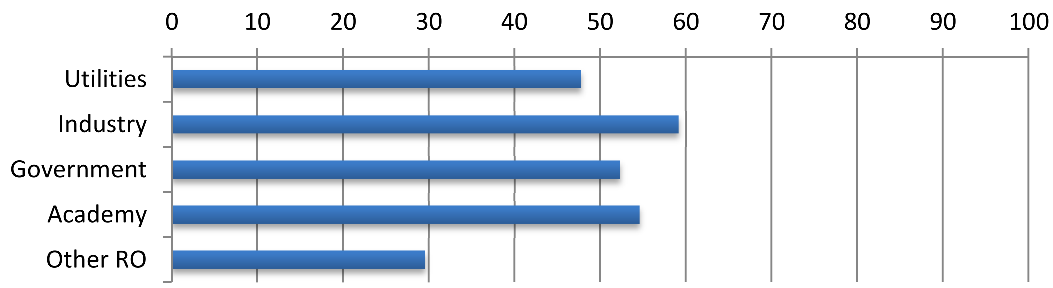
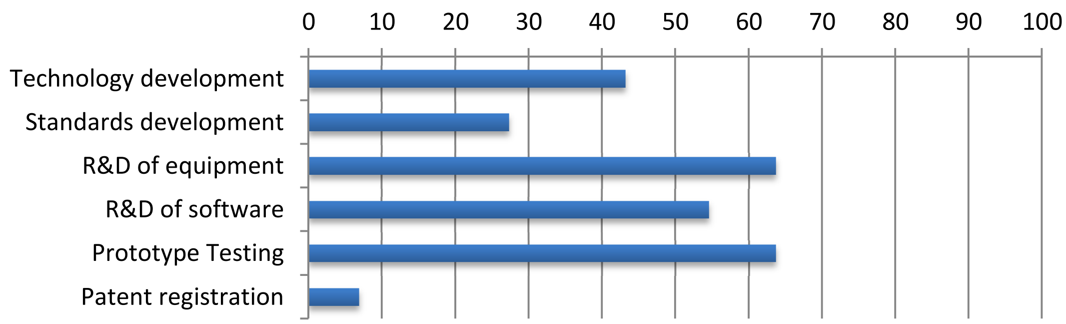



**Figure 66.** Fields of activity for the Electromobility category




From Figure 68 it can be concluded that for Electromobility, the majority of the activities are sporadic collaborations for specific projects (close to 60%), with permanent

collaborations (a bit more than 40%) and stand-alone activities (31%) to follow. As it is anticipated, the vast majority of the activities are focused in Europe followed by a 23% in North America, whereas the other continents gather the interest of a small percentage of the participating labs (see Figure 69). Finally, likewise the other smart grid categories, the distribution grid is the part of the network that attracts mostly the scientific interest, followed by islanded and isolated mode with respectively 30% and 25% as depicted in Figure 70.

**Figure 67.** Results dissemination for Electromobility

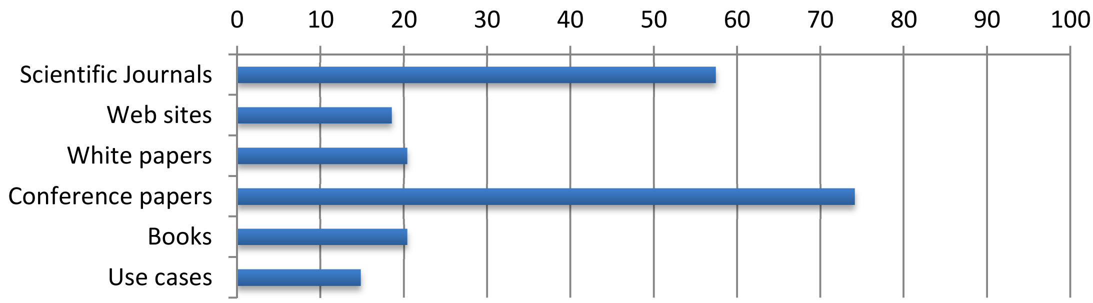



**Figure 68.** Nature of Electromobility activities

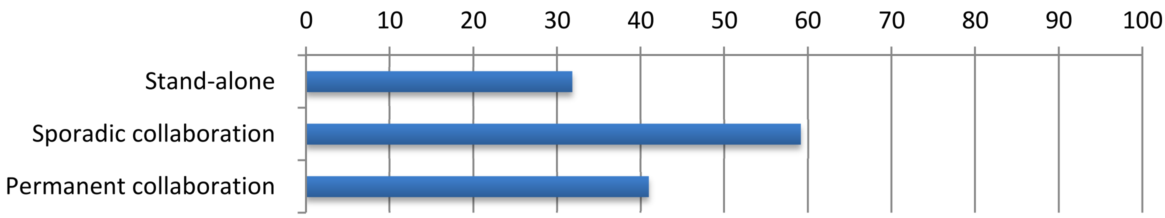
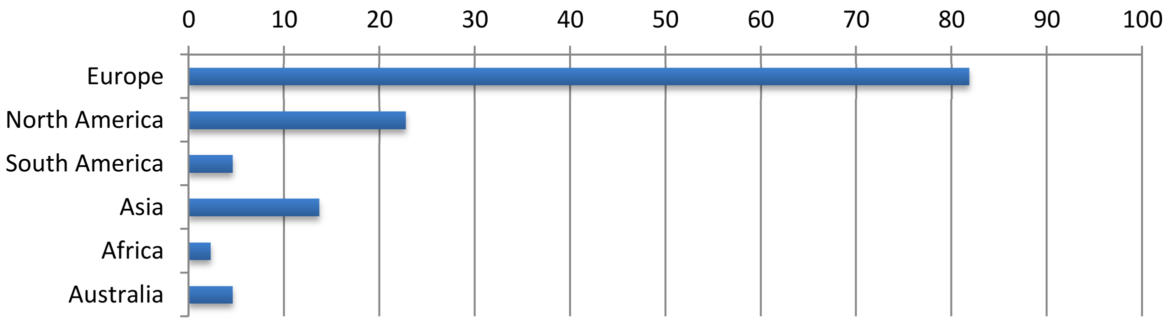



**Figure 69.** Geographical area of interest for Electromobility




There are several areas in which research work is conducted regarding Electric Vehicles and Plug-In Electric Vehicles, like Vehicle-to-grid (V2G), energy storage, grid load impact, charging technologies and demand response seem to be among the top fields for investigation, since the 59%, 52%, 48% and 43% of the EV laboratories conduct research on the subject. Energy efficiency, power quality and interoperability follow as subjects of research interest with a percentage of 34% each among the active research laboratories on the field. The aforementioned information is summarized in Table 18.

An important issue in the EV sector is the variability in the available charging topology modes. As shown by our survey, the IEC 61851 Mode is the most popular for this purpose. Almost half of the laboratories conducting EV/PHEV research (48%) work with the IEC 61851 Mode 3 (AC slow or fast charging using a specific EVs multi-pin socket

with control and protection functions). An important part of these research groups (43%) conducts research on the IEC 61851 Mode 2 (AC low charging from a regular socket equipped with specific EVs protection mechanism). 41% of the laboratories uses the IEC 61851 Mode 1 (AC slow charging from a regular electrical socket) and the IEC 61851 Mode 4 (DC fast charging using special charger technology). In addition to IEC 61851, the SAE AC or DC mode is also used but at a lower extent. Table 19 presents analytically this situation.

**Figure 70.** Networks on which Electromobility is focused

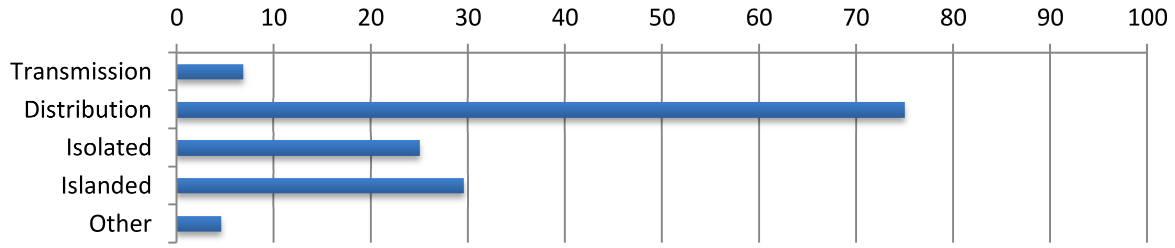



**Table 18:** Areas of work regarding Electromobility

| **Area of work** | **%** |
|---|---|
| Vehicle-to-grid (V2G) | 59% |
| Energy storage | 52% |
| Grid load impact | 48% |
| Charging technologies | 48% |
| Demand response | 43% |
| Energy efficiency | 34% |
| Power quality | 34% |
| Interoperability | 34% |
| Energy management and vehicle autonomy | 25% |
| Car battery technologies | 25% |
| Environmental impact (pollution, noise…) | 20% |
| Citizen behavior | 16% |
| Safety | 7% |
| HVAC | 5% |
| Security | 2% |

Since the charging connectors for EVs and PHEV are a critical part of the whole structure, it has been important to acknowledge the type of connectors or relative

standards used in current research work. The standard IEC 62196 and its various parts is an option for charging purposes, while CHAdeMO is winning place this year as it was selected by approximately one third of the active laboratories in the field. Mennekes and SCHUKO are the standards to follow with small difference. Table 20 presents the available options and the percentage of research groups that performs research with them.

**Table 19.** Current utilization 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 | 48% |
| IEC 61851 Mode 2 – AC low charging from a regular socket equipped with specific EVs protection mechanism | 43% |
| IEC 61851 Mode 1 – AC slow charging from a regular electrical socket | 41% |
| IEC 61851 Mode 4 – DC fast charging using special charger technology | 41% |
| SAE AC level 1 | 11% |
| SAE AC level 2 | 11% |
| SAE AC level 3 | 11% |
| SAE DC level 1 | 7% |
| SAE DC level 2 | 7% |
| Other | 7% |

**Table 20.** Percentage of utilization of the different standards for charging connectors

| Standard for charging connectors | % |
|---|---|
| IEC 62196-2 "Type 2" - single and three phase vehicle coupler | 32% |
| CHAdeMO | 30% |
| IEC 62196-2 "Type 1" - single phase vehicle coupler | 27% |
| Mennekes (VDE-AR-E 2623-2-2) | 27% |
| SCHUKO | 25% |
| IEC 62196-1 - Conductive charging of electric vehicles - Part 1: General requirements | 23% |
| IEC 62196-2 "Type 3" - single and three phase vehicle coupler with shutters | 23% |

| | |
|---|---|
| IEC 62196-3 - Dimensional compatibility and interchangeability requirements for DC and AC/DC. pin and contact-tube vehicle couplers | 14% |
| SAE J1772 - EVs and PHEV Conductive Charge Coupler | 14% |
| Combined charging system (DC) | 9% |
| EVs Plug Alliance | 7% |
| Yazaki | 7% |
| SCAME | 7% |
| CEEplus | 2% |
| Other | 2% |
| Framatome | 0% |

Regarding the charging capacity, the current intensity can vary from 13 A to 80 A, whereas the voltage level can vary from 220 V to 415 V. The usual value for current intensity is 16 A, which is used by half of the research groups. As for the voltage level, in 48% of the cases the value of 230 V is used. With respect to the power line frequency used for the activities, the 68% of the EV research groups use 50 Hz for their experiments. Table 21 shows the values for current capacity, voltage level and frequency that are used by the EV research laboratories.

**Table 21.** Percentage of power capacities for charging purposes

| **Current** | **%** | **Voltage** | **%** | **Frequency** | **%** |
|---|---|---|---|---|---|
| 13 A | 23% | 220 V | 23% | 50 Hz | 68% |
| 15 A | 27% | 230 V | 48% | 60 Hz | 11% |
| 16A | 50% | 240 V | 14% | Other | 7% |
| 30 A | 23% | 400 V | 36% | | |
| 32 A | 34% | 415 V | 11% | | |
| 63 A | 30% | Other | 14% | | |
| 80 A | 20% | | | | |
| 120 A (DC) | 14% | | | | |
| Other | 7% | | | | |

Almost one third of the active laboratories (32%) perform research on the areas of Management (configuration, deployment). Communications/ Protocols, Demand response, Charging infrastructure (location of charging points, availability of charging points, charging status) and Car monitoring follow closely with 27-25% . Control

(alarms, events), Pricing and User account and billing are areas found lower in the list. Table 22 depicts the aforementioned situation.

**Table 22.** Different type of software applications for electromobility

| Software application | % |
|---|---|
| Management (configuration, deployment…) | 32% |
| Communication/protocols | 27% |
| Demand response | 27% |
| Charging infrastructure (location of charging points, availability of charging points, charging status…) | 25% |
| Car monitoring | 25% |
| Control (alarms, events…) | 18% |
| Pricing | 14% |
| User account and billing | 9% |

The communication standard that is used mostly by electromobility research groups is the IEC 61850 and at a lower extent the IEC 61851 and IEC 15118. The potential standards/ protocols that can be used for communication electromobility purposes along with the percentage of the EV/PHEV laboratories that uses them are shown in Table 23.

