



EUROPEAN TECHNOLOGY PLATFORM SMARTGRIDS

# SmartGrids SRA 2035

## Strategic Research Agenda

### Update of the SmartGrids SRA 2007 for the needs by the year 2035

March 2012



# SmartGrids Strategic Research Agenda (SRA) for RD&D<sup>1</sup> needs towards 2035 “SmartGrids SRA 2035”

EUROPEAN TECHNOLOGY PLATFORM SMARTGRIDS

## **STRATEGIC RESEARCH AGENDA FOR EUROPE'S ELECTRICITY NETWORKS OF THE FUTURE**

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<sup>1</sup>RD&D: Research, Development and Demonstration







## FOREWORD

In 2007 the European Technology Platform (ETP) for the Electricity Networks of the Future presented its Strategic Research Agenda (SRA) on SmartGrids. Considering insights from research institutes, industry, regulators and utilities, the document identified the main areas requiring investigation in the short and medium term in Europe. Since then, it served as a decisive input to the European Electricity Grid Initiative (EEGI), laying out SmartGrids RD&D needs to achieve the EU's 20-20-20 targets by 2020.

The goal of this new SmartGrids SRA 2035 consists in determining longer term research and innovation activities, necessary for electricity networks and intelligent electric systems by 2035 and contributing to the EU's envisioned CO2 reduction of minimally 80% by 2050. These activities should start NOW to enable a smooth transition from today – via progress achieved through the EEGI and other SET plan initiatives by 2020 – towards an optimal smart energy system with flexibility in demand and generation by 2035. Similar to the previous SRA, the SRA 2035 is a strategic document. It could serve as key input to the next EU Framework Programme for research and innovation – starting in 2014 – as well as other SmartGrids RD&D initiatives both on national and European level.

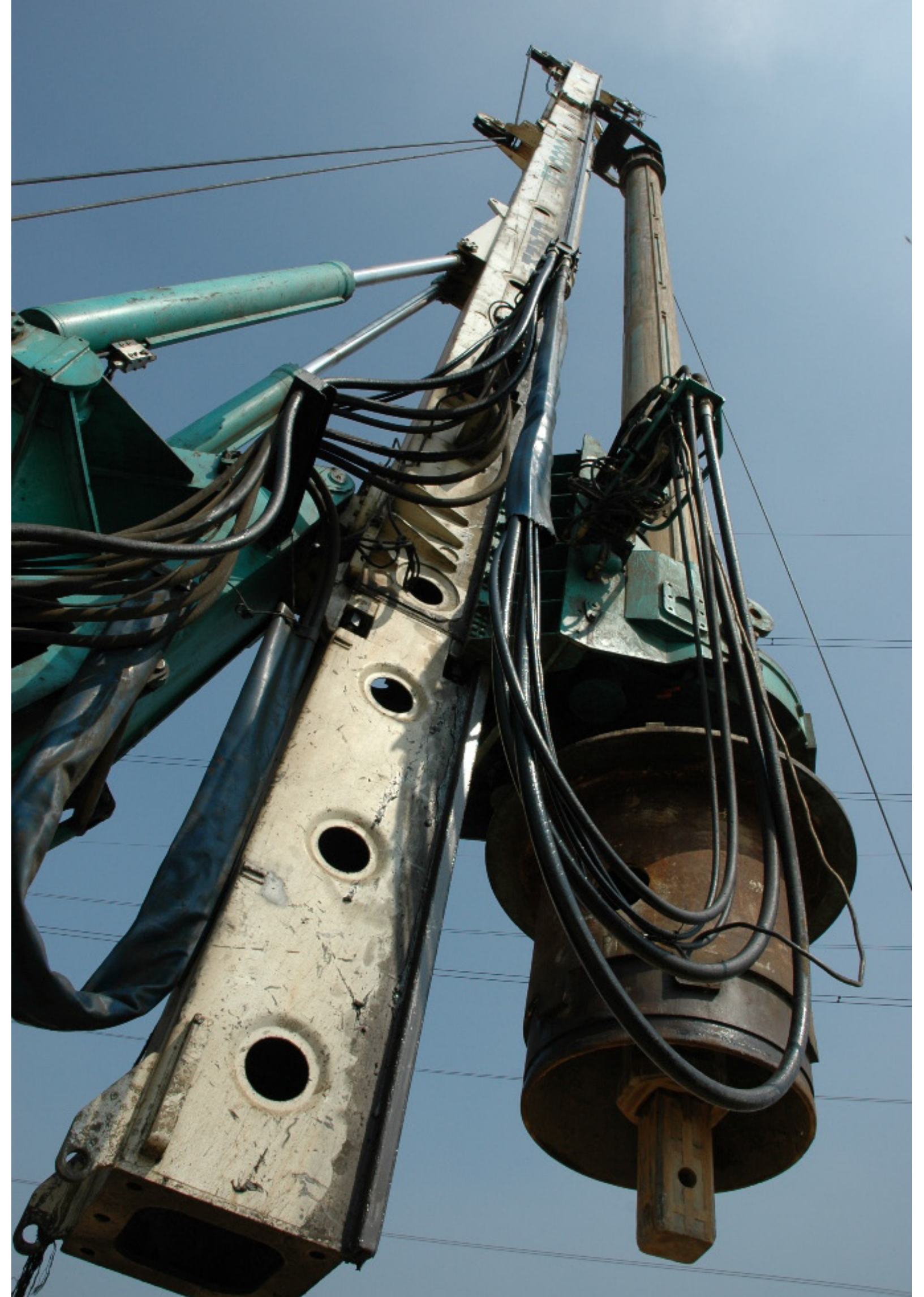
This document evolved from the work of many people. I would like to thank all contributors, more specifically the members of the ETP steering committee whose intensive discussions formed the basis for the final structure and content of this SRA, the more than 40 dedicated experts who provided their input on future RD&D needs in a one-day workshop, the SG ETP WG3 'Demand side, Metering and Retail' – chaired by Maher Chebbo – who played a very active role in the drafting and reviewing process of this SRA, the ETP secretariat that took the responsibility for editing and lay-outing this document and the stakeholders who commented upon it through the public consultation process. A special thank you goes to the representatives of the Commission for their advice and facilitation.

On behalf of the European Technology Platform SmartGrids, I hope you enjoy reading this Strategic Research Agenda and get inspired by the many research challenges lying ahead.



**Ronnie Belmans**

Professor - K.U. Leuven  
Chairman of the European SmartGrids Platform  
Honorary chairman of Elia





## INTRODUCTION

This document describes the research topics and priorities necessary for the advancement of the electricity networks and intelligent electric systems by 2035. The research activities and goals for the years leading up to 2020 were discussed in the previous SmartGrids SRA from 2007. Later in 2010 the European Electricity Grid Initiative (EEGI) laid down the SmartGrids RD&D needs to achieve the European objectives by 2020. The SRA 2035 focuses on technology related research that will be necessary for the further development of the electricity system from 2020 to 2035 and beyond. The SmartGrids research for 2035 has to discover solutions that go beyond the EU 2020 goals: 80% cutting of emissions has been envisioned by 2050 and Europe's energy production will have to be almost carbon-free. SmartGrids research up to the year 2035 must consider the increased impact of renewable energy based electricity generation, which is expected to be approximately 34% of the total energy consumption by the year 2020, and will go well beyond that level by 2035. SmartGrids research by 2035 must also consider the increased stress of maintaining the high quality level of the electricity supply and the security of the electric system – due to an increased participation of distributed electricity generators – by creating a more controllable and intelligent overall system, as well as efficient electricity consumption and integrated energy storage available to consumers. The costs of such a system as well as the associated market prices of products and services will change. This will lead to economic pressures on all parts of the electricity value chain beyond 2020. New actors and stakeholders will emerge; each with their own tasks related to new business models.

While the SRA 2035 mainly concentrates on technological issues, it also highlights the economical and institutional options, market boundaries, and grid regulations that will be necessary for the SmartGrids based electricity systems by 2035.

Key drivers include the degree of decentralization of the system components and their interrelation with electricity networks, the variability of renewable generation, the increased distance between electricity generation and consumption, the intelligence level of the involved systems created by smart products and associated smart services, the legal framework, the associated regulation of market based product and service choices versus natural monopoly products and services and the business roles for actors involved in all aspects of networks and intelligent electric systems.

One central issue for which development for 2035 must go beyond research for 2020 is the nature of the interactions between the transmission and distribution networks. Due to the drastically changing nature of the grid users, electricity generation is becoming less controllable and the electricity consumption is becoming increasingly varied; the architecture and technology used for the transmission and distribution grids and their system interaction will need to change. Legal frameworks must be adapted to go along with this evolution of the electricity system and grids. This means that tasks, obligations, and business activities of those actors that will intervene in the electricity system must be clearly defined. The interfaces between regulated grid monopolies and competitive market based business activities will be challenged due to the increasingly bundled technical system effects, such as the massive introduction of distributed and concentrated storage.

The challenges will increase by 2035 as a result of the increased presence of zero or even positive energy buildings, and the incorporation of renewable sources, which by nature, exhibit fluctuations in availability and productivity. The technology provided by SmartGrids will be necessary to cover the energy demands of night time intervals when PV cells are not generating electricity, winter days in cold climate regions when not enough heat is generated by solar power on the house roof or heat pumps and during intervals (days or weeks) when planned power is not available for unforeseen contingencies. Additionally, future grids will also require massive amounts of storage, relying on technologies such as bulk storage and hydro energy in the mountain regions, and distributed storage relying on other technologies, e.g. electrochemical. The use of hybrid fossil-electric or fully electric vehicles and their need for both slow and fast charging infrastructures will also need to be fundamentally considered.

SmartGrids research must analyze electricity systems as an integrated system, which could possibly be enhanced by other energy carriers for space and process heat and mobility demands. In such a system, the following entities will have to be considered "users" within the SmartGrids system by 2035: any electricity or heat/cold conversion equipment, any mobility vehicle, any power transformation and any storage device. In such a system, users – both technology and human beings – can act individually or aggregate to participate in the market. Aggregated business entities can use standardized ontologies for communicating information to achieve common economic, environmental, security and quality of supply goals. The question of assigning responsibility for supplying energy under abnormal system states must be fundamentally considered in such a

new market based SmartGrids.

Such a vision must be accompanied by SmartGrids research to define how the stakeholders and their business models will need to move towards 2035, based on the new system that will be in place by 2020. Key factors to be researched and analysed include: the associated legal frameworks and rules, the regulatory institutions and the SmartGrids component technologies, and above all, the SmartGrids systems goals such as high quality and security of supply and high sustainability at low cost.

For this transition period, research is needed to determine how the functions and the actions of an initially low number of new actors should be regulated. Designing a legal framework with regulated and measurable goals for each stakeholder will make it necessary to incorporate an increased level of intelligent functionalities, thus supporting the overall SmartGrids systems goals. Research must be done to analyze how this system intelligence can be made easily accessible to the largest majority of the users, while keeping costs as low as possible. Research will also be needed to determine how this intelligence can be made available to all smart grids parties: bringing intelligence from electricity transmission down to the household plug, from inter-TSO communication for preventing blackouts, down to inter-household communication within small communities to support prevention of local or community disturbances.











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## MOTIVATION SRA 2035

The goal of the SmartGrids SRA 2035 is the exploration of the longer-term (Years 2020+) SmartGrids research, innovation, development and deployment needs. These research activities should begin NOW and should have the goal to create the basis for a high quality, economically affordable and sustainable electricity supply transition from today via progress achieved through the EEGI (European Electricity Grid Initiative) and other SET plan initiatives by 2020 towards the energy and electricity system for the year 2035, leading to a CO2 free electricity system by 2050.

### Key drivers

- Ensure that by 2035, Europe's electricity networks continue to function in a manner that optimises cost and environmental performance without giving up traditionally high security and quality of supply, while hosting a very large and further increasing penetration of renewable generation.
- Provide a clear framework, goals and objectives for the research community and all stakeholders to focus today on issues towards the SmartGrids systems of 2035.

### European added value

- Strengthen European collaboration and co-operation to address SmartGrids challenges by 2035 commonly across European Member and Associated States.
- Find solutions for community-wide adoption of research results including active consumer participation.
- Support processes for dissemination and understanding of SmartGrids RD&D priorities and results, thereby ensuring maximum benefit, minimum overlap and avoiding duplication.
- Stimulate stakeholders involved in the EEGI (European Electricity Grid Initiative) to adopt EEGI-products and solutions in a 2020 perspective and to pursue high-end SmartGrids RD&D for the longer term.
- Create an environment which fully utilizes the infrastructure stimulated by the EEGI by 2020 and ensures an efficient use of assets.

### Why now (2011/2012)?

Since the initiation of the SmartGrids revolution in 2006, the world has changed. The large majority of SmartGrids stakeholders, including governments, are now fully aware that a) their overall target of 34% RES-E by 2020 means the grid must be re-engineered and b) intelligent grid based systems can potentially offer a cost-optimal way to re-engineer it. Without SmartGrids technologies, the grid based system would become less stable and disruption in the supply may occur much more frequently. Investments in the grid are long-living. There are long lags between the formulation of an idea for a research topic and the time by when the result of that research can be applied in SmartGrid infrastructure, meaning it is now time to formulate the necessary new RD&D needs in Europe for the year 2035.

The European Commission welcomes the effort of major stakeholders in the field of smart grids to bring together research agendas and priorities with a medium to long-term horizon. It is expected that the SRA 2035 will appropriately complement the ongoing SET Plan European Electricity Grids Initiative with a longer term perspective.

### Distinction Year 2035 from 2020

This document describes research topics, stakeholders, and priorities necessary for electricity networks and intelligent electric systems by the year 2035. The years up to 2020 have been discussed in the previous SmartGrids SRA. SmartGrids RD&D in a 2020 perspective has been developed in the roadmap of the European Electricity Grid Initiative (EEGI). The SRA 2035 focuses on research necessary for the further development of the electricity system for the years 2020 and 2035 and beyond. Clearly, SmartGrids research in a 2035 perspective must contribute to go beyond a reduction of EU greenhouse gases of 20% by 2020: a factor of 4 is envisioned by 2050. SmartGrids research for 2035 must consider the increases of renewable generation well beyond the expected 34% of the final consumption by 2020. Also, SmartGrids research for 2035 must consider the increased stress on maintaining the high level of the quality of electricity supply and of the security of the electric system, in spite of an increased participation of distributed electricity generators, and exploiting it together with a much more controllable and intelligent, efficient electricity consumption, and by more energy storage available near the consumption. The costs of such a system and the associated markets of products and

services will change. This will lead to economic pressures on all parts of the electricity system beyond 2020. Many new actors will take part, each with their own requirements related to costs and profit goals.

The SRA 2035 discusses the reasons why research of technological, economical, and institutional options and of market boundary and grid regulations is necessary for the SmartGrids based electricity systems by 2035.

In case of systems and intelligent electric networks integrating renewable energies and the flexible electricity consumers (prosumers including storage and distributed generation at the consumer sites), certain key drivers have been determined: the degree and form of decentralization of the system and electric networks, the level of intelligence of the involved systems realized by smart products and associated smart services, the legal framework and the associated regulation of competitive product and service choices versus natural monopoly products and services and the business rules for actors involved in all aspects of networks and intelligent electric systems.

