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SMART GRIDS LABORATORIES INVENTORY 2015

Marta Poncela Blanco, Giuseppe Prettico, Nikoleta Andreadou, Miguel Olariaga Guardiola, Gianluca Fulli, Catalin-Felix Covrig

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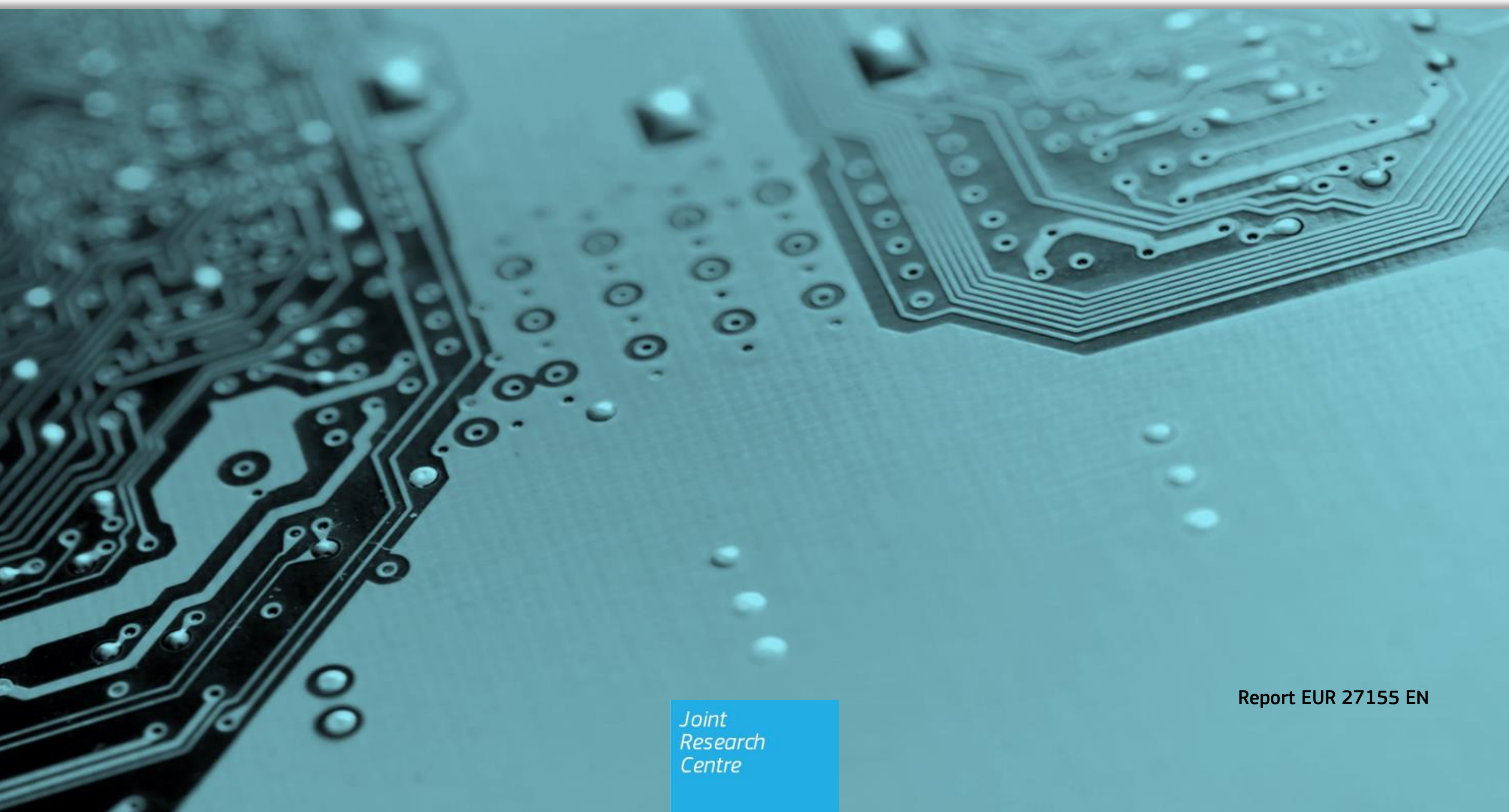

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Contact information

Miguel Olariaga Guardiola

Address: Joint Research Centre. Building 44 Office 114 Via Enrico Fermi 2749

21027 Ispra (VA), Italy

E-mail: miguel.olariaga@ec.europa.eu

Tel.: ++39 0332 78 9689

http://ses.jrc.ec.europa.eu

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Abstract

A smart electricity grid opens the door to a myriad of new applications aimed at enhancing security of supply, sustainability and market competitiveness. Gathering detailed information about smart grid laboratories activities represents a primary need. In order to obtain a better picture of the ongoing Smart Grid developments, after the successful smart grid project survey initiated in 2011, we recently launched a focused on-line survey addressed to organisations owning or running Smart Grid laboratory facilities. The main objective is to publish aggregated information on a regular basis in order to provide an overview of the current facilities, to highlight trends in research and investments and to identify existing gaps.

SMART GRIDS LABORATORIES INVENTORY 2015

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ABBREVIATIONS AND ACRONYMS

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.
CMI	Common Information Model.
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

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- National Renewable Energy Laboratory (NREL)
- INOV INESC INOVAÇÃO
- Centre National de la Recherche Scientifique *(*CNRS)
- STRI
- Centre for Renewable Energy Sources and Saving
- INSIEL s.p.a.
- University of Strathclyde
- National Technical University of Athens
- Kaunas University of Technology
- VITO (as part of EnergyVille)
- ORMAZABAL Corporate Technology
- Instituto Tecnológico de la Energía (ITE)
- ISA Energy Efficiency, S.A.
- Grenoble Electrical Engineering Laboratory
- TELECOM Bretagne / Institut MINES-TELECOM
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EXECUTIVE SUMMARY

This report, the first of a series of periodic publications, systematically gathers and disseminates information on the smart grid laboratories active in Europe and beyond. The underpinning survey developed by the JRC is a comprehensive attempt to get a complete overview of all the smart grid technologies operational at laboratory level.

As known, the drive towards sustainable, secure and competitive energy policies is bringing about deep changes in the way the power system is operated, designed and planned. Particularly, the increasing amount of renewable energy sources connected to the transmission and distribution networks, together with the emerging role of consumers in dispersed power production and electricity demand mitigation, are pushing towards a rethinking of the power system as a whole.

In this light, current operational, control and monitoring practices based on centralised architectures are being challenged by more decentralised approaches and solutions. Indeed, technological advances in ICT (Information Communication Technology) are expected to contribute significantly to these developments. The concept of Smart Grid, as an electricity network that can intelligently integrate the actions of all users connected to it - producers, consumers and those that do both (*prosumers*) - in order to efficiently deliver sustainable, economic and secure electricity supplies, is emerging naturally in the research and innovation domains and moving further beyond.

Assessing these challenges generally requires, as a first step, conducting a number of tests and experiments in dedicated research infrastructure and laboratories before moving to larger scale demonstrators. This report hence aims on the one hand at complementing and on the other hand at going deeper into the other JRC's periodic publication - the "Smart Grids Projects Outlook 2014" - where the enormous number of smart grid R&D and demonstration projects developed in Europe are highlighted and evaluated.

More and more it is becoming apparent how a wide and differentiated set of research infrastructure for technology and solution testing and development is a crucial prerequisite before a larger scale roll out of Smart Grids could take place. There are clear added values for the scientific, research and industrial community in having a systematic overview of the existing smart grid research facilities, their locations, their areas of activity and the standards and technologies in use. This inventorying exercise is planned to evolve towards an interactive platform helping, among others, to address the following needs of the smart grids research and innovation actors: finding proper research partners represents sometimes a hard task, there is the need for accreditation and also to advertise more broadly the services offered.

Web sites are certainly used by organisations as a platform to explain and offer their services but often the *information is very* heterogeneous when different institutions are compared. 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. Evidence indicates that the availability of information regarding Smart Grid research facilities, their activities, locations and connections can represent a key component to contribute to the development of Smart Grids research and innovation in a more coordinated and harmonised way.

With this aim the JRC launched in November 2014 a customized and user-friendly questionnaire, asking leading organizations, institutes and recognized Smart Grid laboratories particularly in

Europe but also in the US, to provide the most up-to-date information regarding their research facilities, the activities being carried out and the infrastructure supporting their work. The survey was created with three main requirements:

- Helping to obtain harmonised and consistent information so that data can be meaningfully aggregated.
- Containing up-to-date information so relevant conclusions could be drawn.
- Be flexible enough to adapt to different world areas, technologies and standards in use.

Over a period of two months several organisations owning a Smart Grid research facility were invited to participate in the survey. The overall feedback was extremely positive and contributions were of the highest quality. 26 organizations completed the survey and the analysis of the information provided has been included in this report in an anonymous and aggregated way. The survey has been structured in 3 main sections:

- General information: includes basic general information regarding the main activities, publications, future expansion plans and collaboration activities.
- Research activities: The survey has been divided into 13 categories: Distribution Automation, Grid Side Management, Storage, Sustainability, Market, Generation and distributed energy resources (DER), Electromobility, Smart Home/Buildings, Smart Cities, Demand Response, Information and Communications Technologies (ICT), Cybersecurity, and Advance Metering Infrastructure (AMI). The questions in each area of activity were structured covering the following topics: Activities or applications, Technologies, Standards in use and Objectives of the research activity.
- Infrastructure: laboratory equipment and facilities.

Some general conclusions drawn from the completed surveys can be summarised as follows[1]:

- The main customers of the smart grid labs are industrial companies, followed by utilities, academia and governments.
- The initial budget for setting up the lab is, on average, around 1 M€, but for large institutions it reaches up to 30 M€. On average, the estimated total annual running cost amounts to 50000 €.
- Among the 13 categories identified those which takes on greater importance (more than 80% of the labs are working on them) are: Grid Management, Storage, Generation&DER, Demand Response and ICT. It is also worth noting that almost every lab carries out activities related to different categories.
- IEC 61850 is the mostly used standard (in 6 out of the 13 categories) for: Distribution Automation, Grid Management, Storage, Generation & DER, ICT and AMI activities. For the other categories, more specific standards are adopted.

For each identified category, the key facts can be summarized as follows:

[1] There is a single response from the US laboratories, so, the conclusions can be regarded as referring only to a European context.

- Distribution Automation: Automation of distribution networks and power inverters are the main focus of interest in this area.
- Grid Management: For this area, real-time simulation, power quality studies and technical feasibility studies are mainly carried out.
- Storage: From the technological point of view, batteries and supercapacitors capture the main attention. Regarding applications, demand shifting and peak reduction, voltage support and frequency regulation complete the picture.
- Sustainability: Life cycle analysis is currently concentrating the bulk of research efforts in this area.
- Market: In this context, Market Structure and Impact of RES integration on electricity prices, represent the core research activities.
- Generation and Distributed Energy Resources: As expected, the focus is on wind and photovoltaic system integration.
- Electromobility: Considering that the related survey questions focused on the interaction between electric vehicles and the grid, vehicle-to-grid and energy storage management are here emerging as the key activities.
- Smart Home and Smart Building: Energy Management and software applications are the activities most commonly carried out in this area.
- Smart city: The main activities in this area include ICT technologies, energy generation and lighting followed by software applications.
- Demand Response: This category is a common activity for those labs working on Electromobility, Smart Home, DER integration and AMI.
- ICT: This is a very broad category. The focus of the survey was on network topology (the most frequent ones are WAN/LAN and FAN), technology developments (PLC and wireless are the most commonly used) and finally, monitoring and control activities.
- Cyber Security: The main topics under study in this area are integrity, confidentiality and authorization.
- Advanced Metering Infrastructure: Apart from Demand Response and Communications, that are also categories considered in this survey, interoperability centers the activity.

It is worth mentioning that these conclusions have been drawn with respect to the present situation as obtained from the participants' sample. Future activities can give an alteration to the current picture, which is why it is necessary to continue improving the survey and expanding the sample.

Periodic (ideally annual) releases of the report are expected, so trends and evolutions can be early identified in the development process and gaps can be targeted in a proactive way. As part of a continuous improvement process a number of actions will be taken:

- In early 2015 external expert input will be sought in order to improve the content and scope of the survey. All participating organisations will be invited to contribute to the development of the questionnaire in order to expand the areas of work, add new activities, technologies and standards and, overall, make it even more relevant for the key actors of this exercise: the research organisations themselves.

- In the same way, external expertise will be sought in order to expand the number of participating organisations as, evidently, the value of the inventory will significantly increase as it does the number of contributions. In addition, it is expected to expand the world areas covered to include further regions outside Europe and USA.
- A completely new online platform will be developed to host future versions of the survey and the online repository. This platform will also integrate the Smart Grid Projects inventory to have a complete, independent overview of the Smart Grid developments in terms of infrastructure and projects. In addition, it will be created with the intention of becoming a common collaboration and sharing platform among research organisations where enhanced joint research activities can be promoted and initiated.

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

- The role of the JRC as a neutral data broker guarantees data accuracy, relevance and independency to all participants, while maintaining all confidentiality needs as required in their research works. In addition, higher visibility to all organisations will be provided by means of advertising campaigns in the JRC Internet Hub and in the European Commission Internet site.
- Secondly, the future collaboration platform will provide ample possibilities for participants to find research partners verify the current Smart Grid state-of-the-art research infrastructure and analyse trends, evolutions and gaps where future expansion needs might be required. In addition, the analysis of the planned investments in different areas, readily available in the repository, combined with gap identification and analysis studies based on aggregated information from the projects and facilities inventories, might guide future investors at the time of studying the allocation of research funds. The precision of such studies will increase as it does the number of participant's data in the repositories, which is why it is in the interest of all to contribute to the inventory.

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 a sustainable production (with the minimum environmental impact) and at an affordable price for all consumers has become one of the most ambitious goals worldwide. This, together with the necessary upgrading and modernization of the infrastructure is bringing the power system at a novel conceptual, technological and organizational level [1]. Many actions have been taken along this way to cope with several related aspects, but many challenges and open questions are still to be addressed.

The increasing amount of renewable energy sources (RES) from one side reduces CO_2 emissions and improves the security of supply, but from the other 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) are core elements 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. There are several definitions of Smart Grids. The one used in this report was developed in 2006 by the European Technology Platform for Smart Grids, and concerns an electricity network that can intelligently integrate the actions of all users connected to it – producers, consumers and those that do both (*prosumers*) - in order to efficiently deliver sustainable, economic and secure electricity supplies. Smart Grids represent also a change in the traditional conception of a power supply system, moving from an electromechanically controlled system to an electronically controlled network.

1.2 Complexity and Interoperability

Smart grid developments are expected to have a significant effect on modern society. Therefore, the number of key stakeholders actively involved in smart grid applications is constantly increasing. However, the smart grid implementation can be quite far from being trivial.

To realize smart grid capabilities, technology deployments must connect large numbers of smart devices and systems involving hardware and software. Interoperability is defined as the capability of networks, systems, devices, applications, or components to share and readily use information securely and effectively with little or no inconvenience to their users. Interoperability is an important enabling aspect of technology deployments that Smart Grids are required to address.

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.

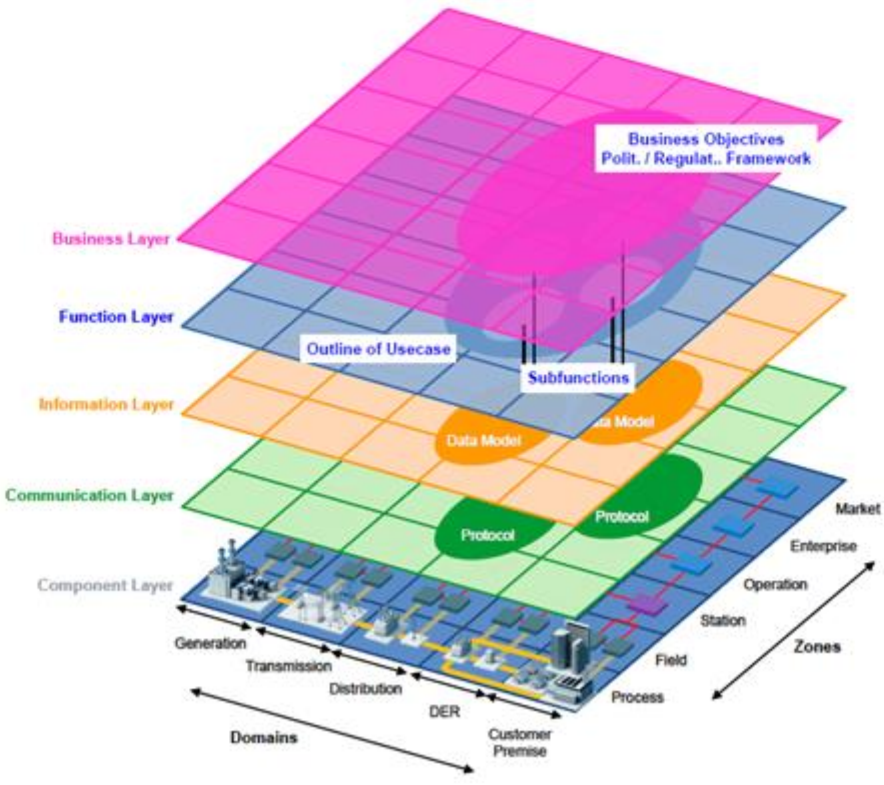

Figure 1: Smart Grid Architecture Model (SGAM)[source: SG-CG/M490]

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.

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 necessary 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.

1.3 The need to test

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.

1.4 Smart grid laboratories

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) [3], DERlab [4], the European Network for cyber security (ENCS) [5] and Futured [6] 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.

1.5 Benefits gathered from knowing the state of art of SG Labs

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 it is 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.

1.6 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) and the assessment framework for the identification of Smart Grid Projects of Common Interest (PCI) [7]. 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.

1.7 Expected outcomes

The analysis of the information provided by laboratories on their websites indicates that it is required to extend such an information to obtain more specific and analytical results. For this reason, it was decided to launch a customizable and focused survey. Initially, the survey has targeted as many as possible European labs/institutions and also some well-known U.S. labs. The ultimate target is to extend it to several world areas in the next years. This global perspective is required in certain areas, as for example communication technologies or cyber security, where the differences among regions become blurred as these technologies evolve worldwide.

The present survey and report is a comprehensive attempt to get a global overview of all the technologies fully operational at laboratory level. In that sense, this report will be useful to readers with various knowledge backgrounds for obtaining a global picture of the on-going activities.

The main objective is 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. Aggregated information will be made public and available on a European Commission Internet site. Additionally, participants will have the possibility to collaborate with each other based on the information provided. So, another benefit from this project is to enhance information and knowledge sharing.

The analysis of aggregated information will provide a strategic vision of which technologies are mostly targeted by research and development in order to be implemented in real cases. The exercise will be repeated on a regular basis (ideally yearly), and will enable us to analyse the evolution of different technologies from a progress speed and maturity level point of view. In addition, an important part of the survey focuses on human resources needs.

Finally, it is necessary to assess to what extent and where, the different standards are used. This would contribute to the successful roll out of the different technologies, since it depends to a great extent on the standards harmonization over the regions.

1.8 Report structure

After having shortly overviewed the Smart Grid realm and the necessity of collecting valuable information on the activities in this field, Chapter 2 presents the structure of our survey. As mentioned, it covers 13 categories involved in the Smart Grid development. Chapter 3 analyses the data collected through the survey and it is structured according to the different categories. This choice of presenting the results is motivated by the high level of specialization for each research area. In this way the reader can focus only on the area of interest. The Conclusions chapter summarizes the main findings and insights and addresses future perspectives and work to be done

2. SURVEY

2.1 Objectives and design

When the idea of building a smart grid repository first started several options for its implementation were considered. 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.

Some organizations published quite detailed information regarding the equipment and facilities they owned, giving ample details about components, topologies and manufacturers. Some other organizations published detailed information regarding the activities they were carrying out, explicitly mentioning the projects and research programs they were participating in. However, not many of them provided information about both aspects, facilities and activities. This was an important drawback as it was very clear that the relation between facilities, equipment and activities would be a crucial factor to analyse.

Information published was very sparse and lacked harmonization. Although common areas of work could be identified, the use of different terms for the activities, objectives and equipment made it difficult to analyse as a whole. Statistical analysis could not be performed due to the lack of a common basis. In addition, there were areas, especially the ones regarding automation and power electronics, which were very differently considered by different organizations. That also heavily depended on the size of the facility and the scope of works.

Information was sometimes outdated or not dated at all, making it impossible to give it the adequate relevance in terms of the moment in time when it was produced. In an immature and fast-changing environment, as the Smart Grids is, timing is very important if the information sought regards gap identification, state-of-the-art facilities and short and medium term evolutions.

In many cases, the information gathered about a given facility was not indeed found on the facility's website but on a separate paper, presentation or conference report. So, there was a risk that the information was partial or incomplete.

All these limitations proved the need to launch a focused survey to collect information in a structured way and with the homogeneity initially sought. In any case, the initial effort already carried out has proven to be very useful during the survey design phase. In fact, and based on the experience acquired during the Internet research phase, some clear and inherent objectives were set up:

- The survey should help in achieving harmonization and consistency of information. With too much room for interpretation, information might become misleading and evidence can go unnoticed. In fact, one of the main problems identified during the Internet search phase was the fact that each organization expressed their activities and facilities from their own perspective. And although this is a very valid approach as it allows for a greater level of detail and for an inside view of what the business is, it does not provide a solid basis for comparison or when statistical studies, gap identification or trends and future evolutions are the main objective of the data analysis. Only by comparing similar data sets, aggregated information becomes relevant.

- The inventory should contain up-to-date information. Five years might seem negligible in a mature business, but in research, and more importantly, with new technologies involved, those five years might mean a complete new approach. Only by acquiring and analysing up-to-date information regarding Smart Grid lab facilities, activities and equipment we can make sure that results can be relevant and can help in identifying current and future needs in the sector.
- As already discussed, different organizations might see the same fact from different angles leading to different conclusions only relevant from their own business perspective. In order to be able to reach to different organizations, entities and sectors, in different world areas and with different needs and visions, flexibility is a key factor. Fixed formulas to gather information might work well for certain organizations but it was very unlikely that would suit to all of them. With the flexibility idea in mind several steps were taken in order to make sure that the exercise would respond and would adapt to any organizations' needs, changes and evolutions happening along the process.

Those three basic objectives were then transformed into technical specifications that lead the way to build the survey during the design phase, which took around four months in total. During this time, the main features, the structure and the content of the survey were decided and further developed and elaborated.

2.2 Main features of the survey

The following aspects were implemented in the survey in order to accomplish the preset list of objectives:

Priority was given to single-choice or multiple-choice questions rather than open questions. The objective was threefold: first it would facilitate and speed up the completion of the survey, second it would simplify the aggregation of information for statistical purposes and third it would reduce the risk of lack of accuracy in the responses provided.

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.

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 part of the survey a check-box was to be made available to specify if the information in that section should be treated as confidential. If marked so, information in that section would be never shared with any other participating organization in a future collaboration platform.

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.

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

Although any organization could complete the survey, only the answers from organizations in EU or in US were processed and included in the results of this first report. Including answers from any other region would defeat the consistency objective as the lack of specific questions and options for other areas would mean that participating organizations from those regions would have to choose from more general options or even select the option of 'No Answer' or 'Not Applicable' and thus severely affecting the consistency of the analysis and results.

Data provided through the online survey was stored in an online repository. POC(s) have access to the provided information at all times, which allows 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 this report. Contributions received after that deadline remained in the system but were not processed and aggregated for the 2014 report. Instead, they would be taken into account for the 2015 exercise.

The survey was designed with the idea in mind of developing a larger online platform to host future survey releases and with collaboration and sharing capabilities. This new platform is expected to be open in time for the next release of the survey in 2015 and will bring a visible additional value to all participating organizations.

2.3 Structure of the survey

The main survey design issue was how to structure the information and what questions should be asked. It is important to highlight that the questions were focused on the link between the research activities and the grid and the interoperability aspects. For that reason no questions were specifically asked about research in new materials or the development of a technology by itself.

The classification regarding areas of activities and topics in each area were done based on a number of factors, including internal and external expert input, the information collected during the Internet research phase and several other references, as for example the ones mentioned in [8], [9], [10].