**Table 23.** Communication protocols applied for electromobility activities

| Communication protocol | % |
|---|---|
| IEC 61850 - Communication networks and systems in substations | 36% |
| IEC 61851 - Electric vehicle conductive charging system | 32% |
| ISO/ IEC 15118 - Vehicle to grid communication interface | 20% |
| IEC 62351 - Power systems management and associated information exchange | 9% |
| Other | 9% |
| IEEE 80211P - Wireless access in vehicular environment | 5% |
| SAE J2847 - Communication between Plug-in Vehicles and the Utility Grid | 5% |
| SAE J2931 - Digital Communication for Plug-in Electric Vehicles | 5% |
| OICP – Open Interchange Protocol (Hubject) | 5% |

### 3.6.8 Smart Home/Building

Industry and academy are the sectors to which the majority of Smart home/building activities are addressed. Utilities and governmental organizations follow next. R&D of software and prototype testing are ranked first as the objective of such activities (65%), following by the technology development and the R&D of equipment with 55%, standards development and patent registration are the least interesting activities among the active laboratories. Figure 71 and Figure 72 depict this situation respectively.

**Figure 71.** Sectors at which Smart Home/Building activities are targeted

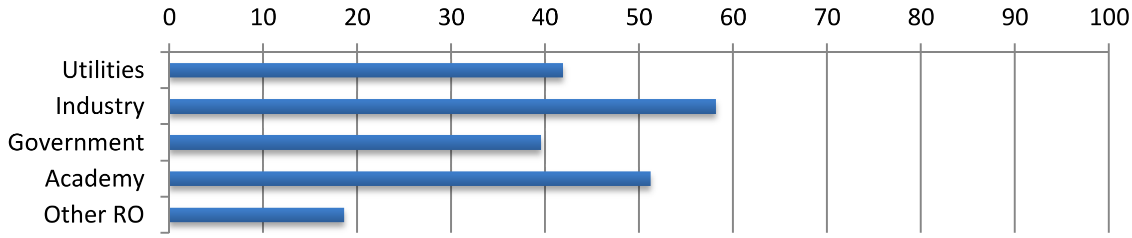
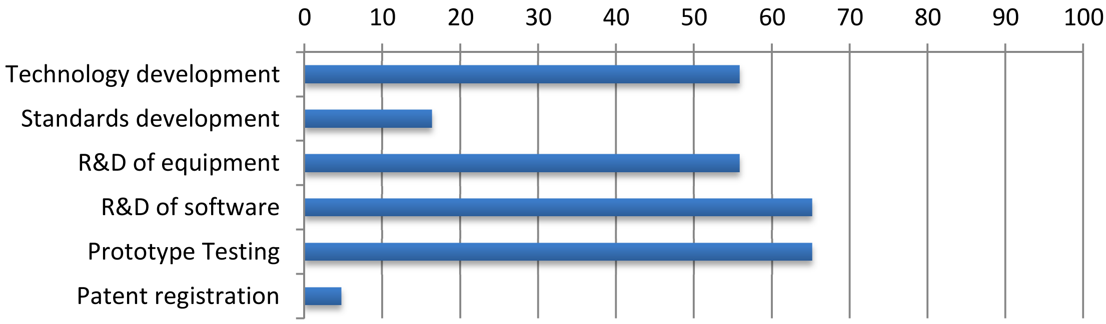
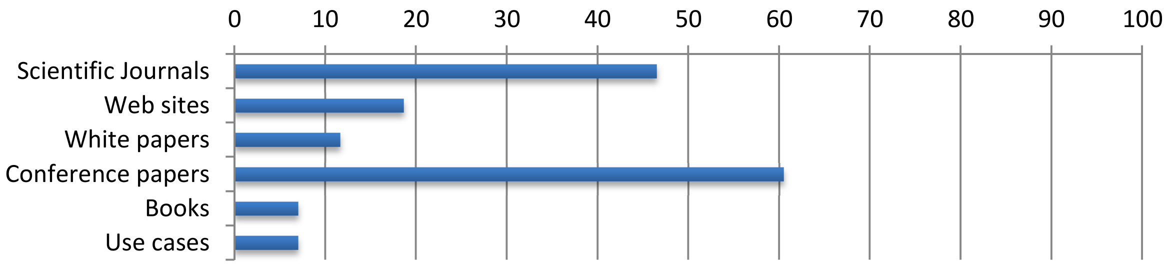



**Figure 72.** Fields of activities for Smart Home/Building activities




Similarly to the other smart grid categories, conference papers and scientific journals are the most popular ways of results presentation. More than a half of the active laboratories are involved in sporadic collaborations whereas stand-alone activities follow with a difference of 7% approximately. Figure 73 and Figure 74 show the dissemination strategies and the nature of activities in Smart Home/Building research.

**Figure 73.** Ways of results dissemination for Smart Home/Building smart grid category




Most activities take place in Europe, whereas a small percentage of the activities are also focused on the other continents and in particular in North and South America, which is clearly noticed by Figure 75. Finally, as Figure 76 illustrates, the distribution network attracts mostly the scientific interest with 79% of the active involved laboratories, whereas isolated and islanded networks follow with a percentage of 39% and 35% respectively.

**Figure 74.** Activities nature for Smart Home/Building smart grid category

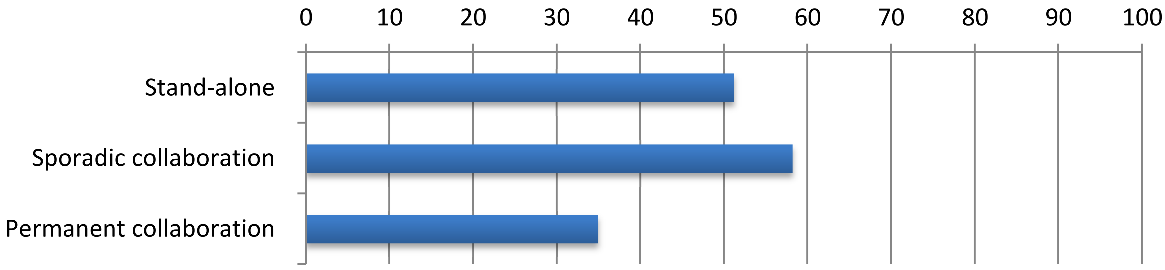



**Figure 75.** Geographical area of interest for Smart Home/Building activities

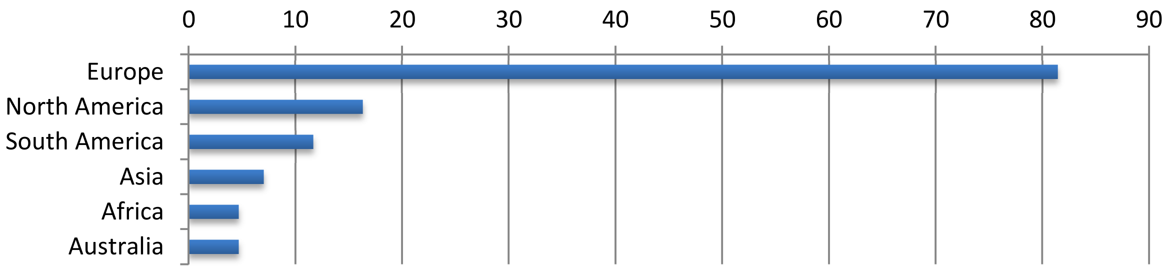
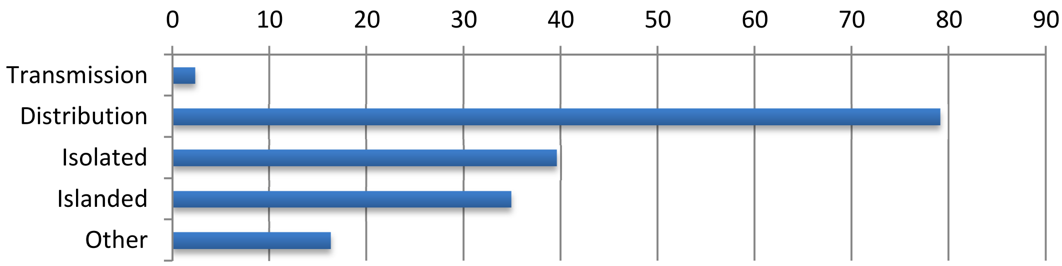



**Figure 76.** Networks on which Smart Home/Building activities are focused




The Smart Home/Building is a broad scientific field entailing many sub-categories. From our survey, it is noticeable, that most of the active laboratories in the field occupy themselves with multiple activities in the sector. The area of Energy management strategies / Cost-control, Demand Response and Integration of RES are ranked first with percentages of more than 50% of the active laboratories in the field. Smart appliances, interoperability, temperature control and power quality attract also more than one third of the researchers in this field. The above results are presented in Table 24.

It is noticeable that more than half of the researchers on the subject also work on the development of software applications in the area of Smart Home. The areas that this development of software applications takes place vary, with Management issues (configuration, deployment) and Demand Response being ranked first with the percentages of 83% and 65% respectively with respect to the total number of laboratories working on the subject. Communications /protocols, Control issues (alarms, events) and Pricing are also popular topics, whereas User Account and billing and Cybersecurity are lower in the list, for the time being. In Table 25, the different areas are presented along with the equivalent percentage of the laboratories among the active ones in the field.

Regarding the telecommunication technologies used in the lab, Wireless and Ethernet cabling are the most widely used, since 60% of the active researchers in the field employ this solution. PLC (Power Line communications) is also good options for

telecommunication purposes, and they are preferred by the 42% of the laboratories. Analytically, the above picture is presented in Table 26.

**Table 24.** Activities regarding Smart Home research

| **Activity** | **%** |
|---|---|
| Energy management strategies / Cost-control | 67% |
| Demand response | 58% |
| Integration of RES | 58% |
| Smart appliances | 44% |
| Interoperability | 40% |
| Temperature control | 37% |
| Power quality | 35% |
| Lighting | 23% |
| Movement sensors | 16% |
| Safety | 16% |
| Security | 12% |
| User account and billing | 9% |
| Audio-visual | 0% |
| Other | 0% |

**Table 25.** Software development for Smart Home applications

| **Smart Home application** | **%** |
|---|---|
| Management (configuration, deployment…) | 83% |
| Demand response | 65% |
| Communication/protocols | 52% |
| Control (alarms, events…) | 35% |
| Pricing | 30% |
| User account and billing | 13% |
| Other | 9% |
| Cybersecurity | 4% |

**Table 26.** Telecommunication technologies used in the laboratories for the Smart Home activities

| **Telecommunication technology** | **%** |
|---|---|
| Wireless (including any technologies) | 60% |
| Ethernet copper cabling | 60% |
| PLC | 42% |
| Other | 12% |
| Fiber | 5% |

With respect to standards used to conduct research work in Smart-Home related areas, few laboratories apply specific standards, with the percentages being lower than 20% among the active laboratories for all standards. Some examples are the EN 13321 - Open data communication in building automation, controls and building management, the EN 50491 - General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS), the IEC 50090 - Home and building electronic systems, the ISO/IEC 14543 - Information technology - Home Electronic Systems (HES) and the IEC 62351 - Power systems management and associated information exchange.

### 3.6.9 Smart Cities

Research activities in this category are mainly supported by local governments, although a non-negligible role is also played by, industry, utilities and academy. This can be explained by the fact that governmental factors are the ones to decide about the technological development of a city. Figure 77 depicts this issue. With respect to the fields of activities in the Smart City sector, the focus is mainly given on technology development and R&D (equipment). R&D of software and prototype testing are activities that also attract close to 50% of the labs actively involved in Smart City research. Analytical information is presented in Figure 78.

The dissemination of these activities and their related results is done mainly through conferences and scientific journals, as shown in detail in Figure 79, with white papers and web sites found lower in the list. The activities are carried out through participation in sporadic (supported) projects followed by fix collaborations and at a minor extent by stand-alone activities, which is shown in Figure 80. Regarding the geographical area on which research is focused, Figure 81 illustrates that more than 80% of research is carried out in Europe, similarly to the other smart grid categories. Although the majority of the labs focus on the distribution grid, a considerable interest is also devoted to islanded and isolated networks, as depicted in Figure 82.

The majority of the researchers in the Smart City field focus in Energy generation and Information and Communication Technologies with a percentage of 50% and 47% among the active laboratories. Energy storage, mobility, lighting are the following popular topics attracting the 41%, 35% and 32% respectively of the active researchers. It is worth noticing that environmental issues are occupying almost a quarter of the active laboratories (24%), while Governmental issues (administration, buildings, etc.) follow with 21%.

It is also worth noting that only the 44% of the active laboratories conducts research work regarding the development of software applications in the area of Smart City. Communication/protocols, control (alarm, events etc) and management are evenly listed as the most popular areas of interest among these labs.