One central question where developments for 2035 must go beyond research for 2020 is the form and nature of the interactions between the transmission and distribution networks. Due to the massively changing nature of the grid users, with generation becoming less controllable and consumption becoming more controllable, the architecture of the involved transmission and distribution grids and their interaction will need to change. Adapted legal frameworks must go along with this evolution of the electric system and grids. This means that the tasks, obligations and business activities of those actors that will intervene in the electric system must be clearly defined. The existing interfaces between today's unbundled regulated grid monopolies and competitive business activities will be challenged due to the closer technical interactions among all system actors.

The challenges will increase by 2035 also due to the increased presence of zero or even positive energy buildings. SmartGrids will need to cover the energy demands of time intervals during nights when PV is not generating electricity, on winter days in cold climate regions when not enough heat is generated by solar power on the house roof and in that time of the day (or even week) when planned power is not available for unforeseen reasons. Storage – both bulk in the mountain regions and distributed for example in batteries – will be a key element of SmartGrids. Also, the use of hybrid fossil-electric or fully electric vehicles with their need of fast and slow charging infrastructure will need to be considered.

SmartGrids research must analyze electricity systems as an integrated system possibly enhanced by other energy carriers for space and process heat and mobility demands. In the future smart energy and electricity system, every electricity (or heat) "production" site, any electricity, heat or consumer with mobility requirements, every site of energy conversion and power transformation and of storage might be considered a user in this system. In such a system users can act individually or aggregate to participate in the market. Aggregated business entities can use standardized ontologies for communicating information to achieve common economic, environmental, security and quality of supply goals. Among others, questions of market power and of equal access to information such as real-time system models, prices, actions limited by system constraints and market bids of actors must certainly be considered. Also, the question of who is responsible for supplying energy under abnormal system states must be fundamentally considered in such a smart, future electricity system.

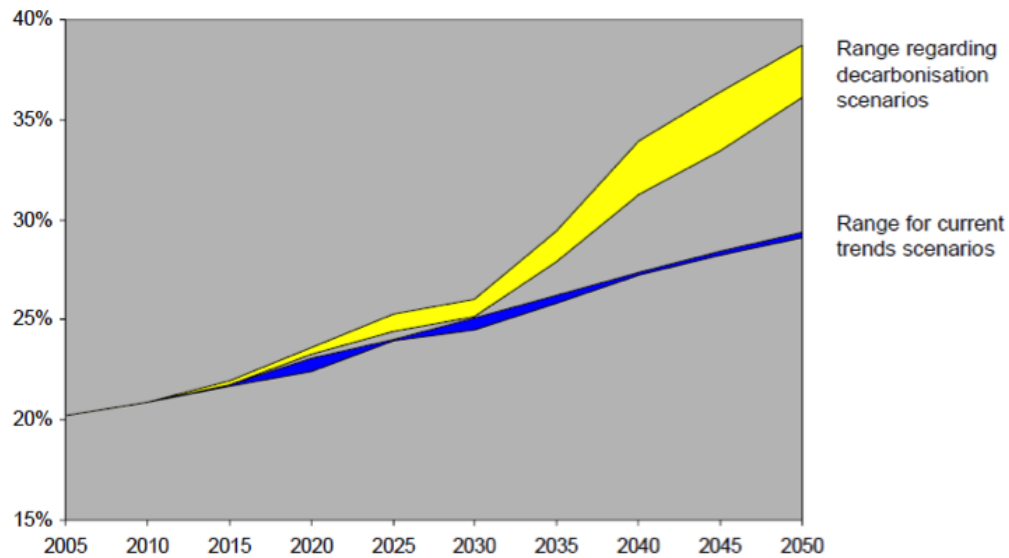
Consumers (industrial, small and medium size enterprises and residential) will play a role in the retail / commodity market, and will participate through new energy services based e.g. on real-time pricing, thus facilitating small-scale generation and storage of electricity. This development does require the use of proper component and systems technology to support emerging markets and new participants.

Until approximately 2020, solutions for these challenges are mostly component, single point related. They work, but cannot be integrated with each other or with similar or competitive systems. They are not modular, are not based on standards. There is the danger of technology lock-in, which is not very desirable. For the 2020 SmartGrids based system, the pilots and small-scale rollouts are justified in this phase of 'proof of principle' and 'proof of concept'. But for a large scale rollout by 2035 these systems must be able to co-operate and be interchangeable. The timeline for these developments is depicted in the following figure:





- Forecasting the long-term future is not possible. The scenarios in this Energy Roadmap 2050 explore routes towards decarbonization of the energy system.
- The energy sector produces the vast majority of man-made greenhouse gas emissions. Therefore, reducing greenhouse gas emissions by 2050 by over 80% will put particular pressure on energy systems.
- High Energy Efficiency: political commitment to very high energy savings including more stringent minimum requirements for appliances and new buildings; high renovation rates of existing buildings; establishment of energy savings obligations on energy utilities. This leads to a decrease in energy demand by 41% by 2050 as compared to the peaks in 2005-2006.
- Increasing household and SME energy expenditure: in all scenarios expenditure on energy and energy-related products (including for transport) is likely to become a more important element in household budgets, rising to around approx. 15-16% from 2030 towards 2050. This trend would also be significant for small and medium-sized enterprises (SMEs).
- Renewables rise substantially: the share of renewable energy (RES) rises substantially in all scenarios, achieving at least 55% in gross final energy consumption by 2050, up 45 percentage points from today's level at around 10%. The share of RES in electricity consumption reaches between 64% to 97%. This includes significant electricity storage to accommodate varying RES supply even at times of low demand.
- New legislation is needed:
  - Renewables will move to the centre of the energy mix in Europe, from technology development to mass production and deployment, from small-scale to larger-scale, integrating local and more remote sources, from subsidised to competitive. This changing nature of renewables requires changes in policy parallel to their further development.
  - Incentives in future, with increasing shares of renewables, have to become more efficient, create economies of scale, lead to more market integration and as a consequence to a more European approach. This has to build on using the full potential of the existing legislation, on the common principles of cooperation among Member States and with neighbouring countries, and possible further measures.
- Effects on the electricity system and its users
  - High level of Renewable Energy Sources (RES): Strong support measures for RES leading to a very high share of RES in gross final energy consumption (75% in 2050) and a share of RES in electricity consumption reaching up to 97%
  - High Electricity Grid Investments: the analysis also shows that cumulative grid investment costs alone could be 1.5 to 2.2 trillion (1012) € between 2011 and 2050 (i.e. in the average 50'000 M€ per year), with the higher range reflecting greater investment in support of renewable energy.
  - Increasing average capital costs: they will increase significantly - investments in power plants and grids, in industrial energy equipment, heating and cooling systems (including district heating and cooling), smart meters, insulation of buildings, more efficient and low carbon vehicles, devices for exploiting local renewable energy sources (solar heat and photovoltaic), durable energy consuming goods etc. This has a widespread impact on the economy and jobs in manufacturing, services, construction, transport and agricultural sectors. It would create major opportunities for European industry and service providers to satisfy this increasing demand and stresses the importance of research and innovation to develop more cost-competitive technologies.
  - Increasing electricity shares in the total energy demand: all scenarios show electricity will have to play a much greater role than now (almost doubling its share in final energy demand to 36-39% in 2050) and will have to contribute to the decarbonization of transport and heating/cooling (see following figure: share of electricity in current trend and decarbonization scenarios (in % of final energy demand)).

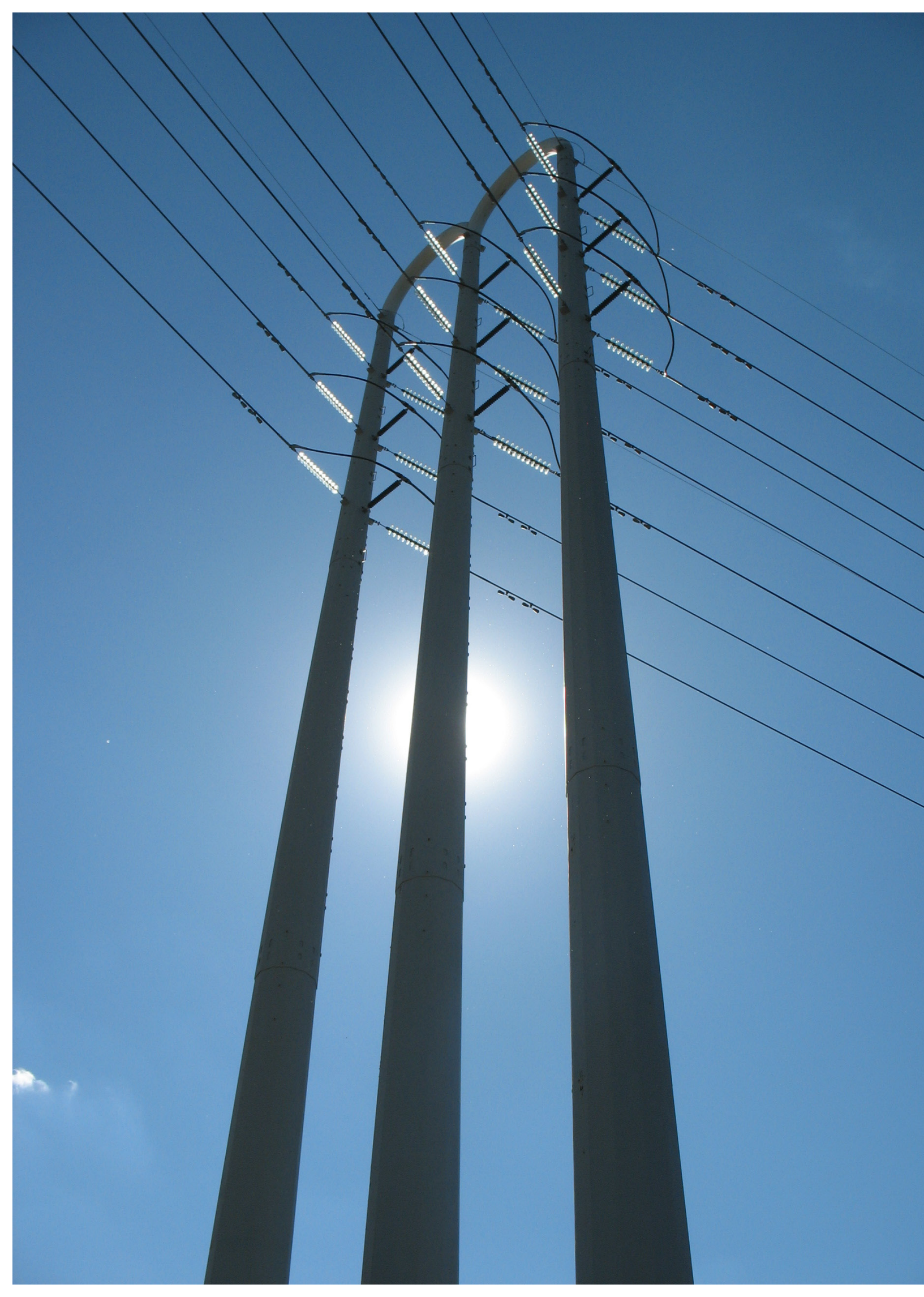


- Increasing electricity share for passenger mobility needs: electricity could provide around 65% of energy demand by passenger cars and light duty vehicles, as shown in all decarbonization scenarios. Final electricity demand increases even in the “high energy efficiency” scenario. To achieve this, the power generation system would have to undergo structural change and achieve a significant level of decarbonization already in 2030 (57-65% in 2030 and 96-99% in 2050). This highlights the importance of starting the transition now and providing the signals necessary to minimize investments in carbon intensive assets over the next two decades.
- Rising electricity prices until 2030 and then a decline: most scenarios suggest that electricity prices will rise until 2030, but fall thereafter. The largest share of these increases is already happening in the reference scenario, and is linked to the replacement in the next 20 years of old, already fully written-off generation capacity.
- Increased electricity system management complexity due to interacting decentralised and centralised systems: decentralization of the power system and heat generation increases due to more renewable generation. However, centralised, large-scale systems such as e.g. nuclear, coal and gas fired power plants and decentralised systems will increasingly have to work together. In the new energy system, a new configuration of decentralised and centralised large-scale systems needs to emerge and will depend on each other, for example, if local resources are not sufficient or are varying in time.
- Critical needs for new storage technologies: storage is currently often more expensive than additional transmission capacity and gas backup generation capacity, while conventional storage based on hydro is limited. Greater efficiencies in their use and competitive costs require improved infrastructure for integration across Europe. With sufficient interconnection capacity and a smarter grid, managing the variations of wind and solar power locally and in wider areas can be improved. This could diminish the need for storage, backup capacity and baseload supply.
- Needs for integration of ICT technologies and technologies for multiple energy carriers and societal needs
  - Integration of wind power generation and distant consumption: wind energy from the Northern Seas and the Atlantic sea basin can supply substantial quantities of electricity to distant users with declining costs. By 2050 wind power provides more electricity than any other technology in the “High Renewables” scenario. In the medium term, wind from the coastal areas and solar power from the Mediterranean countries could deliver substantial quantities of electricity. The opportunity to import electricity generated from renewable sources from neighbouring regions is already complemented by strategies to use the comparative advantage of Member States e.g. such as in Greece where large scale solar projects are being developed.
  - Integrating heating/cooling and electricity: renewable heating and cooling are vital to decarbonization. A shift in energy consumption towards low carbon and locally harvested energy resources (including heat pumps and storage heaters) and renewable energy (e.g. solar heating, geothermal, biogas, biomass), including through district heating systems, is needed.
  - Integrating biomass and electricity, heat and transport: decarbonization will require a large quantity of biomass for heat, electricity and transport. In transport, a mix of several alternative fuels will be needed to substitute oil, with specific requirements of the different modes.
  - Integrating gas and electricity: the gas market needs more integration, more liquidity, more diversity of supply sources and more storage capacity, for gas to retain its competitive advantages as a fuel for electricity generation.



- Integrating ICT and electricity: an increasingly important feature of the required technology shifts is the use of information and communication technologies (ICT) in energy and transport and for smart urban applications, leading to the convergence of industrial value chains for smart urban infrastructure and applications which need to be encouraged to secure industrial leadership. The digital infrastructure that will be needed for the grid smart will also require support at EU level by standardization and research and development in ICT.
- Integrating electric cars and SmartGrids: standardization, infrastructure policy and further research and demonstration efforts, particularly on batteries, and potentially fuel cells and hydrogen, which together with smart grids can multiply the benefits of electro-mobility both for decarbonization of transport and development of renewable energy.
- Integrating electricity markets and SmartGrids: there are national constraints when choosing a national energy mix. However, the cross-border impact on the internal market deserves renewed attention. One challenge is the need for flexible resources in the power system (e.g. flexible generation, storage, demand management) as the contribution of intermittent renewable generation increases. The second is the impact on wholesale market prices of this generation. Electricity from wind and solar has low or zero marginal costs and as their penetration in the system increases, spot prices in the wholesale market could decrease and remain low for longer time periods. This reduces the revenues for all generators, including those needed to ensure sufficient capacity to meet demand when wind or solar are not available. Unless prices are relatively high at such times, these plants might not be economically viable. This leads to concerns about price volatility and for investors, about their ability to recover capital and fixed operating costs. Access to markets needs to be assured for flexible supplies of all types, demand management and storage as well as generation, and flexibility needs to be rewarded in the market. All types of capacity (variable, base load, flexible) must expect a reasonable return on investment. It is, however, important to ensure that policy developments in Member States do not create new barriers to electricity - or gas - market integration. Whether it concerns energy mix, market arrangements, long term contracts, support for low carbon generation, carbon floor prices etc., the impacts on the internal market, on which all increasingly depend, need to be considered. Now more than ever, coordination is required.
- Needs to expand electric power grid infrastructures
  - Transmission Infrastructures and SmartGrids: by 2020 interconnection capacity needs to expand at least in line with current development plans. An overall increase of interconnection capacity by 40% up to 2020 will be needed, with further integration after this point. For the successful further integration after 2020, the EU needs to fully eliminate energy islands in the EU by 2015.
  - Distribution Infrastructure and SmartGrids: to accommodate renewable generation locally, the distribution grid needs to become smarter to deal with variable generation from many distributed sources such as, in particular, solar photovoltaics, but also increased demand response. With more decentralized generation, smart grids, new network users (e.g. electric vehicles) and demand response, there is a greater need for a more integrated view on transmission, distribution and storage. An overarching need is to be able to plan the house network in such a way that it is possible to utilize the equipment for demand response as well.
- Needs for adapted research and policies, legal frameworks
  - SmartGrids Research and related policies: a unified policy framework that would synchronise all instruments from research and innovation policies to deployment policies is needed.
  - Social dimension and SmartGrids: especially for infrastructures, efficient permitting procedures are crucial since it is the precondition for changing supply systems and move towards decarbonization in time. The current trend, in which nearly every energy technology is disputed and its use or deployment delayed, raises serious problems for investors and puts energy system changes at risk. Vulnerable consumers in particular might need specific support to enable them to finance necessary investments to reduce energy consumption.