The survey has been structured in 3 main sections:

1. General information: includes basic data regarding the lab location, name, contacts but also general information regarding the main activities, publications, future expansion plans and collaboration activities.
2. Laboratory research activities, intended to get detailed information of the areas of work and activities performed at each of them. For this, the Smart Grids Laboratory Survey has been divided into 13 categories:
    a. Distribution Automation
    b. Grid Side Management
    c. Storage
    d. Sustainability
    e. Market
    f. Generation and Distributed Energy Resources (DER)
    g. Electromobility
    h. Smart Home/Buildings
    i. Smart Cities
    j. Demand Response
    k. Information and Communications Technologies (ICT)
    l. Cybersecurity
    m. Advance Metering Infrastructure (AMI)

In section 2.3.2 (Research Areas) of this report, each activity will be described in detail. The questions in each area of activity were structured covering the following topics:

- Activities or applications.
- Technologies.
- Standards in use.
- Objectives of the research activity.

3. Infrastructure: laboratory equipment and facilities. As this is very particular for each laboratory, it is an open section of the survey where the lab POCs were encouraged to upload their own information.

2.3.1 General information

The main objective of this part of the survey was to collect information about aspects of the research facility that were considered of general nature and independent of the specific work carried out. In particular the following information was requested:

- Name of the research facility.
- Geographical location of the research facility.
- POC and contact details.
- Human resources: number of staff members working at the research facility on a normal basis.
- Budget: total investment to set up the lab and annual running costs.
- Information regarding standardisation activities carried out at the facility.

- Percentage of work carried out in each area. A dynamic filtering concept was introduced here. All 13 research categories were listed in this question and participants were asked to specify in which ones the facility was carrying out some research work. It had to be expressed as a percentage, so that the results could be weighted accordingly. Later, in the Research Areas Section of the survey, only questions related to the areas that were declared here would be presented, omitting all the other questions related to areas where the organization was not carrying out any research work.
- For each area, the type of activity that was being carried out: technology development, standards development, R&D of equipment and software and prototype testing.
- Publication and dissemination activities of the research results.
- Collaboration work, where participants could specify if the majority of the research work was based on stand-alone activities, sporadic collaboration for specific projects or permanent collaboration with other organizations.
- Planned investments in the different research areas.
- Geographical scope: world area(s) where the research work was focused on.
- Type of electrical system: transmission grid, distribution grid, isolated or islanded systems.

2.3.2 Research Areas

This represented the main part of the survey. The number of areas presented in this section was variable and it depended on the answers provided to the 'Percentage of activity in each area' question of the General Information Section. Only questions related to areas where some activity was previously declared were proposed.

The type for most questions in this section was multiple-choice to ensure that participants could select each and every activity, technology or standard that was relevant. However, the options proposed for each question were not considered to be fully comprehensive. Instead, for all questions in this section, the possibility to add additional information that could not be found as an option was always made available through a free-text box.

In total up of 13 different research areas were included:

a. Distribution automation

By distribution automation we understood the combination of sensors, new control equipment and intelligent software for new and optimized distribution system operations. Distribution automation refers to monitoring, control, supervision and communication functions that transform the distribution grids in flexible systems that will improve capacity utilization, reliability and power quality. It also provides new customer services, reduces operating costs, improves efficiency and permits a better integration of distributed generation and storage.

The main topics covered were:

1. Activities carried out in the area of distribution automation:
    - ✓ Substation automation.
    - ✓ Automation of distributed networks.

- ✓ Inverters
- ✓ Self-healing networks.

2. Research objectives sought in the area of distribution automation:

   - ✓ Reliability
   - ✓ Integration of distributed generation
   - ✓ Efficiency
   - ✓ Voltage control and reactive power

3. Standards in use. Only IEC standards were proposed, although participants could freely specify any others that were relevant to their research work.

b. Grid Management.

By grid management we understood all the systems, applications and actions to control and manage the power grid in an efficient and highly automated way. It was also included under this concept the tools for extracting information from the large amount of data generated by the distributed monitoring and control systems and devices spread out through the physical grid.

The main topics covered were:

1. Activities in the area of grid management:

   - ✓ Real time monitoring of the grid.
   - ✓ Advanced control systems.
   - ✓ Microgrids
   - ✓ Critical Management
   - ✓ Diagnosis tools
   - ✓ Big data analysis for grid management

   Some of these topics were also divided in sub-topics, as it happened, for example, with microgrids.

2. Technologies: mainly focussed on Phasor Measurement Units (PMU).

3. Standards in use: IEC and IEEE standards were proposed with the possibility to specify any additional ones.

c. Storage

Under this concept we understood the use of different technologies for energy storage in different ways and the delivery of this energy in the form of electricity to the transmission and/or distribution grid or at customer level. Storage will play a crucial role in improving the operation of the electrical grid, allowing for higher integration of renewable energy generation. Energy storage systems can provide benefits for different grid operations on different time scales

Regarding storage the questions were related to technologies, applications, tests (performance and reliability) and standards.

1. Areas of work related to Storage in Smart Grids linked to the following technologies and storage system types:

- ✓ Batteries.
- ✓ Pumped-storage hydroelectricity (PSH)
- ✓ Underground Thermal Energy Storage (UTES)
- ✓ Compressed air energy storage (CAES)
- ✓ Thermochemical
- ✓ Chemical-Hydrogen storage
- ✓ Flywheels
- ✓ Super-Capacitors
- ✓ Superconducting Magnetic Energy Storage (SMES)
- ✓ Hot water storage
- ✓ Ice storage
- ✓ Cold water storage
- ✓ Molten Salts

2. Applications: mainly focused on the following functions in the grid:

    - ✓ Seasonal storage
    - ✓ Arbitrage
    - ✓ Frequency regulation
    - ✓ Load following
    - ✓ Voltage support
    - ✓ Black start
    - ✓ Transmission and Distribution (T&D) congestion relief
    - ✓ T&D infrastructure investment deferral
    - ✓ Demand shifting and peak reduction
    - ✓ Off-grid
    - ✓ Variable supply resource integration.
    - ✓ Waste heat utilization
    - ✓ Combined heat and power
    - ✓ Spinning reserve
    - ✓ Non-spinning reserve

3. Standards in use. Only IEC standards were proposed, with the possibility to specify any additional ones.

d. Sustainability.

Although sustainability is a large concept, here only aspects related to the environmental framework were considered. The main topics covered were Life Cycle Analysis, Greenhouse Gas (GHG) analysis and reduction strategies and recycling.

This area is expected to be considerably expanded in future versions of the survey.

e. Market

By market we understood all the activities related with the impact of the smart grids on the electricity markets.

Regarding market activities, questions were mainly related to the areas of research and the standards in use. The topics considered were the following:

1. Activities in the area of Market:

   - ✓ Analysis of technology market barriers in the Smart Grids
   - ✓ Structure of the ESI (Electrical Supply Industry)
   - ✓ Structure of Generation.
   - ✓ Transmission and Distribution intelligence.
   - ✓ Market Structure.
   - ✓ New Regulation Schemes for deregulated actors.
   - ✓ Novel trading schemes
   - ✓ Impact of RES integration on electricity prices
   - ✓ Modeling of new financial frameworks
   - ✓ Marketplace
   - ✓ Trading systems

1. Standards in use. Only IEC standards were proposed, with the possibility to specify additional ones.

f. Generation and distributed energy resources (DER)

By generation we understood all generators connected to the transmission grid. There are two different types: the classical ones, dispatchable generation, and the new ones, not controllable by the system operator.

By distributed energy resources (DER) we understood sources of generation and/or storage that are connected to the distribution system. In this case, the distribution system begins to resemble a small transmission system and needs to consider similar design issues such as non-radial power flow and increased fault current duty

The topics considered were the following:

1. Generation technologies, with the following options being proposed:

   - ✓ Wind Energy
   - ✓ PV
   - ✓ Concentrated Solar Power
   - ✓ Tidal Waves
   - ✓ Biomass
   - ✓ Hydro Fuel Cell
   - ✓ CHP
   - ✓ Gas Power Plants
   - ✓ Nuclear Power Plants
   - ✓ Coal Power Plants

2. Application of the research activities conducted, with the following options proposed:

   - ✓ Renewable Energy Sources (RES)
   - ✓ Forecasting
   - ✓ Advanced Control

3. Standards in use: IEC and European (EN) standards were proposed, with the possibility to specify additional ones.

g. Electromobility

By electromobility (or e-Mobility) we understood the use of electric vehicles with the aggregation of information and communication technologies, utilities, telecom operators, mobile devices, service providers and communication infrastructures that enable the interaction of electric vehicles and the power grid. The e-mobility concept aggregates all operational and market factors required enabling the reduction of operational costs related to the deployment of electric vehicles and the provision of advanced services.

The topics covered in this area of activity have been:

1. Activities related to electromobility:
    - ✓ Energy efficiency
    - ✓ Power quality
    - ✓ Energy management and vehicle autonomy
    - ✓ HVAC
    - ✓ Vehicle-to-grid
    - ✓ Interoperability
    - ✓ Grid load impact
    - ✓ Charging technologies
    - ✓ Car battery technologies
    - ✓ Energy storage
    - ✓ Demand response
    - ✓ Environmental impact (pollution, noise…)
    - ✓ Citizen behaviour
    - ✓ Security
    - ✓ Safety
2. As vehicle charging is the most important interaction with the grid, specific questions regarding this topic were developed. In particular, specific questions regarding charging technologies, charging plugs and charging power capacity were proposed.
3. In the area of software development for electromobility, the following application areas were proposed:
    - ✓ Communication/protocols
    - ✓ Management (configuration, deployment…)
    - ✓ Control (alarms, events…)
    - ✓ Demand response
    - ✓ Pricing
    - ✓ User account and billing
    - ✓ Charging infrastructure (location of charging points, availability of charging points, charging status…)
    - ✓ Car monitoring

4. Concerning communication protocols, a wider set of standards from different Standardization Organizations (IEC, IEEE, ISO, SAE, OICP) have been proposed as this was the area where more regional differences and less "implicit" agreement were found.

h. Smart Home and Smart Buildings

By the concepts of Smart Home and Smart Building we understood an integrated system of communication and information technologies, service providers, telecom operators and utilities that allow consumers to remotely control and monitor household and building appliances, devices, sensors and information systems. The interaction and the information gathered will allow the consumer to react to different events of different nature including, but not limited to, pricing, remote configuration and programming, automation of activities and security and safety conditions.

In view of smart home and buildings the following topics were covered:

1. Activities related to Smart Home and Smart Building:
   - ✓ Temperature control
   - ✓ Lighting
   - ✓ Sensors
   - ✓ Power quality
   - ✓ Audio-visual
   - ✓ Smart appliances
   - ✓ Security
   - ✓ Safety
   - ✓ User account and billing
   - ✓ Demand response
   - ✓ Energy management strategies / Cost-control
   - ✓ Integration of RES
   - ✓ Interoperability
2. In the area of software development for Smart Home and Smart Building, the following application areas were proposed:
   - ✓ Communication/protocols
   - ✓ Management (configuration, deployment…)
   - ✓ Control (alarms, events…)
   - ✓ Cybersecurity
   - ✓ Demand response
   - ✓ Pricing
   - ✓ User account and billing
3. Regarding the communication technologies used in the area of Smart Home and Smart Building, the following ones were proposed:
   - ✓ Wireless
   - ✓ PLC
   - ✓ Ethernet copper cabling
   - ✓ Optical Fiber

4. Standards in use in the area of Smart Home and Smart Building: there was a wide range of EN, IEC, ISO and ITU standards proposed, with always the possibility of adding others where relevant.

i. Smart City

By the concept of Smart City we understood an integrated system of communication and information technologies, service providers, telecom operators, utilities and government entities and actors that will allow citizens to enjoy a wider range of enhanced city services related to, but not limited to, transportation, public information of different nature, public infrastructure, public lighting, natural resources, safety or Internet access to name a few. Those enhanced services will ultimately imply an improvement in the concepts of quality of life, welfare and participation in city governance.

Regarding Smart Cities the questions were focused on:

1. Activities related to Smart City:
   - ✓ Mobility (traffic, transport, parking...)
   - ✓ Information and Communication Technologies (ICT)
   - ✓ Government (administration, buildings...)
   - ✓ Environment (pollution, noise, temperature...)
   - ✓ Lighting
   - ✓ Energy generation
   - ✓ Energy storage
2. In the area of software development for Smart City, the following application areas were proposed:
   - ✓ Communication/protocols
   - ✓ Management (configuration, deployment...)
   - ✓ Control (alarms, events...)

j. Demand Response

By the concept of Demand Response (DR) we understood the intentional modification to the usual consumers' patterns of electricity usage as a consequence of a reaction to one or several events, including, but not limited to, power grid needs, price signals, market competition or personal needs. Consumers' alteration to the timing, level of demand or the total electricity consumption is expected to decrease overall consumption or shift it from on-peak to off-peak periods depending on consumers' preferences and lifestyles.

The topics covered in this area of activity have been:

1. Activities related to Demand Response:
   - ✓ Generation
   - ✓ AMI
   - ✓ EVs
   - ✓ Smart Home and Smart Building
   - ✓ Grid load

- ✓ Storage
- ✓ Demand modelling
- ✓ DRMS – Demand Response Management Systems
- ✓ CEMS – Customer Energy Management Systems
- ✓ Automated demand response
- ✓ DER integration
- ✓ Price signal

2. Standards in use: EN, IEC, IEEE, DRSG, OpenADR, PLMA standards and alliances were proposed. Others could also be added.

k. Information and Communication Technologies

By the concept of Information and Communication Technologies (ICT) we understood the aggregation of computers and hardware components, software, telecommunications equipment, storage units and all related services that enable users to store, retrieve, transmit and manipulate information.

This is a very broad activity that covers several aspects. The following main aspects were addressed:

1. Type of networks were research activities were carried out:
   - ✓ WAN
   - ✓ FAN
   - ✓ Substation LAN
   - ✓ NAN
   - ✓ Subscriber Access Network: PAN - Personal Area Network
   - ✓ Subscriber Access Network: HAN - Home Area Network

2. Wireless technologies in use in the research activities:
   - ✓ GSM
   - ✓ GPRS
   - ✓ 3G
   - ✓ LTE
   - ✓ Wi-Fi
   - ✓ Wi-Max
   - ✓ BlueTooth
   - ✓ NFC
   - ✓ IrDA
   - ✓ High-Rate WPAN
   - ✓ Low-Rate WPAN
   - ✓ Zigbee
   - ✓ DASH7
   - ✓ 6LoWPAN
   - ✓ 802.15.4G
   - ✓ WirelessHart
   - ✓ ISA100.11A

3. PLC technologies and standards or alliances used in the research activities:
   - ✓ BPL – Broadband over power lines
   - ✓ NB-PLC – Narrow Band PLC
   - ✓ UNB-PLC – Ultra narrow band PLC
   - ✓ IEC 61334 – Distribution automation using distribution line carrier systems
   - ✓ IEEE 1901 – Broadband over power line networks.
   - ✓ IEEE 1901.2 - Low-Frequency (less than 500 kHz) Narrowband Power Line Communications

- ✓ for Smart Grid Applications
- ✓ IEEE 1905 – Convergent Digital Home Network
- ✓ ITU-T G.hnem – Narrowband OFDM power line communications transceivers
- ✓ G3-PLC Alliance
- ✓ PRIME Alliance
- ✓ HomePlug
- ✓ HD-PLC Alliance

4. Protocols, specifications or technologies used in the area of ICT communications:

   - ✓ IPv4 – IP version 4
   - ✓ IPv6 – IP version 6
   - ✓ MPLS – Multiprotocol Label Switching
   - ✓ IEC 61850 – Communication networks and systems in substations
   - ✓ SDH - Synchronous Digital Hierarchy
   - ✓ SONET - Synchronous Optical Network
   - ✓ DSL – Digital Subscriber Line (including ADSL, VDSL, HDSL, SHDSL…)
   - ✓ OSGP – Open Smart Grid Protocol
   - ✓ IPS for Smart Grids (IETF RFC 6272)

5. Monitoring and control of communication infrastructure. In addition to enquiring about the networks, technologies and tools used in the area of monitoring and control, the main objectives of this activity were also addressed and some of them were proposed:

   - ✓ Remote equipment configuration
   - ✓ System status monitoring
   - ✓ Event management (ICT-related events)
   - ✓ Response automation
   - ✓ Resilience/protection management

6. In the area of software development for ICT, the following application areas were proposed:

   - ✓ Communication
   - ✓ Management
   - ✓ Control
   - ✓ Monitoring
   - ✓ Security

l. Cybersecurity

By cybersecurity, or IT security, we understood the technologies, devices, processes and practices designed to protect the security of the information in digital media and components, such as computers, smartphones, networks (including Internet) and in general any device with data communication capabilities. It includes all the measures taken to protect any communication device against unauthorised access or any action that could lead to alteration, theft or damage of the information being transmitted over any available channel.

The following topics were covered in this area:

1. Activities related to Cybersecurity:

   - ✓ Identity

- ✓ Confidentiality/Privacy
- ✓ Integrity
- ✓ Authorization
- ✓ Authentication
- ✓ Forensics
- ✓ Incident response
- ✓ Risk assessment
- ✓ Risk response
- ✓ Contingency planning

2. Protocols and technologies used in the area of cybersecurity. Some well-known options were also proposed, giving also the option to mention additional ones:

   - ✓ IPSec – Internet Protocol Security
   - ✓ EAP - Extensible Authentication Protocol
   - ✓ PKI – Public Key Infrastructure
   - ✓ RSA - Ron Rivest, Adi Shamir and Leonard Adleman (crypto system)
   - ✓ AAA – Authentication, Authorization and Accounting
   - ✓ DES – Data Encryption Standard
   - ✓ 3DES – Triple DES
   - ✓ AES – Advanced Encryption Standard
   - ✓ SHA – Secure Hash Algorithm
   - ✓ MD5 – Message Digest algorithm 5
   - ✓ SSH – Secure Shell
   - ✓ RADIUS - Remote Authentication Dial-In User Service
   - ✓ Oauth – Open secure authorization protocol

m. AMI – Advance Metering Infrastructure

By Advanced Metering Infrastructure (AMI) we understood an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers. Customer systems include in-home displays, home area networks, energy management systems, smart meters and any other equipment that enable smart grid functions.

The questions related with AMI were focused on the following aspects:

1. Areas of activity:

   - ✓ Billing
   - ✓ Customer information
   - ✓ Pricing
   - ✓ Installation and configuration
   - ✓ Monitoring
   - ✓ Management
   - ✓ Interoperability
   - ✓ Demand response
   - ✓ Communications
   - ✓ Security

- ✓ Safety
- ✓ Other

2. Communication technologies

   - ✓ Wireless
   - ✓ Wired (copper, fiber…)
   - ✓ Power Line Communications (PLC)

2. Standards in use: IEC, EN, IEEE and ISO standards were proposed, with the possibility to specify additional ones.

2.3.3 Infrastructure

The final part of the survey was intended to record as many details regarding the infrastructure and equipment used in the research facilities as possible.

In a first part several multiple-choice questions were presented enquiring about different specific aspects and equipment of the research facility. In particular:

- The size of the facility in terms of power capacity
- The availability of real time simulation infrastructure and the specification of the research areas where this type of simulation was carried out.
- The availability and use of power amplifiers
- The use of Hardware In the Loop (HIL) tests to carry out research work

In the second part of the Infrastructure Section participating organizations where provided with a file upload tool where diagrams, presentations or any other electronic document describing the equipment and components of the lab and/or their interconnections could be uploaded.

- ✓ The ultimate goal of this section of the survey was to be able to stablish a relation between the activities carried out, the infrastructure needed and used and the investments required to accomplish all that.

3. RESULTS

3.1 Overview

Over a period of two months up to 78 organizations owning a Smart Grid research facility were invited to participate in the survey. The overall feedback was extremely positive and contributions were of the highest quality. Up to 26 organizations completed the survey and the analysis of the information provided has been included in this chapter in an anonymous and aggregated way. Out of the 26 organizations, 2 of them completed the survey outside the deadline and once the data analysis phase had already started. In order to avoid a delay in the publication of this report and in the start of the 2015's survey exercise, the information provided by those 2 research facilities has not been included in this report but will be included in 2015's.

It's necessary to mention that due to the still limited number of contributions at this stage, and although some initial hints and findings can be already gathered, results and conclusions cannot be yet generalized to a European level. It is also important to stress the potential value that such an exercise will have as soon as more labs become interested in having at their disposal such information.

3.2 Analysis of the General Information

With respect to the participant laboratories in this first version of our survey, they cover a sufficiently wide range of countries. The majority of the participants are based in Spain (29%), while 17% in Italy. Both French and Portuguese based laboratories are represented by a 13% in this survey, while 8% is the equivalent percentage for labs from Greece. Finally, countries like Belgium, Lithuania, United Kingdom, Sweden and U.S. are represented by one participant each. In the future, we intend to target more laboratories that would cover a wider range throughout European countries, to extend the American list and to target other countries outside Europe. Figure 2 shows the distribution of the labs that have completed our survey depending on their country.

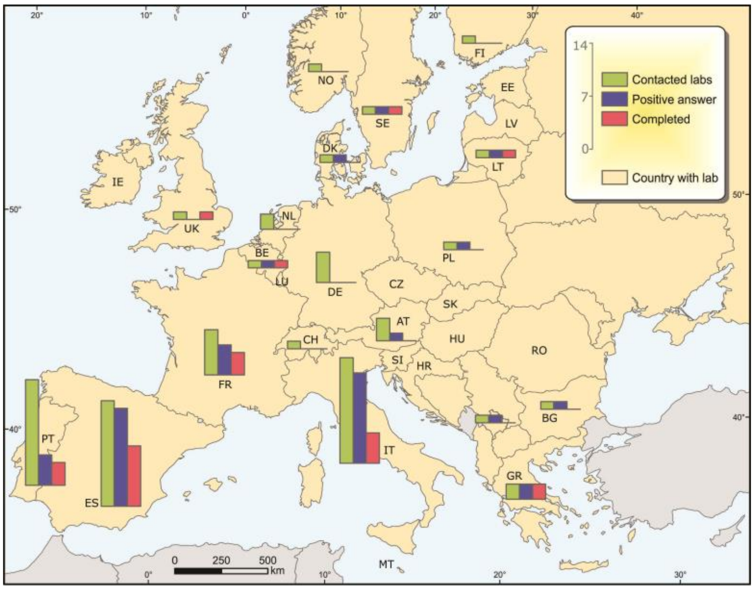

Figure 2: Labs distribution according to the country in which they are based (please note that there was one US Lab participating in this survey but it is not shown on the map).

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

It is worth noting that the majority of the participants (88%) have chosen to share information with the other participants on several topics referring to: their labs activities, areas of research, type of main publications, and purpose of research activities (technology or standards development, R&D of equipment or software, prototype testing), focused geographical area of research and type of grid on which research is conducted.

Another important point to notice is that half of the participant laboratories are working towards the development of a related standard and one fourth of them already hold an accreditation. The budget to build a Smart Grid Lab is on average close to 1.5 million of euros, but for big institutions composed by several labs this can reach up to 32 million of euros (sees Figure 3).

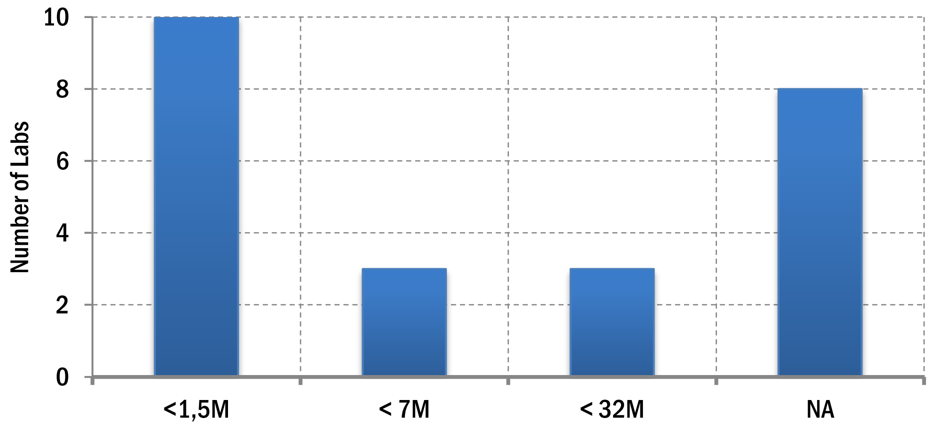

Figure 3: Budget distribution of labs. Histograms refer to ranges in € (i.e. the first column represent the number of labs which spent below 1.5 millions of euros to set their SG lab).