**Figure 77.** Sectors at which Smart City research is focused

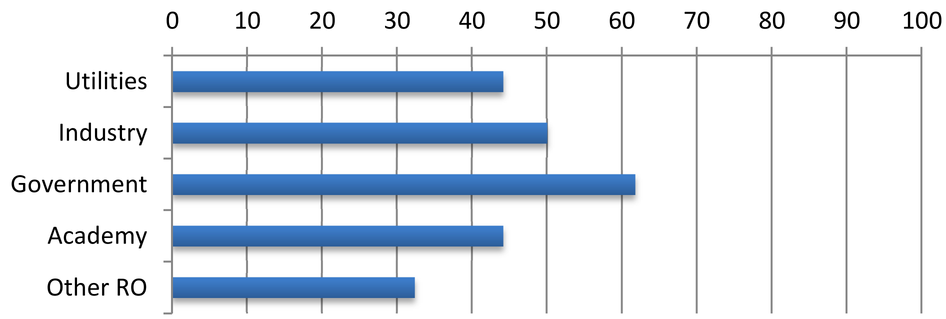



**Figure 78.** Fields of activities for Smart City research

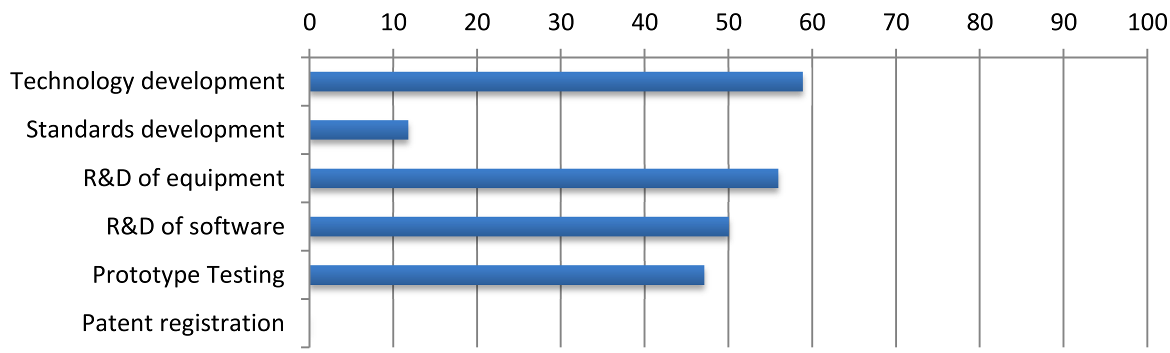



**Figure 79.** Results dissemination in Smart City related activities

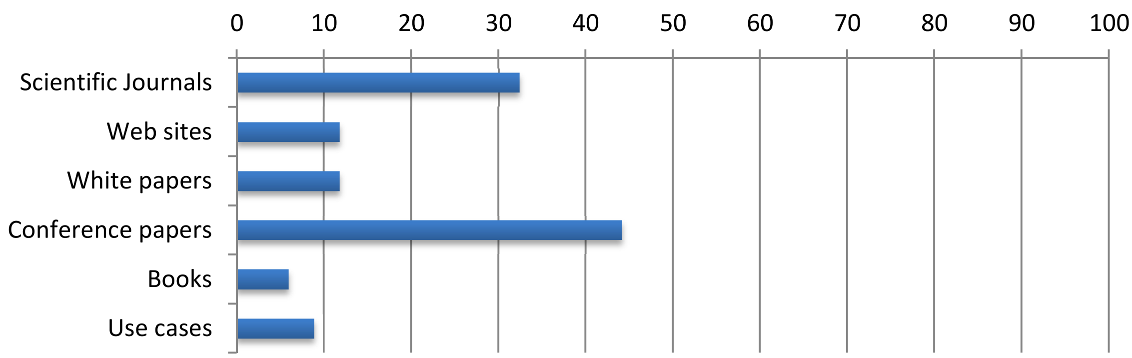



**Figure 80.** Nature of activities in Smart City research

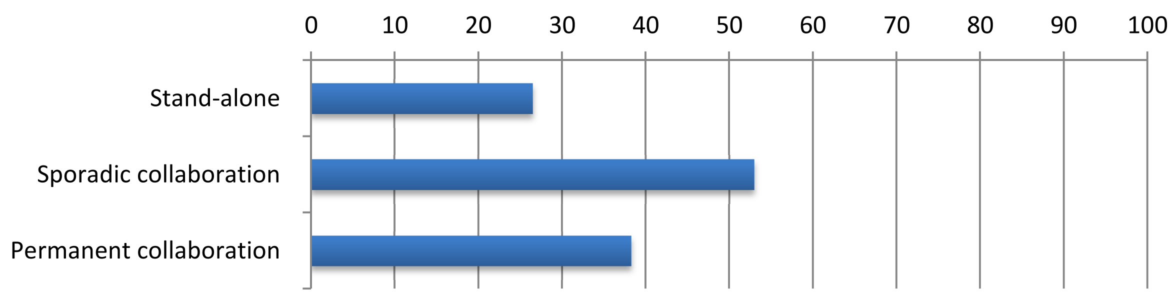


**Figure 81.** Geographical area on which Smart City research is focused

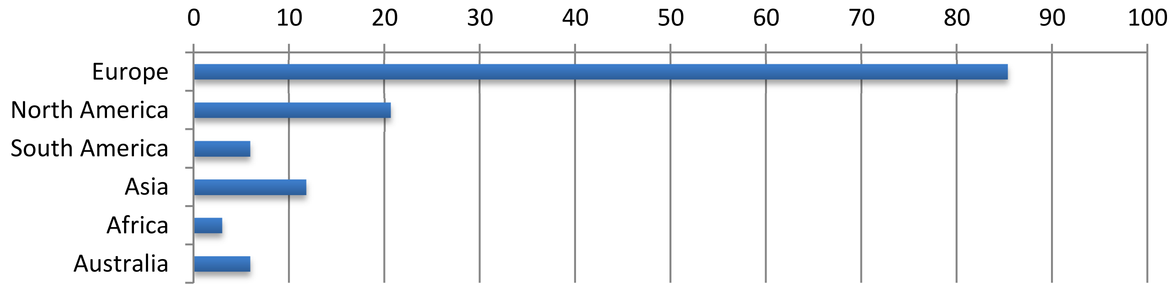
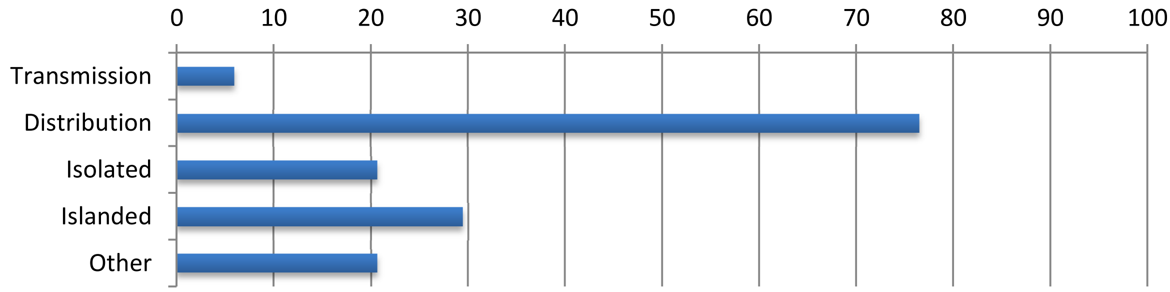



**Figure 82.** Networks on which Smart City research is carried out




### 3.6.10 Demand Response (DR)

Demand Response is a category that attracts the utilities interest, as it is shown in Figure 83. This is rather anticipated since adapting the electricity provided according to the customers' needs is a very important aspect of the whole smart grid for utilities. Academy and industry are also interested in Demand Response research as it is obvious from Figure 83.

Figure 84 shows that Prototype testing, R&D of software and equipment are popular fields of activity along with technology development when it comes to Demand Response issues. It is worth noticing that the percentages presented refer to the labs performing the specific activity among the labs that are actively involved in Demand Response.

With respect to the results dissemination, the situation is similar to the aforementioned categories, meaning that conference and scientific papers are the most popular way of publishing the scientific findings, as shown in Figure 85. Sporadic collaborations for specific projects are common also for the labs that perform Demand Response activities (59%), whereas permanent collaborations and stand-alone activities also attract the interest of the participating labs (33% and 37% respectively), which is depicted in Figure 86. Figure 87 shows that most Demand Response activities are carried out in Europe and secondarily in North America, as it is anticipated, since most of the participating labs are located in Europe. As for the parts of the grid where the activities are performed, the distribution grid is the one that gathers mostly the scientific interest with a percentage of 88% among the actively involved labs, whereas isolated and islanded grids follow with 23% and 25% respectively (Figure 88). This is explained by the fact that the distribution grid entails many parts that need to be developed for the realization of the smart grid.

Table 27 presents the areas on which Demand Response research is focused. As it can be observed, DER integration is first in the list among the areas of interest, gathering a percentage of 67% among the labs that are occupied with Demand Response issues. Other important areas related to Demand Response research are Storage, DRMS (Demand Response management systems), Demand Modeling and Automated Demand Response.

**Figure 83.** Sectors at which research on Demand Response is targeted

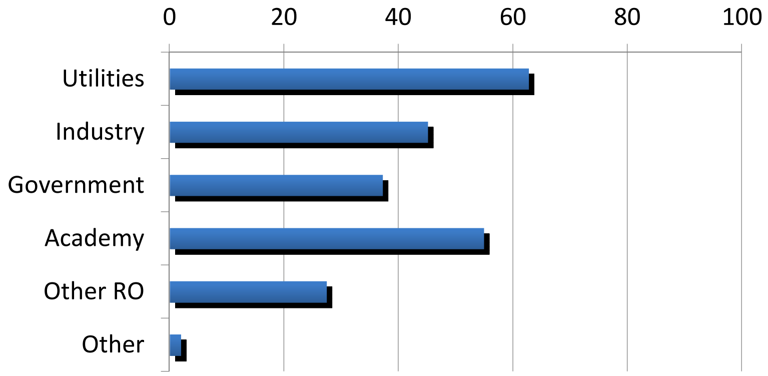



**Figure 84.** Fields of activity for Demand Response issues

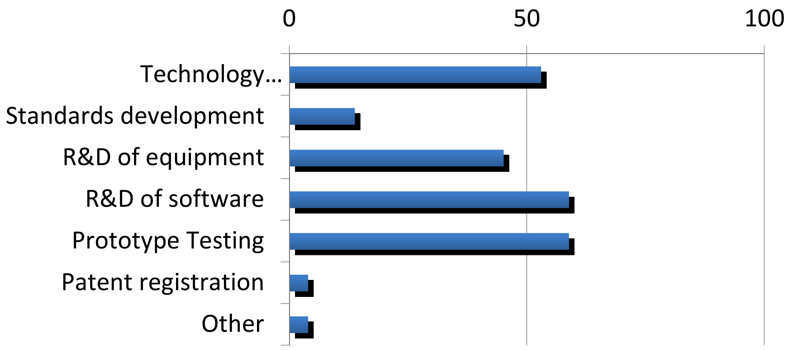



**Figure 85.** Results dissemination for Demand Response research

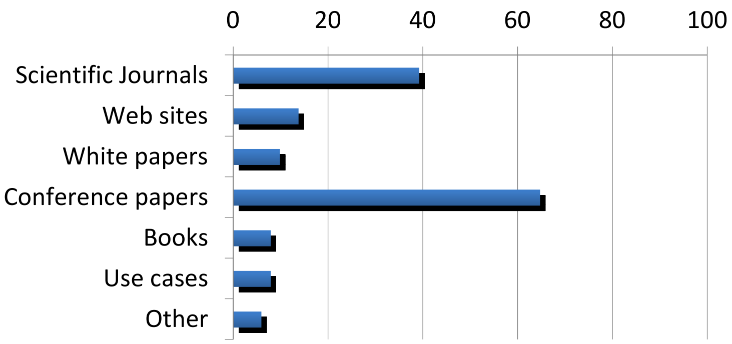



**Figure 86.** Nature of Demand Response activities

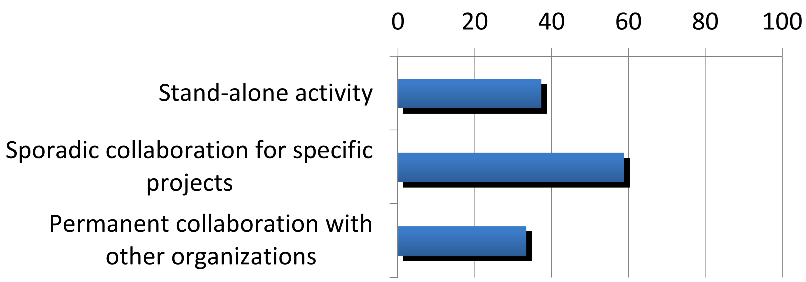


**Figure 87.** Geographical area of interest for Demand Response activities

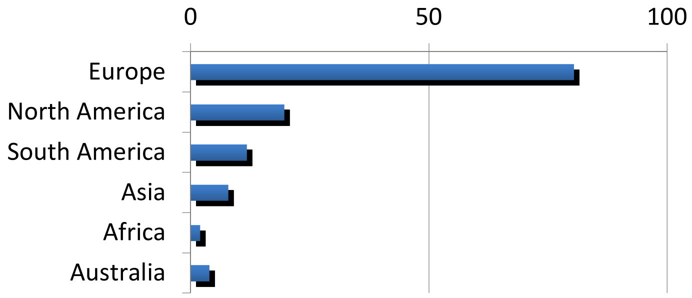



**Figure 88.** Networks on which Demand Response research is focused

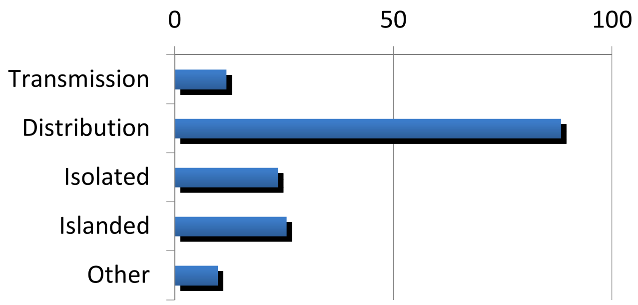



**Table 27.** Areas of work regarding Demand Response

| Area of work | % |
|---|---|
| DER integration | 67% |
| Smart Home/ Smart Building | 45% |
| Storage | 43% |
| DRMS – Demand response management systems | 43% |
| EVs | 41% |
| Demand modelling | 41% |
| Automated demand response | 39% |
| Generation | 37% |
| Grid load | 35% |
| AMI | 24% |
| CEMS – customer energy management systems | 18% |
| Pricing | 18% |
| Other | 2% |

Concerning standards usage, the one mostly used from the involved participants is the Open Automated Demand Response (OpenADR) – 16%. Other standards that are used are the IEC 61970 and the IEC 62351 (12% each).