# SMARTGRIDS 2035 CHALLENGES

The core challenges and possible barriers in this move towards an intelligent electricity supply system by 2035 are:

- Electro-Technologies
  - For enhanced controllability of the electricity system quality and security of supply requirements and associated system states: flexible electricity consumption technology is necessary to increase the flexibility of electricity consumption in place and time. As many technologies as possible should serve the goal of a better electricity load-generation balancing at any time and in flexible geographic aggregations combined with improved security handling of grid system constraints.
  - For electricity storage components and storage control technology to handle the volatility of renewable based electricity generation.
  - For secure long-distance transmission of bulk electricity in meshed grids: switchable HVDC technology for meshed HVDC grids is key to securely transport the excess of physical renewable based generation in the coastal areas from wind and in the southern areas of Europe from solar power to load areas without efficient renewable based generation.
  - For improved materials: more robust, flexible and cost effective materials for grid components in the context of the new SmartGrids systems are critical. They must prevent a sudden malfunction of the overall system; and in case a failure of a grid component occurs, immediate and often automatic actions must be possible for system healing, providing to critical system users a permanent availability of grid products and services.
- ICT (Information and Communication) Technologies
  - For better monitoring, metering: sensors, communication technology and distributed real-time computing platforms will be key technologies to monitor, meter the various electric equipment and system state parameters critical for determination of the current state of the SmartGrids. This captured information will be used as input for many types of model predictive algorithms whose output supports decisions to achieve the goals of the SmartGrids 2035.
  - For an appropriate control structure to stabilize a grid with limited mechanical inertia, with an architecture based on an appropriate combination of central and decentralized control.
  - For better predictive models and algorithms: improved computer based models and algorithms will be needed of the grid elements themselves such as transmission and distribution lines, voltage and current transformers, flexible AC and DC elements, switches and breakers, shunts, protection equipment but also of all grid users including generators, storage, consumer equipment and behaviour.
  - A software architecture allowing consumers and market players to compose new services and to satisfy own requirements related to energy services and products thereby using also market interfaces and at the same time supporting the quality and security of supply of the grid based electricity system.
- EEGI (European Electricity Grid Initiative) Compatibility
  - For smooth evolution of grid systems from today via 2020 towards the year 2035.
  - To avoid developments before 2020 that are not compatible with developments needed in the 2035 perspective, close contacts with the EEGI are needed.
- Legal frameworks, market structures
  - For stakeholder business investment rules: legal frameworks must set the rules for stakeholders both on European and on national levels. The question which stakeholders and their businesses shall be regulated as natural monopoly and which stakeholders shall be based on competitive market rules within a given legal framework is critical. What are the mandated tasks of each stakeholder? What unbundling rules must be satisfied by each stakeholder? How are legal frameworks adapted knowing that the set of stakeholders could change dramatically?
  - For natural monopoly cost and tariff rules: rules are necessary for using the natural monopoly products and services. Legal frameworks must set the rules for tariffs based on regulated, incentive based costs for the electricity grid itself (where not a market based merchant investment is introduced), and for ancillary services where not market based approaches are used. This includes the questions which stakeholders shall pay for which parts of the costs based on which rules.
  - For market-based pricing for goods and services under constrained systems: legal frameworks for market rules and associated pricing principles must be designed which handle the fact that the SmartGrids based systems by 2035 will be operated and planned under temporal, physical, thermal, environmental and social constraints, often coming from the natural monopoly based grid infrastructure. Pricing principles for goods and services must be determined which can handle these constraints so that financial rents can be used to remove constraints and to compensate those being penalized by them.

- Socio-Economic incentives
  - For changed energy consumption behaviour: citizens with individual living habits and businesses with primary business goals other than energy and electricity products and services will need to adapt their behaviour. To achieve the right behavioural change there must be a balance between voluntary change and change mandated through legal framework rules. Legal frameworks must be found which induce change, either by incentives for the individual stakeholders to change bottom-up or mandated top-down.
  - For democratic processes towards decisions about electricity transmission and distribution infrastructure: citizens have individual views on being exposed to the physical infrastructure necessary for the SmartGrids by 2035. The new SmartGrids based system by 2035 will need new infrastructures with new consequences for citizens. Legal frameworks must be found which allow the decision making for installing new and changing present infrastructures for enabling the SmartGrids 2035.

The research and development of “Legal Frameworks” and “Socio-Economic incentives” are not at the core of the SRA 2035 which concentrates on SmartGrids technology. However, the SRA 2035 considers the interface and system integration question related to these topics as very important.



## SMARTGRIDS 2035 TECHNOLOGICAL PRIORITIES

The SmartGrids Technology Platform with this SmartGrids SRA 2035 concentrates its analyses on SmartGrids technology. In addition to the SmartGrids technology innovation, the following technological priorities for RD&D to support the SmartGrids systems 2035 are proposed:

- Small- to medium-scale distributed storage systems for distributions systems exposed to a massive penetration of renewable electricity generation, with the consequence of short- and medium terms deficiencies or excesses of renewable power and, as a consequence, quickly changing local flows that create congestions and endanger system security.
- Real-time energy use metering and system state monitoring systems to increase the real-time knowledge of on-going processes (voltage, flows, short circuit, etc.) and to be able to derive critical system control measures, both ahead of possible and after real incidences (“self-healing”), especially in the electricity distribution systems but also in the potential HVDC based transmission grid layer.
- Grid modelling technologies
  - To design and demonstrate the new HVDC and adapted HVAC transmission systems, the adapted AC medium and low voltage distribution and the new DC consumer home grids and systems.
  - To monitor in real-time the ageing of present electricity materials and cost-efficiently signal predictive maintenance, repair and replacement times.
  - To predict in ahead of delivery up to real-time the generation output of a massive amount of volatile, intermittent generators and the demand of many flexible electricity consumers.
- Communication technologies
  - To enable the secure exchange of information among the many new involved stakeholders for an efficient, secure, low-cost and sustainable electricity system operation at the transmission system down to the consumer (prosumer) of electricity products and services.
  - To enable small-scale islanded systems (short-term or in general without connection to the synchronized European power system) to securely handle distributed, renewable based generators and flexible electricity consumers and to securely connect to and disconnect from the synchronized European power system.
- Protection systems for distributions systems exposed to a massive penetration of renewable based electricity generation with the consequence of new patterns of distribution system flows towards the transmission systems endangering the security of supply.
- Non-technological issues with direct impact on technologies
  - To analyze financial issues for scenarios of SmartGrids 2035 systems and technologies, including investment costs, financial benefits, social welfare analyses, regulated tariffs and market based prices.
  - To define adapted legal frameworks for security and quality of electricity supply, electricity and CO<sub>2</sub>-markets and a legislation procedure for the infrastructure assuming new stakeholder roles and obligations.





## SMARTGRIDS 2035 STAKEHOLDERS

All members of the grids and electricity/energy system research community shall make the concepts presented in this SRA 2035 happen. This includes researchers involved in basic and applied SmartGrids research, in industrial research organizations and within electricity system stakeholder organizations.

It is important that the research is challenged, inspired, supported and finally adopted by the other SmartGrids stakeholders. They will in the end transform the research to commercial products and energy services which again will be used by other stakeholders.

The SRA 2035 classifies the most important involved non-research stakeholders as shown in the following table. Stakeholders are defined in the left column of the following table. The second column describes the main business related to each of the stakeholders. It is assumed that certain business functions will become fully unbundled. For example, DSOs are, by definition, only responsible for services to keep the distribution grid security and quality of supply high.,i.e. DSOs do not supply electricity to consumers. This is assumed to be done by the stakeholders "Energy retailers". The following list assumes certain new roles towards the year 2035. The future role of each stakeholder is, however, subject to research itself.

| Stakeholder                      | Main SmartGrids system needs and roles   |
|----------------------------------|--|
| Consumers                        | Consumption of energy products and services. This is the end-user of electricity. Categories of consumers are residentials, households, and communities. As consumers we also consider SMEs, industries and electricity-intensive industries. A specific example of a consumer category is the set of users with specialized mobility requirements for hybrid or pure electric vehicles. These users need mobility interfaces with quality and security of supply of the electricity system. |
| Prosumers                        | Consumers with the additional role of self-provided (owned) electricity generation and/or storage for private, daily life needs, comfort and SME business needs.   |
| Energy Retailers                 | Selling energy and other (related) services and products to consumers. Retailers will develop consumer oriented programmes and offerings.  |
| Aggregators                      | Broking energy on behalf of a group or groups of prosumers   |
| Energy Service Companies (ESCOs) | Provision of a broad range of comprehensive energy solutions, including designs and implementation of energy savings projects, energy conservation, energy infrastructure outsourcing, power generation and energy supply and risk management.   |
| Electric Appliance users         | The use of electrical appliances at consumer sites for daily life and business needs will increase due to substitution of (fossil based) space heating requirements. The users will be required to interface their needs with quality and security of supply needs of the electricity system.  |
| Electric Vehicle users           | A hybrid or pure electric vehicle is a specialized electricity consumer with mobility requirements. The users will be required to interface mobility needs with quality and security of supply needs of the electricity system.  |
| Generators                       | Large scale centralized generation including wind farms.   |
| Distributed Generators           | Small- and medium-scale generation of mainly renewable based electricity either for third party consumers or for own consumption.  |
| Storage Providers                | Delivery of storage products and services, including their maintenance and operation thereby shifting electricity and energy consumption in time either for third parties or own purposes.   |

|  |   |
|--|---|
| Ancillary Service Providers              | Provision of services such as Power Balancing, Voltage Profile Support, Frequency and Time and Blackstart   |
| ICT equipment and systems providers      | Sales of Information and Communication Technology (ICT System) products and services.   |
| Telecommunications providers             | Provision of telecommunication services, based on dedicated or public infrastructure  |
| Data processing service providers        | Provision of data processing services respecting consumer privacy   |
| Energy Equipment & Systems Manufacturers | Sales of Electro-technology (System) products and services.   |
| Distribution System Operators (DSOs)     | Provision of services for secure, efficient and sustainable operation of electricity distribution systems. Legal obligation of a high quality, secure planning, operation and maintenance of the distribution grid. |
| Transmission System Operators (TSOs)     | Provision of services for a secure, efficient and sustainable operation of transmission system. Legal obligation of a high quality, secure planning, operation and maintenance of the transmission grid.            |
| Wholesale Electricity Market Traders     | Provision of market based prices for products and services by liquid electricity markets.   |
| Policy makers, Regulators                | Setup and control of natural monopoly requirements and for highly effective electricity markets.  |
| Electricity Market Operators             | Operators of market places for energy and other energy products and services  |

In the core text of the SRA2035, a lead role is given to particular stakeholders in each SmartGrids research area and tasks. A lead stakeholder is the first one who needs and “buys” successful research and application results for its own business needs.





# SMARTGRIDS 2035 RESEARCH AREAS (RA)

In the strategic deployment document SDD of the SG ETP (2008), SmartGrids have been defined as follows:

**What is a SmartGrid?**

***A SmartGrid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies.***

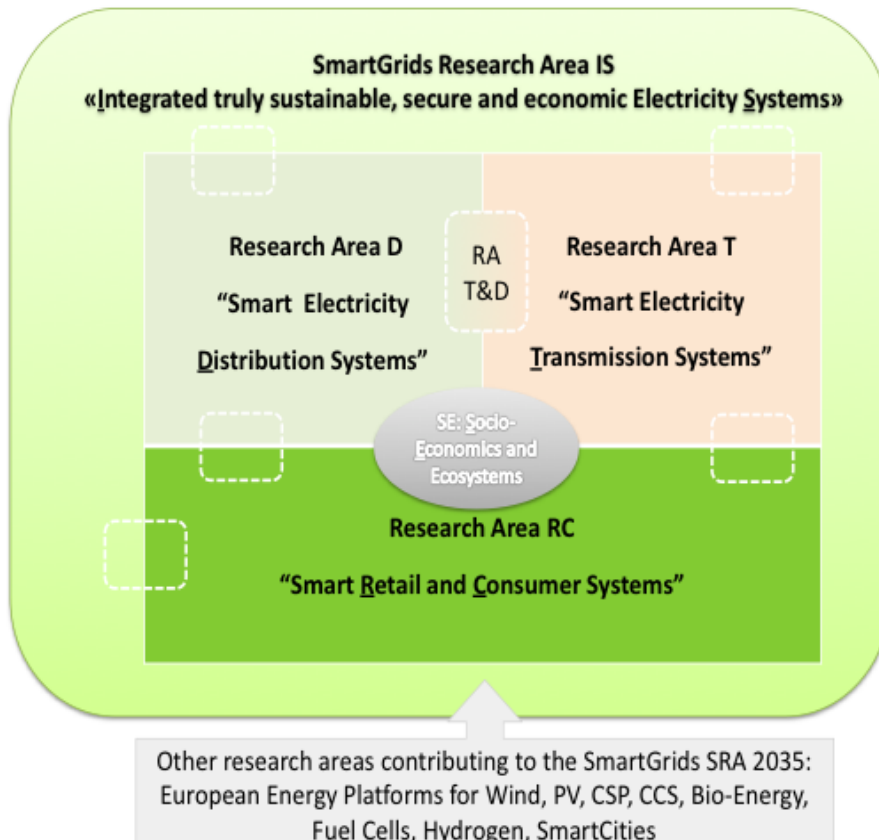
A SmartGrid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies to:

- better facilitate the connection and operation of generators of all sizes and technologies;
- allow consumers to play a part in optimizing the operation of the system;
- provide consumers with greater information and choice of supply;
- significantly reduce the environmental impact of the whole electricity supply system;
- deliver enhanced levels of reliability and security of supply.

SmartGrids deployment must include not only technology, market and commercial considerations, environmental impact, regulatory framework, standardization usage, ICT (Information & Communication Technology) and migration strategy but also societal requirements and governmental edicts.