With respect to the total running yearly costs of the lab, they are different depending on the type of lab. Also it has to be specified that some participants took in account the cost of the personnel working in the lab. Such a number is also very different depending on the size of the facility. More details are shown in Figure 4 and Figure 5.

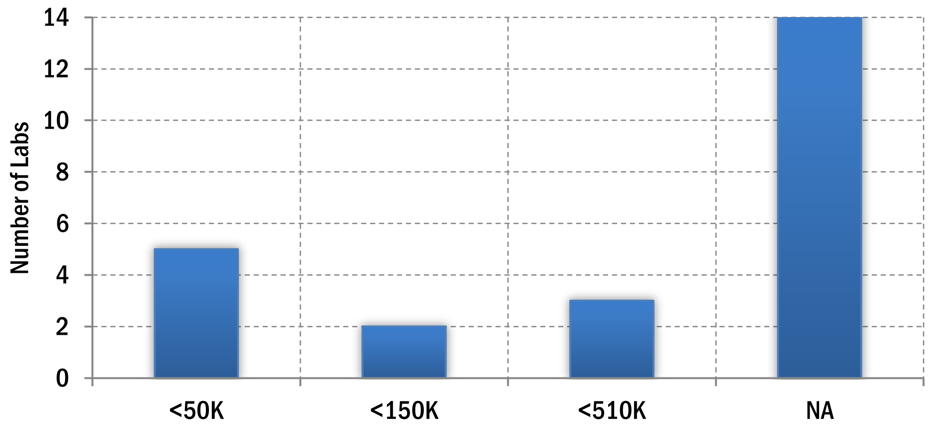

Figure 4: Running yearly costs distribution. Histograms refer to ranges in euros as previously explained.

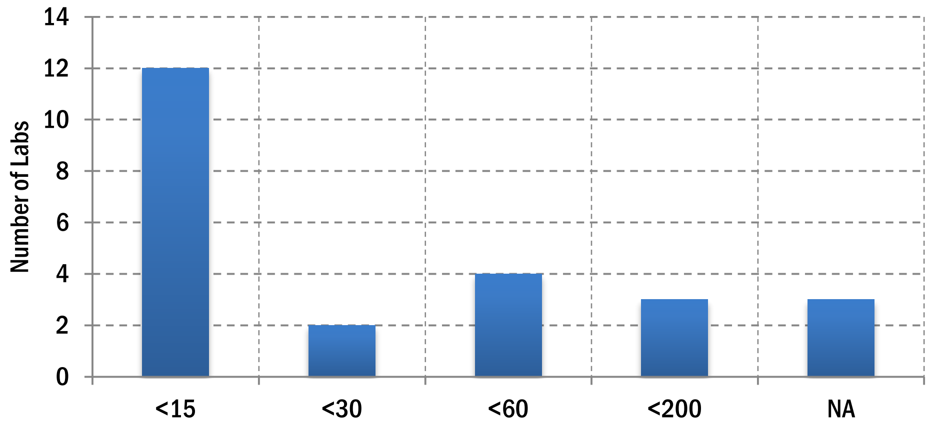

Figure 5: Number of employees per lab. The majority has less than 15 employees.

From our survey it results that all the involved smart grid laboratories are working along multiple lines of research. Table 1 reports the exact percentage of labs per activity (also called category in the rest of the report). The percentage on the right side of Table 1 indicates the percentage of the total labs in the survey which are leading some research activity in the category reported on the left side. It is easy to identify those categories for smart grid research which are most popular: Grid Management (88%), Storage (80%), Demand Response (88%) and ICT (84%). It is also noteworthy that none of the categories goes below 40%.

Distribution automation	66%
Grid management	88%
Storage	80%
Sustainability	41%
Market	45%
Generation and DER	84%
Electromobility	70%
Smart Home/Building	75%
Smart City	63%
Demand Response	88%
ICT:Communication	84%
Cyber Security	46%
AMI: Advanced Metering Infrastructure	50%

Table 1: Percentage of laboratories per activity

With respect to each of the aforementioned categories, some general information has been gathered like identifying the sectors at which research is targeted, the way the results are disseminated, the geographical areas of interest, the type of grid on which research is conducted.

Starting from the sectors at which smart grid activities are targeted, five of them have been identified, which are namely the Utilities, Industry, Government, Academy and Other Research Organizations. Figure 6 gives a picture of the labs that work for a particular sector. The percentages presented refer to the aggregated values for each sector normalized by the activities as a whole. From this figure it is clear that industry, utilities and the academy are the sectors for which research is performed most.

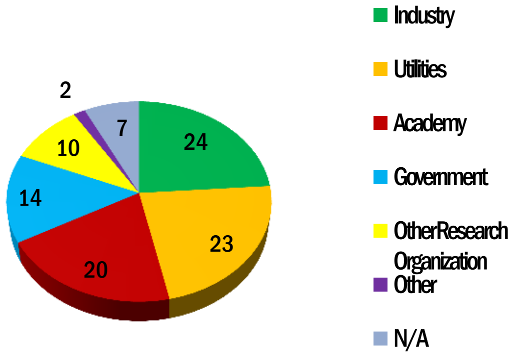

Figure 6: Sectors at which Lab research is targeted

Another important issue is the different fields of activity that are available for the smart grid categories. In this report, we present six of such fields and an indication of the amount of work carried out on each one with respect to each smart grid category. These fields of activity are: Technology Development, Standards Development, R&D of Equipment, R&D of Software, Prototype Testing and Patent Registration. Figure 7 depicts the fields of activity to which smart grid research is focused on. The numbers illustrated refer to the aggregated percentages of each field normalized by the activities as a whole. It is derived from the figure that R&D of software and technology development comes first in the list, with prototype testing and R&D of equipment following with a small difference.

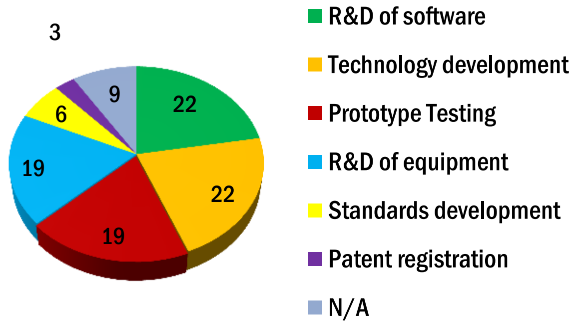

Figure 7: Fields of activity

The dissemination of results can also vary. Some of the options can be: Scientific journals, Conference papers, White papers, Websites, Books and Use cases. In Figure 8 the different ways of results dissemination are presented along with the percentages referring to the amount of activities using a specific means of dissemination with respect to the whole amount of activities. It is obvious that conference papers and scientific journals are the most common way of results dissemination for all topics. The other solutions attract much less than 20% of the corresponding labs.

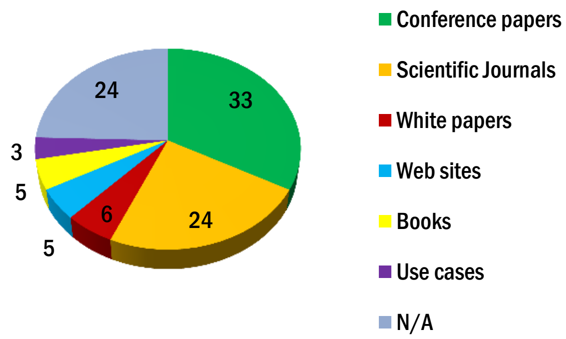

Figure 8: Results dissemination

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 9 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 sporadic collaborations correspond to the 32% of the smart grid research, whereas the 29% and 26% stand for stand-alone and permanent activities respectively. It is worth noticing at this point that one lab/institution can carry out simultaneously more than one activity on a given category.

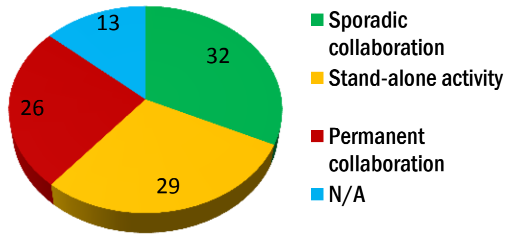

Figure 9: Types of collaborations

Figure 10 depicts the geographical areas in which smart grid research is. It is concluded from the figure that the majority of smart grid activities are carried out in Europe. It is obvious that most labs focus in Europe, which was rather anticipated since the survey participants are mainly based in Europe. It is noteworthy that for all categories, there are some activities carried out in North America. Australia attracts at the smallest extent the scientific interest, which is rather expected given the location of the particular continent and its long distance with the labs' basis.

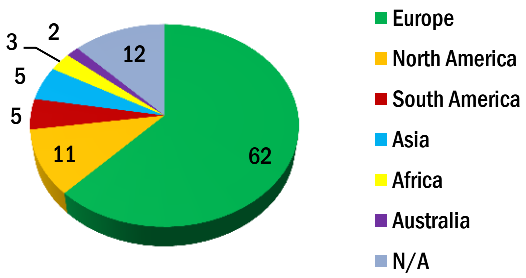

Figure 10: Geographical area of interest for smart grid research

Finally, we have gathered information about the type of grid on which research is performed. There are several types of grid, like the transmission, distribution, isolated and islanded grid. Figure 11 gives information about the networks on which research is focused. As it can be observed 41% of the total activities are dedicated to the distribution grid, as opposed to only 10% that is devoted to the transmission grid. The equivalent percentages for the isolated and islanded grid are 17% and 18% respectively.

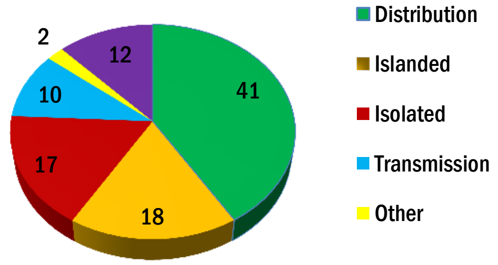

Figure 11: Types of grid to which research is dedicated

3.3 Analysis of Smart Grid Areas

For each of the aforementioned categories of smart grid activities, we have identified some useful, preliminary trends, presented in the following sections. Typically, we focus on the possible areas of interest for each category analyzed. Further on, emphasis is given on the standards, protocols or technologies that can be used by the survey participants with respect to each smart grid category. Where necessary, further analysis is performed on issues of vital importance for a specific category. For reasons of completeness, we initially present for each category relative information to the one presented in Section 2.3.2 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.

3.3.1 Distribution Automation

The activities in this area are mainly targeted for the industry sector and the utilities, with the former sector gathering more than the 80% of the actively involved labs in the sector. An important percentage (56%) also focuses on academic subjects, since academy attracts the interest of more than 50% of the Distribution Automation labs. The situation is depicted in Figure 12.

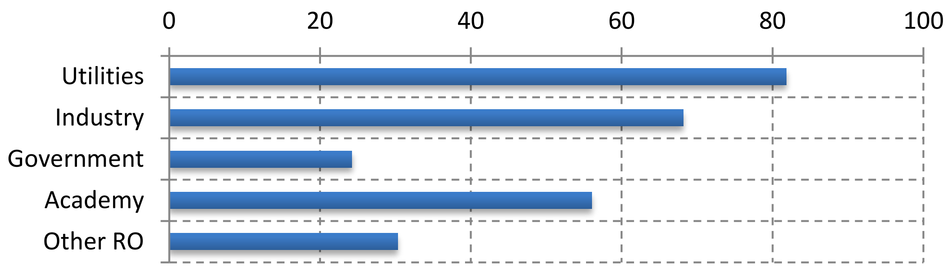

Figure 12: Sectors at which research is targeted in Distribution Automation

The vast majority of the Distribution Automation involved laboratories (94%) are focusing on Technology development; however, a significant percentage (over 80%) focuses on Prototype Testing, R&D of equipment and software, as shown in Figure 13. Regarding the dissemination of the scientific results, it can be observed from Figure 14 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.

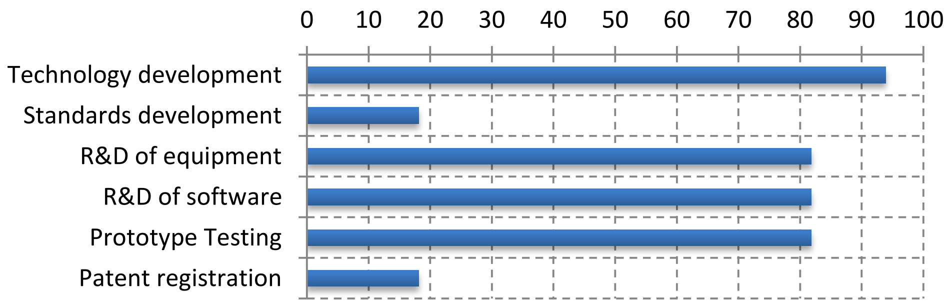

Figure 13: Fields of activity for the Distribution Automation smart grid category

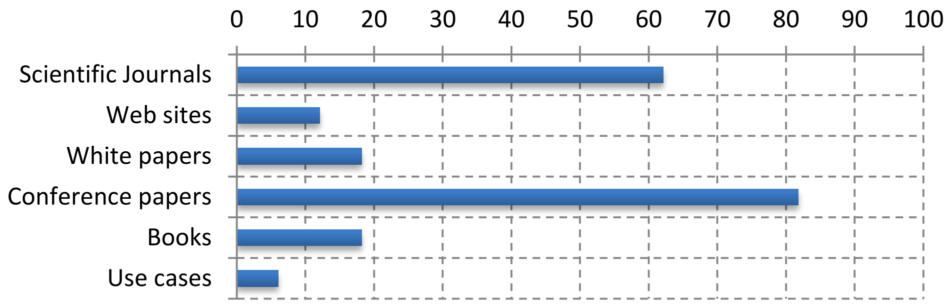

Figure 14: Results dissemination in Distribution Automation.

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 differences at the range of 7%, as depicted in Figure 15. Figure 16 shows that the 94% 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 apart from Australia gather a small percentage of the research activities. According to Figure 17 the distribution network is the main asset on which Distribution Automation research activities are focused. However, the islanded and isolated networks are important fields of research, since more than 40% and 20% of the actively involved labs in the sector conduct research on them respectively.

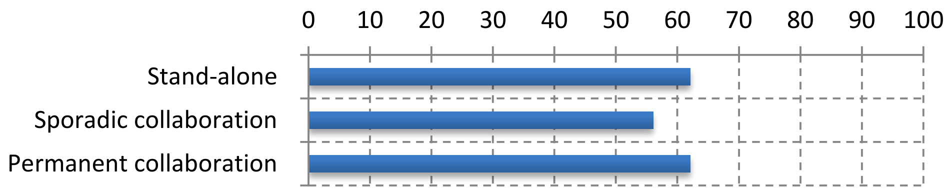

Figure 15: Nature of activities in the Distribution Automation

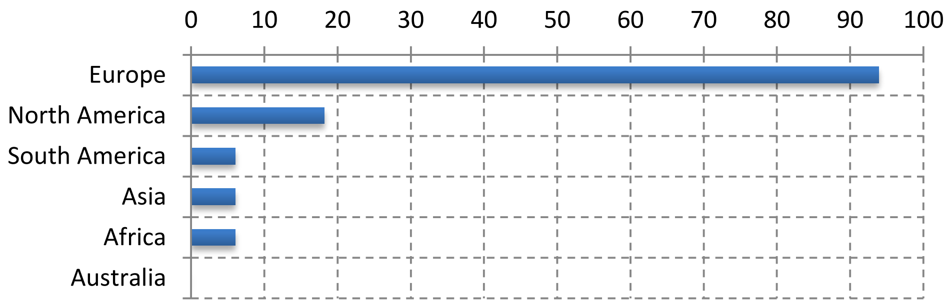

Figure 16: Geographical area where research activities are focused in Distribution Automation

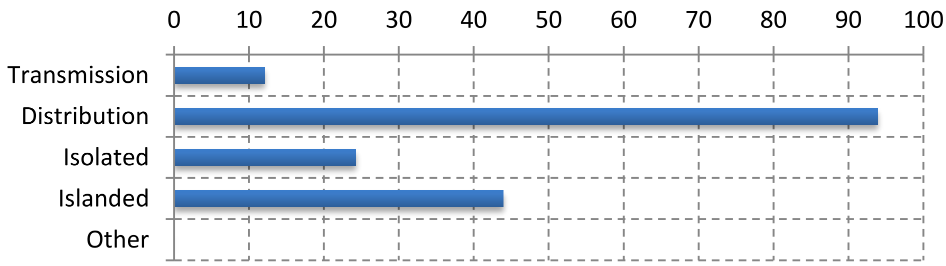

Figure 17: Networks on which research in Distribution Automation is carried out

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

Substation automation	50%
Automation of distribution networks	88%
Inverters/power inverters	70%
Other	6%
Self-healing networks	58%
Don't know/no answer	0%

Table 2: Percentages of Distribution Automation topics per laboratory

In our survey, automation of distribution networks is ranked first among the activities of the labs involved in distribution automation with a percentage of 88%. The topic of power converters/inverters occupies the 70% of the active labs in the field, whereas the equivalent percentages for self-healing networks and substation automation are 58% and 50%. This is depicted in Table 2.

IEC 60255-24 - Electrical relays - COMTRADE	12%
IEC 60870 - Telecontrol equipment and systems	32%
IEC 61850 – Communication networks and systems in substations	70%
IEC 61869 – Instrument transformers	26%
IEC 61968 - Common Information Model / Distribution Management	38%
IEC 61970 - Common Information Model / Energy Management	38%
IEC 62351 - Power systems management and associated information exchange	32%
IEC 62439 - Highly Available Automation Networks	6%
Other	6%
Don't know/No answer	38%

Table 3: Standards used for Distribution Automation activities

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 70% of the activities of the laboratories involved in the field. A percentage of 25% 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 62351 - Power systems management and associated information exchange - Data and communications security and the IEC 60870 - Telecontrol equipment and systems are used by a 32% of the DA laboratories. Table 3 gives a complete picture of the situation.

The main objective of the research conducted in Distribution Automation is the integration of distributed generation, with voltage control and reactive power coming second in the list. Reliability and efficiency also play an important role to the research community.

For what concerns planned investments for the short, medium and long period, we have asked the participants to report if they plan to increase, to decrease, or to keep them fixed. Figure 18 illustrates the obtained answers. As it can be observed from this figure, the majority of labs intend to increase their investments in the next five years. Only a low percentage declared that will maintain them equal or still does not know.

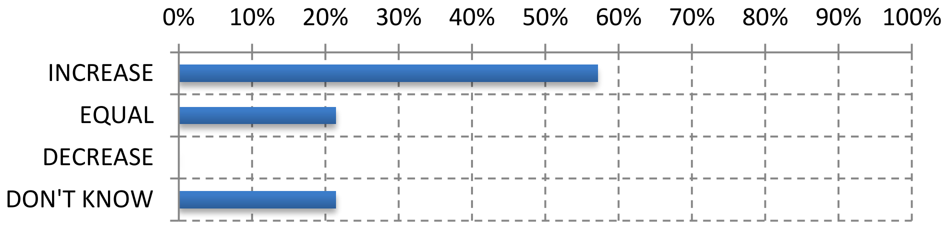

Figure 18: Expected R&D infrastructure investment plans in Distribution Automation within the next five years

3.3.2 Grid Management

With respect to the sectors at which Grid Management activities are targeted, Figure 19 reveals the situation. Utilities, but also the industry and the academy are interested in grid management research activities, with the former two sectors attracting more than 60% 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 50%, as Figure 20 illustrates.

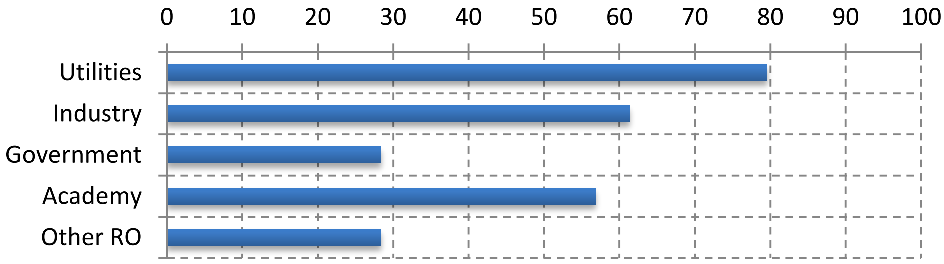

Figure 19: Sectors at which Grid Management research is targeted

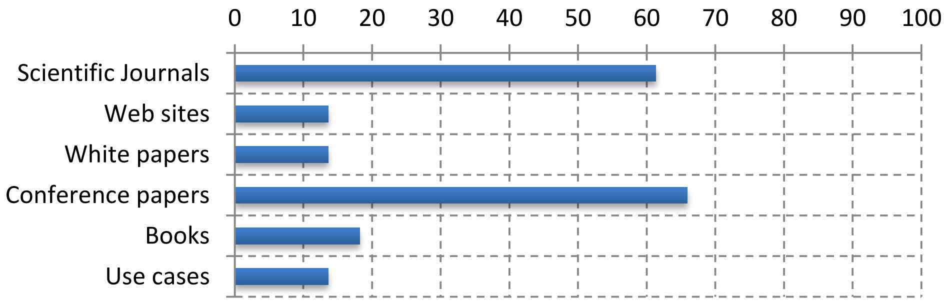

Figure 20: Results dissemination in Grid Management

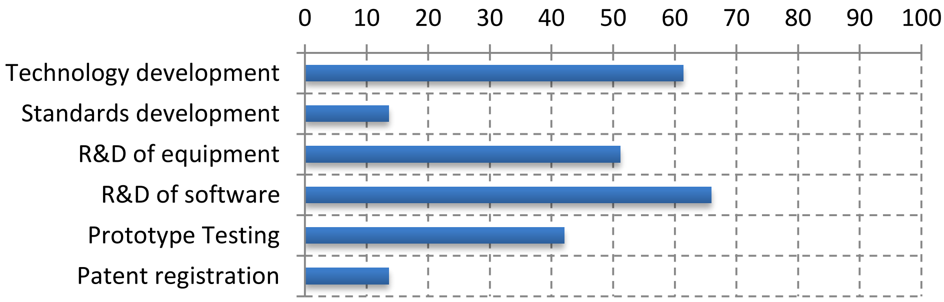

Figure 21: Fields of activity for the Grid Management category

Figure 21 displays that technology development and R&D of software and equipment are the main topics of investigation, since more than 60% of the actively involved labs in the sector occupy themselves with such topics. The activities, again, vary from stand alone to collaborative ones, either sporadic or permanent with other organizations, whereas the variations between the different types of activities are relatively small, at the extent of 10%, as illustrated in Figure 22. The vast majority of the activities are carried out in Europe. However, Figure 23 shows that there is a small percentage of research activities that are focused also on the other continents.

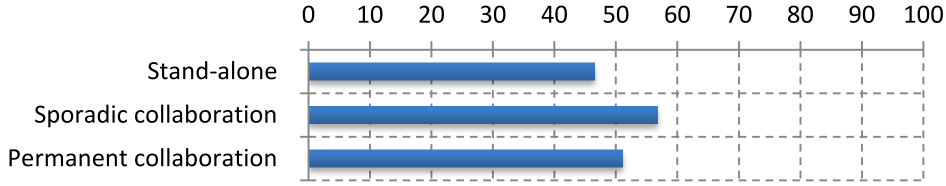

Figure 22: Nature of activities in Grid Management

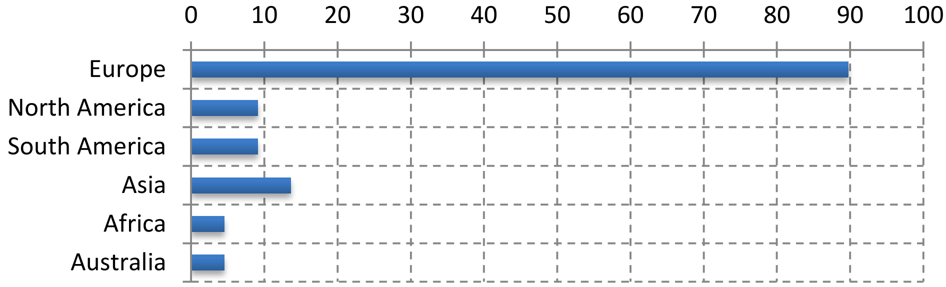

Figure 23: Geographical area on which Grid Management activities are focused

Regarding the part of the network that the Grid Management research activities are focused on, according to Figure 24, the distribution network comes first on the list, gathering almost the 90% of the actively involved labs in the sector. The other types of network, like the transmission, the isolated and the islanded network, also attract the scientific interest, since they gather approximately the 42% of the questioned labs.