### 3.6.11 ICT: Communication

Figure 89 and Figure 90 show the sectors at which ICT research is focused and the fields of activities respectively. Similarly to the previous smart grid categories, utilities and industry are the sectors for which ICT research is addressed to, whereas technology development, prototype testing and R&D of equipment are the most popular fields of activities among the labs that perform ICT research. Conference papers and scientific journals are the main ways of results dissemination for the labs that perform ICT research activities, as shown in Figure 91. Although sporadic collaborations for specific projects are the main form of collaborations among the ICT research labs (63%), it is noticed that stand-alone activities and permanent collaborations also gather an important percentage of the actively involved ICT labs (46% and 39% respectively), as shown in Figure 92.

The majority of the ICT activities are carried out in Europe (85% of the labs with ICT activities), which is in accordance with the aforementioned categories (Figure 93). The distribution grid attracts the majority of the ICT lab activities (80%). It is also noteworthy that a significant percentage of the labs that perform ICT research work also on the transmission grid (28%), as presented in Figure 94.

**Figure 89.** Sectors at which ICT research is focused

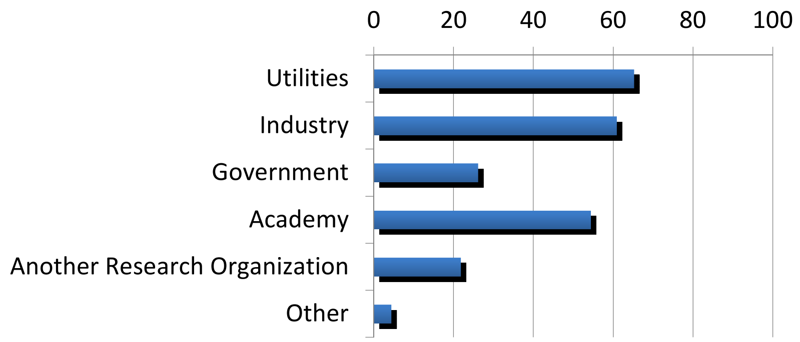
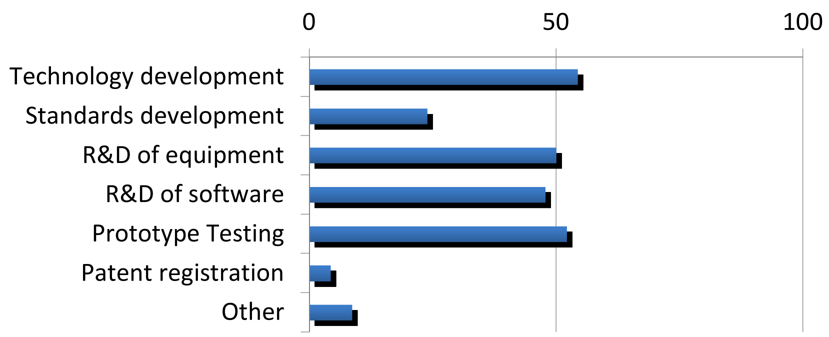



**Figure 90.** Fields of activities for the ICT communication smart grid category




The networks on which research is focused can vary from the Substation LAN (Local Area Network) to the HAN (Home Area Network). 48% of the active laboratories in the field conduct research on the LAN and 43% on the WAN (Wide Area Network). The FAN (Field Area Network) and HAN comprise the research object for 28% of the ICT smart grid laboratories, while the NAN (Neighborhood Area Network) and PAN (Personal Area

Network) completes the picture with lower percentages. More specifically, the above information is summarized in Table 28.

**Figure 91.** Results dissemination for the ICT category

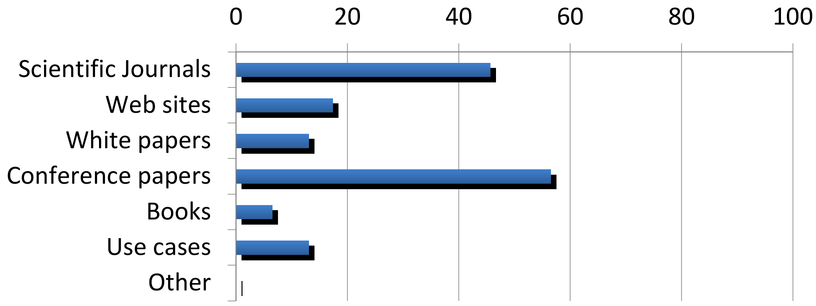



**Figure 92.** Nature of activities for the ICT category

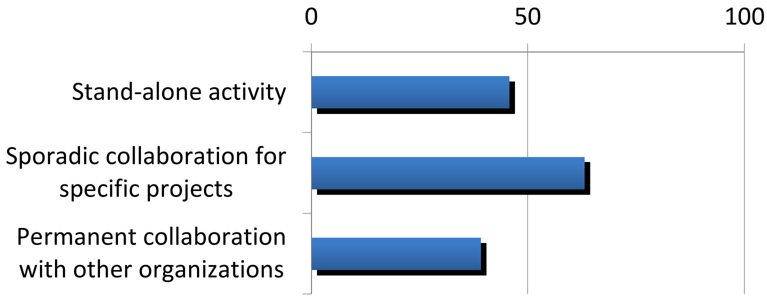



**Figure 93.** Geographical areas on which ICT related research is carried out

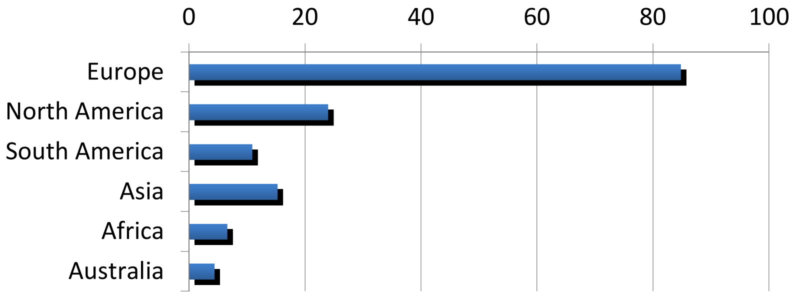
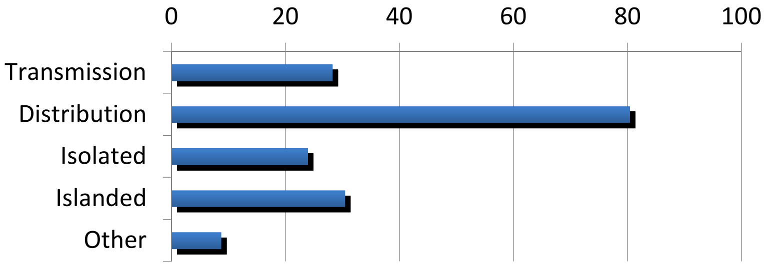



**Figure 94.** Networks on which ICT research is carried out



In general, there are many protocols, specifications and technologies that can be used in the area of ICT communications. The most popular one is the IEC 61850 – Communication networks and systems in substations standard, reaching the percentage of 57% in terms of utilization among the active labs. IPv4 and IPv6 are the solutions that come next with equivalent percentages of 37% and 26% respectively. Other solutions can be the MPLS – Multiprotocol Label Switching or the SDH– Synchronous Digital Hierarchy, which are used at a lower extent compared to the IP options. This situation is depicted in Table 29.

**Table 28.** Telecommunication networks research in ICT activities

| **Networks** | **%** |
|---|---|
| Substation LAN - Local Area Network | 48% |
| WAN - Wide Area Network | 43% |
| FAN - Field Area Network | 28% |
| HAN - Home Area Network | 28% |
| NAN - Neighbourhood Area Network | 22% |
| PAN - Personal Area Network | 9% |
| Other | 2% |

**Table 29.** Communication protocols used by the laboratories

| **Communication protocols** | **%** |
|---|---|
| IEC 61850 – Communication networks and systems in substations | 57% |
| IPv4 – IP version 4 | 37% |
| IPv6 – IP version 6 | 26% |
| MPLS – Multiprotocol Label Switching | 17% |
| Other | 11% |
| SDH - Synchronous Digital Hierarchy | 7% |
| DSL – Digital Subscriber Line (including ADSL, VDSL, HDSL, SHDSL…) | 7% |
| SONET - Synchronous Optical Network | 4% |
| OSGP – Open Smart Grid Protocol | 4% |
| IPS for Smart Grids (IETF RFC 6272) | 2% |

It is noteworthy that close to half of the ICT smart grid laboratories (45%) conduct research with wireless technologies (respectively to last year's 35%). There is a wide range of the available wireless technologies for this purpose, so the scientific research is

divided into each one of them. There are also many laboratories that conduct research in multiple wireless domains. Namely, the technologies that attract mostly the scientific interest are the Wi-Fi, ZigBee, GSM, GPRS and LTE. The technological options to follow closely are Bluetooth, 3G, 6LoWPAN, Wi-Max, Low-Rate WPAN and 802.15.4G. Table 30 shows these wireless technologies along with the percentages of the laboratories that use them among the active ones in the field.

**Table 30.** Research in the different Wireless Technologies

| **Wireless Technology** | **%** |
|---|---|
| Wi-Fi | 76% |
| Zigbee | 52% |
| GSM | 48% |
| GPRS | 48% |
| LTE | 48% |
| BlueTooth | 38% |
| 3G | 33% |
| 6LoWPAN | 29% |
| Wi-Max | 19% |
| Low-Rate WPAN | 19% |
| Other | 19% |
| 802.15.4G | 19% |
| NFC | 10% |
| High-Rate WPAN | 10% |
| IrDA | 5% |
| DASH7 | 5% |
| WirelessHart | 0% |
| ISA100.11A | 0% |

Half of the ICT laboratories are using PLC technological solutions. Half of the PLC activities are carried out on the Substation LAN and on the HAN, with a percentage of 50% for both options among the active laboratories on the field. The NAN, WAN and FAN follow with respective percentages of 44%, 33% and 33%. Table 31 reveals the picture of the networks on which PLC solutions are applied. Half of the active ICT smart grid laboratories conducts research with the PLC technology.

It is worth noting that Narrow Band PLC (NB-PLC) attracts more the scientific interest than Broadband PLC (BPL), since 65% of the active laboratories in the field research on

the former technology in contrast to 47% that investigate on the latter one. Ultra Narrow Band PLC comes last in the list with a respective percentage of 16%.

**Table 31.** Network topologies used in Power Line Communications

| **Topology** | **%** |
|---|---|
| Substation LAN - Local Area Network | 50% |
| HAN - Home Area Network | 50% |
| NAN - Neighbourhood Area Network | 44% |
| WAN - Wide Area Network | 33% |
| FAN - Field Area Network | 33% |
| PAN - Personal Area Network | 11% |

**Table 32.** Research in the different Power Line Communication Technologies

| **PLC Technology** | **%** |
|---|---|
| NB-PLC – Narrow Band PLC | 65% |
| BPL – Broadband over power lines | 47% |
| UNB-PLC – Ultra narrow band PLC | 16% |

When emphasizing more on the technologies and standards used with respect to the PLC technology, there is again a variety of possible standards/technologies to be used, with PRIME Alliance being the most popular. Other popular technologies are the G3-PLC, HomePlug and IEEE 1901,2. Table 33 shows the technologies/standards used among the ICT labs together with the percentages of the laboratories that utilize them for research purposes.

**Table 33.** Standards and Technologies used in Power Line Communication research activities

| **Standard / Technology** | **%** |
|---|---|
| PRIME Alliance | 67% |
| G3-PLC Alliance | 33% |
| HomePlug | 33% |
| IEEE 1901.2 - Low-Frequency (less than 500 kHz) Narrowband Power Line Communications for Smart Grid Applications | 22% |
| IEEE 1901 – Broadband over power line networks. | 17% |
| ITU-T G.hnem – Narrowband OFDM power line communications transceivers | 17% |
| IEC 61334 – Distribution automation using distribution line carrier systems | 11% |
| Other | 11% |

Our survey reveals that the 56% of the active laboratories performs research in the area of monitoring and control of the communications infrastructure. 62% and 58% of these laboratories apply monitoring and control of the communications infrastructure on the Substation LAN and WAN respectively, while the other parts of the network attract a lower percentage of the researchers on the field. The respective percentages among the total number of ICT smart grid labs are listed in Table 34.

**Table 34.** Network Topologies for Monitoring and Control of communications Infrastructure

| **Topology** | **%** |
|---|---|
| Substation LAN - Local Area Network | 62% |
| WAN - Wide Area Network | 58% |
| FAN - Field Area Network | 38% |
| HAN - Home Area Network | 27% |
| NAN - Neighbourhood Area Network | 19% |
| PAN - Personal Area Network | 15% |

The most popular areas of research regarding monitoring and control activities are the wired, PLC and wireless fields, whereas cyber security is also a possible area of investigation (see the next section). Table 35 shows the situation, while the percentages represent the number of laboratories performing such research among the active ones in the specific field.

**Table 35.** Areas of research for Monitoring and Control of the Communications Infrastructure

| **Area of research** | **%** |
|---|---|
| Wired | 62% |
| PLC | 54% |
| Wireless | 50% |
| Cyber security | 42% |

For 85% of the research laboratories on Control and monitoring applications, System status monitoring is their main objective. Event management (ICT-related events) and Remote automation configuration are the next objectives on the list with 58% and 54% each. Response equipment configuration and Resilience/protection management are other two goals for control and monitoring issues (see Table 36).