This definition remains valid also for the SRA 2035. SmartGrids clearly play the central role in the integration of all electricity grid users with the goal to have a system which satisfies the same societal goals such as long-term sustainability (CO2-emission reduction), economics (market based prices for electricity taking into account grid based system constraints); regulated grid prices (with incentives for the most efficient use of the grid infrastructure) and security of supply goals (with the goal of having electricity supply at all times, at all locations and with the right technical quality).

The following research areas have been defined for the SRA 2035.





The dashed boxes in the figure indicate that certain research task and topics can cover more than one area.

### Technology:

- D: Smart Distribution Systems: Satisfaction of distribution system stakeholder
- T: Smart Transmission Systems: Satisfaction of transmission system stakeholder
- T&D: Research common for both Research Areas D and T
- RC: Smart Retail and Consumer systems: Satisfaction of retail and consumer requirements
- IS: Integrated truly sustainable, secure and economic electricity systems: SmartGrids system for integration issues going beyond the other research areas.

### Non-Technology:

- SE: Socio-Economical and Ecosystem SmartGrids barriers and opportunities

### Introduction

The research area IS “Integrated Systems” deals with all issues where a special separation between distribution, transmission, consumer and other stakeholders such as generators, wholesale traders, balance group responsables, service aggregators, etc. is not possible. Research in this research area IS is necessary to satisfy the needs of all stakeholders as an integrated group towards a truly sustainable, secure and economic electricity system.

Research Areas D and T deal with Distribution and Transmission Grids related research respectively to cover the needs of all stakeholders for designing, building, operating and maintaining a secure, sustainable and economical electricity system by 2035, including the interactions between D and T. Both D and T include research related to interfaces to other energy carriers and storage devices. The optimal integration of all electricity grid related issues as the core energy system by 2035 is the primary goal. Both D and T also include research related to ICT integration needs for smart distribution and transmission.

Due to the increased importance of the active role of the consumer in a SmartGrids system by 2035 and later, a new research area RC around the retail and consumer as key stakeholders has been established. Area RC includes research for the specific needs of the retail business and consumers within and for SmartGrids.

In addition to these four core technology oriented SRA 2035 research areas, area SE is seen as important for the overall SmartGrids developments. It deals with the research related to “Socio-Economical and Ecosystem SmartGrids barriers and opportunities”.

Other research areas play important roles for a well working electricity system. All kinds of technologies such as (large and small scale) electricity generation, storage, communication, information, modelling issues and associated research questions could be placed in parallel with the Smart Retail and Consumer systems (Area RC). This has not been done to highlight the special role of the SmartGrids in general.

For the retail and consumer related research area, however, an exception has been made. In contrast to the research questions related to the various generation technologies, no retail and consumer European Technology Platform exists today. As a consequence a new dedicated SmartGrids area RC has been devoted to retail and consumers in this SRA 2035. The research of systems and technology for retail and consumers in the context of SmartGrids is seen as very important for an electricity system based on the above SmartGrids definition.

The SmartGrids SRA 2035 describes these four technologies and one socio-economics and ecosystem related SmartGrids Research Areas. They are described in the following sub-sections.

For each research area, we define

- **The research purpose**, describing briefly the main research goals;
- **research triggers**, saying what are the main reasons for the need of research;
- **research tasks**, giving a short description of the concrete challenges and questions to be solved with specific dedicated research topics;
- **dedicated research topics**: they could serve as input for the upcoming research topics of the European commission and national research funding organizations;
- **lead stakeholders**: a lead stakeholder is the first one who needs and “buys” successful research and ap-

plication results for the own business.

## The SRA 2035 Research Areas with tasks and research topics

For each of the research areas (RA), the SRA 2035 defined research topics which can be mapped to research tasks. Research tasks often cover more than one research topic. Both research tasks and research topics have been associated to a main research area IS, D, T, T&D, RC and SE.

| Research Area   | Research Task Description  | Research Task No |
|---|--|------------------|
| <b>Integrated truly sustainable, secure and economic electricity Systems IS</b> | Ancillary services, sustainable operations and low level Dispatch: Smart Integrated Ancillary System Services  | IS.1             |
|   | Advanced forecasting techniques for sustainable operations and power supply: Smart Look-Ahead System Demand and Supply   | IS.2             |
|   | Architectures and tools for operations, restorations and defence plans: Smart System Large-Scale Disturbance Defence and Restoration   | IS.3             |
|   | Advanced planning, operation and maintenance of electricity systems - seamless SmartGrids: Smart electricity system planning, operation and maintenance                      | IS.4             |
|   | Pre-standardization - Information and Communication needs for SmartGrids: Smart standardization of DER interconnections  | IS.5             |
|   | Smart Materials for SmartGrids   | IS.6             |
| <b>Distribution systems D</b>   | Distribution system power and energy management strategies including storage and demand response: Smart Network, Demand and Storage Response for Distribution System Control | D.1              |
| <b>Transmission Systems T</b>   | Transmission networks of the future – long distance power wheeling at affordable costs: Smart Long Distance Electricity Wheeling   | T.1              |
|   | HVDC and under-ground / under water transmission grids of the future – new architectures & new equipment: HVDC and under-ground / under-water transmission grids             | T.2              |
|   | System technologies and incentives for flexible electricity consumption of large scale consumers   | T.3              |
| <b>T&amp;D</b>  | Network asset management   | TD.1             |
| <b>Retail and Consumer Systems RC</b>   | Retail and Consumer Information and Communication Technology Infrastructures: Smart Service architectures for secure, private and standardized consumer services             | RC.1             |
|   | Retail and Consumer Energy Services & Management: Smart Consumer participation for Energy Service Requirements   | RC.2             |
|   | Consumer Interfacing Technologies: Smart Interfaces to the Consumers   | RC.3             |
|   | Consumer Driven markets: Smart Consumer Driven, Local Markets  | RC.4             |
|   | Active Consumer Programs: Smart Active Consumers   | RC.5             |
| <b>Socio-Economics and Ecosystem SE</b>   | SmartGrids Business Models   | SE.1             |
|   | Economic SmartGrids Models   | SE.2             |
|   | New legislation for markets, grids, energy carriers and involved stakeholders  | SE.3             |
|   | Compatibility of SmartGrids and SmartCity Evolution  | SE.4             |
|   | SmartGrids Evolution and Transition  | SE.5             |
|   | Opposition and Support to Proposed Power Line Projects   | SE.6             |
|   | Interactions between Industry, Regulatory Authorities and NGOs   | SE.7             |



In the following, we begin with the overall system research aspects in the area IS "Integrated Systems". We then describe research in the area D "Distribution systems", T "Transmission systems", T&D "Transmission & Distribution", RC "Retail and Consumers" and finally SE "Socio-Economical and Ecosystem research aspects".

## **Research area IS "Integrated truly sustainable, secure and economic electricity Systems"**

**Purpose:** "Integrating Distribution, Transmission, Consumer technologies for a truly sustainable, secure and economic electricity system"

**Triggers:** Research in area IS is triggered by changes expected between 2020 and 2035:

- Grid operation on both transmission and distribution levels close to the limits, i.e. integrated systems covering both transmission and distribution and all connected users
- Security and quality of supply issues for an integrated, well working system
- Storage solutions both by large concentrated technology (e.g. hydro reservoirs) and massive amounts at small and distributed scale (e.g. batteries)
- Markets for both wholesale and retail

### **Lead Stakeholders:**

DSO, TSO, Consumers, Generators, Storage Providers, Ancillary Service Providers, European Commission

### **Tasks:**

IS.1 Ancillary services, sustainable operations and low level dispatch

IS.2 Advanced forecasting techniques for sustainable operations and power supply

IS.3 Architectures and tools for operations, restorations and defence plans

IS.4 Advanced planning, operation and maintenance of electricity systems - seamless SmartGrids

IS.5 Pre-standardization - Information and Communication needs for SmartGrids

IS.6 Smart Materials for SmartGrids 2035

### **Objective and Purpose**

The current and future increase of renewable and distributed generation results in a less flexible generation mix by 2035 compared to the set of generators before the year 2020. Without further measures, the reduced flexibility of the generation by 2035 would lead to a major increase in the generation capacity simply to have more reserves in the overall system. This would induce extra costs if no new ways to deal with this less flexible generation are introduced. New solutions from flexible and controllable storage and demand response will be necessary by 2035.

The integration of storage technologies, will pave the way for tackling these challenges. A variety of technologies may be considered to address the different needs that may come up: quick response, high grid security, long term energy storage, lowering peak demand, etc.

By 2020, the demand is still participating very little into the markets. The main reasons are the lack of correct incentives for the investments needed to enable the demand response, of business cases and of knowledge about demand elasticity. By 2035 this must be corrected.

Two main drivers are going to promote the demand response programs by then:

A first driver is the meter replacement for the smart meters with communications. With the requirements of Art.13 of the European Energy Services Directive (2006/32/ED,ESD) and the adoption of the Directive on the internal electricity market (2009/72/EC), it became clear that the modernization of the European meter infrastructure and the introduction of intelligent metering systems will have to happen. This replacement is happening through all Europe by 2020. The exact knowledge of the hourly - or even shorter time periods - consumption and the deployment of the communication will allow SmartGrids stakeholders to have dynamic tariffs and to send specific demand response commands to the consumers.

The second driver is the introduction of electric vehicles. The electric vehicle constitutes a very elastic load because it remains connected long time to the grid and the battery of electric vehicles as load could be very easily managed. The electric vehicle is an attractive application in order to introduce demand response in the residential level.

Although bidirectional energy flows from the grid to the EV are in principle already possible (V2G, Vehicle to Grid), it is foreseen that before 2020 the batteries of electric vehicles will only be connected as a load, i.e. controlled charging. However, by 2035 some V2G services, i.e. injecting battery power into the grid, will appear. In the final picture, generation, demand and storage solutions will compete under equal conditions in a market based procedure. Demand and storage, with different aggregation levels will participate in such a flexibility market.

In the final picture, generation, demand and storage solutions will compete under equal conditions in a market based procedure. Demand and storage, with different aggregation levels will participate in such a flexibility market.

The presence of generation and demand in the distribution network opens new possibilities for optimization of the distribution system, supporting the network stability and helping to alleviate network constraints.

The flexibility market that today exists at a transmission level will be introduced and implemented at distribution level taking into account the local reality. New relations between network operators and retailers/aggregators need to be re-defined in order to enable new interfaces between the DSO and the final consumers.

As the complexity of the distribution grid based system increases (more distributed, volatile generation, more intelligent and flexible consumers) the grid needs to be updated in order to have full state monitoring and to automate system control. Distribution grid state monitoring will be achieved with the deployment of different sensors to capture information on power flows, power quality (harmonics, etc.), remaining capacity (dynamic rating), other physical properties (temperature of cables, gas analysis in transformers, etc.).

Fully automatic distribution control will be realized with the incorporation of a massive number of centralised and local agent based control systems, change to more flexible grid architectures, incorporation of power electronics and a combined central/distributed intelligence to operate all flexible components attached to and within the grid.

In both cases (sensors and actuators) the standardization, the reliability and the cost of the components are key factors to allow a low-cost, time-wise distributed and repetitive equipment roll-out.

Collaboration between the electricity sector stakeholders and other energy carrier providers and Smart City stakeholders will be necessary to have optimal society solutions for the whole energy system.

A more automatic, optimized grid operation and more and "denser" connections between the DSOs and the retailers/aggregators/consumers will strengthen the need for the cyber-security on communication and information exchange in general. The work in this area should be considered very urgent because the sophistication of the cyber-attacks will increase with the sophistication of the protection of the ever more complex grid operation by 2035.

### **The challenge of a higher flexibility in the electricity based power system**

In the perspective of even higher levels of RES penetration in the European power system both at transmission and distribution levels (distributed electricity generation), the challenge will be to build up innovative energy and power management system strategies in order to develop a higher degree of flexibility consistent with a high level of quality and security of system services by the various involved stakeholders. Large penetration of intermittent energy resources can affect the stability and safe operation of power systems both on the distribution and transmission level and therefore requires additional controllability (flexibility) of the in- and outputs of the power system.

Clearly, in the medium to long term (2035), the European power system will be facing an increasing uncertainty at the generation side.

Different sources of flexibility already exist in the electrical power system (conventional flexible generation, bulk energy storage, etc.) and some complementary or extended ones can be found (for instance an increased demand response from industrial or domestic use of electricity, from electric vehicles if properly controlled, from European power system integration and reinforcement of interconnection capacities).

It is necessary to anticipate relevant market designs to be able to give right economic incentives and to take into account some new market products linked to flexibility such as flexible ramping of generators.



By 2035, conventional generation must be adapted to higher flexibility requirements. Bulk energy storage will get a major role as it has proven its efficiency to balance generation and demand at large scale and reasonable costs.

At the different scales in time (long term/real time) and space (continent wide/regional/national/local) in the power system, R&D strategies have to focus on developing system related energy management strategies combining and optimizing control solutions and processes within:

- Centralized and distributed generation,
- Active demand,
- Bulk and distributed storage,
- Smarter networks.

The wide penetration of smart meters by 2020 and the new ICT technologies will allow researchers to open new research fields for such solutions and management strategies. They have to take into account on one hand, the increase in new uses of electricity (e.g. electric vehicles, heat pumps, flexible heating and cooling, etc.) as well as the development of smart and zero-energy buildings, and on the other hand, the willingness of public authorities for developing a global approach towards "smart cities".

### **TASK IS.1 Ancillary services, sustainable operations and low level dispatch**

**Purpose: "Tools, equipment, approaches and business models to achieve an all-time secure operation of the electric power system from transmission to distribution"**

The traditional way of thinking that global ancillary services such as frequency control, active power balancing and black start/network restoration, are more of the responsibility of the TSO whereas "local" ones (e.g. voltage control, relief of network congestion/overload) concern both TSOs and DSOs. The terminology, however, sometimes changes (e.g. we generally speak of network congestions on meshed transmission networks and of network overloads on radial distribution networks). This distinction may progressively change with increasing role taken by DSOs in balancing and frequency control due the increased penetration of DG (Distributed Generation) and Renewable Energy Sources (RES) at the distribution level and the present trend to enhance energy optimization at the local level. In this respect, the local dispatching of generating units, storage and demand resources to achieve this optimization may be carried out in different ways, for instance involving a commercial player such as an aggregator, or an organised market structure, or a technical dispatch function. In any case, the DSO should be involved to validate the technical feasibility and ensure the safe and secure operation of the network.

A further question that needs to be addressed is whether it might become technically possible and economically more viable for TSOs to substitute some ancillary services where appropriate by grid investments leading to the equivalent technical and operational performance. Increased contribution of DG and RES, DSU (Distributed Storage Units) and Demand Side Response solutions to the ancillary services market, on equal conditions with traditional suppliers and its coordination with the TSOs should also be assessed in detail.

The technical feasibility and economic viability of DG, RES, and Demand Side Response solutions to the ancillary services market at the distribution level should be assessed in detail and compared with traditional solutions at the DSOs hand such as network investments.

Finally, the evolution of the DSO with a more and more complex responsibility closer to the one of the TSO raises the question of the necessary enhanced interaction and coordination between both types of players to actually ensure the advent of Integrated SmartGrids systems both at transmission and distribution level.

In an unbundled and deregulated market model, the operation of 'distributed' ancillary services from DR (Demand Response) and DER (Distributed Energy Resources including Storage) is a complex issue where neither DSO nor TSO have much experience both from a consumer engagement and a technical (infrastructure beyond the meter) perspective.