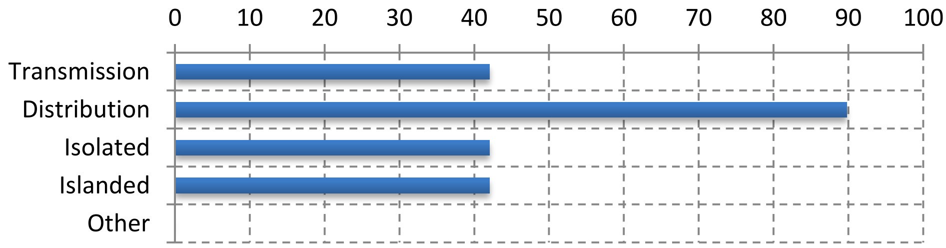

Figure 24: Networks on which Grid Management research is carried out

Technical feasibility studies	66%
Design	48%
Pre-Deployment Validation	43%
Dynamical Analysis	43%
Real time simulation	72%
Protection and control relays	33%
Power Quality studies	66%
Interconnection and Integration of DER	81%
Other	9%

Table 4: Percentages of Grid Management topics per laboratory.

Among the topics which are more targeted by labs active in grid management activities there are the interconnection and integration of distributed energy sources, real time simulation activities, power quality and technical feasibility studies but also others as reported in Table 4.

More than one third of the participants is testing Phasor Measurements Units (PMUs). The main purposes behind this kind of technology are: to provide differential protection schemes for fault detection, to implement post-disturbance analyses through PMUs and GPS synchronization and for advanced control through remote feedback. Almost all the labs involved in Grid Management activities are coping with Microgrids. The main topics of interest are the interconnection and integration of Distributed Energy Resources (DER), Real Time Simulation, Power Quality and technical feasibility studies. 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 in Table 4).

Another important fact is that more than 45% 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.

IEC 60870 - Telecontrol equipment and systems	24%
IEC 61158 - Digital data communications for measurement and control	4%
IEC 61968 - Common Information Model / Distribution Management	24%
IEC 61970 - Common Information Model / Energy Management	28%
IEC 61131 - Programmable controllers	19%
IEC 61499 - International Standard for Distributed Systems	15%
IEC 61784 - Digital data communications for measurement and control	4%
IEC 61850 - Communication networks and systems in substations	66%
IEC 62325 - Common Information Model (CIM) for Energy Markets	9%
IEC 62351 - Power systems management and associated information exchange	19%
IEC 62357 - Power system control and associated communications	4%
IEC 62361 - Power systems management and associated information exchange	4%
IEEE 1344 – Standards for synchrophasors for power systems	15%
Other	4%
Don't know/No answer	28%

Table 5: Standards used for Grid Management activities

An 85% 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: the 43% 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 5).

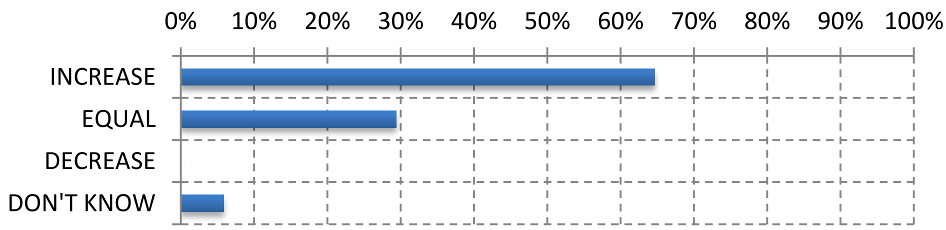

Figure 25: Expected R&D infrastructure investment plans in Grid Management activities within the next 5 years

For what concerns planned investments for the next five years, Figure 25 displays the obtained answers. Similarly to Distribution Automation, most of the labs plan to increase their investments and only a low one fort declares to keep them constant.

3.3.3 Storage

Storage activities are primarily dedicated to industries and the academia, and secondarily to utilities and governmental organizations, since the 78%, 63%, 46% and 41% respectively of the active laboratories in this sector are working for the aforementioned sectors, as Figure 26 depicts. Prototype testing, technology development and R&D equipment and software are the main goals for storage smart grid activities, while each field attracts a percentage of 68%, 63%, 56% and 51% of the active laboratories. Standards development and patent registration are the objectives to follow with a corresponding percentage of 20% and 15%. Figure 27 describes the situation.

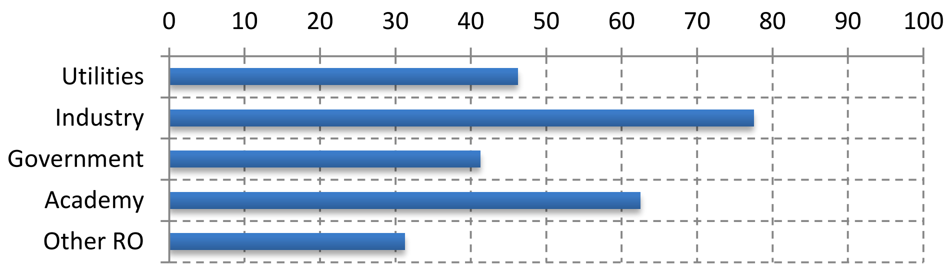

Figure 26: Sectors at which Storage smart grid activities are targeted

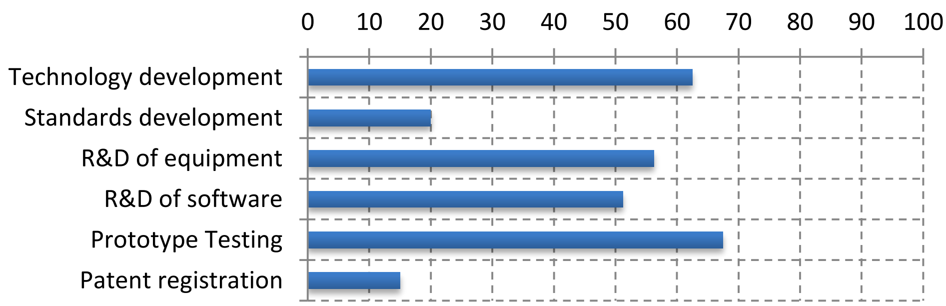

Figure 27: Fields of activities for Storage

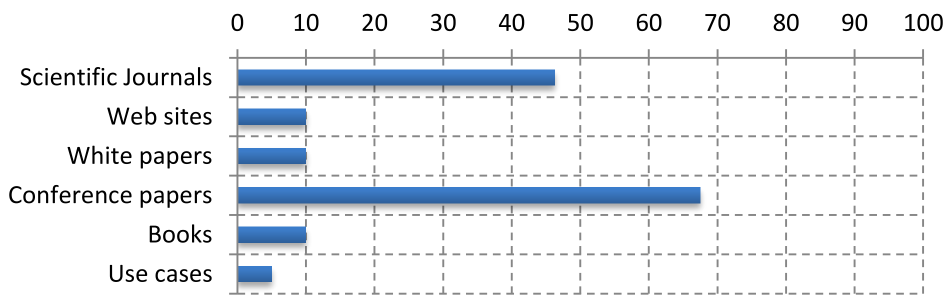

Figure 28: Results dissemination for Storage

Conference papers and scientific journals are ranked as top options for the results dissemination, whereas web sites, books and white papers gathering only 10% each of the active labs. As it can be observed from Figure 28, conferences are the preferred way of results dissemination for more than the 65% of the actively involved labs.

Figure 29 illustrates that the major part of the activities is stand-alone, while sporadic or permanent collaborations are the options that follow with a difference at the range of 10% and 20% respectively. 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 15% and 20% of them in Asia and North America. However, there is a small percentage of the research that is carried out worldwide, as shown in Figure 30.

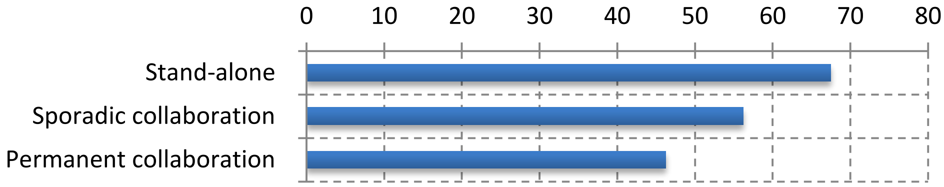

Figure 29: Nature of Storage smart grid activities

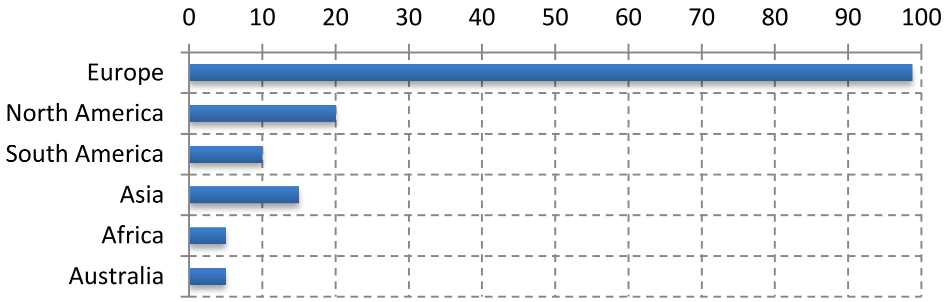

Figure 30: Geographical area of interest for Storage smart grid activities

The distribution network is the asset that attracts mostly the scientific interest, whereas isolated and islanded networks play also an important role in storage issues, as it can be observed in Figure 31. The transmission network comes lower in the list, since it gathers the interest of around 25% of the questioned labs.

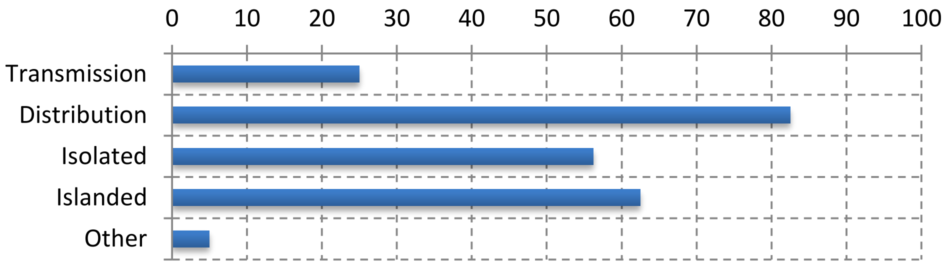

Figure 31: Networks on which Storage smart grid activities are focused

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 89% among them. Super-capacitors are a topic of interest that comes next with a noticeable difference of 48% with respect to batteries for active research in the field. Flywheels and PSH are other two topics of research with a percentage of 21%. Other possible topics under Storage smart grid related fields are the Chemical-Hydrogen Storage, the Cold water storage, CAES, Molten Salts, and Ice storage. More analytically, the described situation is depicted in Table 6.

The Energy Storage applications that mostly attract the scientific interest are Demand Shifting and Peak Reduction, Frequency Regulation, Load-following, Voltage support, Variable Supply Resource Integration and Off-Grid. Each of them is the research topic for the 79%, 68%, 58%, 68%, and 58% respectively of the active research on the field. Variable supply resource integration is another popular topic gathering the interest of the 63% of the active laboratories. In general, it is noted that many of the research organizations questioned, perform investigation on many of the storage subtopics simultaneously. Other areas covered are the Transmission and Distribution congestion relief, Seasonal storage, Black start, Spinning reserve, Arbitrage, Seasonal storage, Transmission and Distribution infrastructure investment deferral and Combined heat and power. The details of the topics and the equivalent percentages are shown in Table 7.

Batteries	89%
PHS	21%
UTES	0%
CAES	10%
Thermochemical	0%
Chemical-Hydrogen Storage	10%
Flywheels	21%
Super-Capacitors	41%
SMES	0%
Hot water Storage	21%
Ice Storage	5%
Molten Salt	5%
Cold Water Storage	10%
Other	5%
Don’t know/No answer	5%

Table 6: Percentage of activity regarding Energy Storage Technologies

Seasonal storage	36%
Arbitrage	31%
Frequency regulation	68%
Load following	58%
Voltage support	68%
Black start	36%
Transmission and Distribution (T&D) congestion relief	48%
T&D infrastructure Investment deferral	36%
Demand shifting and peak reduction	79%
Off-grid	58%
Variable supply resource integration	63%
Waste heat utilization	16%
Combined heat and power	21%
Other	0%
Spinning reserve	31%
Don’t know/No answer	5%
Non-spinning reserve	21%

Table 7: Percentage of activity regarding Energy Storage applications

The survey reveals that 58% of the researchers on the field perform practical tests/measurements. On the other hand, only the 26% performs reliability tests.

Concerning the standards used for storage in smart grids, more than one third of the storage-related researchers uses the IEC 61850 – Communication networks and systems in substations standard. Around one fifth uses the IEC 61970 - Common Information Model / Energy Management standard, whereas the standard IEC 62351 - Power systems management and associated information exchange is used at a lower extent. Analytically, the standards used with their equivalent percentages are shown in Table 8.

For what concerns planned investments within the next five years, Figure 32 illustrates the obtained answers. Similar conclusions can be deducted as with the previous two analyzed categories. An investment increase is planned for over than 60% of the labs for the near future. Around 20% instead plans to keep them equal.

IEC 61850 - Communication networks and systems in substations	36%
IEC 61970 - Common Information Model / Energy Management	26%
IEC 62351 - Power systems management and associated information exchange	10%
Other	5%
Don't know/No answer	41%

Table 8: Standards used for Storage activities

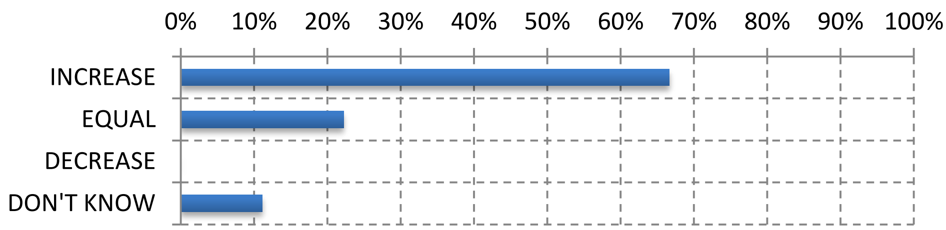

Figure 32: Expected R&D infrastructure investment plans in Storage activities within the next five years

3.3.4 Sustainability

Industrial and academic interests are ranked at the first places when it comes to sustainability tasks among the active laboratories in the field, since they gather the interest of more than 70% and 60% respectively of the actively involved labs in the field. Utilities and government are the sectors that follow, with equivalent percentages of less than 50% and 40%. Figure 33 illustrates the above situation.

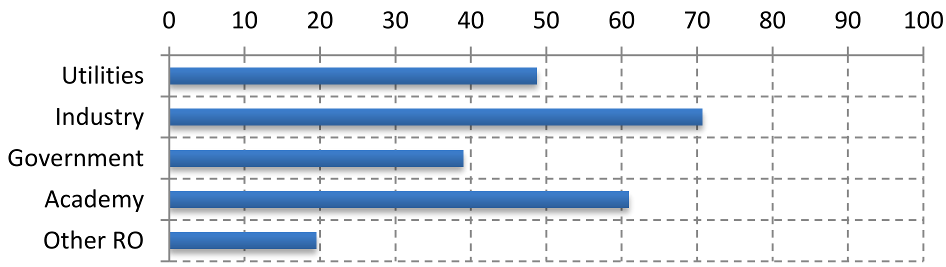

Figure 33: Sectors at which research for smart grid Sustainability is focused

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. The other identified fields show a smaller preference among the Sustainability focused participants with a percentage around 10%, as Figure 34 shows.

When it comes to results dissemination, as it is shown in Figure 35, conference papers are the number one choice for the labs performing research on Sustainability, with scientific journals to follow. 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.

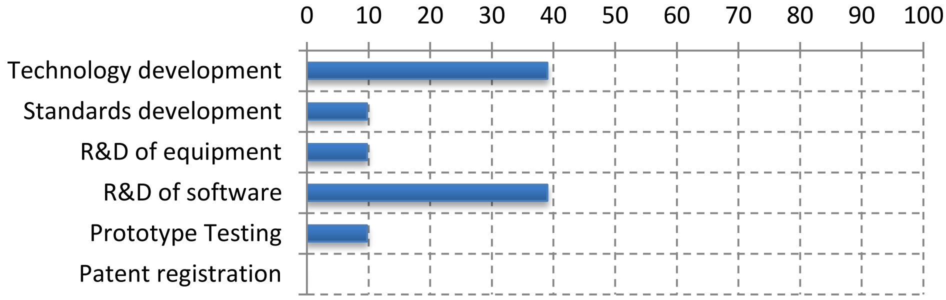

Figure 34: Fields of activities on which sustainability research is focused

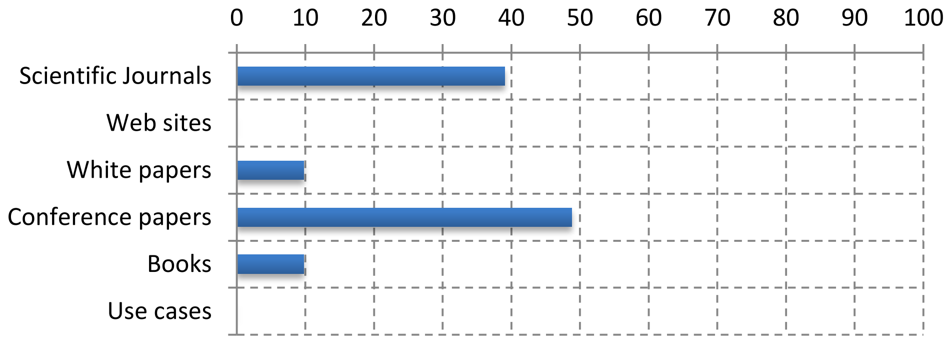

Figure 35: Results dissemination for Sustainability

More than two thirds of the labs work on this topic in a stand-alone fashion. Sporadic and permanent collaborations are less popular with a gradual percentage decrease at the range of 20%, as it can be observed by Figure 36. 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 20% of the actively involved labs conducts research in North and South America and Africa. Figure 37 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 by Figure 38.

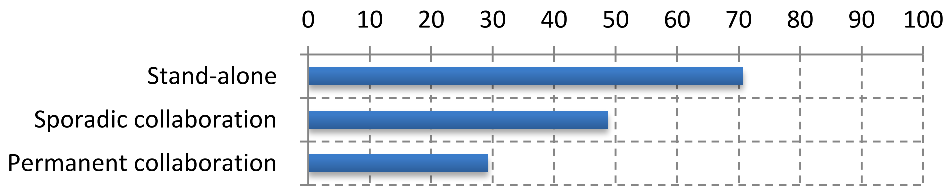

Figure 36: Nature of Sustainability activities

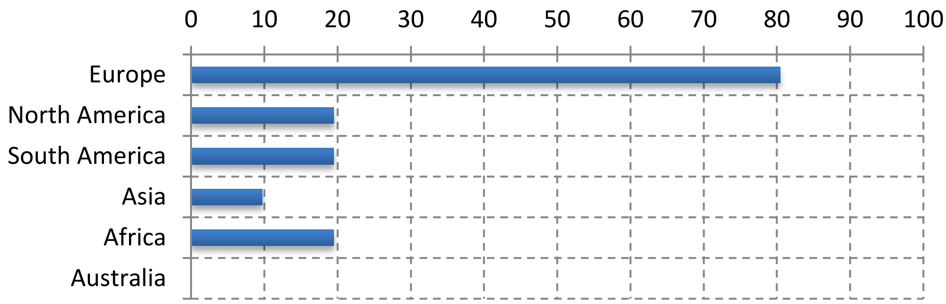

Figure 37: Geographical area on which research for Sustainability is focused

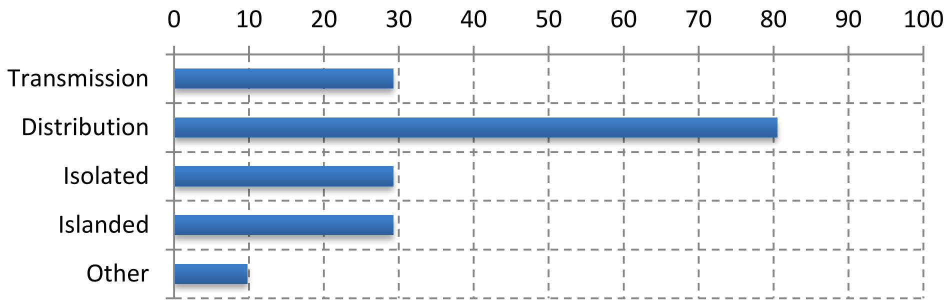

Figure 38: Networks on which Sustainability research focuses

Among the labs which are contributing to sustainability issues, the majority is involved in life cycle analysis in Smart Grids but also on Green House Gas (GHG) analysis and development of reduction strategies (the percentages are 71%, 41%, 51% respectively). Only a 10% is studying the recycling processes for new Smart Grid equipment.

For what concerns planned investments for within the next five years, Figure 39 shows the obtained answers. From the figure a different trend can be observed when compared with the previous categories. More than 55% of the labs investments will remain at the same level for the short period. An increase in the investments is foreseen for slightly more than 40% of the labs.

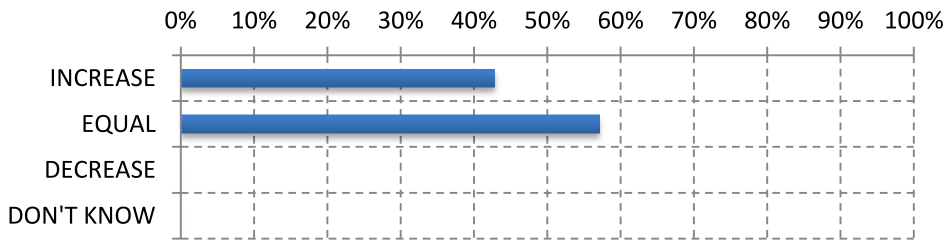

Figure 39: Expected R&D infrastructure investment plans in Sustainability activities within the z next five years

3.3.5 Market

For Market related activities in the smart grid, the laboratories involved are mainly supported by utilities, according to the 73% of the active laboratories in the field and secondarily by the industry, government and academy, with a percentage of 44%, as shown in Figure 40. Regarding the fields of smart grid Market activities, as revealed by Figure 41, 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. Other fields of activity like Standards or Technology development follow with a relative high difference. 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 20% of the actively involved labs, as depicted in Figure 42.