**Table 36.** Objectives for Monitoring and Control of the Communications Infrastructure

| **Objective** | **%** |
|---|---|
| System status monitoring | 85% |
| Event management (ICT-related events) | 58% |

| | |
|---|---|
| Response automation | 54% |
| Remote equipment configuration | 50% |
| Resilience/protection management | 27% |
| Other | 12% |

Regarding the type of management/monitoring tools that are used in the area of monitoring and control, proprietary/custom-made software is the number one option, since it is used by the 58% of the active laboratories in the field. Vendor-specific software and off-the-shelf software are both alternative solutions that are used by the 42% of the active laboratories. Table 37 shows this situation.

**Table 37.** Management/Monitoring tools for Monitoring and Control of the Communications Infrastructure

| **Management / Monitoring tool** | **%** |
|---|---|
| Proprietary/custom-made software | 58% |
| Off-the-shelf software | 42% |
| Vendor-specific software (Cisco, Siemens…) | 42% |

Finally, it is worth noticing that a relatively high percentage of the laboratories performing research on the subject also develop specific software for several functionalities in the area of monitoring and control. Management and control, Monitoring and Communication are the most popular functionalities for this purpose. In Table 38 the respective percentages of the active laboratories that construct specific purpose software are shown.

**Table 38.** Functionalities for software development for Monitoring and Control of the Communications Infrastructure

| **Functionality for software development** | **%** |
|---|---|
| Management & control | 46% |
| Monitoring | 38% |
| Communication | 35% |
| Security | 19% |

### 3.6.12 Cyber Security

The activities carried out in this area are mostly targeted for utilities and secondarily for industry. However, it is also noteworthy that a more evident interest is shown by local governments on this issue, which is depicted in Figure 95. Similarly to the other smart grid categories, the focus also in this case is on Technology development with Prototyping, R&D of software appearing lower in the list, as shown in Figure 96.

Conference papers are the dominant way of publishing scientific findings, since almost 40% of the actively involved labs in the field use this way for results dissemination (Figure 97). As it can be observed from Figure 98, the majority of Cyber Security

activities are a result of sporadic collaborations, with stand-alone activities coming second in the list.

**Figure 95.** Sectors at which research in Cyber Security is focused

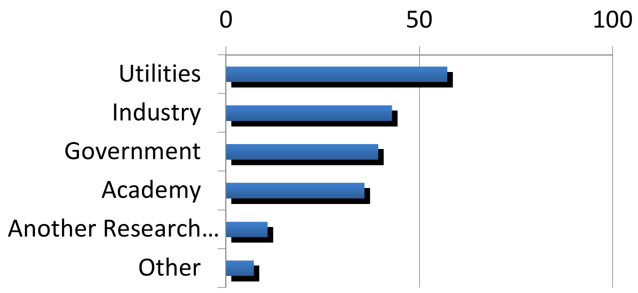



**Figure 96.** Fields of activities for Cyber Security

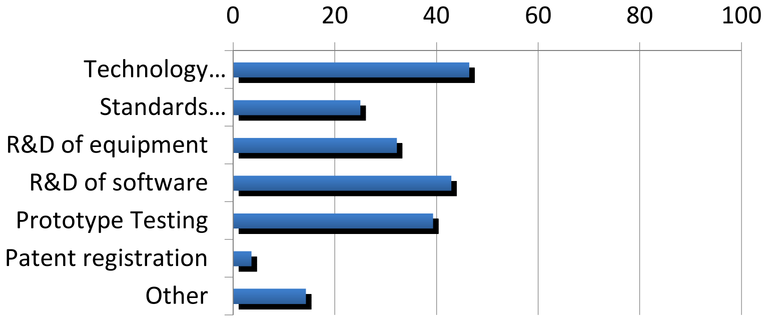



**Figure 97.** Results dissemination for Cyber Security

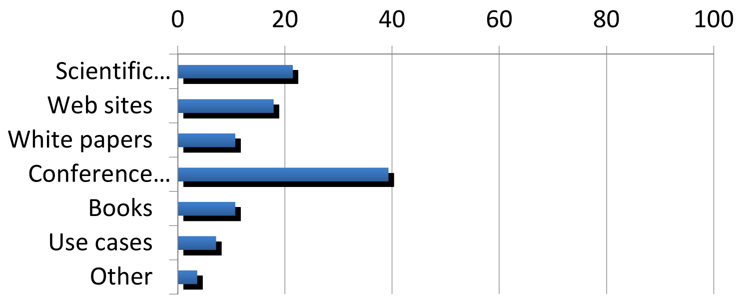
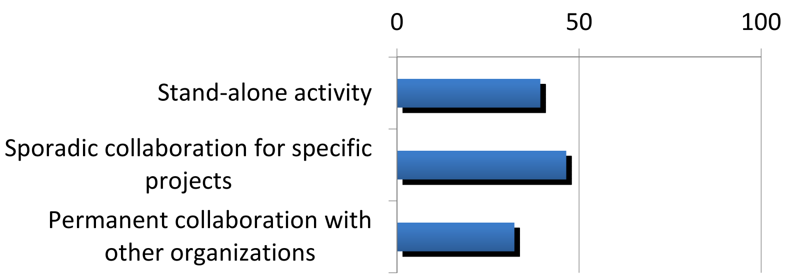



**Figure 98.** Nature of activities for Cyber Security



Almost 80% of research activities on cyber security are carried out in Europe whereas the equivalent percentage for North America is 36% (see Figure 99). It is also worth noticing that a relatively large amount of the participant labs focuses Cyber Security research on the transmission network (32%). On the other hand the distribution network gathers the interest of the 82% of the labs with cyber security activities, as illustrated in Figure 100.

**Figure 99.** Geographical areas on which Cyber Security research is focused

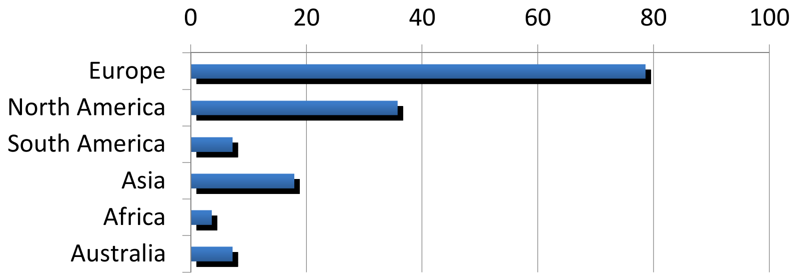
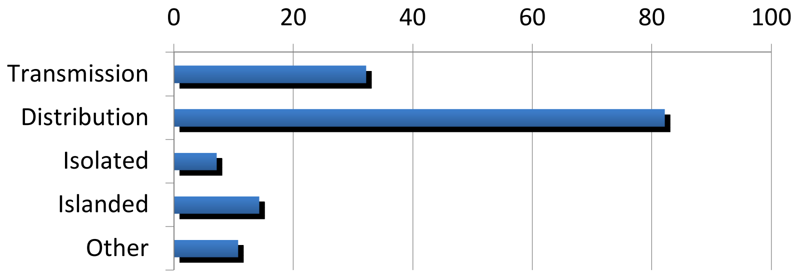



**Figure 100.** Networks on which Cyber Security is focused




Likewise the other fields of smart grids, there are many topics of interest regarding cyber security. Integrity issues are the most popular ones, gathering the interest of 36% of the cyber security researchers. Confidentiality topics, incident response and authentication are also important topics of investigation, with a percentage of 32%, 28% and 32% of the active researchers being occupied on them respectively. Authorization and Risk assessment are also topics of research, with a percentage of 25% among the active researchers. Table 39 describes better the aforementioned situation.

There is a variety of protocols that can be used for Cyber Security issues. IPSec (Internet Protocol Security) is a protocol that is preferred by the 39% of the cyber security researchers, whereas other options are the PKI (Public Key Infrastructure), the SHA (Secure Hash System) and the AES (Advanced Encryption Protocol) with equivalent percentages of 32%, 25% and 32%. More analytically, Table 40 presents the possible technological options for cyber security.

**Table 39.** Sub-topics in the Cyber Security field

| **Sub-topic** | **%** |
|---|---|
| Integrity | 36% |
| Confidentiality/Privacy | 32% |
| Authentication | 32% |

| | |
|---|---|
| Incident Response | 28% |
| Identity | 25% |
| Authorization | 25% |
| Risk Assessment | 25% |
| Contingency Planning | 18% |
| Risk Response | 18% |
| Forensics | 11% |
| Other | 7% |

**Table 40.** Protocols/ standards for Cybersecurity

| Protocol / standard | % |
|---|---|
| IPSec – Internet Protocol Security | 39% |
| PKI – Public Key Infrastructure | 32% |
| AES – Advanced Encryption Standard | 32% |
| SHA – Secure Hash System | 25% |
| RSA – Ron Rivest, Adi Shamir and Leonard Adleman (crypto system) | 21% |
| SSH – Secure Shell | 21% |
| AAA – authentication, Authorization and Accounting | 18% |
| 3DES – Triple DES | 18% |
| DES – Data Encryption Standard | 14% |
| MD5 – Message Digest Algorithm 5 | 14% |
| EAP – Extensible Authentication Protocol | 11% |
| RADIUS – Remote Authentication Dial-In User Service | 11% |
| Other | 7% |
| Oauth – Open secure authorization protocol | 4% |

### 3.6.13 Advanced Metering Infrastructure (AMI)

The activities carried out in this area are mainly targeted at the utilities, the academy and industry sector, which comes in accordance to the situation noticed for the other smart grid categories, as shown in Figure 101. Regarding the fields of the smart grid AMI activities, prototype testing comes first on the list (61% of the actively involved labs), with R&D of software and equipment and technology development to follow with percentages varying from 35% to 45%, as it can be seen from Figure 102.

**Figure 101.** Sectors at which AMI research is targeted

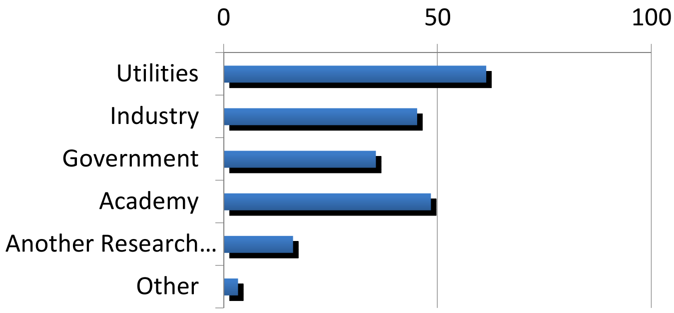
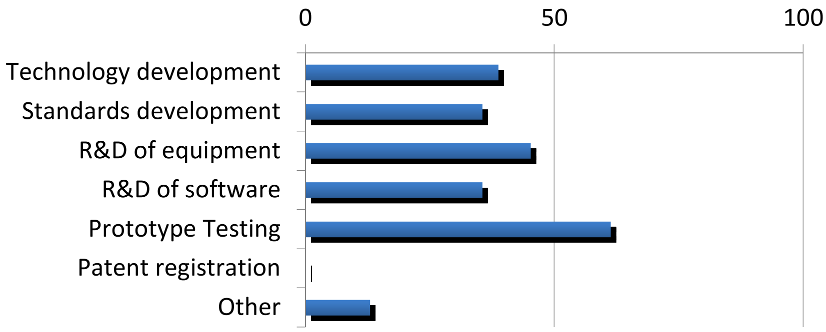



**Figure 102.** Fields of smart grid AMI activities




The majority of the results are disseminated through conferences with scientific journals being the second choice for publications, as it can be observed in Figure 103. The activities vary from stand alone to collaborative ones, either sporadic or permanent with other organizations, whereas the variations noticed are approximately around 20% (see Figure 104). Figure 105 shows that more than 70% of the activities on AMI are carried out in Europe, while North America gathers 30% of the activities. South America and Asia follow with a smaller percentage approximately to 15%. Again, Figure 106 reveals that the distribution network is the main asset on which such research activities are done. Isolated and islanded grids are type of networks that also attract the scientific interest, although at a lower extent. It is worth noticing that the transmission network is barely the research objective for AMI, which is explained by the fact that AMI activities are by definition focused on the low voltage part of the network.

The AMI topics that mostly attract the scientific interest are Monitoring, Communications and Demand Response, which gather a percentage of 48%, 48% and 45% respectively among the active labs in the field. This is rather anticipated, since AMI is closely related to smart metering functions, which play a key role in load monitoring and demand response, whereas communications is an important subject for smart metering research. Other important AMI topics are the interoperability, management and customer information (39%, 35% and 29%). Table 41 presents the AMI topics under investigation by the participant labs.

With respect to the means used for AMI communication purposes, there are two main options, namely power line communications (PLC) and wireless solutions. It is noteworthy that almost half of the questioned labs use wireless technologies for AMI communication and half of them use PLC technology. It should also be noted that one lab may be using both options. Solutions like copper of fiber for AMI communication are also used but at a lower extent. It is also noteworthy that the IEC 61850 standard is also used for AMI purposes.