Already in 2020, it is expected that new market places for ancillary services have been realized, where aggregators offer their services to TSO's and DSO's. However, it is expected that they operate mostly still on proprietary infrastructure (running either proprietary or open protocols).

To make full use of the capabilities smaller and larger 'generation and consumption units', the power system

needs to progress beyond the closed infrastructure of an aggregator, addressing specific loads with specific infrastructures and control technology, to a mode where all generation and consumption units can participate automatically and individually as ancillary services, without the need for the DSO, TSO or an aggregator (effectively a service provider) to control. The size and scale of a fully electrified smart city is beyond the grasp of such a centrally operated balancing system. Consumer interest to participate actively is most likely also limited. Auto-balancing or active appliances may be needed to fill this gap and keep the system of the future balanceable.

## **TASK IS.2 Advanced forecasting techniques for sustainable operations and power supply**

**Purpose: "Provide tools and business models for very accurate variable time-horizon forecasting of generation and load"**

A large fraction of the generation capacity in 2035 will be stochastic and/or intermittent. Both challenges have to be handled by the following options: reserve capacity / "shadow power (stand-by) plants", storage, matching over large geographic areas and improved demand-side management in industry and households. Forecasting will permit better and more efficient management of all options.

Much distributed and/or renewable generation by 2035 must be considered as variable, highly depending on its type (PV, CSP, wind) and the resource (depending on prevailing weather conditions – in turn depending on location). Forecasting for generation does not need to be perfect because generating capacity is not totally rigid and because errors in forecasts in electricity generation from uncorrelated, connected geographic areas will tend to cancel each other out.

The energy infrastructure businesses are assumed to be linked, i.e. gas, heat and electricity. To improve the forecast it will be necessary to understand and forecast jointly supply and demand for electricity, heat and gas, since there will be compensating effects.

### **Demand-side forecasting**

Forecasting demand for electricity today is relatively straightforward and well understood and is based on observed correlations. Even as demand patterns change e.g. because electric vehicles ("EVs") are introduced and heat pumps become more common, forecasting demand will remain relatively straightforward as these changes will happen sufficiently gradually to be incorporated into demand forecasting models.

Exposure of a large number of consumers to real-time electricity prices, and more automation that activates loads in response to those prices or other signals could make demand harder to model. Also, the huge potential of industrial demand-side management is not well understood. In addition, it is necessary to distinguish between short-term reactions to price signals and medium- and long-term reactions from the industry to highly volatile or even negative energy prices.

In 2035 there may be a system which incentivises or mandates frequency control from appliances in households or industry or EVs. The operators of the power grid must be able to include the effect of this policy in simulations.

It is safe to assume that by 2035 industry demand will be more elastic (price sensitive) than residential, with the greater elasticity will come a greater ability to use price signals to influence demand.

By 2035, models will be needed that account for these circumstances at the level of individual consumers and individual industrial/commercial sites. Up till today, the final consumer has not been the focus of European SmartGrids projects and more data on consumer behaviour in response to price and other signals must be gathered to make such models reliable. Forecasting of demand for thermal energy will lead to better forecasting of the electricity demand if the systems are coupled. Forecasting with very high resolution is needed to better manage the distribution grid.

### **Supply-side forecasting**

Forecasting supply is much more a challenge. Better forecasts are necessary at all system levels, from supply aggregated at pan-European level down to individual feed-in to a low-voltage line.

## **PV forecasting**

Progress must be made on forecasting PV power output on short (hour-ahead) time scales. This forecast is difficult if there are clouds involved. Models are needed that account for cloud movement and thickness, requiring high-resolution observations from satellites or ground-based camera networks.

## **Wind forecasting**

Progress in forecasting wind is also needed on timescales of up to a week. Wind forecasting techniques for shorter timescales will not be a bottleneck to wind's penetration in the grid by 2035, but before then errors in short-term forecasts will put a higher cost on the energy system than errors in long-term forecasts. On the wind farm level new strategies will be implemented to optimise the behaviour of individual turbines. The effect of this optimization must be integrated in the forecast of the output of the whole wind farm.

## **General forecasting**

To give renewables a stabilising role in the system, it is necessary to forecast the power output from more than just one source. Depending on the "mode of use" - e.g. compensation of reactive power, direct trade of power, frequency control, constituent of a virtual power plant - forecasting of correlation of many sources of generation and demand, correlation of market prices and generation forecasting of gradients, volatility etc. is necessary.

The system is highly dynamic: Forecasts of generation and supply will lead to re-dispatching, demand-side and price effects on regional markets. These feedback effects are neither modelled nor understood. To reach a stable energy system based on renewables, system forecasts and control should be developed.

It is assumed in these recommendations on forecasting that by 2035 Europe will have a common reserve power pool, maybe regionally organized, to address fluctuations beyond the reach of forecasting.

## **Forecasting techniques**

The full spectrum of forecasting tools must be used e.g. neural networks, fuzzy logic, statistical and probabilistic methods.

The quality of algorithms is evaluated not only by the accuracy of forecasting, but by other criteria. E.g. is the algorithm able to deliver forecasts in real time for grid operations? Can a forecasting method cope with incomplete measurement/sensor data? Does the algorithm have any special strength, like forecasting signals of great variability or robustness against monitoring errors?

By 2035, forecasts will be fundamentally necessary for many components connected to and within the distribution grid. Even single components will need forecasts, maybe to anticipate market prices, or to make assumptions on the state of the system in order to be able to react autonomously to prevent critical grid states such as overloading, over-voltages ("self-healing").

## **Standardized use of forecasting**

Forecasting is not only about new algorithms. New standards have to be developed to integrate forecasts in model-based management systems for both transmission and distribution grids. These standards must be rigid enough to facilitate integration while retaining enough flexibility to allow for innovation. In a distributed system the intelligence will be dispersed, with a lot of small ICT-applications in many devices. The cost of integrating ICT into these devices must be kept low. The standards for forecasting applications must have attributes which describe the quality of service (response time, accuracy etc.).

## **Sensitivity of research priorities in forecasting to different scenarios of the future development of the renewables market**

1. RES-E generation is concentrated in remote locations using the best, most efficient resources and transported to centres of demand versus RES-E is generated close to consumption.



Forecasting remains important in both cases. However, a grid able to transport electricity in large quantities over long distances can, along its route, compensate deficits or surpluses of electricity generated in a particular area compared to the forecast for that area. This is in addition to its basic purpose of matching the forecasted electricity demand of a given area at a given time.

## 2. Withdrawal of priority access for renewable energy or of feed-in-tariff support schemes.

Priority access to the grid of renewable power generation has been imposed to meet the political objective of a cleaner and more diverse energy system.

The more predictable that supply from stochastic renewable energy sources, the easier it is to integrate it into the grid and to argue for feed-in tariff-type mechanisms or, at least, priority access to the grid to be maintained. But if priority access is withdrawn advances in forecasting become even more important because the owners of renewable energy generation capacity will definitely need precise forecasts to supply their bids to the electricity market. In general, withdrawing the responsibility for balancing the grid from the entity with the highest visibility of power flows over the grid will lead to suboptimal use of generation or storage assets, or flexible loads.

Controlled flexibility of grid-connected electricity-consuming or -generating devices can compensate poor predictions, but flexibility is not the only or even overall goal: the overall goal is to minimise the cost of an electricity system that must accommodate increasing shares of stochastic (wind, PV) generation. This implies minimizing the cost of building or maintaining stand-by capacity (including storage) and of investments in technology to manage electricity flows, such as transmission capacity and ICT based SmartGrids technology. All are necessary for ensuring that enough power is available when output from stochastic sources is low relative to demand, whether or not this has been forecasted.

## Modelling and simulation

The models used to simulate the energy system that will begin to emerge by 2020 and continue to grow as 2035 approaches will need to take into account:

- *Automatic network reconfiguration*: This technique will be used to optimise network operation in order to meet demand in the most efficient way at any time. Network controllers will receive information on grid topology, generation and demand and have algorithms capable of integrating this information and activating grid hardware to reconfigure the grid if necessary.
- *Self-healing*: A special case of automatic network reconfiguration is where it is done to recover from a fault as fast as possible. This is known as "self-healing". The ability for grids to self-heal will become increasingly important as 2035 approaches. Self-healing should be fundamentally assumed in system models. Distributed resources should include black start capabilities.
- *Micro-grid control*: Models of the post-2020 electricity system must include algorithms that take into account of dispersed micro-generation, micro-storage and load management. This is not restricted to islanded microgrids but to any distribution grid (or part of it) where a large share of energy generation is from stochastic resources.
- *EV management*: EVs might have less impact on the grid in sum than e.g. heat pumps (an order of magnitude less impact for a town of 100 000 inhabitants: 30 MW versus 300 MW). EVs are, however, one of the loads that might be connected to future micro-grids. EVs can provide ancillary services which should be taken into account in models. Modelling EV's should be possible down to the consumer's site. There is some scepticism that vehicle-to-grid flows of electricity ("V2G") will be common by 2035. Most ancillary services, such as frequency control will be based around grid-to-vehicle flows ("G2V"). Models and algorithms should assume charging that is both controlled and slow given the need to preserve the lifetime of (presently) expensive batteries of EVs.
- *New protection systems required*: As energy generation capacity becomes more distributed and power flows across the grid cease to come from large, centralised plants, it will become harder to detect and locate faults. Fault current injections will increasingly originate in the MV and LV grids. Today, the protection of distribution systems is not designed for this (the assistance provided by the power electronics of generation units is weak – traditional overcurrent relays are inappropriate), so they will need to be upgraded to new state control. Models of the future electricity system will need to take such changes into account both in the new source of faults and the technology to prevent or react to them. Future protection systems will be equipped with intelligent electronic devices which communicate with other protection systems, sensors etc. They will have a strong need for real-time knowledge and forecasts of grid states.
- *Modelling in different voltage levels and time scales*

Forecasting will have to be done at all voltage levels and time scales and has to be integrated into the simulation systems developed.

Imagining that by 2035 SmartGrids technology reveals a much greater elasticity in demand for energy by end-consumers than currently the case, grid-based energy management models and algorithms to optimise system operation, planning and control systems will need to be enhanced as currently they do not consider demand elasticity.

It will be necessary to assume penetrations of energy storage technology in load flow models, as well as in models simulating transient and stable grid operation. Technologies providing storage allow the movement of electricity over the grid to be controlled and make the grid more flexible if the storage units can be controlled (a plausible scenario for uncontrolled – i.e. determined entirely by the end-consumer without reference to a price signal – local storage applied to residential PV systems is that on a typical day, shortly before noon the grid suddenly becomes exposed to the output from all the PV installations as the batteries fill up). Storage fulfils many roles. Storage can contribute to grid stability in distribution and transmission grids and compensate for fluctuating generation on different timescales. When to use distributed or centralised storage is an open question.

### **Grid planning and operation tools**

Today's grid planning tools, which start to take into account new technologies like storage systems, FACTS configurations or demand elasticity, will be outdated by 2035. New capabilities of RES capacity (e.g. reactive power, black start capabilities) integrated into the grid by means of power electronics are not taken into account either. For example the ability of power electronics to act or react in a few milliseconds and act more effectively and efficiently than current protection systems will need to be considered. Modelling work must also explore micro-grid concepts and the possibility for direct current connections between generation and storage systems.

New grid-based energy management models and algorithms based distribution management systems should integrate such new functions.

## **TASK IS.3 Architectures and tools for operations, restorations and defence plans**

**Purpose: Integrated SmartGrid systems for enhanced controllability and increased power transfer capability.**

Integrated SmartGrids systems call for enhanced controllability and increased power transfer capability. In this respect, the essence of modern grids is their ability to prevent or contain major disturbances in power supply and to recover from problems in a timely manner.

Preventive rules for optimizing networks by the year 2020 need to be enhanced or even be replaced by the year 2035 by real time optimal control tools, allowing in particular for fast and transparent adaptations of grid element settings before and after severe disturbances. In many cases this should be accomplished more and more automatically, where the human reaction time would be inadequate to detect, decide and act to avoid cascading or instability.

Research activities shall focus both on grid based system models and on the grid management systems. Having reliable models and related systems will allow advanced network operations to overcome current limits of the electricity grid. The research shall focus on models, equipment and information systems.

Accurate grid models are required for advanced network management system, e.g., decisions on the network operation have to be supported by reliable evaluation of the evolution of the grid status after such decisions. These models shall be used both for ordinary operations and optimizations of the grid as well as for the operations under critical conditions like black-start or islanding-operations in a micro-grid configuration.

Grid models themselves cannot manage a grid; consequently research shall also focus on the devices:

- a) monitoring the network states by measuring network operation parameters (most of them can be used also for evaluating devices expected lifetime and expected time to failure);
- b) controlling the network states by executing decisions taken according to centralized or distributed/shared



policies.

The research shall focus on designing and industrializing such network components, promptly providing required devices according to grid operation requirements.

Finally, models and devices have to be merged into a system managed according to given policies and decision schemes. Research has to focus on radical innovations providing useful feedback to the research activities focused on models and devices. These policies have to reconsider the whole electricity grid, going beyond the hierarchical operation (HV via MV down to LV) designed more than one century ago, towards a distributed, self-adapting, self-healing, self-optimizing electricity grid. Concepts like fault identification, fault isolation and grid restoration have to be considered in order to improve the overall quality of service.

The self-healing concept should overcome the intrinsically limited concept of a defence plan and evolve to a more general trend not only in emergency situations.

The self-healing grid performs continuous self-assessments to detect, analyze, respond to, and, as needed, restore grid components or network areas.

Handling problems too large or too fast moving for human action, self-healing:

- Increases operational flexibility during normal, emergency and restoration conditions;
- Reduces system restoration time following major events;
- Reduces the risk of a common mode failure affecting overall operation of the entire grid.

The following stakeholders will benefit from the self-healing grid concept and its improved performance: consumers (industrial, commercial, residential), utilities (TSOs, market operators, generators, distributors), government, policy and regulators, vendors (technology, services), others (researchers, financial firms, environmental associations).

Furthermore, advanced concepts like meshed-grid based operations (both at transmission and distribution level), micro-grid operations, controlled islanding, electricity backbones congestion avoidance, loss reduction by dynamic routing of electricity flows and advanced electricity dispatching (both at transmission and distribution levels) shall be deeply studied. All concepts have to be studied considering the integration of distributed generation, introduction of electric mobility and energy storage systems. New electricity consuming appliances and electricity generators have to be monitored and controlled in a fine grained way allowing them to actively contribute to network stability, generation-consumption balancing and overall network quality of service.

## **TASK IS.4 Advanced planning, operation and maintenance of electricity systems - seamless SmartGrids**

**Purpose: "Integrated transmission and distribution planning, operation and maintenance"**

### **Grid Status Monitoring**

The grid calls for robustness at all levels. High penetration of fluctuating generation from RES requires novel control methodologies based on multiple integrated control systems to ensure the security of supply on both coarse and fine-grained levels.

Controlling the power balance and frequency requires multiple control loops handling different power markets to always match generation and consumption both at transmission and distribution level (a DSO's level energy balance can be provided as a service to the TSO; the latter may promote this kind of local balancing activity to better address RES variability). The detailed status information must be kept updated, particularly for each critical component in the system.