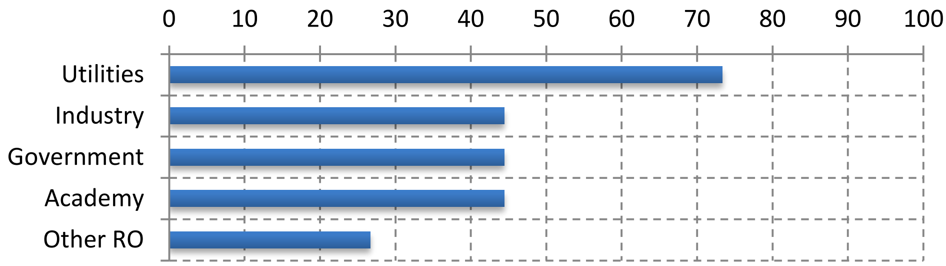

Figure 40: Sectors at which Market smart grid activities are targeted

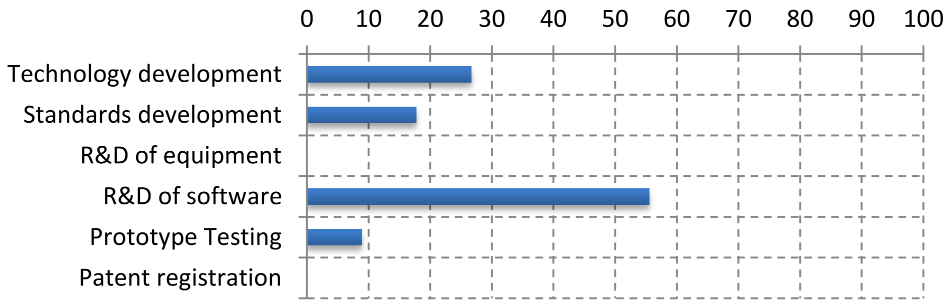

Figure 41: Fields of activities for smart grid Market

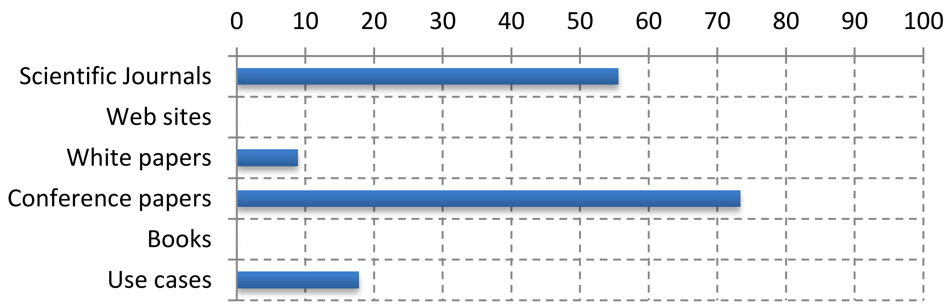

Figure 42: Results dissemination for Market

There is equal distribution among stand-alone activities and collaborations with other organizations (sporadic or permanent), since all these types of activities attract the 55% of the labs that conduct research in Market (Figure 43). With respect to the network on which Market related smart grid research is performed, the major part of the activities focus on the distribution network, which attracts the interest of approximately the 90% of the labs actively involved in the sector. It is noteworthy that a considerable part of these labs also target the transmission system (more than 40%). This situation is illustrated in Figure 44. 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, the survey participants conduct no relevant research in the other continents, as shown in Figure 45.

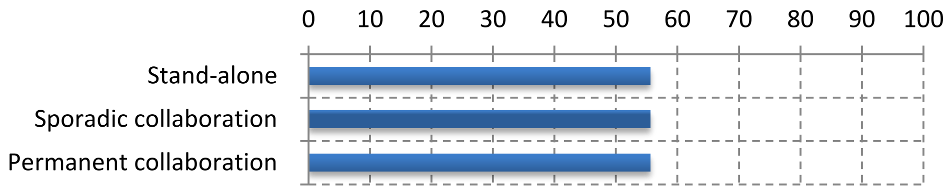

Figure 43: Nature of Market smart grid activities

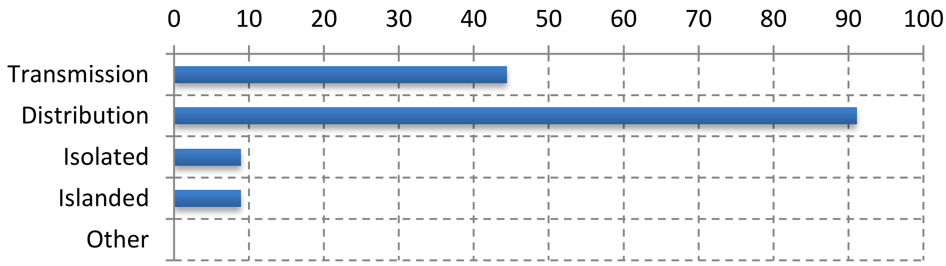

Figure 44: Networks on which Market research is focused

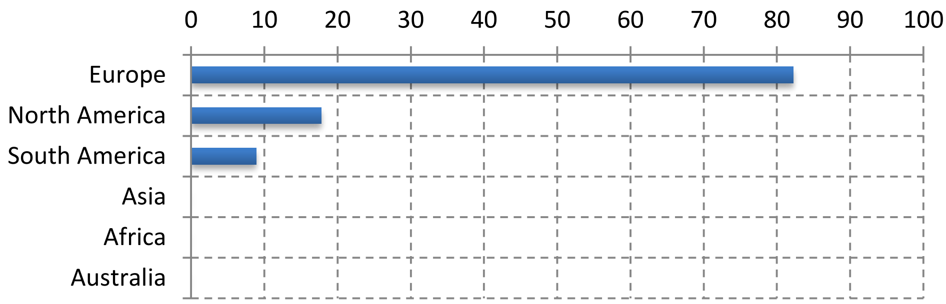

Figure 45: Geographical areas on which Market smart grid activities are targeted

Analysis of technology market barriers in the Smart Grids	56%
Structure of the ESI (Electrical Supply Industry)	18%
Structure of Generation	29%
Transmission and Distribution Intelligence	56%
Market Structure	100%
New Regulation Schemes for deregulated actors	56%
Novel trading schemes	56%
Impact of RES integration on electricity prices	84%
Modeling of new financial frameworks	18%
Other	18%
Trading Systems	38%
Don't know/Don't answer	0%
Marketplace	38%

Table 9: Percentage of activity regarding Market topics

Table 9 reveals that there are several topics under investigation regarding market. The most popular one is Market structure that occupies all of the active researchers in the field, while Impact of RES integration on electricity prices is ranked at the second place. Four different topics gather the interest of 56% of the active research laboratories, which namely are: Analysis of technology market barriers in the Smart Grids, New Regulation Schemes for deregulated actors, novel trading schemes and Transmission and Distribution intelligence. 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 18% of the active laboratories. The topics of Trading Systems and Marketplace reach both a percentage of 38% among the laboratories interested in this area. Finally, the topic of Structure of Generation attracts the 29% of the questioned laboratories.

IEC 60870 – Telecontrol equipment and systems	9%
IEC 61968 – Common Information Model / Distribution Management	18%
IEC 61970 – Common Information Model / Energy Management	38%
IEC 62352 – Common Information Model (CIM) for Energy Markets	9%
IEC 62351 – Power systems management and associated information exchange	9%
Other	9%
Don't know/No answer	56%

Table 10: Standards used for Market activities

The 38% of the participants performing research work on the field of Market use the standard IEC 61970 - Common Information Model / Energy Management. At a lower extent the standard IEC 61968 - Common Information Model / Distribution Management is used, with the standards IEC 60870 - Telecontrol equipment and systems, IEC 62325 - Common Information Model (CIM) for Energy Markets and IEC 62351 - Power systems management and associated information exchange completing the picture. More analytically, the standards used are listed in Table 10.

For what concerns planned investments in the short period (next five years), Figure 46 shows that more than 40% of the Market involved labs intend to increase their investments while more than 30% of the labs intend to keep their investments at the same level. It is also worth noting that more than 20% has no idea with respect to it.

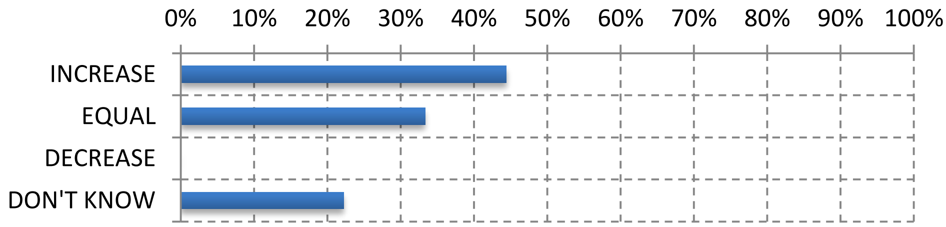

Figure 46: Expected R&D infrastructure investment plans in Market activities within the next five years

3.3.6 Generation and DER

Generation and Distributed Energy Resources (DER) activities are mainly targeted to the academy sector, since 74% of the questioned laboratories are involved in academic work tasks whereas utilities and industry are the sectors that come next with a percentage of 76% and 53% respectively, as revealed in Figure 47. According to Figure 48, the objectives of such activities are primarily prototype testing, technology development and R&D software and equipment. It is also noteworthy that all of these fields of activities are the topic for more than 50% of the participant laboratories. The means of results dissemination are conference and journal papers with a percentage of 74% and 53% of the active laboratories using these solutions, whereas books attract the 24% of them, as it can be observed in Figure 49.

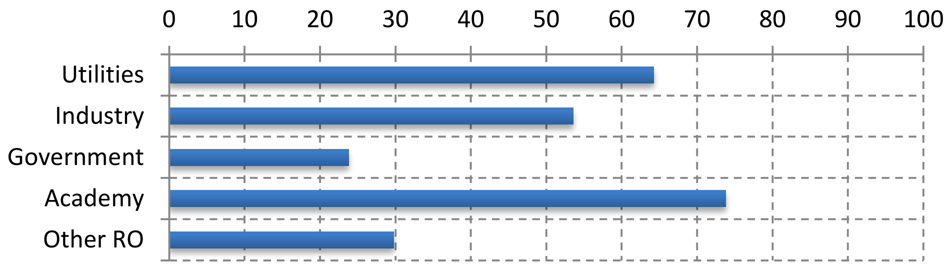

Figure 47: Sectors at which Generation & DER research is targeted

Regarding the nature of the activities in the Generation & DER field (see Figure 50), there is small deviation between stand-alone activities and collaborations with other organizations (sporadic or permanent), meaning that all types of collaborations are followed in order to obtain high-class results in the Generation & DER category. Figure 51 shows that the vast majority of the activities are led in Europe, with more than 90% of the actively involved labs performing research in Europe. North America attracts the interest of 30% of these labs, whereas there are a small percentage of them working worldwide.

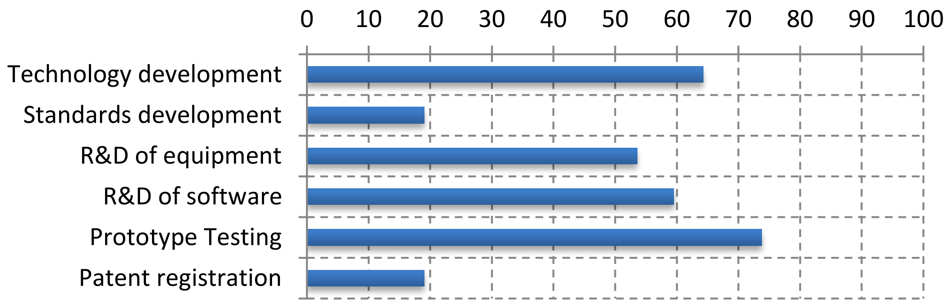

Figure 48: Fields of activities for Generation and DER

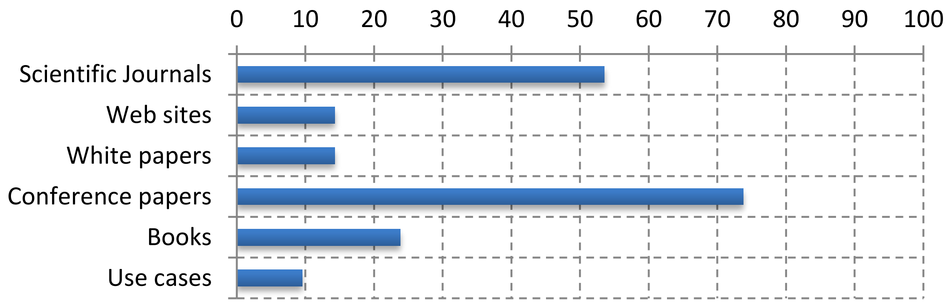

Figure 49: Results dissemination for Generation & DER

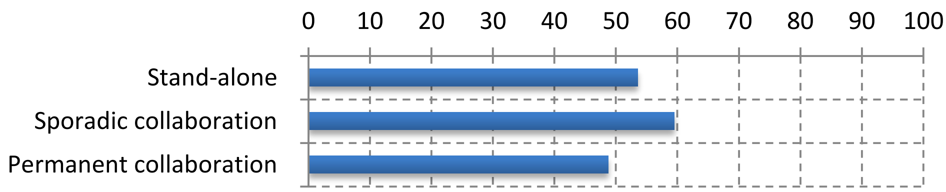

Figure 50: Nature of the Generation & DER activities

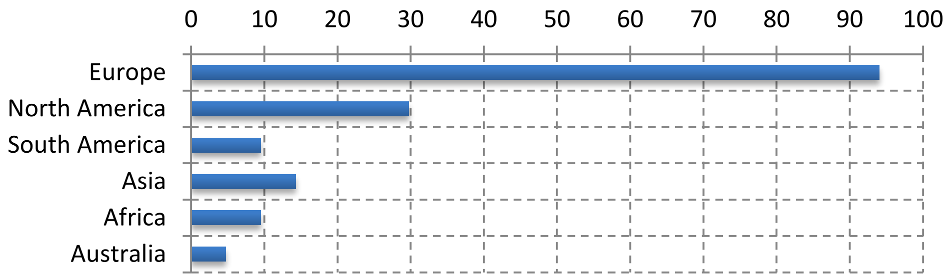

Figure 51: Geographical area on which Generation & DER activities are focused

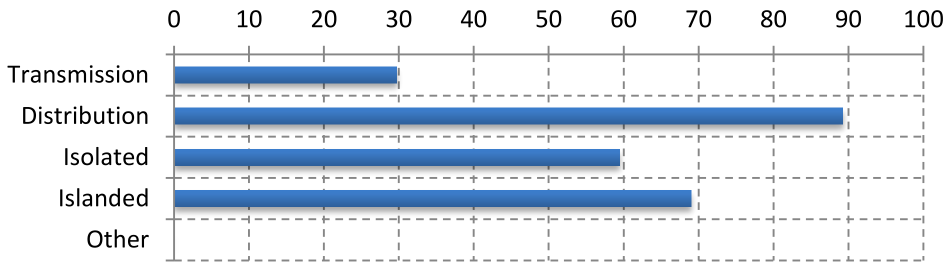

Figure 52: Networks on which Generation & DER activities are focused

As shown in Figure 52, 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 (69%) and isolated (59%) networks. The transmission network comes lower in the list, likewise the other smart grid categories.

Table 11 reveals that, with respect to technologies used to produce energy, the most common are wind-farms and photovoltaic panels. It is worth also to stress the role played by Combined Heat and Power (CHP) units together with Biomass and Hydro production. With 34% and 30%, respectively, more relevance has been also acquired by the Fuel cells and the Solar concentrators in the production of clean energy.

Wind Energy	• 89%
PV	• 89%
Concentrator Solar Power	• 30%
Tidal	• 6%
Waves	• 15%
Biomass	• 39%
Hydro	• 39%
Fuel Cell	• 34%
Gas Power Plants	• 25%
Nuclear Power Plants	• 9%
CHP	• 45%
Coal Power Plants	• 15%

Table 11: Percentage of work on the different Generation and DER technologies

The research activities mainly focus on RES integration and advanced control but also on forecasting analysis and processing.

EN 50438 - Requirements for the connection of micro-generators in parallel with public LV distribution networks	30%
IEC 60904 - Photovoltaic devices	20%
IEC 61194 - Characteristic parameters of stand-alone photovoltaic (PV) systems	20%
IEC 61400 – Wind Turbines	20%
IEC 61499 - International Standard for Distributed Systems	15%
IEC 61724 - Photovoltaic system performance monitoring	24%
IEC 61727 - Photovoltaic (PV) systems. Utility interface	9%
IEC 61730 - Photovoltaic (PV) module safety qualification	15%
IEC 61850 - Communication networks and systems in substations	55%
IEC 61869 - Instrument transformers	5%
IEC 61968 - Application integration at electric utilities - System interfaces for distribution management	15%
IEC 61970 - Common Information Model / Energy Management	24%
IEC 62351 - Power systems management and associated information exchange	15%
IEC/TS 61836 Solar photovoltaic energy systems - Terms definition and symbols	5%
IEC/TS 62257 Recommendations for small renewable energy and hybrid systems for rural electrification	5%
Other	20%
Don't know/No answer	30%

Table 12: Percentage of Standards usage in the Generation and DER activities

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). But it's worth mentioning also the EN 50438 (Requirements for the connection of micro-generators in parallel with public LV distribution networks) and the IEC 61724 (Photovoltaic system performance monitoring) given the high usage of photovoltaic modules for energy production. For more details please refer to Table 12.

For what concerns planned investments within the next five years, the majority of the Generation and DER labs intend to increase their investments in the near future. Even though, more than one forth plans to keep them equal (see Figure 53).

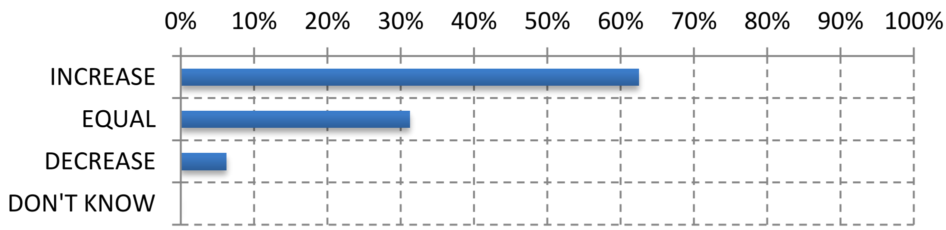

Figure 53: Expected R&D infrastructure investment plans in Generation and DER activities. Short, medium and long term investment plans is labelled as short, medium and long respectively.

3.3.7 Electromobility

For electromobility issues, utilities, industry, government and the academia are all high in the list as percentages of the targeted sectors of the active laboratories, whereas the 29% of these laboratories work for other research organizations, as shown in Figure 54. According to Figure 55, 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 29% 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 56.

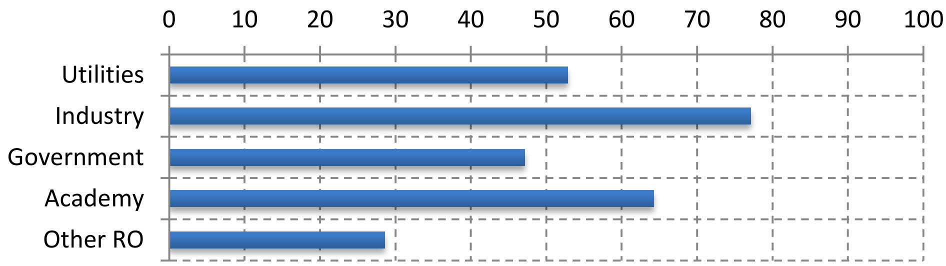

Figure 54: Sectors at which Electromobility research is targeted

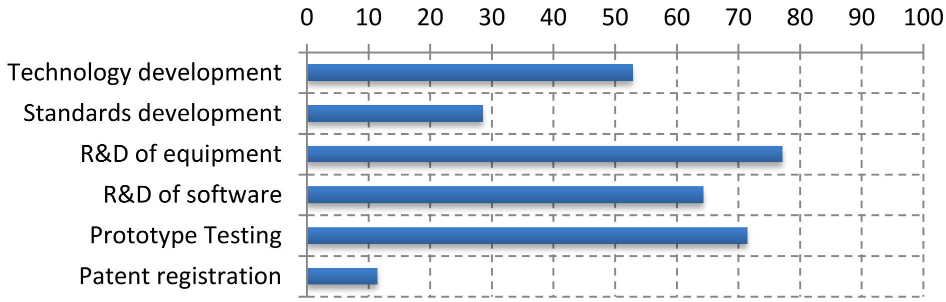

Figure 55: Fields of activity for the Electromobility category

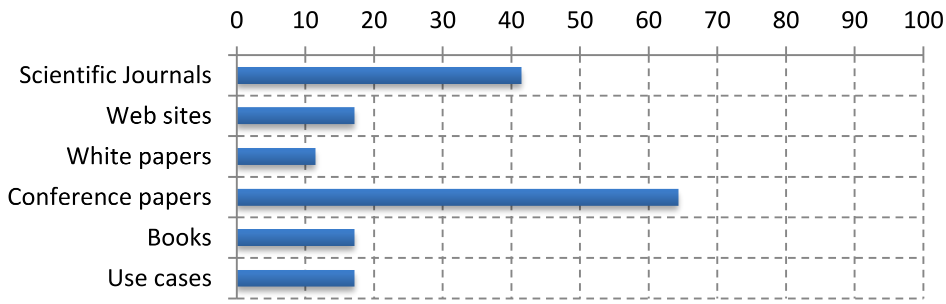

Figure 56: Results dissemination for Electromobility

From Figure 57 it can be concluded that for Electromobility, the majority of the activities are sporadic collaborations for specific projects (64%), with permanent collaborations (47%) and stand-alone activities (41%) to follow. As it is anticipated, the vast majority of the activities are focused in Europe, whereas the other continents gather the interest of a small percentage of the participating labs (see Figure 58). Finally, likewise the other smart grid categories, the distribution grid is the part of the network that attracts mostly the scientific interest, as depicted in Figure 59.

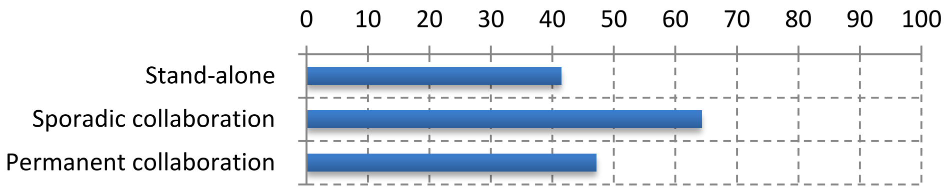

Figure 57: Nature of Electromobility activities

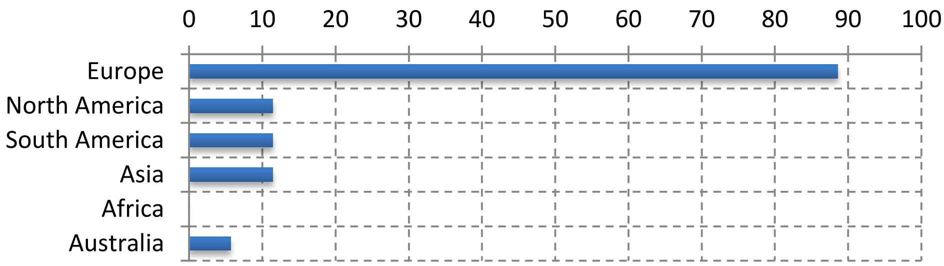

Figure 58: Geographical area of interest for Electromobility

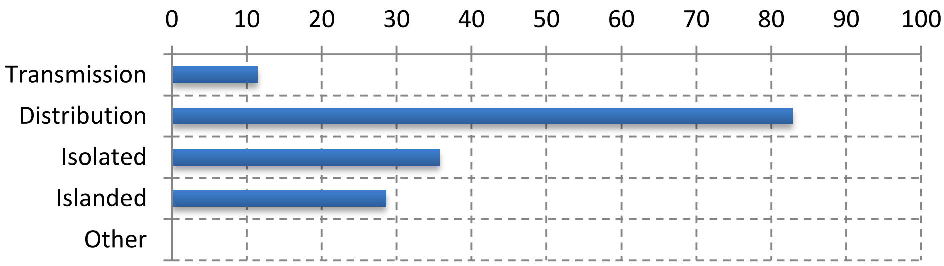

Figure 59: Networks on which Electromobility is focused

Energy Efficiency	47%
Power Quality	41%
Energy management and vehicle autonomy	41%
Vehicle-to-grid (V2G)	83%
Interoperability	41%
Grid load impact	77%
Charging technologies	60%
Car battery technologies	36%
Energy storage	77%
Demand response	60%
Environmental impact	36%
Citizen behavior	30%
Other	6%
Safety	11%
Security	6%

Table 13: Areas of work regarding Electromobility

There are several areas in which research work is conducted regarding Electric Vehicles and Plug-In Electric Vehicles, like Vehicle-to-grid (V2G), Interoperability, Energy management and vehicle autonomy, car battery technologies, energy storage, grid load impact or even environmental impact. Energy storage, Vehicle-to-grid and grid load impact seem to be among the top fields for investigation, since the 77%, 83% and 77% of the EV laboratories conduct research on the subject.