**Figure 103.** Results dissemination in AMI category

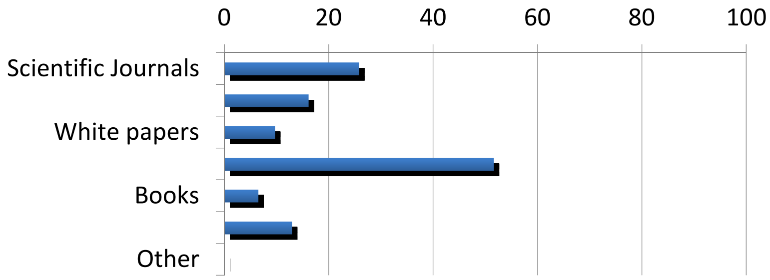



**Figure 104.** Nature of AMI activities

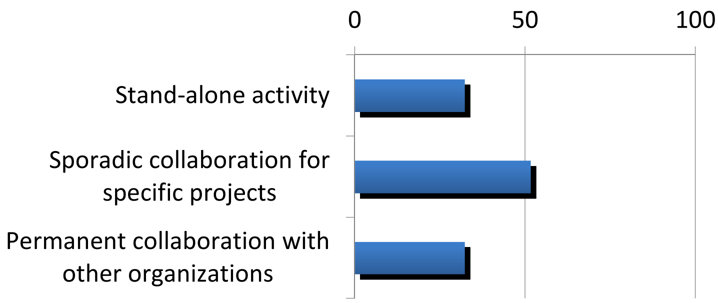



**Figure 105.** Geographical areas on which AMI research is carried out

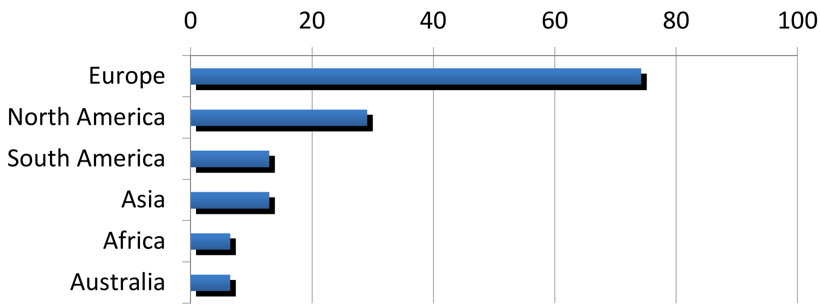



**Figure 106.** Networks on which AMI research is carried out

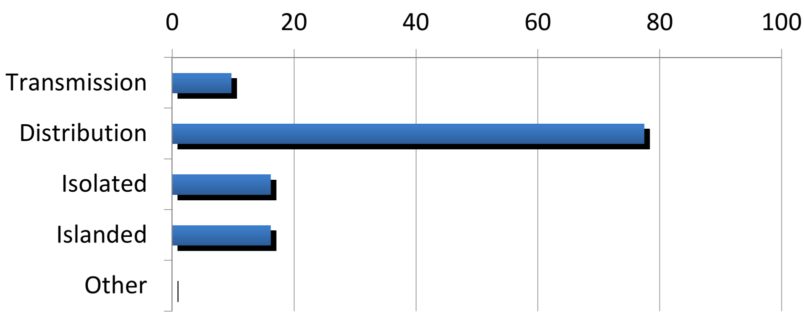


**Table 41.** Sub-topics in the AMI field

| Sub-topic | % |
|---|---|
| Monitoring | 48% |
| Communications | 48% |
| Demand response | 45% |
| Interoperability | 39% |
| Management | 35% |
| Customer information | 29% |
| Security | 29% |
| Installation and configuration | 19% |
| Pricing | 16% |
| EMC – Electromagnetic compatibility | 13% |
| Billing | 10% |
| Safety | 10% |
| Other | 0% |

## 3.7 Analysis of Infrastructure

The infrastructure used by smart grid laboratories is of vital importance, since it reveals the trends of the scientific community and it can be a good example for identifying research gaps that institutions can target through their smart grid lab. Regarding the infrastructure used/installed in the labs several important facts arise. For instance, 60% of the interviewed labs has shared information about the total AC power installed in their labs and 37% about their DC power installed. Figure 107 shows the percentage of labs as a function of the power (kW) range in use. While for AC the more common range seems that between 200 and 1000 kW, for the DC the more common is that between 0 and 50 kW. Very high power values (7500 kW) are also used by a restrict number of labs.

With respect to the voltage levels used in the smart grid laboratories of this study, the median values indicate 400V both for AC and DC. The boxplots reported in Figure 108 provide a more detailed picture of this fact. It is worth mentioning also that few labs operate higher voltage levels in the range 11kV - 50kV (AC) and in the range 1kV - 24kV (DC). Those labs have been considered as outliers and do not appear in the boxplots reported in the following (Figure 108).

The majority (almost 90%) of the surveyed labs operates both three-phase and single-phase systems. Only very few work only on single phase. Additionally, almost one out of four labs owns a microgrid. To measure its size we have asked participants to indicate the number of busbars which are part of the system. Figure 109 summarizes this aspect. As seen, the majority of labs has between one and five busbars on which they operate. Some labs also exist that are able to operate up to 30 busbars. An important feature of

the microgrids owned by the interviewed lab is that in 60% of the cases they are fully reconfigurable and in 40% partially reconfigurable.

**Figure 107.** Percentage of labs as a function of the power (kW) range in use

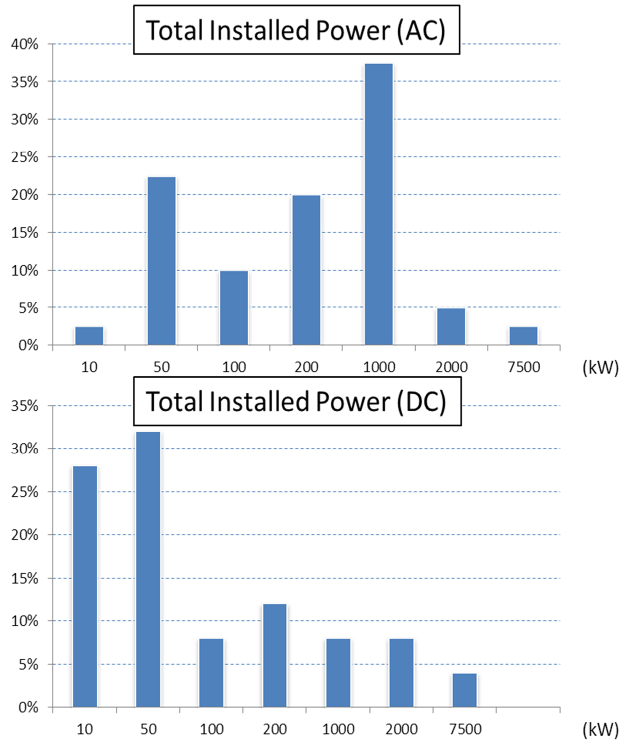
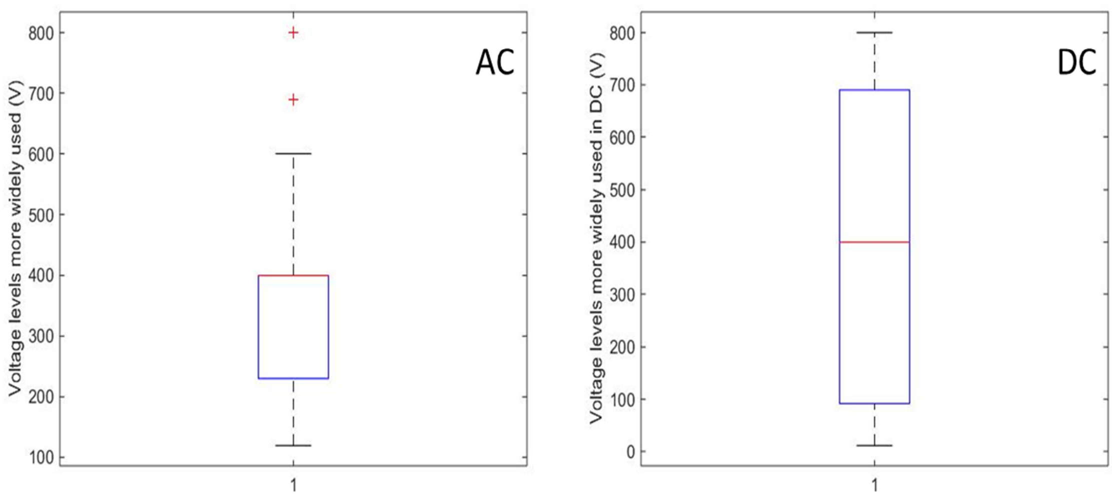



**Figure 108.** Voltage operation levels for labs




Testing through Hardware in the Loop (HIL) simulations is being conducted by 47% of the labs interviewed particularly for control in the loop and power in the loop. Almost half use a Real Time Simulator to conduce its research work activities which are distributed as shown in Table 42 among the 13 introduced categories.

With respect to Hardware Simulator emulation, 47% of the labs are involved in this kind of research activities which are related to the equivalent categories (Table 43). 57% of

the labs are also using Software Simulator/Emulator in the relevant categories (Table 44).

Only 9% of the labs declare to use a high performance cluster system to perform their research activities, especially related to the Market category. A more detailed picture of this aspect is provided through Table 45.

**Figure 109.** Busbars used by labs

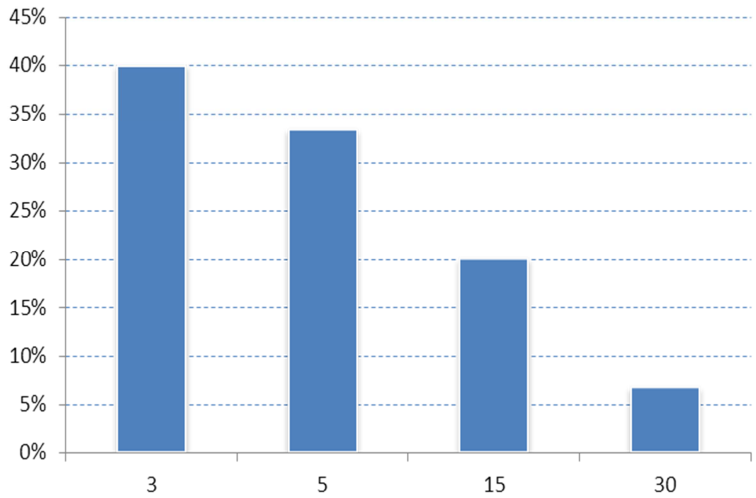



**Table 42.** Percentage of labs using an RTS for research on the specific categories

| **Category** | **%** |
|---|---|
| Grid Management | 15% |
| Generation and DER | 15% |
| Distribution Automation | 13% |
| Demand Response | 12% |
| Storage | 10% |
| ICT | 9% |
| Smart Home | 5% |
| ElectroMobility | 5% |
| Smart Cities | 4% |
| Market | 4% |
| AMI | 4% |
| Sustainability | 2% |
| Cybersecurity | 1% |

**Table 43.** Percentage of labs using Hardware Simulator Emulation for research on the specific categories

| Category | % |
|---|---|
| ICT | 23% |
| Demand Response | 19% |
| Smart Cities | 17% |
| Smart Home | 15% |
| Cybersecurity | 8% |
| AMI | 8% |
| ElectroMobility | 6% |
| Generation and DER | 4% |

**Table 44.** Percentage of labs using Software Simulator / Emulator for research on the specific categories

| Category | % |
|---|---|
| Generation and DER | 12% |
| Grid Management | 12% |
| Demand Response | 10% |
| ICT | 10% |
| Storage | 10% |
| Distribution Automation | 9% |
| ElectroMobility | 8% |
| Market | 6% |
| Smart Cities | 6% |
| Smart Home | 6% |
| AMI | 4% |
| Sustainability | 4% |
| Cybersecurity | 2% |

**Table 45.** Percentage of labs using high performance cluster system for research on the specific categories

| Category | % |
|---|---|
| Market | 13% |
| Demand Response | 9% |
| Electromobility | 9% |
| Generation and DER | 9% |
| Grid Management | 9% |
| ICT | 9% |
| Smart Home | 9% |
| Storage | 9% |
| AMI | 6% |
| Distribution Automation | 6% |
| Sustainability | 6% |
| Cybersecurity | 3% |
| Smart Cities | 0% |

## 3.8 Extended Research

In an attempt to obtain a better picture of the smart grid research that is carried out, we performed an extended internet search so as to identify the smart grid activities of more research organizations/laboratories. The extended sample comprised of extra 31 organizations/labs, which are mainly located in the USA. Particularly, 27 out of these 31 organizations are located in the USA and 4 in Europe. The entire list of these institutions can be found in Appendix along with the equivalent web sites where the information has been extracted from. The selection of the labs has been made so as to obtain a better picture of the situation in the USA, since the sample we got from the submitted questionnaires can be considered small with respect to the number of organizations that carry out smart grid research in the country overall. It should be noted that the extended sample as a whole of the labs that participated in our survey plus the extra organizations results in 100 labs/organizations, which allows us to make some conclusions with respect to the trends in the smart grid research area.

To keep the report coherent, we have tried to identify the categories in which the activities are focused, as they are presented in Section 3.3, for these 31 organizations. However, several problems came up since the information found in the internet may not depict in a straightforward way all the activities carried out. Furthermore, mapping the smart grid activities to the categories as they are presented in 3.3 can be a complicated task to do. For this reason, we have considered that a particular organization/lab performs research on a specific category only when explicit information has been found that proves the equivalent research task. Table 46 shows the percentages of these 31 organizations that perform research on each of the smart grid categories.

**Table 46.** Percentage of laboratories per activity – extra sample of 31 labs

| **Category** | **%** |
|---|---|
| Distribution automation | 61% |
| Grid management | 52% |
| Storage | 55% |
| Sustainability | 12% |
| Market | 18% |
| Generation and DER | 70% |
| Electromobility | 18% |
| Smart Home/Building | 15% |
| Smart City | 3% |
| Demand Response | 9% |
| ICT: Communication | 30% |
| Cyber Security | 9% |
| AMI: Advanced Metering Infrastructure | 15% |

It should be noted that the percentages shown may not depict the real situation, since many labs may hold activities on more categories, but this has not been clearly depicted on the equivalent website or the information found about the smart grid activities has not been assigned to the overall categories under investigation. In addition, the interpretation of some categories is by definition hard to define with precision. On the other hand, other categories are easier to define and to assign smart grid activities to them. For instance, information about activities related to RES and their integration to the grid can be easily interpreted as smart grid activities on the Generation and DER. On the contrary, it is hard to identify smart grid activities on sustainability (related to the environmental framework) or on smart cities and demand response unless this is clearly stated. Therefore, there is a deviation between the percentages presented in Section 3.3 and the percentages presented for the extra sample of 31 labs, which is evident for specific categories. However, it can be noticed that a relatively high percentage of this extra sample performs research on topics like Distribution automation, Storage, Generation and DER, which comes in accordance to the situation presented in Section 3.3.