Usage of measurement devices as PMU's (Phasor Measurement Units) for enhanced online and real-time data measurement and a WAMS (Wide Area Measurement System) with intelligent software processing of the huge amount of data opens new system awareness and even an early warning approach for the control systems at all levels in the grid.

Also more "simple" approaches like online temperature sensors to optimize the power flow in lines and cables allow for a much more secure control of the grid while allowing for short term stress.

The meshed grid with a growing share of HVDC and even UHVDC cables indicates that the TSO control structure and cross-border integration and harmonization are critical topics.

Distribution equipment shall be equipped with measurement units in order to monitor the parameters characterizing distribution grid operations: medium voltage equipment (like network automation fault locators or relays) shall actively contribute to the monitoring of the network status as well as low voltage equipment (like electricity smart meters); all equipment will be able to promptly provide a huge amount of data to supply information on the grid status.

Distribution Management Systems shall rely on the fine-grained measured data in order to promptly evaluate the best grid operation condition (e.g., meshed operation with respect to a radial operation considering, for example, detected faults, physical network topology and current congestion line management)

At transmission level new control architectures will allow neighboring TSO's to enhance cross border operation by utilizing the resources in HVAC and HVDC interconnectors in a more advanced way. Operation of the Trans-European grid with high shares of RES from Wind, Solar and other weather dependent generation emphasizes the need for advanced pan European forecasting tools.

At the distribution level both market actors (e.g. aggregators) and DSOs will be able to directly control DG (Distributed Generation), DS (Distributed Storage) or DR (Demand Response) units and SmartGrids appliances. The properties and responses of this DG will gradually be aggregated and managed in a probabilistic way (e.g., virtual power plant). In future, both generation from renewables and consumption patterns will be managed according to advanced probabilistic frameworks, exploited by networks operators (to ensure security of supply) and market operators (e.g., aggregators, retailers and wholesale actors) accounting for distributed storage.

In the distribution grid new Smart Meters with real-time collection of power and network parameters measurements will provide the DSO with valuable information on the actual situation in the grid. Such data might be used for grid dimensioning, investment planning and grid operation and control. Research shall also focus on designing advanced data mining techniques to be applied on the huge amount of data collected by smart meters.

### **Storage in all energy carrier forms and strategic impact on energy grids.**

The evolution of the power generation from traditional thermal power plants to fluctuating generation from wind turbines, solar energy and other RES calls for storage facilities in the grid. Storage of electricity comes at a price and induces substantial losses. This is why storage should be used as a strategic and intelligent part of the power system and not only a convenient tool for power market arbitrage. Storage of electricity has a significant impact on the market performance and is therefore not just a technical matter, requiring a huge ramping up R&D efforts.

*Direct storage of electricity in the power system - transmission and distribution.*

Bulk storage of large quantities of electricity is feasible when converting electricity to compressed air in CAES (Compressed Energy Air Storage); when converting electricity to hydrogen with electrolyze production; when converting electricity to a chemical storage in batteries; and of course the easy low cost high efficiency of pumped hydro storage. Batteries might be installed in the distribution grid as SmartGrids integration with PV (Photo Voltaic)-systems, in the DC-circuit of wind turbines systems or provided as a result of the aggregation of thousands of electric vehicles. According to their discharge time, different technologies may be used for different applications: long discharge time technologies will be used to firm the capacity of RES while short ones will be adopted to perform frequency regulation or voltage control.

Once hydrogen is produced from electrolyzes - traditional alkali or SOEC (Solid Oxide Electrolysis Cell) - the hydrogen might be converted into electricity and heat again by using Fuel Cells or Combined Cycle gas turbines. The ultimate indirect energy storage is still hydropower. The turn-around efficiency is more than 80% and the energy capacity in the dam is very high. RES and hydropower are an excellent match calling for strong interconnectors in a Trans-European grid.

*Indirect storage of electricity in the power system - transmission and distribution.*

It is also possible to obtain storage capacity by indirect means. Electricity might be stored as heat or cold in

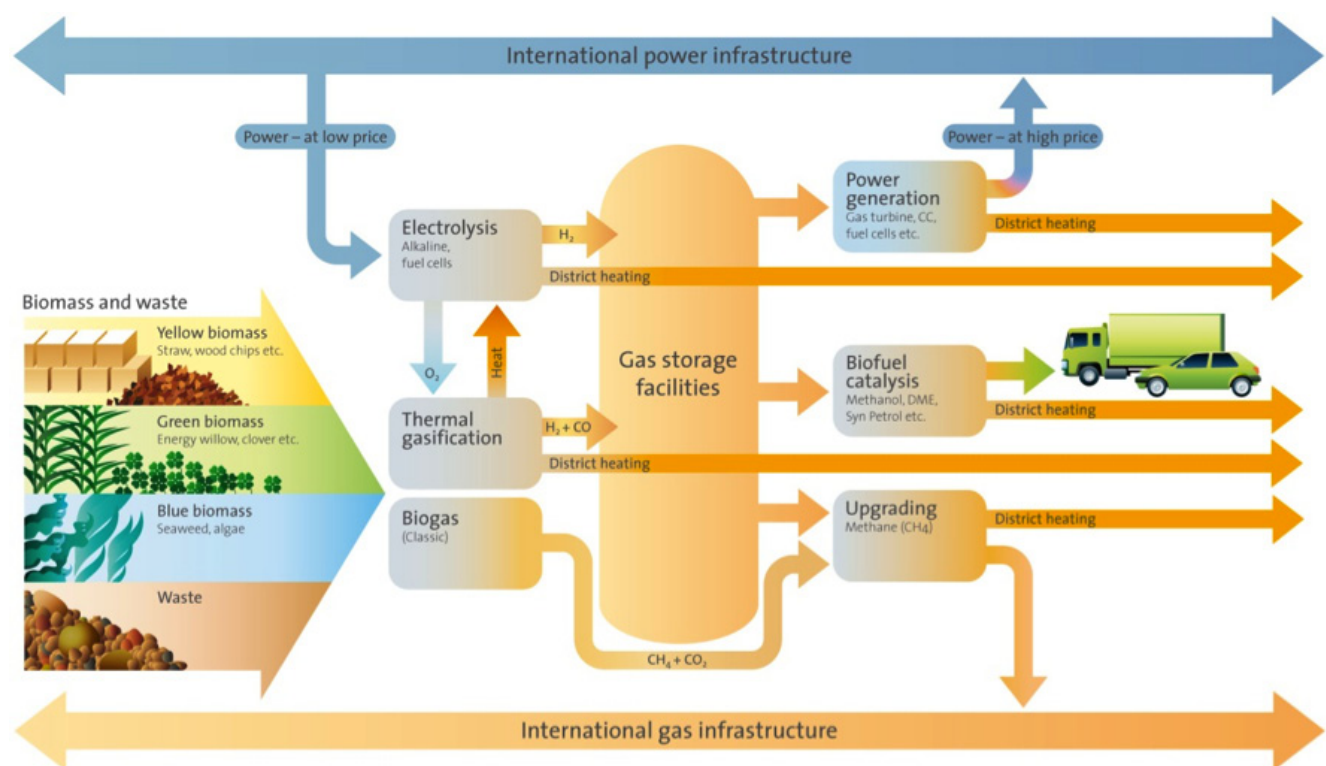


water and other materials. Solar energy can be stored as very hot salt or other heat storage and delay the electricity generation for night hours or non-sunny days.

### Storing electricity as coherent cooperation with the gas system

Large amounts of energy from fluctuating electricity generation like wind turbines, solar systems, wave energy and others need to be stored with a high density, a low price and where re-generation of electricity is possible. Direct or indirect conversion of electricity to renewable gas is an option. Many power plants and units are today using natural gas. The fossil gas must be exchanged with different types of RE-gas. The total benefit is to use surplus of electricity generation to be stored as a RE-gas and then later being used for electricity generation when there is neither sun nor wind.

The picture below shows a vision - a futuristic picture of how electricity and gas once again are obligated to work close together. The illustration shows that there is a significant need for RD&D projects to enable such a future and to find ways of reducing losses and achieving a sustainable high efficiency for the total process from electricity to gas as storage and back to electricity into the grid. In some countries the option of using district heating as storage for the surplus of heat from the processes might ensure a significant efficiency.



### Information and Communication needs for SmartGrids

First of all, the integration requires fast data transfer architectures between grid control areas and between distribution and transmission system operators' systems: a huge amount of data has to be exchanged as much as possible in real time and with a high reliability between areas in order to promptly react to any change in the grid operation parameters. In order to exploit economies of scale and to provide scalable solutions, the deployed field devices and systems have to be as much as possible interoperable and standardized. Consequently, a lot of effort has to focus on standardization processes and on the definition of interoperable interfaces.

Secondly high volumes of data coming from smart monitoring devices and smart (energy) meters must be managed efficiently. Such growth in data flow needs to be organized and structured to be relevant information ready for distribution and communication.

The novel approach in power systems should rely on role based data access. Data must be owned by and located at the data "originator". Data should from here be utilized for all relevant purpose - but with restricted access to what is relevant for the owner of the data. This calls for enhanced activities for ensuring high level of cyber security and respect of the privacy issue. Like in any other ICT-based infrastructure, cyber security has to be deeply analyzed. A single point of failure or back-door in the grid management system may be

exploited to cut electrical supply to a country, resulting in enormous economic losses and endangering the whole community. Furthermore, SmartGrids based ICT will transfer a lot of sensitive data that can be exploited to breach privacy, consequently, research has to ensure that state-of-the-art data-protection and data-privacy approaches are taken into account. To this end the communication systems and ICT should be upgraded to fast and diversified paths of data infrastructure.

Should aggregated resources (both consumers and generators) be considered and introduced in the power market, consequently strong Market-VPP concepts have to be introduced. The same aggregated resources are also valuable for the technical control of the grid. This means that the same resources might also be aggregated in Technical-VPP solutions for the DSO operation, e.g. voltage control, congestion management.

Such a future is only possible if common open international standards are applied at all levels. The traditional grid community must continue working and cooperating closely with the ICT community about these matters. It is very important to highlight interoperability of the SmartGrid solutions.

### **Simulators and training facilities for operators of SmartGrids.**

The power system of tomorrow will by all standards be much more advanced than the present SCADA systems operated by both TSO's and DSO's. The amount of data and requirements for fast response calls for computerization of many routines. The power system will be operated closer to its limits. Dynamically and probabilistically based changes of operation mode from hour to hour and second to second responses to early warning from WAMS systems and other novel data collecting tools will change the man-to-machine interface and operation in a gradual way.

SmartGrids appliances connected to the grid with aggregated market response require dynamic measures to ensure the technical balancing and control of the grid. DSO's will be able to aggregate demand and supply providing ancillary services to the TSO's, further ancillary services may be provided by DSO's or third parties having a role as storage facility operators.

However, all possible new operation strategies call for a whole new education and training of control room staff. DSO's should cooperate on response patterns and protocols for novel operation of a grid with SmartGrids applied resources.

TSO's must interact and harmonize response protocols and algorithms for their control room once introducing early warning options. The alternative might be "early death" when not complying with the needs for pan-European response.

In future, power system operators must be able to be trained in faster than real-time simulators, with all kinds of dynamically simulated contingencies, just like professional pilots are trained in realistic cockpit flight simulators today.

Education, simulation, training facilities and cross-border cooperation are the key to ensuring the full benefit of automated control rooms with higher situation awareness.

## Task IS.5 Pre-standardization - Information and Communication needs for SmartGrids

**Purpose: "Harmonized European DER interconnection standards beyond grid codes today"**

### Grid Status Monitoring

#### a) Generic approach linking R&D with Standardization

With the creation of the STAIR Working Group, CEN and CENELEC promote an "integrated approach between **ST**andardization, Innovation and **R**esearch". In such integrated approach, standardization is not an afterthought but is considered already in an early project definition phase.

ETSI is promoting a similar approach: "In many cases research projects do not include standardization early enough, because they are not aware of the benefits."<sup>3</sup> Alongside their current Technical Organization, ETSI promotes the Industry Specification Group structure in the context of relating research and standardization. By their nature Industry Specification Groups (ISGs) offer a very quick and easy alternative to the creation of industry for, and are focused on a very specific activity. Their speed makes them a good candidate to create the conditions of a good and efficient interface between the R&D and standardization communities that have different background and mindset. Their deliverable is the ETSI Group Specifications (GS)

CEN and CENELEC have a similar deliverable which is very useful in combining the standardization principles of consensus with the Research projects' need for speed: the CEN Workshop Agreement and the CENELEC Workshop Agreement (CWA). A Workshop is a consensus working group open to direct participation of any interested party and is tasked to produce as deliverable a CWA.

Where projects fall within the scope of a Technical Committee (TC), the project may lead to a Technical Specification considering their short average production time. The European R&D Projects can liaise with the TC through project liaisons, a new instrument enabling the projects to participate in European standardization.

The European Standardization Organizations (ESO) have thus created a flexible framework to quickly respond to standardization needs resulting from R&D projects.

#### b) European standardization supporting Smart Grids

CEN, CENELEC and ETSI are responding to the Commission's Standardization Mandate M/490 in a coordinated way. The role of the CEN-CENELEC-ETSI Smart Grid Co-ordination Group (SG-CG) is to advice on European requirements relating to Smart Grid standardization, to assess ways to address them and to serve as a focal point concerning smart grid standardization issues in respect to Mandate M/490.

The Group created 4 sub-groups:

- Sub-group on sustainable processes
- Sub-group on architecture
- Sub-group on first set of standards
- Sub-group on Smart Grid Information Security (SGIS)

#### c) Concrete opportunities for interlinking Smart Grids Research and Standardization.

Research projects can make use of the use cases identified in the CEN-CENELEC-ETSI Smart Grid Co-ordination Group's (SG-CG) sub-group on sustainable processes. They can serve as basis for researchers to identify new research needs and enabling them to put their research into context.

Research projects should inform the standards community on any new use cases which would result from their research so that these can be considered by the standards community, for which the CEN-CENELEC-ETSI Smart Grid Co-ordination Group represents a unique entry point.

<sup>3</sup>Note: This section uses parts from the paper "SEC(2011) 1609 final: COMMISSION STAFF WORKING PAPER, Materials Roadmap Enabling Low Carbon Energy Technologies"



## Task IS.6 Smart Materials for SmartGrids

### Purpose: “Improved materials to allow robust SmartGrids system functionality”<sup>4</sup>

Electricity storage is a key technology to improve the manageability and flexibility of the European power system. Materials are often the limiting but also the determining factor in making storage technologies affordable, efficient, and reliable options for a secure and dependable electricity grid. Bringing storage technologies to a stage of commercial maturity and accelerating the transition to mass commercialization is an overriding priority for SmartGrids.