Demand response and charging technologies are also popular subjects with a percentage of 60% each among the active research laboratories on the field. Interoperability, Energy efficiency, Power quality and Energy management and vehicle autonomy occupy 41% of the EV/PHEV research organizations. In addition, more than one third of them conduct research on car battery technologies and Environmental impact, while Citizen behaviour is the subject for 30% of the active laboratories. The aforementioned information is summarized in Table 13.

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 two thirds of the laboratories conducting EV/PHEV research (66%) 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 (60%) conducts research on the IEC 61851 Mode 2 (AC low charging from a regular socket equipped with specific EVs protection mechanism). On the other hand, the IEC 61851 Mode 1 (AC slow charging from a regular electrical socket) is preferred by the 33% of the active research labs on the field and the IEC 61851 Mode 4 by the 41%. In addition to IEC 61851, the SAE AC or DC mode is also used but at a lower extent. Table 14 presents analytically this situation.

IEC 61851 Mode 1 – AC slow charging from a regular electrical socket	47%
IEC 61851 Mode 2 – AC low charging from a regular socket equipped with specific EVs protection mechanism	60%
IEC 61851 Mode 3 – AC slow or fast charging using a specific EVs multi-pin socket with control and protection functions	66%
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	11%
SAE DC level 2	11%
Other	11%
Don't know/ No answer	24%

Table 14: Current utilization percentage of the different charging topologies for EV and PHEV

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 SCHUKO and CHAdeMOare technological solutions adopted by approximately one third of the active laboratories in the field. Table 15 presents the available options and the percentage of research groups that performs research with them.

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 71% of the research groups. As for the voltage level, in 66% of the cases the value of 230 V is used. With respect to the power line frequency used for the activities, the 83% of the EV research groups use 50 Hz for their experiments. Table 16 shows the values for current capacity, voltage level and frequency that are used by the EV research laboratories.

IEC 62196-1 - Conductive charging of electric vehicles: General requirements	30%
IEC 62196-2 "Type 1" - single phase vehicle coupler	36%
IEC 62196-2 "Type 2" - single and three phase vehicle coupler	41%
IEC 62196-2 "Type 3" - single and three phase vehicle coupler with shutters	30%
IEC 62196-3 - Dimensional compatibility and interchangeability requirements for DC and AC/DC. pin and contact-tube	19%
SAE J1772 - EVs and PHEV Conductive Charge Coupler	24%
Mennekes (VDE-AR-E 2623-2-2)	36%
EVs Plug Alliance	6%
SCHUKO	30%
CHAdeMO	30%
Combined charging system (DC)	19%
Yazaki	19%
Framatome	0%
SCAME	6%
CEEplus	0%
Other	0%
Don’t know/No answer	41%

Table 15: Percentage of utilization of the different standards for charging connectors

Current		Voltage		Frequency	
13 A	36%	220 V	24%	50 Hz	83%
15 A	41%	230 V	66%	60 Hz	19%
16A	71%	240 V	19%	Other	0%
30 A	36%	400 V	36%	Don’t know/NA	6%
32 A	41%	415 V	19%		
63 A	36%	Other	0%		
80 A	36%	Don't know/NA	11%		
Other	6%				
Don't know/NA	11%				

Table 16: Percentage of power capacities for charging purposes

Communication/protocols	66%
Management (configuration, deployment)	66%
Control (alarms, events)	50%
Demand response	66%
Pricing	42%
User account and billing	27%
Charging infrastructure (location of charging points, availability of charging points, charging status)	66%
Car monitoring	66%

Table 17: Different type of software applications for electromobility

It is also worth noticing that 71% of the research groups conduct work regarding the development of software applications in the area of electromobility. Almost half of them (66%) perform research on the areas of Communication/protocols, Management (configuration, deployment), Demand response, Charging infrastructure (location of charging points, availability of charging points, charging status) and Car monitoring. Control (alarms, events), Pricing and User account and billing are areas found lower in the list. Table 17 depicts the aforementioned situation.

The communication standard that is used mostly by electromobility research groups is the IEC 61851 and at a lower extent the IEC 15118 and the IEC 61850. 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 18.

IEC 61850 - Communication networks and systems in substations	36%
IEC 61851 - Electric vehicle conductive charging system	47%
IEC 62351 - Power systems management and associated information exchange	6%
IEEE 80211P - Wireless access in vehicular environment	6%
ISO/ IEC 15118 - Vehicle to grid communication interface	41%
SAE J2847 - Communication between Plug-in Vehicles and the Utility Grid	11%
SAE J2931 - Digital Communication for Plug-in Electric Vehicles	11%
OICP – Open Interchange Protocol (Hubject)	6%
Other	11%
Don't know/No answer	24%

Table 18: Communication protocols applied for electromobility activities

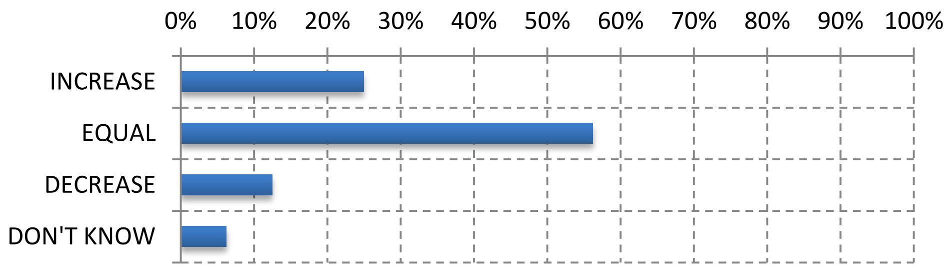

Figure 60: Expected R&D infrastructure investment plans in electromobility activities within the next five years

For what concerns planned investments for the short period (next five years), Figure 60 displays the obtained answers. As for sustainability category a different trend is observed in this case. The majority of labs plan to keep constant their investments in electromobility and only one forth plans to increase them in the near future.

3.3.8 Smart Home/Building

Industry and academy are the sectors to which the majority of Smart home/building activities are addressed. Governmental organizations and utilities follow next. R&D of software is ranked first as the objective of such activities (88%), whereas technology development (77%) and R&D of equipment (72%) come next, with prototype testing (67%) to follow with a small difference. Figure 61 and Figure 62 depict this situation respectively.

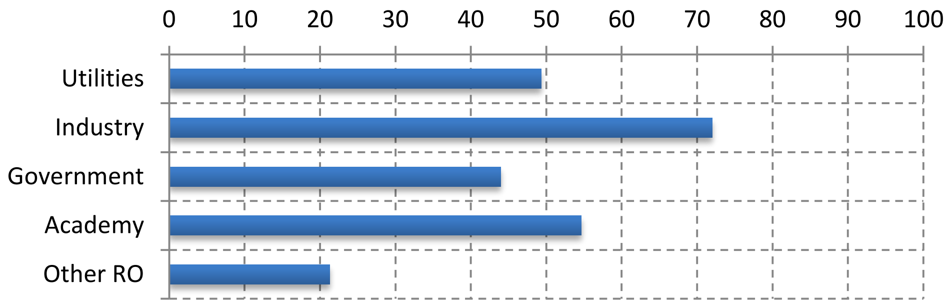

Figure 61: Sectors at which Smart Home/Building activities are targeted

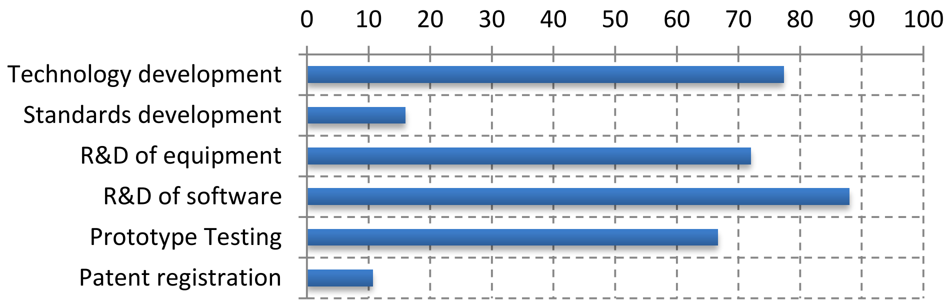

Figure 62: Fields of activities for Smart Home/Building activities

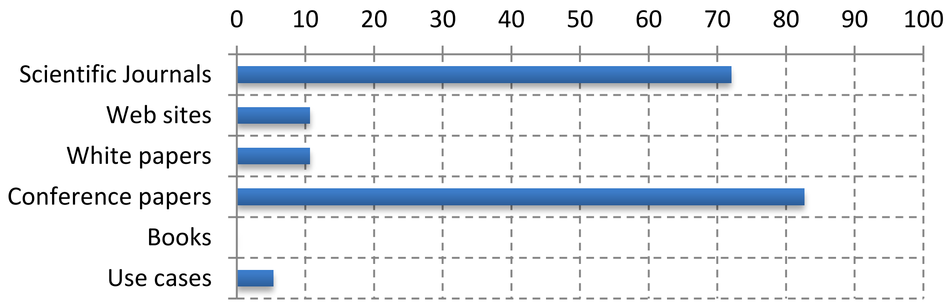

Figure 63: Ways of results dissemination for Smart Home/Building smart grid category

Similarly to the other smart grid categories, conference papers and scientific journals are the most popular ways of results presentation. Most active laboratories are involved in stand-alone activities (72%), whereas sporadic and permanent collaborations also occupy a non-negligible percentage of the active laboratories (49% each). Figure 63 and Figure 64 show the sectors and the fields of Smart Home/Building research. 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 America, which is clearly noticed by Figure 65. Finally, as Figure 66 illustrates, the distribution network attracts mostly the scientific interest with 83% of the active laboratories involved, whereas isolated and islanded networks follow with a percentage of 60% and 44% respectively.

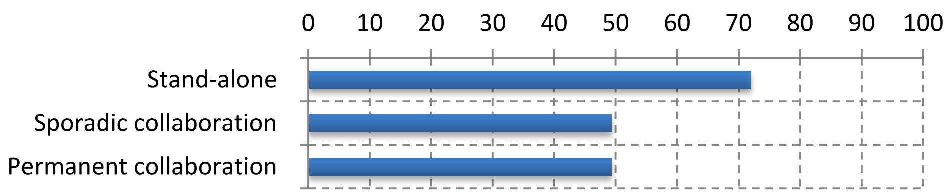

Figure 64: Activities nature for Smart Home/Building smart grid category

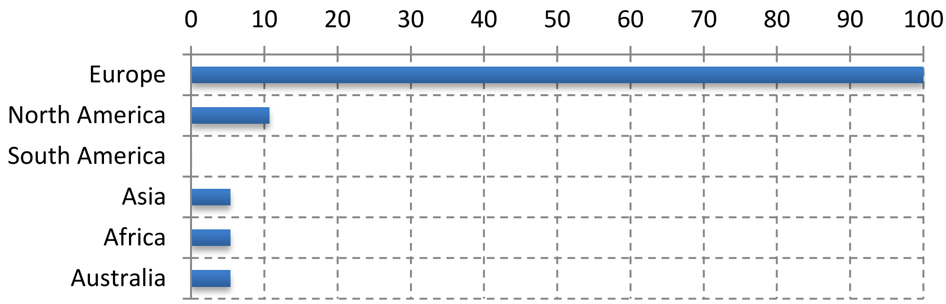

Figure 65: Geographical area of interest for Smart Home/Building activities

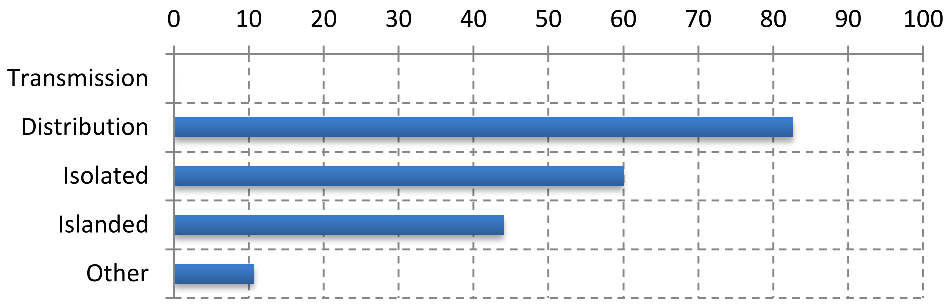

Figure 66: Networks on which Smart Home/Building activities are focused

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 and Integration of RES are ranked first with a percentage of 84% among the researchers in the field each. Demand response and Temperature control come next with percentages of 77% and 72% respectively. Smart Appliances is another popular topic attracting the interest of the 61% of the researchers. Power quality and Lighting comprise the 39% and 28% of the smart home/building activities. Other subjects that are under investigation are the Movement sensors, Safety issues and User account and billing, as revealed in the survey. The above results are presented in Table 19.

Temperature Control	72%
Lighting	28%
Movement Sensors	23%
Power Quality	39%
Audio-Visual	0%
Smart Appliances	61%
Security	11%
Safety	23%
User Account and Billing	17%
Demand Response	77%
Energy Management Strategies / Cost-control	84%
Other	0%
Interoperability	56%
Don’t know/Don’t answer	0%
Integration of RES	84%

Table 19: Activities regarding Smart Home research

It is noticeable that two thirds 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 Demand Response and Management issues (configuration, deployment) being ranked first with the percentages of 66% and 93% respectively with respect to the total number of laboratories working on the subject. Communications / protocols and Control issues (alarms, events) are also popular topics, whereas Cyber Security, Pricing and User Account and billing are lower in the list, for the time being. In Table 20, the different areas are presented along with the equivalent percentage of the laboratories among the active ones in the field.

Communication/protocols	59%
Management (configuration, deployment, etc)	93%
Control (alarms, events, etc)	51%
Cyber Security	8%
Demand Response	67%
Other	0%
User Account and Billing	8%
Don't know/No answer	0%
Pricing	16%

Table 20: Software development for Smart Home applications

Regarding the telecommunication technologies used in the lab, Ethernet cabling is the one most widely used, since 84% of the active researchers in the field employ this solution. Wireless and PLC (Power Line communications) are also good options for telecommunication purposes, and they are preferred by the 77% and 72% of the laboratories. Analytically, the above picture is presented in Table 21.

Wireless (including any technologies)	77%
PLC	72%
Ethernet Copper Cabling	84%
Other	23%
Fiber	28%
Don't know/ No answer	5%

Table 21: Telecommunication technologies used in the laboratories for the Smart Home activities

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 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), IEC 62351 - Power systems management and associated information exchange and the EN 13321 - Open data communication in building automation, controls and building management.

For what concerns planned investments for the next five years, Figure 67 shows the obtained answers. From the figure it can concluded that the majority of the labs intend to increase their investments in the future period, whereas there are no plans for investments decrease in the future.

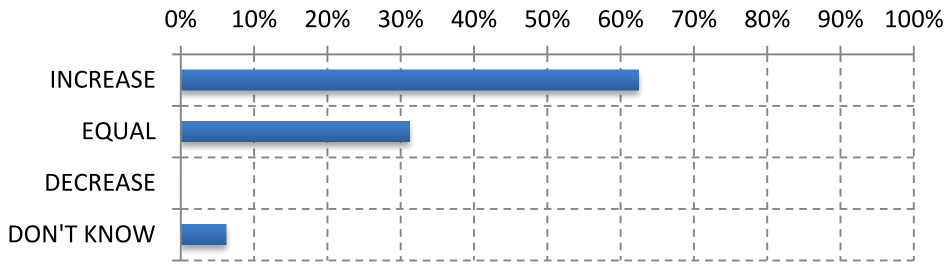

Figure 67: Expected R&D infrastructure investment plans in Smart Home activities. Short, medium and long term investment plans is labelled as short, medium and long respectively.

3.3.9 Smart Cities

Research activities in this category are mainly supported by local governments and industry, although a non-negligible role is also played by 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 68 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 and software). R&D of equipment and software are activities that also attract more than the 50% of the labs actively involved in Smart City research. Analytical information is presented in Figure 69.

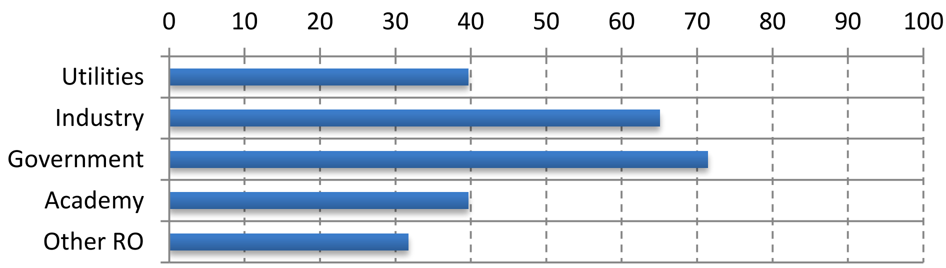

Figure 68: Sectors at which Smart City research is focused

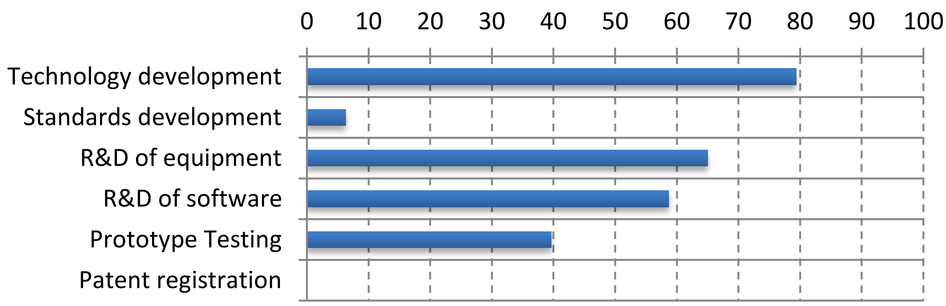

Figure 69: Fields of activities for Smart City research

The dissemination of these activities and their related results is done mainly through conferences and scientific journals, as shown in detail in Figure 70, with white papers and web sited found lower in the list. The activities are carried out through participation in sporadic (supported) projects and at a minor extent by stand alone and fix collaborations, which is shown in Figure 71. Regarding the geographical area on which research is focused, Figure 72 illustrates that more than 90% 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 isolated and islanded networks, as depicted in Figure 73.

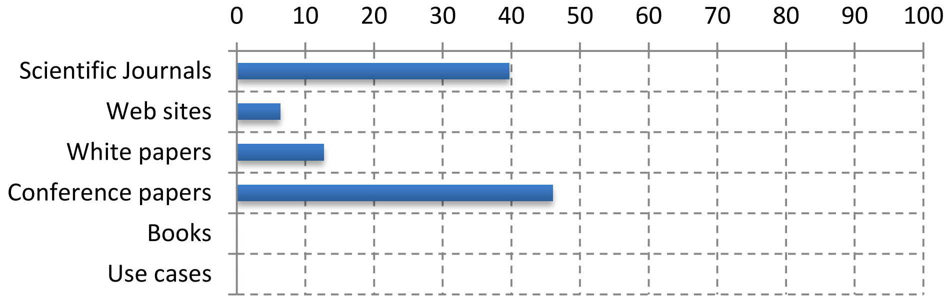

Figure 70: Results dissemination in Smart City related activities

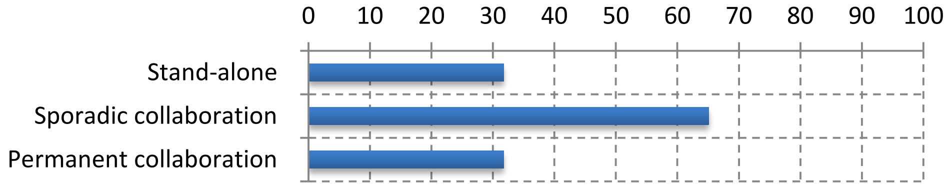

Figure 71: Nature of activities in Smart City research

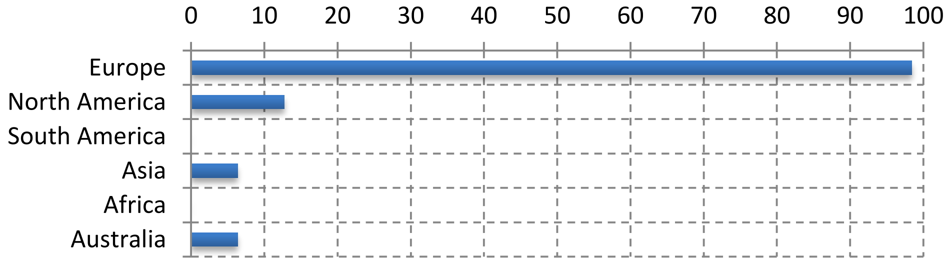

Figure 72: Geographical area on which Smart City research is focused

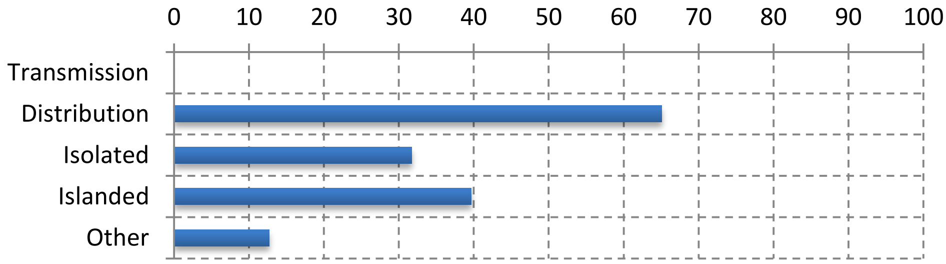

Figure 73: Networks on which Smart City research is carried out

The majority of the researchers in the Smart City field focus on the Information and Communication Technologies with a percentage of 67% among the active laboratories. Lighting is another popular topic attracting the 52% of the active researchers, while the respecting percentage for Energy Generation is 60%. Mobility (transport, traffic and parking) is also ranked high in the list (46%). It is worth noticing that environmental issues are occupying a relatively high percentage of the active laboratories (33%), while at the same position is found the topic of Energy Storage. Governmental issues (administration, buildings, etc.) are the least popular among Smart City researchers (21%).

It is also worth noting that only the 46% of the active laboratories conducts research work regarding the development of software applications in the area of Smart City. Among them, a 72% performs research on communication/protocols, whereas another 33% researches on control issues (alarms, events, etc). Finally, a 57% performs investigation on Management related topics like configuration and deployment.

The planned investments for the next five years are depicted in Figure 74. Similarly to the Smart Home category, the major part of the labs plan to increase their investments in the near future. It is also important to notice that there are no current plans for investments decrease.

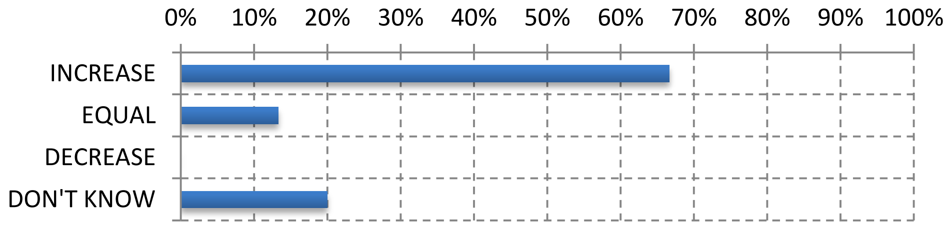

Figure 74: Expected R&D infrastructure investment plans in Smart City activities within the next five years

3.3.10 Demand Response (DR)

The results obtained from our survey show that the industry sector, utilities, and academy are very interested in Demand Response programs and their consequences on the network infrastructure and in new business opportunity. But also local governments are supporting research along this path, as shown in Figure 75. For Demand Response issues focus is primarily given on Technology development, Prototype testing and R&D (equipment and software), as noticed also in the other smart grid categories. Details are given in Figure 76.