During our research, we also found useful information about the usage of a real time simulator. A motive for this particular search has been the fact that our survey has revealed the extended usage of this technology. Among the extra organizations under investigation, at least the 27% uses a real time simulator, according to the information found on the respective websites. In addition, it has been found that a minimum of 27% of the extra labs performs research activities on microgrids.

Table 47 shows a comparison regarding the percentages of the organizations performing research on a specific category with respect to our survey sample, the extra sample of 31 labs and the extended sample as a whole (100 labs). Whereas the percentages presented for our survey sample depict the percentages among the questioned labs, the

percentages for the extended samples refer to the minimum number of labs/organizations that perform smart grid activities on a specific category.

**Table 47.** Percentage of laboratories per activity – A) initial sample of 69 questioned labs, B) extra sample of 31 labs and C) extended sample of 100 labs

| | **A** | **B** | **C** |
|---|---|---|---|
| **Category** | **% - initial sample of 69 questioned labs** | **% – extra sample of 31 labs** | **% – extended sample of 100 labs** |
| Distribution automation | 61% | 61% | 61% |
| Grid management | 73% | 52% | 66% |
| Storage | 70% | 55% | 65% |
| Sustainability | 33% | 12% | 26% |
| Market | 45% | 18% | 36% |
| Generation and DER | 81% | 70% | 77% |
| Electromobility | 66% | 18% | 50% |
| Smart Home/Building | 64% | 15% | 48% |
| Smart City | 51% | 3% | 35% |
| Demand Response | 76% | 9% | 54% |
| ICT: Communication | 69% | 30% | 56% |
| Cyber Security | 42% | 9% | 31% |
| AMI: Advanced Metering Infrastructure | 46% | 15% | 36% |

The big deviation between columns A and B for categories like Smart City and Demand Response is due to the fact that column B refers to the minimum number of the labs performing such research, while column A refers to the actual number. It is evident from Table 47 that some categories clearly attract the scientific interest for smart grids, like Distribution automation, Grid Management, Storage, Generation and DER, since a minimum of 61%, 66%, 65% and 77% respectively of the labs performs equivalent research activities. From our extended research it can be also concluded that a minimum of 40% of the labs uses a real-time simulator for smart grid research. It is also noteworthy that a minimum of 47% of the labs in total performs research on microgrids.

# 4 CONCLUSIONS AND FUTURE PERSPECTIVES

## 4.1 General Information

The second release of the Smart Grid Lab Inventory is a continuation of the successful project initiated early 2013 aiming at presenting important outcomes for the smart grid research performed nowadays. Similarly to the previous release, analytical results for each smart grid category are revealed along with information about the technologies that mostly attract the scientific interest. In the 2016 version of the report, the sample of the labs/organizations questioned has been by far more than doubled; precisely it is 2.87 times larger than the previous sample (69 labs), which allows us to draw more accurate conclusions about the smart grid research situation. The organizations to be contacted have been mainly in Europe and the USA, whereas other 2 laboratories outside this territory have participated in our survey.

Furthermore an extended research has been performed in an attempt to gain information about the smart grid activities of more labs/organizations. For this purpose, an internet-based search has been performed around an extra sample of 31 labs, mainly located in USA to compensate for the relatively low number of labs included in the initial sample of the 69 labs. By this way, useful information can be deducted with respect to the minimum number of organizations that perform research on specific smart grid categories. It should be also noted that the extended sample results in 100 labs.

In the following we present above all the scientific conclusions based on the detailed information obtained by the 69 labs that have participated in our survey together with information about investment plans. Secondarily, information is presented about the categories that mostly attract the scientific interest based on the extended sample of 100 labs.

## 4.2 Scientific Conclusions

### 4.2.1 Initial survey sample

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, when examining the type of grid on which research is conducted, it can be concluded that the majority of the activities focus on the distribution grid. Other types of grid, like the islanded and the isolated grid are much lower in the list, which is also the case for the transmission grid. 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. Regarding the fields of smart grid activities, it is shown that R&D of software, technology development, prototype testing and R&D of equipment are the ones on which smart grid laboratories/institutions are focused more. It is also noticeable that the differences in the percentages between these fields of activity are very small. In addition, the major part of the smart grid research is performed for the utilities, the academic and industrial sector. 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. In addition, it is noticed that the main way of results dissemination are conference and journal papers, whereas sporadic collaborations for specific projects are the most popular way of research activities on the smart grid field.

The smart grid activities have been classified in 13 categories. Among them, the ones cited more frequently by the participating organizations as the core research areas are Generation and DER, Demand Response, Grid Management and Storage. It is noticed that these top 4 categories were the same with the ones noticed in the first release of

the project. The equivalent percentages with the larger sample have dropped for around 10% in the latter three categories with respect to the old sample of 24 labs; however, it seems that it has remained at the same level for Generation and DER, which is still over 80% of the laboratories working on smart grids. Electromobility and ICT are categories that attract more than 65% of the questioned labs. For each smart grid category further sub-topics of investigation have been identified and emphasis has been given also to the standards used for each category. For some categories, a more in-depth analysis has been made, depending on the complexity of the topics under research and the possible technological solutions for crucial issues. For example, in the ICT category the wireless and the PLC technological solutions have been highlighted along with issues regarding the monitoring and control of the communications infrastructure. In Electromobility, the most popular sub-topics are the vehicle-to-grid and energy storage. Apart from this, the available charging modes have been listed; the different types of charging connectors for electric vehicles along with the most common voltage and current values have been identified; the topics on which software applications development focuses have been pointed out. The survey highlights that there are some sub-topics that attract more the interest of the researchers, encompassing more than 65% of the laboratories working on the broader category. For example, PV seems to be the most popular sub-topic for Generation and DER (78%); Batteries for Storage (77%); DER integration for Demand Response (67%); Energy management strategies/ cost control for Smart Home / Building (67%). Compared to the previous report's results, the popular sub-topics mentioned here have remained unchanged, which indicates that the smaller sample of labs was also indicative about the smart grid research situation.

With respect to the standards that are mostly used for smart grid research, they can vary according to the examined category. However, it is 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. For the other categories, more specific standards are the ones to be mostly used, according to the activities that are carried out.

The survey reveals important information not only about the investment plans of the scientific community in each particular category, but also about the initial investment of the laboratories/institutions. The study highlights that the majority of the labs is placed around the amount of 2 M€ (median value) in terms of initial investments to set-up the lab. Note that this figure duplicated if compared with the value of 1 M€ observed in the first run of the Smart Grid Labs Inventory 2015. It is still true that large institutions are able to spend even more than 20 M€ to set-up. Another important figure strictly connected with the costs to setting-up is that of the annual running costs that the labs must undertake. The median value for this figure amounts to 135,000 euros and the third quartile of the same distribution corresponds to 450,000 euros. Very extreme values up to 30 M€ are also present which have been considered as outliers of the distribution. It is worth also mentioning that a first quartile close to 45,000 euros seems to suggest that some participants in the survey could have not taken into account the cost of personnel. To avoid this kind of misunderstandings in future versions of the questionnaire we plan to separate the annual running cost record into personnel cost and other costs (licenses, maintenance, software, etc.).

About future investments plans three periods have been considered in the survey: short (up to 5 years), *medium* (5-10 years) and *long term* (+10 years). The following numbers give a first hint on how uncertainty on future investments is perceived by the smart grid laboratories taking part in the study: the median for each period (short, medium, long) of the obtained replies for the 13 categories are in fact 47%, 37% and 32% respectively. Even though less than one out of three labs knows what to do in terms of investments after then years from now the majority of half of them plans either to increase or at least to keep them at current levels. For the categories Market, Electromobility and

Cybersecurity some evidences of an increase of the investments in the medium term range when compared with short term are observed. This fact seems to suggest that before increasing the investments in these three areas the surveyed labs do expect some technological milestones or decisions related to other interrelated areas of Smart Grids to come in the next 5 years. It is also noteworthy to mention that no plans for decreasing investments are observed in 10 out of the 13 smart categories. Only in Electromobility, Generation & DER and Sustainability there is a tiny percentage of labs which has planned a decrease in their investments for the next years.

### 4.2.2 Extended sample

For the extra organizations that have been under investigation, important information has been deducted regarding some of the categories on which research activities are focused. The search has been internet-based and therefore, it has been considered that a lab/organization works on a specific category only when explicit information has been found to prove such a fact. The extended sample reveals that Generation and DER, Grid Management and Storage are the categories that attract mostly the scientific interest, which comes in accordance to the conclusions drawn in the previous sub-section. It is also interesting to note that a real-time simulator is used by a minimum of 40% of the total number of labs, whereas at least 47% of the labs perform research on microgrids.

To sum up, there are numerous findings for the research that is conducted in the smart grid domain. The survey results are expected to give an insight about the technologies used and contribute in streaming and promoting synergies in future activities.

## 4.3 Future work

In 2017, a revision of the structure of the survey is expected. Areas will be adapted to actual trends in Smart Grids and further collaboration with the main standardization organizations in the world is expected. Simplification of the overall structure will be also tackled.

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.

Also in 2017, 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 will been planned along the year.

Finally, a further increase of the number of Smart Grid research facilities will be sought. The survey will be further customized to target the different world areas and the report will be divided accordingly.

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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. |
| BPL | Broadband over Power Lines |
| CAES | Compressed air energy storage |
| CEMS | Customer Energy Management System |
| CEN | European Committee for Standardization |
| CENELEC | European Committee for Electrotechnical Standardization |
| CHP | Combined Heat and Power. |
| DA | Distribution Automation |
| DC | Direct Current |
| DER | Distributed Energy Resources. |
| DES | Data Encryption Standard |
| DR | Demand Respond |
| DRMS | Demand Respond Management System |
| DSL | Digital Subscriber Line |
| EAP | Extensible Authentication Protocol |
| ESO | European Standardization Organization |
| ETSI | European Telecommunications Standards Institute. |
| EV | Electric Vehicle |
| FAN | Field Area Network. |
| GPRS | General Packet Radio Service |
| GPS | Global Positioning System. |
| GSM | Global System for Mobile (communications) |
| HAN | Home Area Network |
| ICT | Information and Communication Technologies. |
| IEC | International Electrotechnical Commission |

| | |
|---|---|
| IPSec | Internet Protocol Security |
| JRC | Join Research Centre |
| LAN | Local Area Network |
| LTE | Long Term Evolution |
| MD5 | Message Digest algorithm 5 |
| MPLS | Multiprotocol Label Switching |
| NAN | Neighborhood Area Network |
| Oauth | Open secure authorization protocol |
| OpenADR | Open Automated Demand Response |
| OSGP | Open Samrt Grid Protocol |
| PAN | Personal Area Network |
| PHEV | Plug-in Hybrid Electric Vehicle |
| PKI | Public Key Infrastructure |
| POC | Point of Contact |
| PSH | Pumped-storage hydroelectricity |
| PLC | Power Line Communication |
| PMU | Phasor Measurements Unit. |
| RADIUS | Remote Authentication Dial-In User Service |
| RSA | Ron Rivest, Adi Shamir and Leonard Adleman (crypto system) |
| R&D | Research and Development. |
| RES | Renewable Energy Sources |
| SAE | Society of Automotive Engineers |
| SDH | Synchronous Digital Hierarchy |
| SGAM | Smart Grids Architecture Model (SGAM) |
| SHA | Secure Hash Algorithm |
| SMES | Superconducting Magnetic Energy Storage |
| SONET | Synchronous Optical Network |
| SSH | Secure Shell |

| | |
|---|---|
| UTES | Underground Thermal Energy Storage |
| WAN | Wide Area Network |
| WI-FI | Wireless Fidelity |
| 3DES | Triple DES |

## List of figures

## List of tables

# Annexes

## Annex 1. List of Participating Labs

In this part, the list of participating labs together with their equivalent websites is presented.