The following material related developments are seen as critical for SmartGrids:

- Advanced composites for cables (including new carbon fibre and plastic core composite material and metal matrix composite) with enhanced mechanical, electrical and thermal performance.
  - Development of new carbon fibre and plastic core composite materials with enhanced mechanical, electrical and thermal performance i.e. high capacity, low sag, less losses and low electromagnetic field emissions. Increase the current carrying capacity (ampacity) performance of composite materials by at least a factor of 3.
  - Development of advanced composites resistant to moisture ingress, and having reduced sensitivity to water for overhead lines.
  - Development of metal matrix composites, with reduced brittleness for overhead lines.
- Polymer based insulating materials and their manufacturing processes for high voltage insulated cables, on line and substation insulators.
  - Development of better performance polymer materials for high voltage cables with increased specific stress resistance (increase of electric field), increased critical temperatures, reduced sensitivity to impurities and to water, and increase mechanical performances (longitudinal to carry stresses during layout and radial to carry stresses in service);
  - Development of better materials to reduce the sensitivity of DC cables to trapped charges and enhance their capability to polarity reversal;
  - Study of the long term ageing properties and processability of nano-composites, and addressing environmental and HSE concerns in connection with the use of nanoparticles.
  - Enhancement of ageing performance of line insulators under different environmental conditions, reduction of their sensitivity to pollution deposits, increase of their capability for self-cleaning, increase of the allowable mechanical stresses and enhancement of their self-healing capabilities.
  - Enhancement of ageing performance of substation insulators, their mechanical strength and insulation performance without the need of internal glass fiber insulation (longitudinal and radial strength); increase of fire resistance, enhancement of the resistance to chemical aggression; increase of performance in pollution conditions of short and long duration.
  - Improvement of extrusion techniques aiming at cost reductions.
  - Improvement of on-line quality monitoring and better testing of technology for the finished product.
- Wide band gap semiconductor materials for 20 kV power electronics devices for high power injection operation.
  - Applied research and development in the SiC and GaN areas by including research effort on the SiC, GaN on Si or GaN on SiC wafer while addressing epitaxial growth issues.
  - Development of high lifetime materials suitable for 20 kV devices for high injection operation to enable single SiC switch devices able of handling 30-50 kV and rated to 1000 A.
- Structural materials for advanced packaging for power electronic devices at high temperatures as well as on the thermal behaviour of materials at cryogenic temperatures.
  - High temperature packaging materials for power electronic devices to enable them to work reliably, and have an acceptable performance in the specified temperature range. Development and selection of suitable materials to minimize mismatch in coefficients of thermal expansion (CTE) that could lead to die fracture and fatigue.
- Simulation and testing of new HTS materials and components and their interaction with the grid including pre-stress application for advanced composites.
  - Basic and applied research on the fundamental material properties for HTS, especially second generation YBCO to ensure high uniformity of the critical current along the conductor length, enhanced magnetic field performance and reduced AC-losses.
  - Simulation, qualification and testing of new materials and components and their interaction with the grid to reduce operational risks.
  - Development and deployment of HTS components such as fault current limiters at bus bar level to con-

<sup>4</sup>Note: This section uses parts from the paper “SEC(2011) 1609 final: COMMISSION STAFF WORKING PAPER, Materials Roadmap Enabling Low Carbon Energy Technologies”

nect sub-grids, especially at bottlenecks and constructions, where high power has to be transferred in a limited space, e.g. converter stations, tunnels, bridges of HVDC lines, or as urban backbones at medium voltage.

- Improve the manufacturing processes of HTS materials.

### SmartGrids 2035 Research Topics in research area IS (Integrated truly sustainable, secure and economic electricity systems)

The SRA 2035 defines the following research topics with sub-topics for research area IS:

| <b>IS01</b> | <b>Interactions and responsibilities between distribution grid operators and other stakeholders</b>   |
|-------------|---|
| a           | Options for responsibility partitioning and sharing the stakeholder interface issues and costs between stakeholders (TSOs, DSOs and DGs...) |
| b           | Strategies for managing the voltage level and the reactive power flows between the different levels: HV - MV - LV grids                     |
| c           | Nature and value of the services that distributed generation should provide at the MV and LV levels for managing all grid layers            |
| d           | Combine consumer load management, and voltage management at the MV-LV transformer   |

| <b>IS02</b> | <b>Compatibility issues between Pan-European and national markets and stakeholders</b>  |
|-------------|---|
| a           | Local/national flexibility markets versus a pan-European commodity market: Allow multiple local players to trade flexibility. The different kinds of present and possibly future ancillary services should be considered for the foreseen markets structures in 2035. The necessary regulatory evolutions should also be studied (see research area SE) |

| <b>IS03</b> | <b>Ancillary system services, sustainable system operations and low level system user dispatching</b> |
|-------------|---|
| a           | Optimized ancillary services by simplified Retail and Network data exchange and interaction           |

| <b>IS04</b> | <b>Advanced forecasting techniques for sustainable operations and power supply</b>          |
|-------------|---|
| a           | Forecast line capacity margins at least 4 hours ahead to be integrated in operation process |

| <b>IS05</b> | <b>Grid State monitoring</b>   |
|-------------|--|
| a           | Tools for pan-European network observability   |
| b           | Tools for coordinated operations with stability margin evaluation                        |
| c           | Tools for pan-European network reliability assessment                                    |
| d           | Increased observability of the electric system for network management and control        |
| e           | Multi-VPP system operation: Technical and business processes, interfaces, and operations |
| f           | Improved system state visualization  |
| g           | Autonomous, distributed control systems  |
| h           | Autonomous self-controlling and healing grids (dynamic topology, power re-routing)       |

| <b>IS06</b> | <b>Architectures and tools for operations under abnormal conditions, restorations and defence plans</b>  |
|-------------|--|
| a           | Advanced sensors on network equipment: to identify anomalies and communicate with nearby devices when a fault or another issue occurs; Sensors have to detect patterns as precursors to faults |
| b           | Advanced monitoring technologies to provide detailed information of component and equipment conditions   |
| c           | Advanced component and switching equipment to respond quickly to emerging problems by using strategies like promptly changing flow patterns and voltage conditions                             |
| d           | At transmission level, Flexible AC Transmission Systems (FACTS) or superconducting synchronous condensers to provide instantaneous voltage support to reduce sags;                             |

|   |   |
|---|---|
| e | At distribution level, high-speed transfer switches instantly remove disturbed sources and replace them with backup power supplies  |
| f | Voltage control equipment to control reactive power are designed and deployed in order to overcome fast and slow voltage variation  |
| g | Advanced integrated communication and control systems for gathering a wide set of information from the field and communicating with local and remote devices to enable rapid analysis and initiation of automatic corrective actions            |
| h | Advanced models to provide new visualization tools revealing congestion issues, overlays of failure probabilities and resulting threat levels   |
| i | Extended applications of Wide Area Monitoring Systems (WAMS); Similar solutions may be adopted by DSOs, introducing fine-grained measuring devices and advanced prosumer grid interfaces to keep under control the evolution of the grid status |
| j | Applications of dynamic islanding using Distributed Energy Resources and intelligent switching at the distribution level  |
| k | Options for self-healing grids i.e. the ability of a power system to automatically prevent, detect, counteract and repair itself  |
| l | Dynamic Security Assessment: defence plans covering part of the automatic detection and counteraction phases necessary by 2035  |

|             |  |
|-------------|--|
| <b>IS07</b> | <b>Storage in all energy carrier forms</b>   |
| a           | Real-time simulation and demonstrations of storage power technologies                                    |
| b           | Storage of bulk quantities of electricity from fluctuation renewable sources production with low losses  |
| c           | Off-shore energy storage associated on-site with off-shore wind farms (e.g. marine hydro pumped storage) |
| d           | Synergies between storage technologies   |
| e           | Energy storage associated to conventional generation   |

|             |  |
|-------------|--|
| <b>IS08</b> | <b>Information and communication needs for SmartGrids</b>                      |
| a           | Tools for the integration of active demand in the electrical system operations |
| b           | Protocols and standards: Joint task force on IT system                         |

|             |   |
|-------------|---|
| <b>IS09</b> | <b>Training tools</b>   |
| a           | Tools and methods for SmartGrids training and education: New tools, simulators, methods and training facilities for operators of SmartGrids |

|             |   |
|-------------|---|
| <b>IS10</b> | <b>Pre-Standardization Models and functions</b>   |
| a           | Standardized object models and functions towards open source use of standards   |
| b           | Zero energy / Energy-efficient / energy-producing buildings and grid model based forecasting: The advent of the highly energy-efficient building will affect the deployment of SmartGrids |

|             |   |
|-------------|---|
| <b>IS11</b> | <b>Materials</b>  |
| a           | Structural materials; Fibre reinforced materials; High temperature, low temperature and corrosion resistant materials   |
| b           | Functional materials; High temperature; superconducting materials, (High temperature) insulating materials, Materials for power electronics: Catalyst and electrolytes, High temperature heat storage materials |
| c           | Manufacturing techniques; Condition monitoring techniques   |
| d           | HVDC technology for under water grid connection (capsulation etc.) and under water offshore substations; HVDC technology for offshore grids beyond using onshore technology                                     |



|   |  |
|---|--|
| e | UHV AC, UHV DC, Gas insulated lines, UHV XLPE cables, superconductors, compact but optimized tower designs |
|---|--|

From the research defined in SmartGrids research area IS the following technologies shall be provided:

## **Research Area IS (Integrated Systems): Key Technology, Hard- and Software**

### **SmartGrids Technology**

- Monitoring devices for analyzing the aging of the equipment
- Specific infrastructures and control technology for specific loads such that all generation and consumption units can participate automatically and individually in ancillary services, without the need for the DSO, TSO or an aggregator (effectively a service provider) to centrally control this
- Component and switching equipment such as FACTS, FACDS
- High-speed transfer switches; voltage control equipment; advanced sensors and monitoring of location, time, temperature, electro-magnetical signals (voltage, current, fields) in network equipment; advanced DG controls (e.g. provided with communication interfaces with the Distribution Management Systems) in order to control islanding and enabling micro-grid operations Monitoring devices allowing large scale state measurement of margins for transiting more energy through the line

### **SmartGrids ICT**

- High speed, highly reliable and redundant communication infrastructure
- Real time optimal communication, infrastructure and control for fast and transparent system-coordinated controls before and after disturbances
- Dedicated communication infrastructure e.g. fiber cables for monitoring of underground cables

### **SmartGrids Software**

- Tools which allow the use of additional capacity margins for grid operation and markets (transmission and distribution); stochastic models and methods for operation, based on the reliability of each component to decide the safest network topology and operation scheme
- Local flexibility market platform & algorithm
- Tools for energy/electricity demand-side forecasting considering exposure of consumers to real-time energy prices and a system which incentivises or mandates frequency control from appliances in households or industry or EVs
- Tools based on accurate real-time synchronized grid models for preventative and emergency grid management system; WAMS (Wide Area Measurement System) with smart mass information processing; Tools for pan-European network observability, coordinated operations with stability margin evaluation, pan-European network reliability assessment
- Tools to simulate future behaviour of the whole energy/electricity system (taking into account automatic network reconfiguration, self-healing, micro-grid control, EV management, new protection systems required, modelling at different voltage levels and time scales)

## Research area D “Smart Electricity Distribution Systems”

**Purpose:** “Integration of distribution grid connected consumers, generators and storage by Smart Electricity Distribution by the year 2035”

**Triggers:** Research in area D is triggered by changes expected between 2020 and 2035:

- Strongly increased percentage of stochastic renewable based generation connected to the various voltage levels within the distribution grid
- Higher efficiency and increased time-of-use-flexibility of the electricity consumer electrical equipment
- Exposure to a much larger number of electric vehicles with the need to manage electric batteries
- Considerable number of stationary and mobile batteries and other storage systems available with the option to store and release electricity.

**Lead Stakeholders:**

DSO’s, consumers, distributed electricity generator, electric vehicle owners, storage service providers, Retailers, Aggregators, ESCOs

**Task:**

D.1: Distribution system power and energy management strategies including storage and demand response

**All tasks of research area IS (Integrated Systems) and SE (Socio-Economical and Ecosystem research issues) have a strong effect of how the distribution system by 2035 will function. In addition, we define a special task dedicated for the distribution system.**

### **TASK D.1: Distribution system power and energy management strategies including storage and demand response**

**Purpose: To achieve flexible, price and system state sensitive use of masses of small-scale, distributed consumer devices.**

#### **Demand response for Secure Distribution Grids**

Demand response programs based on basic technologies, will by 2035 already be implemented in various countries in Europe and will have fully proven their efficiency for the overall power system, bringing several important environmental and financial benefits within today’s electricity markets.

Indeed, prosumer equipment controls or price based incentives for demand response substantially reduce the need for investment in peaking generation by shifting consumption away from peak load hours. In that sense, demand response is more and more integrated towards improved security of supply mechanisms, as for instance in generation capacity markets. Demand response also acts as a cost effective GHG (Green-house gases) free balancing resource for renewables generation.

The development of advanced ICT, combined with smart metering programs opens the need for large R&D fields with the goal to achieve higher efficiency and to increase time of day flexibility of the electrical equipment at consumer’s sites. One of the challenges will be to develop solutions and processes to fully integrate flexible equipment to contribute to the optimization of the management of the power system locally and globally, and in a time-dynamic way during the hours, minutes or even seconds of a day. In that sense, research has to be focused on the intra-day dynamic management of demand response.

For houses and buildings demand response is only one possibility of many. The real challenge is about global energy management in terms of integration with all energy needs within the buildings.

By 2035 the energy management within buildings will have to take into account important features like the maintained or increased comfort of inhabitants, the compliance to increased requirements in favour of energy savings and the environment, the ability to manage man-machine interactions (displays, remote information/actions of smartphones...), the necessary interoperability between equipment, controllers, and the power system, energy storage (thermal and/or electric), sensors and other smart appliances spread in buildings or

houses. All improvements are linked to global economics based on costs/benefits analysis that will derive the most efficient solutions.

### **Secure Distribution Grids control strategies**

In the context of large distributed generation penetration, a more flexible management at the distribution level and an optimized responsibility partitioning between the TSOs, DSOs and DGs are required. Indeed, the high level of distributed generation (DG) connected to the distribution grid will also lead to important constraints for DSOs, facing difficulties to define and operate satisfactory solutions for all players, and add unnecessary costs.

First, the challenges for more flexibility in the distribution grid are to develop new solutions (technology innovation: sensors, power electronics, new SmartGrids devices, etc.) and strategies to ensure an efficient control of networks coupling with both centralized and decentralized intelligence. The spectrum of control strategy options is widely open and contributions of distributed energy resources to local and overall grid stability and quality of service have to be considered so far. Specific research has to be focused on the low voltage (LV) networks where PV and micro generation strongly increase and which will by 2035 be automated and precisely observed by monitoring equipment.

The above developments by 2035 need to be supported by full observability of the distribution grid including LV and local "energy hub" – with less sensors, low accuracy but taking advantage of (huge) monitored data volumes made available by smart meters and monitoring devices. For the LV network, considering the vast majority of appliances (e.g.: low consumption bulbs, TVs, computers, electronic appliances, PV generation, electrical vehicles, etc.) by 2035 using DC in their internals, R&D challenges are to explore if DC could be an option for the next future in a more technical and cost effective way. Innovative equipment and systems must ensure that the level of quality of service at the LV level is maintained or increased.

But the "hybridization" of electrical & telecommunication networks needs an overall assessment of risks on the reliability of the network operation and power system management. Indeed interconnection of complex systems from generators to consumers through open standardised protocols will bring serious challenges in terms of handling overall system-security.

Depending on how new energy-markets are created and by introducing dynamic automated or semi-automated transactional mechanisms, new operational risks by system-instability could emerge by 2035. This calls for research in complex system stability and as a follow-up might require new regulatory frameworks to assign new responsibilities and duties.