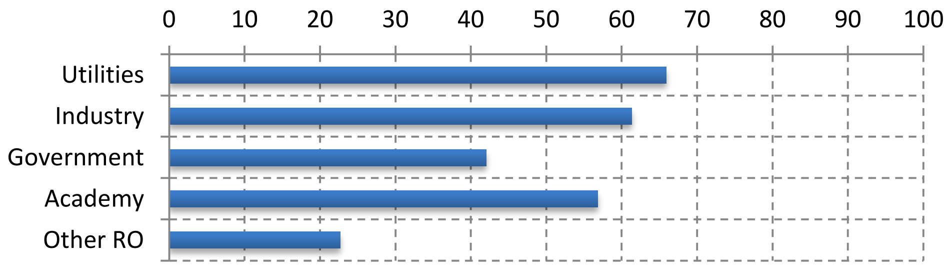

Figure 75: Sectors at which research on Demand Response is targeted

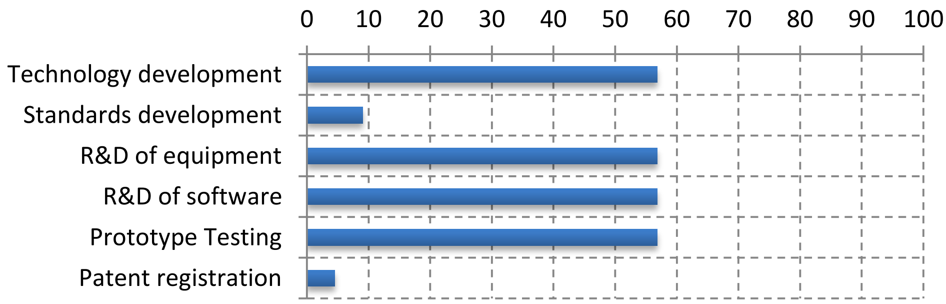

Figure 76: Fields of activity for Demand Response issues

The dissemination of these activities and their related results is done mainly through conferences and scientific journals, whereas the other options gather a small percentage of the survey participants, as depicted in Figure 77. In comparison with other categories, collaboration with other institutions or research centers is more common for Demand Response, as shown in Figure 78. On the other hand, stand-alone activities gather a percentage of approximately 30% of the actively involved labs on the sector.

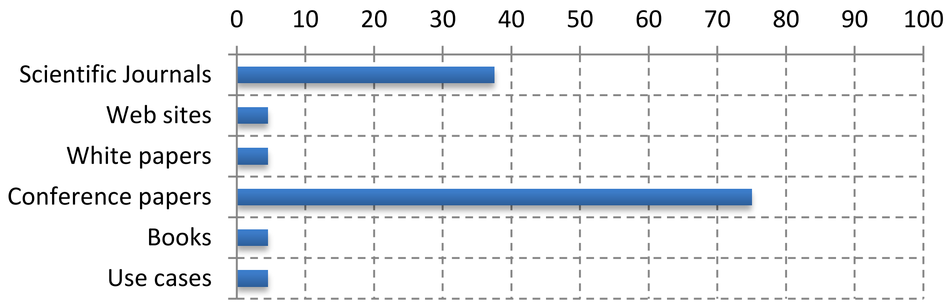

Figure 77: Results dissemination for Demand Response research

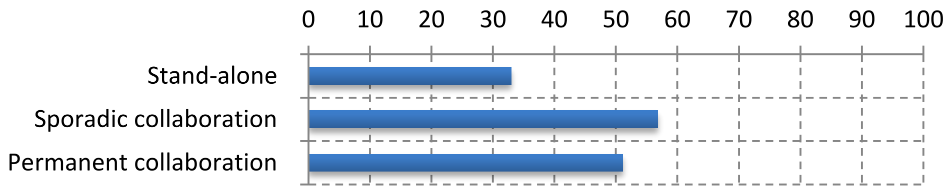

Figure 78: Nature of Demand Response activities

Figure 79 depicts the geographical areas where research regarding Demand Response is carried out. More than 85% of research is carried out in Europe, whereas a small percentage of the activities are focused in North America. IT is noteworthy that none of the participants conducts research on any other geographical area. Finally, Figure 80 shows that even though the majority of the labs carry out DR research on the distribution grid, a considerable interest is also devoted to isolated and islanded networks.

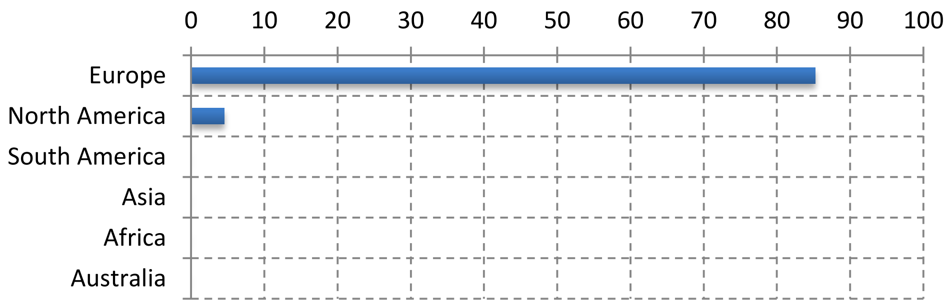

Figure 79: Geographical area of interest for Demand Response activities

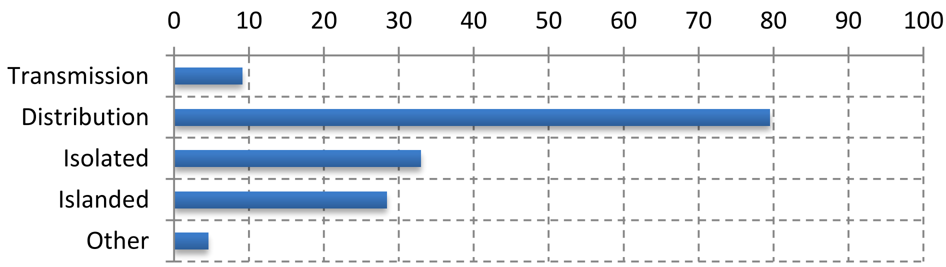

Figure 80: Networks on which Demand Response research is focused

The areas in which research is conducted for demand response and the relative percentages are reported in Table 22. Notice that a considerable percentage of DR research involves DER integration.

Generation	33%
AMI	19%
EVs	61%
Smart Home/ Smart Building	66%
Grid load	43%
Storage	52%
Demand modelling	52%
DRMS – Demand response management systems	48%
CEMS – customer energy management systems	33%
Automated demand response	48%
DER integration	81%
Other	0%
Pricing	19%
Don't know/No answer	9%

Table 22: Areas of work regarding Demand Response

Concerning standards usage, the one mostly known and also used from the involved participants is the Open Automated Demand Response (OpenADR).

For what concerns planned investments for the short, medium and long period, Figure 81 reveals the obtained answers. From the figure it can be seen that 60% of the labs intend to increase their investments in a short term perspective. More than 30% of the labs intend to keep their investments at the same level in the near future. None of the survey participants has made plans for investments decrease so far.

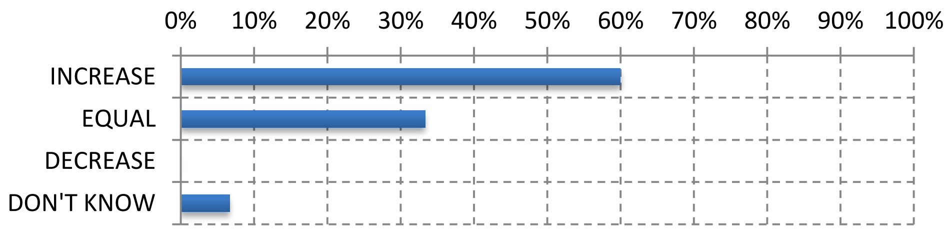

Figure 81: Expected R&D infrastructure investment plans in Demand Respond activities within the next five years

3.3.11 ICT: Communication

Activities in this area are almost equally distributed between industry sector, utilities, and academy. Although the focus of the ICT involved laboratories is mainly on technology development, Prototyping, R&D (equipment and software) an important part is interested in development of standards. It has to be stressed also that several laboratories are interested in patenting their results. Figure 82 and Figure 83 depict these issues respectively.

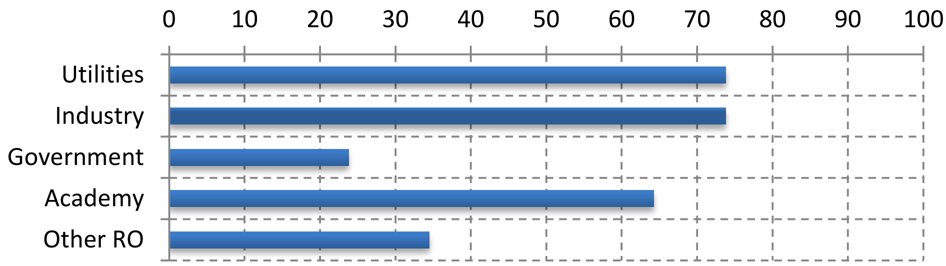

Figure 82: Sectors at which ICT research is focused

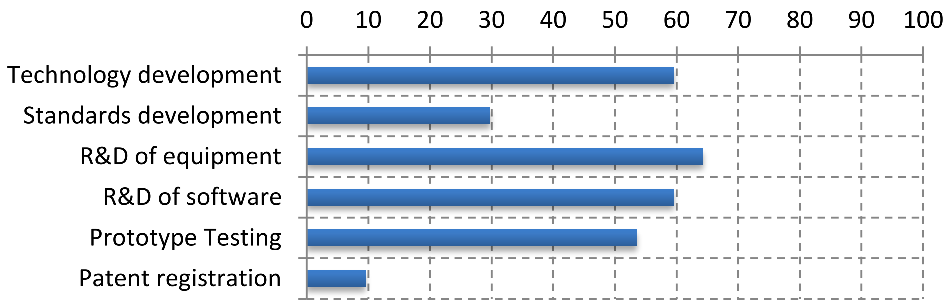

Figure 83: Fields of activities for the ICT communication smart grid category

The dissemination of these activities and their related results is often done through scientific journals and conferences, as it can be anticipated judging from the picture given by the other smart grid categories (see Figure 84). The activities vary from stand alone to collaborative ones, either sporadic or permanent with other organizations, with a maximum variation noticed nearly around 20%, as it can be observed by Figure 85.

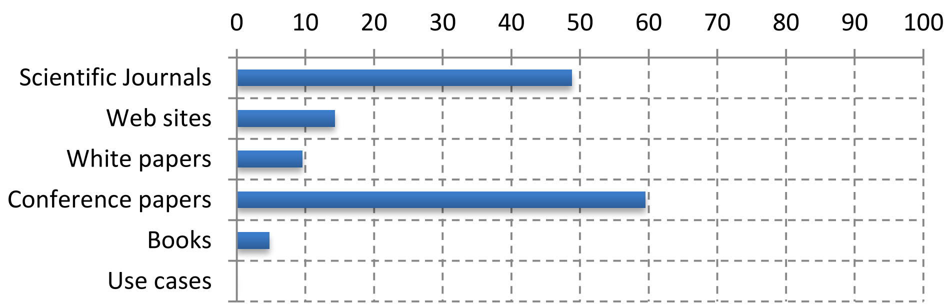

Figure 84: Results dissemination for the ICT category

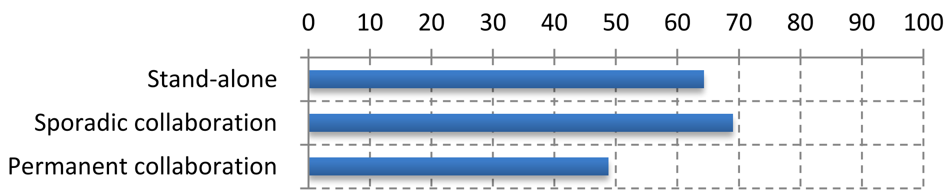

Figure 85: Nature of activities for the ICT category

Figure 86 shows that more than 85% of research in the ICT category is carried out in Europe. North America, Asia and lastly Africa gather a small percentage of the ICT research activities. Although the majority of the labs conduct research on the distribution grid, an important role is played also by the transmission grid and by isolated and islanded networks, as illustrated in Figure 87.

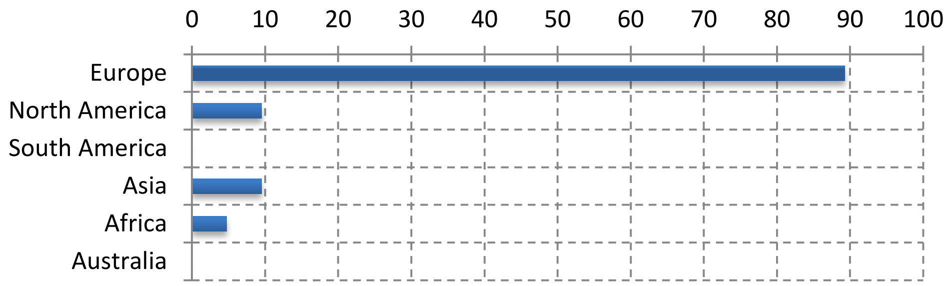

Figure 86: Geographical areas on which ICT related research is carried out

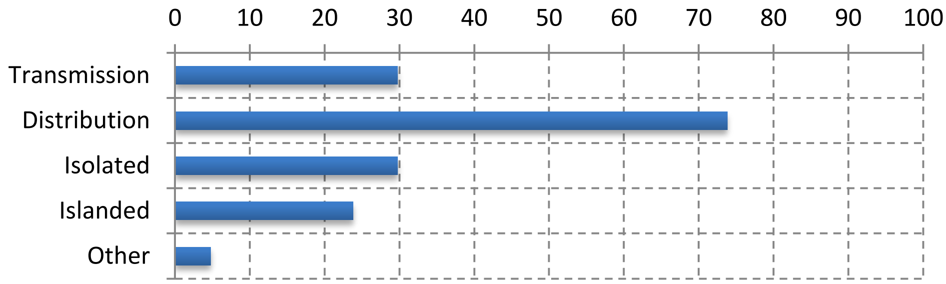

Figure 87: Networks on which ICT research is carried out

The networks on which research is focused can vary from the WAN (Wide Area Network) to the HAN (Home Area Network). 45% of the active laboratories in the field conduct research on the WAN, the FAN (Field Area Network) and the LAN (Local Area Network). The NAN (Neighborhood Area Network) and HAN comprise the research object for the 25% and 35% of the ICT smart grid laboratories, while the PAN (Personal Area Network) completes the picture with the 15% of the research activities. More specifically, the above information is summarized in Table 23.

WAN – Wide Area Network	45%
FAN – Field Area Network	45%
LAN – Local Area Network	45%
NAN – Neighbourhood Area Network	25%
PAN – Personal Area Network	15%
HAN – Home Area Network	35%
Other	0%
Don’t know/No answer	20%

Table 23: Telecommunication networks research in ICT activities

IPv4 – IP version 4	39%
IPv466 – IP version 6	35%
MPLS – Multiprotocol Label Switching	20%
IEC 61850 – Communication networks and systems in substations	64%
SDH - Synchronous Digital Hierarchy	10%
SONET - Synchronous Optical Network	10%
DSL – Digital Subscriber Line (including ADSL, VDSL, HDSL, SHDSL…)	15%
OSGP – Open Smart Grid Protocol	5%
IPS for Smart Grids (IETF RFC 6272)	5%
Other	10%
Don’t know/No answer	20%

Table 24: Communication protocols used by the laboratories

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 64% in terms of utilization among the active labs. IPv4 and IPv6 are the solutions that come next with equivalent percentages of 39% and 35% respectively. Other solutions can be the MPLS – Multiprotocol Label Switching or the DSL – Digital Subscriber Line, which are used at a lower extent compared to the IP options. This situation is depicted in Table 24.

1 Wireless Technological solutions

It is noteworthy that a relatively small percentage of the ICT smart grid laboratories (35%) conduct research with wireless technologies. 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, 3G, GSM. GPRS follows with a marginal difference, together with the evolving LTE, Bluetooth, ZigBee and 6LoWPAN. The technological options to follow closely are WiMAX and 802.15.4G. Other wireless communication options are the low-rate and high-rate WPAN, the IrDA, the NFC and the DASH7. Table 25 shows these wireless technologies along with the percentages of the laboratories that use them among the active ones in the field.

2 PLC Technological Solutions

The major part of the PLC activities are carried out on the HAN and secondarily on the NAN, with a percentage of 55% and 47% respectively among the active laboratories on the field. The WAN, FAN and LAN follow with a respective percentage of 23%. Table 26 reveals the picture of the networks on which PLC solutions are applied. On the other hand, Table 27 displays that the 64% of the active ICT smart grid laboratories conducts research with the PLC technology.

GSM	74%
GPRS	59%
3G	74%
LTE	59%
Wi-Fi	91%
Wi-MAX	44%
BlueTooth	59%
NFC	15%
IrDA	15%
High-rate WPAN	29%
Low-Rate WPAN	29%
ZigBee	59%
DASH7	15%
6LoWPAN	59%
Other	15%
WirelessHart	0%
ISA 100.11A	0%
Don’t know/No answer	0%
802.15.4G	44%

Table 25: Research in the different Wireless Technologies

It is worth noting that Narrow Band PLC (NB-PLC) attracts more the scientific interest than Broadband PLC (BPL), since 70% 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%.

WAN – Wide Area Network	23%
FAN – Field Area Network	23%
LAN – Local Area Network	23%
NAN – Neighbourhood Area Network	47%
PAN – Personal Area Network	16%
HAN – Home Area Network	55%
Other	0%
Don't know/No answer	8%

Table 26: Network topologies used in Power Line Communications

BPL – Broadband over power lines	47%
NB-PLC – Narrow Band PLC	70%
UNB-PLC – Ultra narrow band PLC	16%
Other	8%
Don't know/No answer	16%

Table 27: Research in the different Power Line Communication Technologies

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, both for NB-PLC and for BPL, like the IEEE 1901.2, the ITU-T G.hnem and the IEEE 1901. Other popular technologies are the G3-PLC and the PRIME for the NB-PLC, and the HomePlug for the BPL. Table 28 shows the technologies/standards used among the ICT labs together with the percentages of the laboratories that utilize them for research purposes.

3 Monitoring and Control of the Communications Infrastructure

Our survey reveals that the 55% of the active laboratories performs research in the area of monitoring and control of the communications infrastructure. More than two thirds of these laboratories apply monitoring and control of the communications infrastructure on the WAN and LAN, 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 29.

IEC 61334 – Distribution automation using distribution line carrier systems	8%
IEEE 1901 – Broadband over power line networks	8%
IEEE 1901.2 - Low-Frequency (< 500 kHz) Narrowband PLC for Smart Grid Applications	23%
IEEE 1905 – Convergent Digital Home Network	0%
ITU-T G.hnem – Narrowband OFDM power line communications transceivers	16%
G3-PLC Alliance	31%
PRIME Alliance	47%
HomePlug	31%
HD-PLC Alliance	0%
Other	16%
Don't know / No answer	23%

Table 28: Combination of Standards and Technologies used in Power Line Communication research activities

WAN – Wide Area Network	66%
FAN – Field Area Network	45%
LAN – Local Area Network	66%
NAN – Neighbourhood Area Network	27%
PAN – Personal Area Network	27%
HAN – Home Area Network	45%
Other	0%
Don't know/No answer	9%

Table 29: Network Topologies for Monitoring and Control of communications Infrastructure

The most popular areas of research regarding monitoring and control activities are the wired, wireless and PLC fields, whereas cyber security is also a possible area of investigation (see the next section). Table 30 shows the situation, while the percentages represent the number of laboratories performing such research among the active ones in the specific field.

Wired	71%
Wireless	45%
PLC	55%
Other	0%
Cyber Security	36%
Don't know/No answer	9%

Table 30: Areas of research for Monitoring and Control of the Communications Infrastructure

For 91% of the research laboratories on Control and monitoring applications, System status monitoring is their main objective. Event management (ICT-related events) and Remote equipment configuration are the next objectives on the list with 45% each. Response automation and Resilience/protection management are other two goals for control and monitoring issues (see Table 31).

Remote equipment configuration	45%
System status monitoring	91%
Event management (ICT-related events)	45%
Other	18%
Resilience/protection management	27%
Don't know/No answer	0%
Response automation	36%

Table 31: Objectives for Monitoring and Control of the Communications Infrastructure

Off-the-shelf software	55%
Other	0%
Proprietary/custom-made software	82%
Don't know/No answer	0%
Vendor-specific software (Cisco, Siemens...)	64%

Table 32: Management/Monitoring tools for Monitoring and Control of the Communications Infrastructure

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 82% of the active laboratories in the field. Vendor-specific software and off-the-shelf software are alternative solutions that are used by the 64% and 55% of the active laboratories respectively. Table 32 shows this situation.

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. Monitoring, Communication and Management and control are the most popular functionalities for this purpose. In Table 33 the respective percentages of the active laboratories that construct specific purpose software are shown:

Communication	55%
Management & Control	82%
Monitoring	71%
Other	0%
Security	27%
Don’t know/No answer	9%

Table 33: Functionalities for software development for Monitoring and Control of the Communications Infrastructure

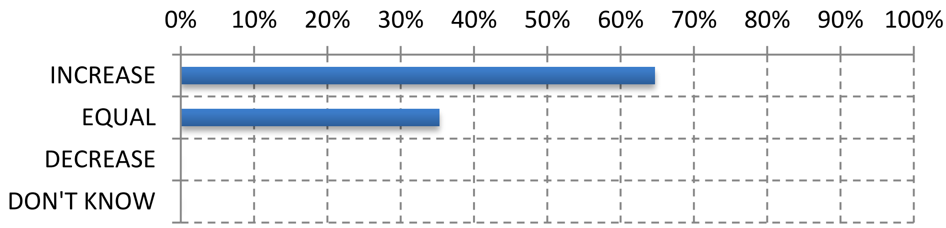

Figure 88: Expected R&D infrastructure investment plans in ICT activities within the next five years

For what concerns planned investments for the short, medium and long period, Figure 88 shows the obtained answers. Likewise the aforementioned categories, the situation is similar for the ICT planned investments. No plans for investment decrease exist for the time being. Regarding the next years in the near future, over 60% of the labs plan to increase investments, whereas the rest intend to keep them at similar levels.

3.3.12 Cyber Security

Although the activities carried out in this area are almost equally distributed between industry sector, utilities, and academy a more evident interest is shown by local governments on this issue (see Figure 89). Similarly to the other smart grid categories, the focus also in this case is on Technology development with Prototyping, R&D of equipment and software appearing lower in the list, as shown in Figure 90.

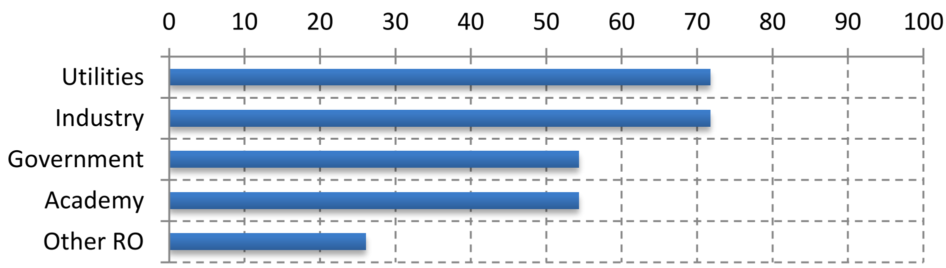

Figure 89: Sectors at which research in Cyber Security is focused

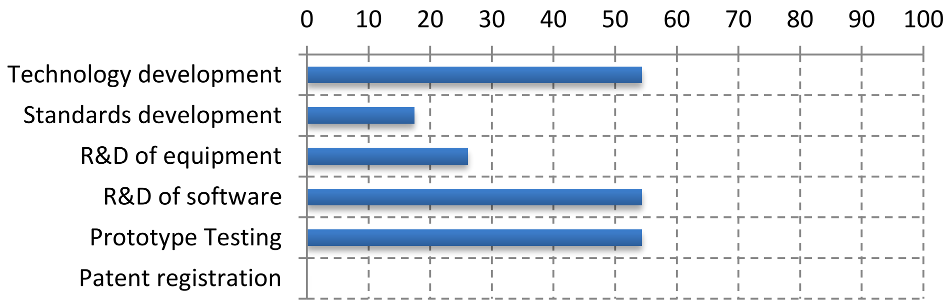

Figure 90: Fields of activities for Cyber Security

Being a really new field of interest few publications are being disseminated at the moment, mainly through conferences, as shown in Figure 91. The activities vary from stand alone to collaborative ones, either sporadic or permanent with other organizations. As it can be observed from Figure 92, the majority of Cyber Security activities are a result of sporadic collaborations, with stand-alone activities coming second in the list.