List of participating labs – sorted by countries in alphabetical order

| No | Name of the organization | Name of the laboratory | Acronym of the lab | Country | Website |
|---|---|---|---|---|---|
| 1 | CYBERGRID GMBH | cyberGRID Smart Grids LAB | cyberLAB | Austria | www.cyber-grid.com |
| 2 | IMEC | Photovoltaics Department | | Belgium | www.imec.be |
| 3 | VITO (as part of EnergyVille) | EnergyVille Technology lab | | Belgium | www.vito.be |
| 4 | University of São Paulo | Research Center in Smart Energy Grids | NAPREI | Brazil | http://143.107.255.134/enerq/contato.html |
| 5 | Technical University of Sofia | Power Electronics Laboratory | PEL | Bulgaria | www.tu-sofia.bg |
| 6 | Centre for Urban Energy, Ryerson University, Toronto, Canada | Schneider Electric Smart Grid Laboratory | SESG Lab | Canada | www.ryerson.ca/cue |
| 7 | University of Cyprus | Research Centre for Sustainable Energy (FOSS) | FOSS | Cyprus | www.foss.ucy.ac.cy |
| 8 | VTT Technical Research Centre Of Finland Ltd | VTT Multipower test environment | Multipower | Finland | www.vtt.fi |
| 9 | L2EP | Laboratory of Electrical Engineering and power | L2EP | France | http://l2ep.univ-lille1.fr/?lang=en |

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| | | electronics | | | |
| 10 | CNRS | Procédés-Matériaux-Energie Solaire | PROMES | France | www.promes.cnrs.fr |
| 11 | Grenoble Electrical Engineering Laboratory | PREDIS | PREDIS | France | http://www.g2elab.grenoble-inp.fr/ |
| 12 | TELECOM Bretagne / Institut MINES-TELECOM | Smart Grid Competence Center | SGCC | France | |
| 13 | Electricité de France | Concept Grid | | France | http://networks-lab.edf.com |
| 14 | TU Dortmund University | Smart Grid Technology Lab | SGTL | Germany | www.smartgrid-tec-lab.com |
| 15 | RWTH Aachen University - Institute for Automation of Complex Power systems | ACS Real Time Laboratory | | Germany | www.acs.eonerc.rwth-aachen.de |
| 16 | TU Berlin | Energiewende Laboratory | | Germany | |
| 17 | National Technical University of Athens | Electric Energy Systems lab | EES-lab | Greece | www.ece.ntua.gr |
| 18 | Centre for Renewable Energy Sources and Saving | Microgrid and Distributed Energy Resources Laboratory | | Greece | www.cres.gr |
| 19 | ABB Italy | Smart Lab | Smart Lab | Italy | www.abb.com |
| 20 | European Commission, Joint Research Centre | Smart Grid Interoperability Centre - Ispra | | Italy | |
| 21 | European Commission, Joint Research Centre | EPIC | EPIC | Italy | |

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| 22 | European Commission, Joint Research Centre | Electric and Hybrid Testing Facility | VeLA8 | Italy | |
| 23 | European Commission, Joint Research Centre | Semi-Anechoic Chamber for Electromagnetic Compatibility Testing | VELA9 | Italy | |
| 24 | Ricerca sul Sistema Energetico SpA | RSE Distributed Energy Resources Test Facility | RSE DER-TF | Italy | www.rse-web.it |
| 25 | Selta S.p.A. | Selta Smart Grid Lab | Selta_SGL | Italy | www.selta.com |
| 26 | INSIEL s.p.a. | Divisione Telecomunicazioni | | Italy | www.insiel.it |
| 27 | Politecnico di Bari | PrInCE Microgrid - Electric Power System Laboratory | MG-Lab PrInCE | Italy | |
| 28 | University of Pisa | SmartGrid Lab | SGL | Italy | |
| 29 | University Mediterranea of Reggio Calabria | Measurement Laboratory | | Italy | |
| 30 | Institute of Physical Energetics (IPE) | Smart Grid Research Centre | SGRC; SmartHome Lab; PMULab | Latvia | http://fei-web.lv/ |
| 31 | Kaunas University of Technology | Laboratory of Smart Electric Energy Technologies & Electric Power Networks | | Lithuania | |
| 32 | DNV GL | Flex Power Grid Lab | FPGL | Netherlands | |
| 33 | DNV GL | Protocol test lab | | Netherlands | https://www.dnvgl.com/services/protocol-standardization-and-testing-6828 |

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| 34 | DNV GL | Battery lab | | Netherlands | https://www.dnvgl.com/services/battery-laboratory-arnhem-59065 |
| 35 | European Commission, Joint Research Centre | Smart Grid Interoperability Centre - Petten | | Netherlands | |
| 36 | NTNU / SINTEF | National Smart Grid Laboratory | NSGL | Norway | http://www.ntnu.edu/smartgrid |
| 37 | WROCLAW UNIVERSITY OF TECHNOLOGY | Laboratory of Power Line Communications | | Poland | |
| 38 | Lodz University of Technology | Institute of Electrical Power Engineering, Laboratory of Distributed Generation | DGLab | Poland | www.i15.p.lodz.pl/en |
| 39 | EDP Labelec | Laboratory of Smartgrids | SMARTLAB | Portugal | http://www.edplabelec.com |
| 40 | 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/ |
| 41 | National Laboratory for Energy and Geology (LNEG) | National Laboratory for Energy and Geology (LNEG) | LNEG | Portugal | www.lneg.pt |
| 42 | Universidade do Minho | Group of Energy and Power Electronics - Centro ALGORITMI | GEPE | Portugal | https://www.gepe.dei.uminho.pt/ |
| 43 | INESC TEC - INESC Technology and Science | Smart Grid and Electric Vehicle Laboratory | SGEVL | Portugal | http://reive.inescporto.pt/en |
| 44 | INOV INESC INOVAÇÃO | N/A | INOV | Portugal | www.inov.pt |

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| 45 | ISA Energy Efficiency, S.A. | Innovation & Product | | Portugal | www.isasensing.com |
| 46 | Instituto Tecnológico de la Energía (ITE) | Renewable energy integration and demand side management laboratory | | Spain | www.ite.es |
| 47 | IMDEA | Smart Energy Integration Lab | SEIL | Spain | http://www.energy.imdea.org/scientific-facilities/smart-energy-integration-lab |
| 48 | 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/ |
| 49 | Tecnalia | InGRID. Smart Grids Testing and Research Infrastructure | InGRID | Spain | http://www.tecnalia.com/en/energy-environment/index.htm |
| 50 | Catalonia Institute for Energy Research (IREC) | IREC Energy SmartLab | | Spain | www.irec.cat |
| 51 | Catalonia Institute for Energy Research (IREC) | Semi-virtual Energy Integration Laboratory (SEILAB) | SEILAB | Spain | www.irec.cat |
| 52 | RESEARCH CENTRE FOR ENERGY RESOURCES AND CONSUMPTION | SMART GRIDS LABORATORY | CIRCE | Spain | www.fcirce.es |
| 53 | ORMAZABAL Corporate Technology | Demonstration & Experimentation Unit | UDEX | Spain | http://www.ormazabal.com/en/about-us/our-own-technology/technological-innovation-center |
| 54 | IK4-CEIT (Centre of Studies and Technical | iSare Microgrid Gipuzkoa | iSare | Spain | www.i-sare.net |

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| | Research) / JEMA ENERGY | | | | |
| 55 | GAS NATURAL FENOSA | Interoperatibility Laboratory | LINTER | Spain | http://www.unionfenosadistribucion.com/es/redes+inteligentes/1297137260045/conozca+nuestro+laboratorio.html |
| 56 | CARTIF | ENERGY DEPARTMENT | | Spain | www.cartif.com |
| 57 | STRI | STRI Smart Grid Research, Development and Demonstration Platform | STRI RD&D | Sweden | www.stri.se |
| 58 | École Polytechnique Fédérale de Lausanne | Distributed Electrical Systems Laboratory | DESL | Switzerland | http://smartgrid.epfl.ch |
| 59 | Durham University | Smart Grid Lab | | UK | https://www.dur.ac.uk/ecs/smart.grid/ |
| 60 | Imperial College of London | Smart Energy Laboratory | | UK | http://www.imperial.ac.uk/electrical-engineering/research/control-and-power/ |
| 61 | University of Strathclyde | Power Networks Demonstration Centre | PNDC | UK | www.strath.ac.uk/pndc |
| 62 | EnerNex | Smart Grid Labs | SGL | USA | |
| 63 | Princeton University | Princeton Laboratory for Energy Systems Analysis | PENSA | USA | http://energysystems.princeton.edu |
| 64 | Florida State University | Center for Advanced Power Systems | CAPS | USA | www.caps.fsu.edu |
| 65 | Lawrence Berkeley National Laboratory (LBNL) | FLEXLAB | | USA | flexlab.lbl.gov |

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| 66 | UCI Microgrid Testbed | University of California, Irvine Advanced Power and Energy Program | UCI APEP | USA | www.apep.uci.edu |
| 67 | Kansas State University | Smart Grid Lab | | USA | http://www.ece.k-state.edu/research/powerandenergy/sgl/index.html |
| 68 | Argonne National Laboratory | | | USA | https://www.anl.gov/ |
| 69 | National Renewable Energy Laboratory (NREL) | Energy Systems Integration Facility | ESIF | USA | http://www.nrel.gov/esif/ |

## Annex 2. List of extra labs used for the extended sample

In this part, the list of the extra labs that were used for the extended sample is presented, along with the websites where the information has been extracted from.

List of extra labs used for the extended sample and website(s) where information has been extracted from

| No | Name of the organization / laboratory | Country | Website(s) |
|---|---|---|---|
| 1 | Ameren Technology Application Center | USA | https://www.ameren.com/illinois/map/tac<br>http://www.elp.com/articles/2013/8/ameren-illinois-opens-smart-grid-testing-center-in-illinois.html |
| 2 | AEP Dolan Labs | USA | http://www.dolantechcenter.com/<br>http://dolantechcenter.com/Focus/SmartGrid/Default.aspx |
| 3 | California State Smart Grid User Center | USA | www.ecs.csus.edu/csgc |
| 4 | Carnegie Mellon University (CMU) | USA | http://www.ece.cmu.edu/<br>https://www.src.org/program/eri/sgrc/<br>http://www.sei.cmu.edu/smartgrid/ |
| 5 | IIT-Galvin Center - CSMART Smart Grid Lab (The Center for Smart Grid Application, Research and Technology) | USA | http://www.iitmicrogrid.net/galvincenter.aspx<br>http://iitmicrogrid.net/csmart.aspx |
| 6 | Iowa State University - PowerCyber testbed | USA | http://powercyber.ece.iastate.edu/<br>http://powercyber.ece.iastate.edu/powercyber_testbed_flier.pdf |
| 7 | Oak Ridge National Laboratory – Distributed Energy Control and Communications (DECC)/ | USA | https://www.ornl.gov/content/solving-big-problems<br>http://web.ornl.gov/sci/renewables/docs/factsheets/Security-DECC.pdf |

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| | Microgrid | | |
| 8 | Pacific Northwest National Laboratory | USA | http://www.pnnl.gov/about/<br>http://eioc.pnnl.gov/<br>http://energyenvironment.pnnl.gov/default.asp |
| 9 | PowerTech | USA | http://www.powertechlabs.com/home/ |
| 10 | Rensselaer Polytechnic University | USA | http://www.rpi.edu/cfes/research/distributed-generation.html<br>http://www.rpi.edu/cfes/EnergyScholars/CFES-EnergyScholars-Student%20FY14.pdf |
| 11 | Edison International | USA | http://insideedison.com/?redirect=.html<br>http://inside.edison.com/content/inside/2012/03-12/f-atlabs.html<br>https://www.edison.com/content/dam/eix/documents/innovation/Advanced-Technology-Labs-Backgrounder.pdf |
| 12 | Colorado State University | USA | http://www.engr.colostate.edu/ece/research/centers_and_laboratories.php<br>http://www.engr.colostate.edu/ece/research/research_areas.php |
| 13 | University of Tennessee (CURENT - Center for Ultra-Wide-Area Resilient Electric Energy Transmission Networks) | USA | http://curent.utk.edu/contact-us/facilities/university-of-tennessee/ |
| 14 | Georgia Tech | USA | https://www.ece.gatech.edu/<br>http://aces.ece.gatech.edu/pages/home.html |
| 15 | Idaho National Lab | USA | https://www.inl.gov/<br>http://www.inl.gov/research/electric-grid-reliability/ |
| 16 | University of Wisconsin (Energy | USA | http://energy.wisc.edu/ |

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| | Institute) | | |
| 17 | Florida International University (Energy Systems Research Laboratory – Smart Grid Test Bed Laboratory) | USA | https://energy.fiu.edu/<br>https://energy.fiu.edu/2014/12/smart-grid-test-bed-lab/<br>https://energy.fiu.edu/wp-content/uploads/2015/11/Brochure-Esrl-2015.pdf |
| 18 | UCLA – Smart Grid Energy Research Center | USA | http://smartgrid.ucla.edu/ |
| 19 | FREEDM systems Center | USA | https://www.freedm.ncsu.edu/ |
| 20 | University of Illinois | USA | http://www.iti.illinois.edu/<br>http://www.iti.illinois.edu/research/energy-systems |
| 21 | NEC Laboratories America | USA | http://www.nec-labs.com/<br>http://www.nec-labs.com/research-departments/energy-management/energy-management-home<br>http://www.nec-labs.com/research/smart-grid-and-energy-systems-laboratory_2/90 |
| 22 | S&C Electric Company (ATC – Advanced Technology Center) | USA | http://www.sandc.com/company/advanced-technology-center.asp |
| 23 | Stanford University (TomKAt center for sustainable energy) | USA | https://tomkat.stanford.edu/ |
| 24 | University of California—Santa Barbara (Institute for Energy Efficiency) | USA | http://iee.ucsb.edu/research |
| 25 | MIT | USA | http://web.mit.edu/research/ |
| 26 | University of Pittsburgh | USA | http://www.engineering.pitt.edu/Departments/Electrical- |

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| | | | Computer/_Content/Research/ECE-Research-Page/ |
| 27 | Northwestern University (Insitute for Sustainability and Energy) | USA | http://isen.northwestern.edu/research<br>http://isen.northwestern.edu/research-areas |
| 28 | Laborelec | Belgium | http://www.laborelec.be/ENG/<br>http://www.laborelec.be/ENG/research-and-innovation/ |
| 29 | Institute of Power Engineering | Poland | https://www.ien.com.pl/home<br>https://www.ien.com.pl/activity-areas |
| 30 | Iberdrola | Spain | http://www.futured.es/en/capability/?prettyUrl=iberdrola-distribucion |
| 31 | ZIV Aplicaciones y Tecnologia | Spain | http://www.futured.es/en/capability/?prettyUrl=laboratorio-de-smartgrids |

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