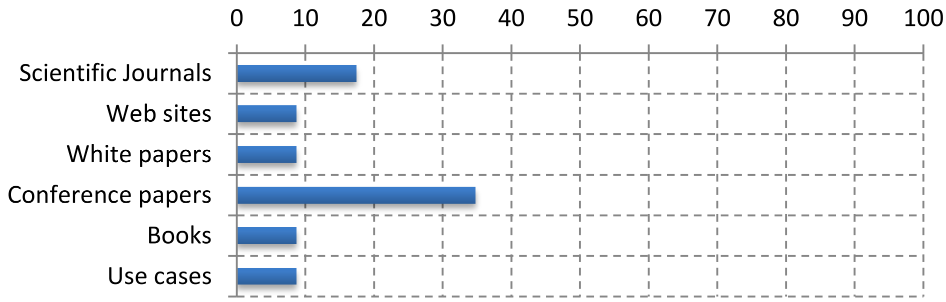

Figure 91: Results dissemination for Cyber Security

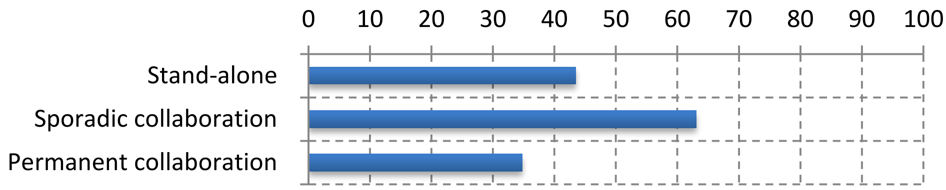

Figure 92: Nature of activities for Cyber Security

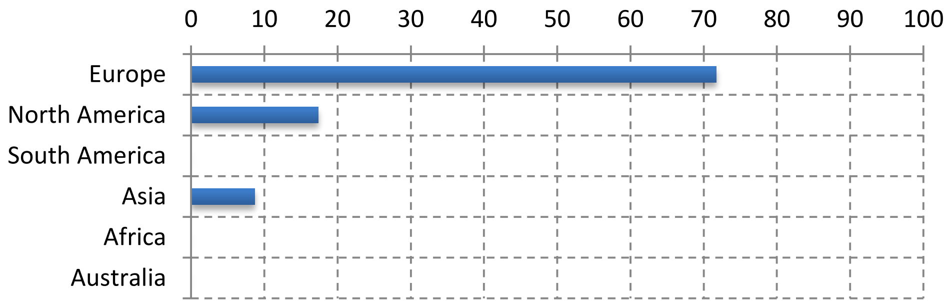

Figure 93: Geographical areas on which Cyber Security research is focused

The 72% of research on cyber security is carried out in Europe. More than 15% of the cyber Security activities focus in North America, whereas a smaller percentage is dedicated to Asia, as shown in Figure 93. The distribution network is the core asset, on which such a research is being devoted, gathering 80% of the research activities, as illustrated in Figure 94, whereas the transmission network is far behind with a percentage of around 25%.

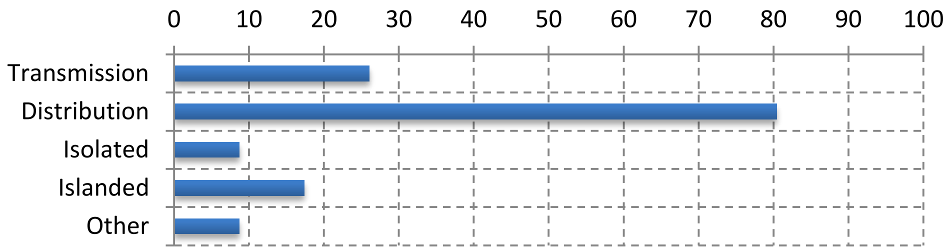

Figure 94: Networks on which Cyber Security is focused

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 63% of the cyber security researchers. Confidentiality topics, authorization and authentication are also important topics of investigation, with a percentage of 37% of the active researchers being occupied on them respectively. Incident response, Identity and Risk response are also topics of research, with a percentage of 28% among the active researchers. Finally, Risk assessment, Forensics and Contingency planning complete the picture of cyber security topics under investigation. Table 34 describes better the aforementioned situation.

Identity	28%
Confidentiality/Privacy	37%
Integrity	63%
Authorization	37%
Authentication	37%
Forensics	17%
Incident Response	28%
Risk Assessment	17%
Other	0%
Contingency Planning	9%
Risk Response	28%
Don’t know/No answer	37%

Table 34: Sub-topics in the Cyber Security field

IPSec – Internet Protocol Security	46%
EAP – Extensible Authentication Protocol	17%
PKI – Public Key Infrastructure	46%
RSA – Ron Rivest, Adi Shamir and Leonard Adleman (crypto system)	28%
AAA – authentication, Authorization and Accounting	17%
DES – Data Encryption Standard	17%
3DES – Triple DES	17%
AES – Advanced Encryption Standard	28%
SHA – Secure Hash System	28%
MD5 – Message Digest Algorithm 5	9%
SSH – Secure Shell	28%
RADIUS – Remote Authentication Dial-In User Service	17%
Oauth – Open secure authorization protocol	0%
Other	9%
Don’t know/No answer	54%

Table 35: Protocols used in the cyber security field

Regarding the protocols that are mostly used, there areno protocols/technologies that would attract more than two thirds of the active researchers. One of the top technologies used is the IPSec – Internet Protocol Security that occupies the 46% of the active researchers. PKI – Public Key Infrastructure is also widely used with the same percentage. The AES – Advanced Encryption Standard, the SHA – Secure Hash Algorithm, the SSH – Secure Shell and the RSA – Ron Rivest, Adi Shamir and Leonard Adleman (crypto system) are some of the technologies that can be utilized for cyber security, and they all show a usage at a percentage of 28% among the active laboratories. Other possible technologies that can be used are the 3DES – Triple DES, the DES – Data Encryption Standard and the AAA – Authentication, Authorization and Accounting. Table 35 depicts the situation.

For what concerns planned investments for the short, medium and long period, Figure 95 shows the obtained results. As it is obvious from the figure, 50% of the labs intend to increase their investments in the near future. Almost 40% of them will keep the investments unchanged in the short term perspective. No plans for decrease are made so far.

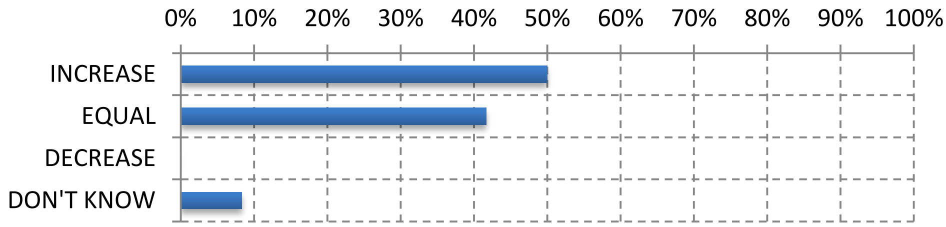

Figure 95: Expected R&D infrastructure investment plans in Cyber Security activities within the next five years

3.3.13 Advanced Metering Infrastructure (AMI)

The activities carried out in this area are mainly targeted at the industry sector, the utilities, and the academy, which comes in accordance to the situation noticed for the other smart grid categories, as shown in Figure 96.

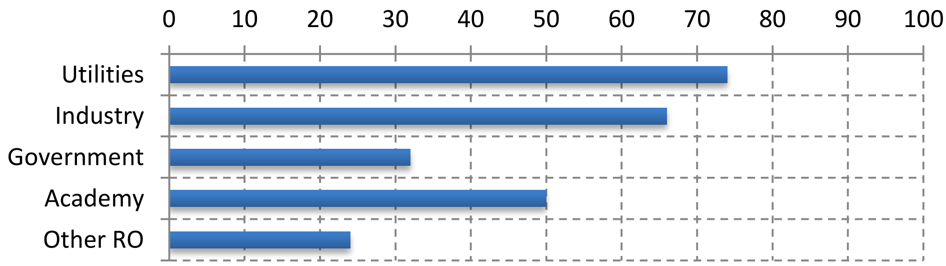

Figure 96: Sectors at which AMI research is targeted

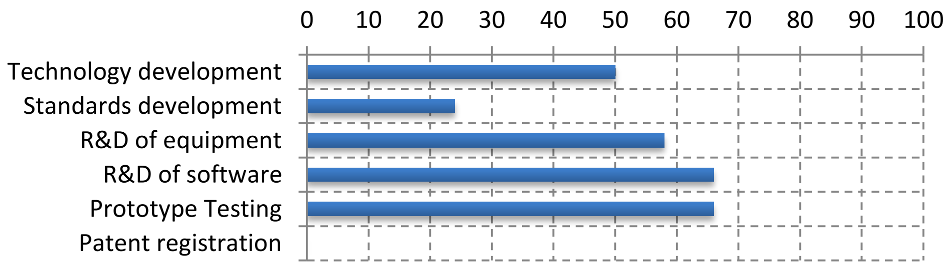

Figure 97: Fields of smart grid AMI activities

Almost 30% of the activities are supported by local Governments. The focus of the AMI involved laboratories is mainly on Technology development, Prototype testing, R&D of equipment and software and at a minor extent on standard development, similarly to most of the other smart grid categories, as depicted in Figure 97.

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 98. The activities vary from stand alone to collaborative ones, either sporadic or permanent with other organizations, whereas the variations noticed are not greater than 10% approximately (see Figure 99). Figure 100 shows that more than 80% of the activities on AMI are carried out in Europe. North and South America gather a smaller percentage between 15% and 20%. It is also noteworthy that none of the survey participants conducts research on other continents. Again, Figure 101 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 not 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.

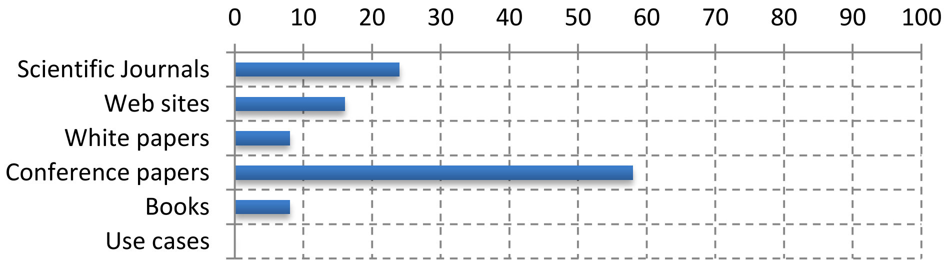

Figure 98: Results dissemination in AMI category

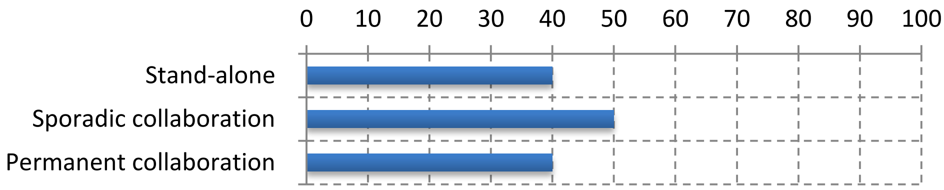

Figure 99: Nature of AMI activities

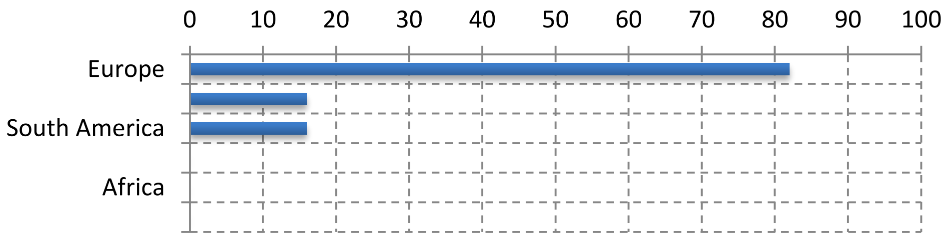

Figure 100: Geographical areas on which AMI research is carried out

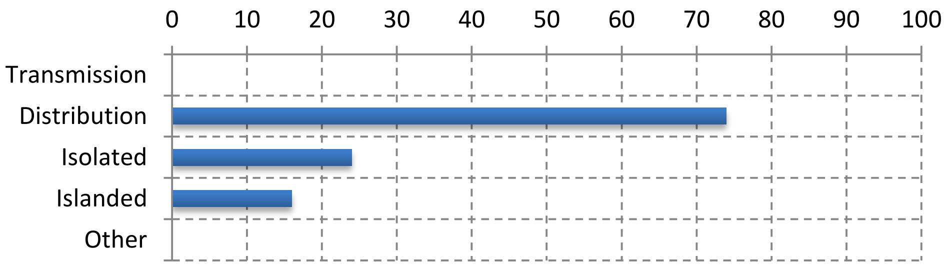

Figure 101: Networks on which AMI research is carried out

The research works on AMI are mainly carried out in Demand response and Communication areas. But more areas of interest have been identified through our survey (please find details in Table 36):

Billing	16%
Customer information	34%
Pricing	26%
Installation and configuration	16%
Monitoring	42%
Management	42%
Interoperability	50%
Demand response	66%
Other	0%
Security	16%
Safety	8%
Don't know/No answer	8%
Communications	58%

Table 36: Sub-topics in the AMI field

Regarding the data communication in AMI devices the majority of labs rely on Power Line Communications (PLCs) but also on wireless communication technologies. Only the minority uses wires like copper and fiber.

For AMI also the most used standard is the IEC 61850 (Communication networks and systems in substations).

For what concerns planned investments, Figure 102 shows the obtained answers. As it is observed from the figure, almost 45% of the labs intend to keep their investments at the same levels for the near future. Between 35% and 40% of the labs has planned to increase investments for the same time period. None of the survey participants has planned to decrease investments in the future.

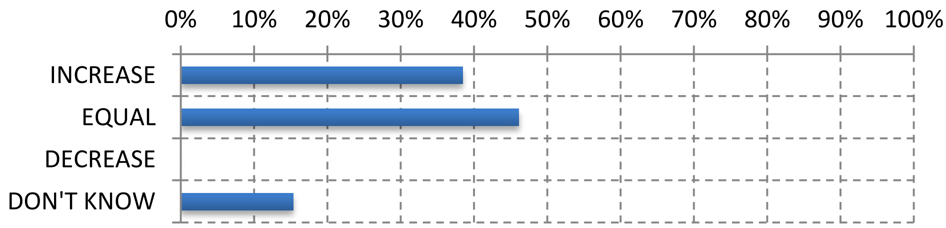

Figure 102: Expected R&D infrastructure investment plans in AMI activities within the next five years

3.4 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 this infrastructure used in the labs by participants to the survey, several important facts arise. Almost the 80% of them is working with three-phase electric power systems (AC). 42% is conducting system tests through Hardware in the Loop (HIL) simulations equally shared between Control Hardware In the Loop (CHIL) and Power Hardware In the Loop (PHIL).

50% is using a Real Time Simulator (RTS) for research work activities. The RTS is mostly used in generation and DER, Distribution Automation and Grid Management research, as reported in Table 37.

Distribution Automation	25%
Grid Management	29%
Storage	16%
Sustainability	8%
Market	4%
Generation and DER	37%
E-Mobility	8%
Smart Home	12%
Smart City	12%
Demand Response	16%
ICT: Communication	16%

Table 37: Topics on which RTS is used

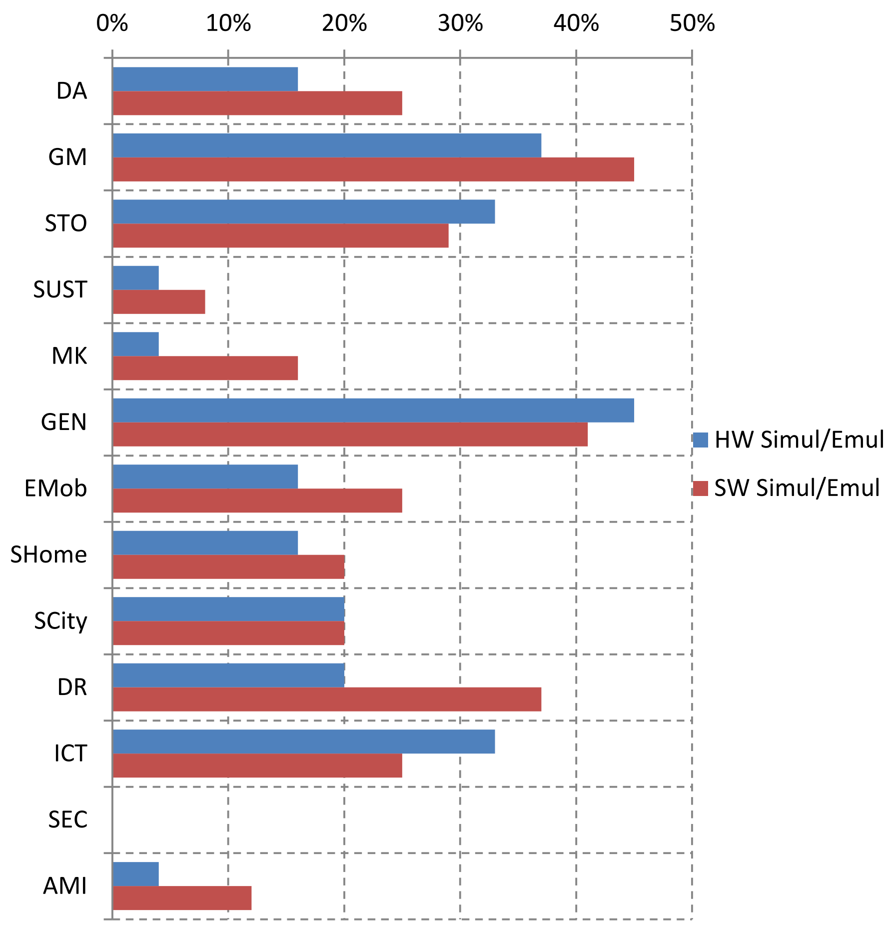

Figure 103: Comparison of Hardware Simulation/Emulation to Software Simulation/Emulation on each category

Figure 103 compares the usage of Hardware Simulation/Emulation and Software Simulation/Emulation in each identified category. As it can be observed, for many categories, software simulation/emulation is preferred to hardware simulation, which can be explained by the fact that hardware can be expensive in many cases, thus working with software is a more affordable and cost-effective solution. However, this is not the case for some categories, like Storage, Generation & DER, ICT or even Smart City, where the two options are at comparable levels. In these cases, the cost of hardware acquisition is not a big issue or hardware is a crucial part of the corresponding research.

4. CONCLUSIONS AND FUTURE PERSPECTIVES

The survey presents important outcomes for the smart grid research performed in Europe nowadays and analytical results for each smart grid category. Information about the technologies that mostly attract the scientific interest is revealed. Moreover, information about investment plans can be deducted regarding each of the smart grid categories. Emphasis is also given on the infrastructure used by the laboratories/institutions that conduct smart grid research.

4.1 Conclusions

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, whereas microgrids, like the islanded and the isolated grid concepts, are also topics under investigation. The transmission grid is lower in the list, which can be also explained by the fact that the electricity transmission grid already contains several elements of automation and smartness. On the other hand, the smart 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 academic and industrial purposes, whereas utilities also attract the smart grid research interest. 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 the survey, 13 Smart Grid research areas have been identified. Among them, the ones cited more frequently by the participating organizations as the core research areas are Grid Management, Storage, Demand Response and ICT, since they gather the interest of more than 80% of the questioned labs. Electromobility and Smart Home/Building are next in the list for the time being. It should be noted that 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 higlights that there are some sub-topics that attract more the interest of the researchers, encompassing more than 80% of the laboratories working on the broader category. For example, Batteries seem to be the most popular sub-topic for Storage; DER integration for Demand Response; Energy Management for

Smart Home and Smart Building; Automation of distribution networks for Distribution Automation; Market Structure for Market. For Generation and DER, Wind energy and PV are the most important sub-topics, as it is also expected.

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 6 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 6 categories, namely: Distribution Automation, Grid Management, Storage, Generation & DER, 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.

Apart from the research subject in smart grids, 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. So, it is concluded that the majority of the labs is placed around the amount of 1 M€ in terms of initial investments. It is demonstrated that large institutions are able to spend even more than 20 M€. Referring to the future plans, the majority of the labs/institutions almost in all categories intend to increase their investments in the next 5 years. For sustainability, Electromobility and AMI the majority of the labs plan to keep the investment at the same level as it is formed currently or to increase them. In all the rest of the categories, the upward invetsment plans outstand, gathering percentages close to 60%. It is also noteworthy that there are no plans at all for decreasing the investments in 11 out of the 13 smart categories. Electromobility and Generation & DER are the only categories that show a small percentage of labs to have planned a decrease in their investments for the next 5 years.

An important objective of the survey is to give information about the infrastructure used by the involved labs/institutions in the smart grid domain. The majority of the labs use a three phase electric power systems (AC) for carrying out research activities. Hardware-In-the-Loop simulations are also becoming an important activity for smart grid labs, since they are used by 42% of the labs participating in the survey. Another important outcome is that Real Time Simulation attracts more and more the scientific interest, while the most important topics on which it is applied are Grid Management, Generation & DER and Distribution Automation.

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 streamling and promoting synergies in future activities.

4.2 Benefits for the participants

Participants can greatly benefit from the results of the present and future exercises and also letting relevant aggregate information being disseminated to wider audience.

First of all, the role of the JRC as a neutral and honest data broker guarantees data accuracy, relevance and independency to all participants, while maintaining all confidentiality needs as required in their research works. By participating in the survey, organisations will contribute to the expansion of the inventory while, at the same time, will benefit from accessing up-to-date and accurate information in the field. In addition, participating organisations will be involved in the development of new releases of the survey and will be able to contribute to validate the collected information. Additionally, their participation will ensure that their view is included.

Higher visibility to all organisations will be given by means of advertising campaigns in the JRC Internet Hub and in the European Commision Internet site. As a key actor in observing the trends and evolutions of the Energy Systems in Europe, the JRC will continuosly expand the scope and range of studies and inventories relevant to the research community in particular and to the citizens in general. In a steady and progressive way, the JRC has become a reference for such studies and is continuously consulted by other organisations, member states and fellow researches in the different areas of expertise. The presence in JRC's repositories guarantees hence higher visibility.

Finally, the future collaboration platform will provide ample possibilities for participants to find research partners, verify the current Smart Grid state-of-the-art research infrastructure and analyse trends, evolutions and gaps where future expansion needs might be envisaged. In addition, the analysis of the planned investments in different areas, readily available in the repository, combined with gap identification and analysis studies based on aggregated information from the projects and facilities inventories, might guide future investors at the time of studying the allocation of research funds. The precision of such studies will increase as it does the number of participants contributions in the repositories, which is why it is in the interest of all to contribute to the inventory.

4.3 Future perspectives

It is worth mentioning that the conclusions have been drawn with respect to the present situation as obtained from the participants' sample. Future activities can modify the current picture, which is why it is necessary to continue improving the survey and expanding the sample. Therefore, a direct objective is to make this type of survey a periodic (ideally annualy) activity, reporting the latest smart grid developments.

As a first step, further improvements with regard to the content and structure of the survey will be made, based on the conclusions drawn so far, in order to depict in the best possible way the emerging smart grid. For this purpose, collaboration with other organisations that have performed or are performing similar initiatives will be targeted. The scope is to make this survey a reference tool for identifying the state-of-the-art smart grid technologies. In future exercises we would like to expand the survey convering not only that areas of activity but also the type of tests carried out and also to collect information regarding education and training activities.

Another goal of the survey is to create a common platform combining the information obtained from this activity with the Smart Grid Projects activity, which identifies and analyses the smart grid R&D and demo projects that take place in Europe. Finally, it is planned to develop an online tool, where participant organisations can cooperate in common projects, thus facilitating and promoting collaboration.

As a future perspective, it is intended to expand the participant organisations starting from attracting more laboratories/institutions in Europe. As a further step, it is also intended to identify some of the top-class organisations outside Europe, in order to obtain results that would depict the smart grid picture worldwide. Such an action will contribute in defining the smart grid research-oriented differences between European and non-European institutions and help scientists to set future objectives for their research.

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