### **Increased role of storage in distribution grids**

However, in the frame of SmartGrids, the energy storage technologies that are emerging into electrical power systems (namely batteries of various technologies, flywheels, super-capacitors, etc.) can be considered as "distributed" energy storage. For these "distributed" energy storage solutions, the future is more uncertain than for centralized (bulk) energy storage that follows a quite good development in Europe (and a large one in Asia). In this field, new developments of compressed air energy storage, and especially its adiabatic version, seem very promising to follow and demonstrate.

One major challenge is to prove a positive economic value for energy storage. New and more widely used energy storage technologies still – by 2011 – face high investment costs and often insufficient performance (e.g. losses, lifetime). But, by 2035, costs will decrease for some technologies, mostly batteries.

However progress in storage technology will not be sufficient to prepare the future of energy storage in European power systems by 2035. An investment/risks/benefits sharing between different players is needed to catch the maximum of energy storage added value. In other words, the energy storage topic is highly transversal and strongly linked with other political, regulatory, technical topics. The answer to the question of the global economic value of massive distributed storage is therefore quite complicated, and is one of the most important topics for R&D in the perspective of 2035.

The main challenges will be around the development of distributed energy storage technologies (mainly in the range of kWh per storage device, and less, to MWh) and the assessment of the value (social surplus) it could bring to the power system at different locations, for different purposes and players, especially in distribution grids, in communities, or even at home.

Many researches and demonstrators are currently (2011) already under way in Japan, USA, and Europe.



These initiatives will lead to the emergence of innovative and valuable applications and source of fierce competition for industry.

Economics (and also regulations defined in legal frameworks) are currently often considered as barriers. However, other innovative development drivers could emerge and pull distributed energy storage development e.g.: very innovative uses for energy storage, marketing, emerging needs of some consumers for being autonomous in energy or mastering high-tech appliances.

### **Distribution system management for and with EV's (Electric Vehicles)**

EV charging could have a lot of potential impact on distribution system operation especially with a significant disproportion in the increase in peak demand and overall energy demand, but also other impacts like:

- Generation and markets: increase of committed capacity, use of peaking plants with higher CO<sub>2</sub>-emissions and reserve requirements; higher electricity prices at peak
- T&D networks: congestions in transmission networks, high risk of local constraints in distribution networks, need for operating closer to the network limits, network reinforcement costs, disturbances on power quality due to EV connections: increasing the contracted power, new or reinforced connections to the grid, increase of electricity prices

On the contrary, controlling EV charge and V2G (Vehicle to grid) opens diverse opportunities to support "smart" power and distribution system operation and contribute to improve flexibility:

- Generation and markets: shaping demand to reduce marginal cost of generation, reduce price volatility, contribute to the integration of intermittent generation, increase output of low CO<sub>2</sub>-emissions plant
- T&D networks: support the TSOs transmission congestion and DSOs local grid constraints management, provide frequency regulation services, reactive power support, reduce or postpone the need for network reinforcement
- Consumers: reduce the mobility cost by selling flexibility services, open the ability of using EV battery to provide V2G services

Controlling EV charging requires an interaction with the consumers which can be done with:

- Fixed tariff signals (fixed for long periods such as a year) do not require advanced ICT but do not allow direct interaction nor visibility of the EV status
- Unidirectional signals are simple systems taking account network local constraints, but not giving visibility of the EV status
- Bidirectional communication requires more complex ICT systems, but allows direct interaction with the EV and full visibility of the EV status
- Real-time price signals may be used to influence the EV charging times but require advanced ICT and interaction with the user.

R&D challenges cover both technology and economics elements:

- The choice of the adequate control strategies needs to be based on a cost/benefit analysis of solutions with different levels of complexity and different scenarios of EV deployment. User defined charging strategies without additional communication requirements would, however, keep installation costs low. Future solutions should try to keep additional costs as low as possible to enable higher penetration of EV's.
- The feasibility and the cost of flexibility services which could be generated by EV deployment have to be assessed. The aggregation function facilitates the provision of flexibility services by EV's, given the volumes and time-scales required to participate in different markets. Key factors influencing the value of EV flexibility services are:
  - System factors: supply price curve, flexibility of the generation mix, penetration of intermittent generation
  - EV factors: mark-up for the services, connection power, level of EV penetration
  - Consumer factors: possibility of controlling charge/discharge power, driving patterns (km/day)
  - Network factors: impact on grid reinforcement, mitigation of congestion risks, etc.

The value of the EV flexibility services is system specific and very sensitive to the charging power, efficiency losses and battery degradation costs. Further development of models for the value assessment of flexibility services able to capture the complexity of system operation, is required.

- Market Based Approach with different scenarios to be designed and tested like pragmatic slow charge (spread in charging in time and location - e.g. at home - to departure time next morning), or decentralized market based approach (EV "decides locally" when to charge/discharge according to price signals

- including costs of generation and costs of network constraints). Decentralized market based approaches improve the ability of integrating EV but require complex ICT and a migration from centralized to decentralized markets.

- More cost/benefit assessment studies, field trials, pilots and standardization are needed in order to implement advanced strategies. Indeed complicated models may require more intelligence and hence significantly high ICT costs.

When assuming a strong increase of electric and plug-in hybrid vehicles by 2035, research topics are numerous in order to design and implement solutions ensuring a more flexible and cost effective power system management for the whole community.

## SmartGrids 2035 Research Topics in research area D (Smart Distribution Systems)

The SRA 2035 defines the following **research topics** with sub-topics for research area D:

| <b>D01</b> | <b>Smart, flexible distributed demand and generation response for Secure Distribution System Control</b>  |
|------------|---|
| a          | Smart demand response and renewable, distributed generation control for secure Distribution System Control and services                           |
| b          | Development of self-adapting and self-healing distribution networks and assessment of reliability, redundancy and self-healing                    |
| c          | Distribution Cell Structures: Local energy management for partly or full self-supplied local distribution areas even with degraded operating      |
| d          | Devices and systems for more automation and flexibility in the LV network in an economically suitable way   |
| e          | Flexible LV and MV network control strategies with increasing automation and making the best use of new equipment in an economically suitable way |
| f          | Observability of the LV and MV distribution grids in a cost effective way (e.g. number of sensors, coupling with AMM data management)             |
| g          | LV and MV Advanced monitoring and operational planning  |

| <b>D02a</b> | <b>Extended Distribution System Protection across the value chain</b> |
|-------------|---|
|-------------|---|

| <b>D03</b> | <b>Integrated Distributed Energy Storage infrastructure planning in distribution systems</b>  |
|------------|---|
| a          | Stationary storage integration into distribution planning   |
| b          | Effects and use of very dispersed energy storage: very small size storage technologies included in domestic appliances, PV panels and domestic networks |
| c          | Portable energy storage (tens or hundreds watts range), with intelligent grid charging  |

| <b>D04</b> | <b>EV integration into Distribution systems</b>  |
|------------|--|
| a          | Charging of EV's shifted to valleys of demand if the grid state is fragile, e.g. with local RES supply at times when the load on the grid must be reduced  |
| b          | Development and assessment of technical EV options (connection, charging,...) and communication technologies and systems allowing EV management  |
| c          | Assessment of feasibility and value of flexibility services generated by EV deployment - identification of key factors influencing the value   |
| d          | Establishment of clear roles and interactions amongst EV and relevant stakeholders (DSOs, retailers, aggregators, municipalities etc.)   |
| e          | Clear definition of the terms and conditions of the e-roaming related agreements among involved market players   |
| f          | EV integration into distribution planning  |
| g          | To investigate how EVs could be utilised as an energy storage/back-up generation capacity during forced outages. The benefit of energy storage during an outage is much higher than during normal operation. |

|             |  |
|-------------|--|
| <b>D05a</b> | <b>Risk Based DSO Operation: Real time calculations to identify additive margins offered by line monitoring, could help to solve critical situations</b> |
|-------------|--|

|            |   |
|------------|---|
| <b>D06</b> | <b>ICT System security for Distribution Operation</b>   |
| a          | Cyber security of electrical power systems through the protection of all IT systems linked to the operation, metering, end-use of electricity                         |
| b          | Modelling of electrical power systems and IT systems to assess the impacts of failures in both systems operating with close interactions                              |
| c          | New standards for IT systems based on their potential impact on power system security   |
| d          | Ability to keep a high level of security of supply of electricity even if telecommunication networks fail or are attacked (redundancy of information, degraded modes) |

|             |  |
|-------------|--|
| <b>D07a</b> | <b>Power Electronics Technology for Smart Distribution</b> |
|-------------|--|

|            |  |
|------------|--|
| <b>D08</b> | <b>DC: an option for the LV grid in the future</b>   |
| a          | Structure and equipment of a DC network: in home area or in a secondary substation area                                |
| b          | Number of connections with the AC network; number of DC converters, impact on global losses, compared to an AC network |
| c          | Impact on power quality, stability of DC networks, protection schemes  |
| d          | Mastering the level of harmonics on AC networks facing the massive use of DC   |
| e          | New DC standards   |
| f          | Assessment of retrofit strategies of already built existent LV networks  |

From the research defined by this SmartGrids research area D the following technologies shall be provided:

### **Research Area D (Smart Distribution Systems): Key Technology, Hard- and Software**

#### **SmartGrids Electro-Technology**

- Smart meters with voltage and current transformers, asymmetric power meters, magnetic, electric and field and frequency sensors, GPS location and time; Actuators for DER, flexible power electronics adapted to DER
- Electrical protection technology adapted to DER including new switch technologies and smart transformers; Sensors capturing information about power flows, power quality (harmonics, etc), remaining capacity (dynamic rating) and other physical properties (temperature in cables, gas analysis in transformers, etc.)
- Small size storage (very small size storage technologies included in domestic appliances and domestic networks; portable energy storage with tens or hundreds watts range with intelligent grid charging capability.
- Charging infrastructure (including sensors & actuators)

#### **SmartGrids ICT**

- Communication infrastructure
- Smart meter communication infrastructure and technology such as PLC, GPRS, ISDN, PSTN, broadband access networks; communication gateways, data concentrators; home communication infrastructure such as wireless (e.g. radio chip technology) and/or wireline e.g. PLC
- EV charging communication infrastructure ranging from simple solutions to more complex strategies as EV penetration increases
- Smart User Appliances: Built-in sensors for energy use and grid parameters (voltage, frequency, phasor, harmonics, flicker, etc.) within electrical equipment and internet-linked objects and equipment controls (actuators); simple, accurate, reliable, and intuitive displays and interfaces for the inhabitants/electricity consumers

#### **SmartGrids Software**

- Tools for model-predictive and auto-adaptive optimization processes (grid state monitoring, optimization & control): directly contributing to optimization of the power system operation locally and globally and in



a time-dynamic way (intra-day dynamic management of demand response); Data concentrator tools and algorithms

- Tools for distribution grid planning and operation; Grid model based distribution management tools e.g. taking into account new capabilities of RES capacity integrated in the grid by means of power electronics, exploring micro-grid concepts and the possibility for DC connections between distribution generation and storage systems
- Tools for storage optimization and control algorithms with the aim to contribute to grid stability
- Tools for E-mobility optimization and control algorithms for the optimization of grid states (peak management, price dependent, dependent on weather, sun shine, wind, etc.) depending on business models (e.g. fitting to decentralised market based approach)

### **SmartGrids ICT SW at consumer side**

- Model-predictive and auto-adaptive optimization processes and tools for home energy use monitoring, optimization and control: indirectly (by decentralized, distributed mechanisms) contributing to optimization of the power system locally and globally and for the local user needs in a time-dynamic way (intra-day dynamic management of demand response)
- Storage optimization and control algorithm for the consumer and grid stability requirements
- E-mobility optimization and control algorithms (depending on business models) for the consumer and grid stability requirements

### **Research area T “Smart Electricity Transmission Systems”**

**Purpose:** “Technologies to enable the integration of large renewable generation, flexible large storage and large consumers in transmission systems by 2035”

**Triggers:** Research in area T is triggered by changes expected between 2020 and 2035:

- Strongly increased the percentage of off-shore stochastic renewable-based wind and distant solar generation connected at the transmission grid in concentrated parts of the Sea in Northern Europe and in the south
- A part of the new HVDC transmission grids layer will be realized connecting the hydro power reservoirs in the Nordic countries and the Alps to balance the volatility of the North-Seas wind power generation and solar (-thermal) power generation in the south
- Due to the low storage capabilities attached to the distribution system, strongly varying power flows will appear from distribution towards transmission and vice versa
- A large number of the presently operating nuclear power generators in the European countries are phased out and switched off
- Increased public opposition against new grid infrastructure.

#### **Lead Stakeholders:**

TSO, Large Scale renewable generators, Bulk Storage providers, Hydro generators, Large industrial consumers

#### **Tasks:**

T.1: Transmission networks of the future – long distance power wheeling at affordable costs

T.2: HVDC and underground/under water transmission grids of the future – new architectures and new equipment

T.3: System technologies and incentives for flexible electricity consumption of large scale consumers

**All tasks of research area IS (Integrated Systems) and some of SE (Socio-Economical and Ecosystem research) have a strong effect of how the transmission system by 2035 must function. In addition, we define special tasks dedicated to the transmission system.**

### **TASK T.1 Transmission networks of the future – long distance power wheeling at affordable costs**

*Research must contribute towards*

- Demonstration installations of long distance VSC HVDC (Voltage Source Converter High Voltage Direct Current)
- Tools for truly meshed overlay DC and/or AC grids



- Questions if Europe needs 800 kV DC or higher voltage transmission, i.e. research contributions towards what voltage level Europe ultimately needs
- Alternatives to DC for bulk power transmission, e.g. superconducting, UHV DC (Ultra High Voltage DC), gas insulated lines.
- Tools for the operation of hybrid AC/DC grids
- Driving down costs for undergrounded transmission solutions.

The long distance transmission infrastructure by 2035 has to be operated harmoniously with the existing grid. The reliability of the global system has to be studied, with focus on the dynamic behavior of the combination of various technologies and transients and overloads in case of loss of high capacity links. This calls for adequate grid architecture, new terminal equipment, protection strategy, devices, and security criteria (for hybrid grids or for meshed DC grids).

The supervision and control of this long distance network has to be organized along the actual structures, while complemented with a global structure able to deal with management of transnational flows and contingencies.

As the benefits from the long distance transmission infrastructure are spread over generators and consumers in different members states, adequate arrangements to allocate the costs to tariff payers have to be developed.

### **TASK T.2 HVDC and under-ground / under water transmission grids of the future – new architectures and new equipment**

The need to transmit increasingly large amounts of electric energy over increasingly long distances is brought about by different factors, not least of which is the development of large renewable energy sources. Satisfying the very long distance or the subsea transmission needs with traditional AC transmission of up to 500 kV can be very difficult or expensive; stability, right-of-way, and infrastructure permitting problems can cause difficulties. Employing DC transmission technology can alleviate several of these problems, partly thanks to recent technical advances in insulation techniques for voltages above 750 kV, in high voltage extruded cables, and in AC/DC converters. For long subsea distances, DC cables are the only option.

It is anticipated that the HVDC grids of the future will move away from solely inter-connectors, between regions or countries, radial off-shore wind farm connections and limited multi-terminal systems. When in close proximity at both the offshore and onshore stations, multiple radial wind farm connections are not the optimum economic or technical solution. Connecting the off-shore terminals to form a grid, with fewer larger radial feeds to shore, will lead to significant cost reductions and ease the connection problems (way-leaves, consents, etc.) onshore. From such individual systems the grid of the future will evolve.

The prime function of the future grid will be the transmission and balancing of remote sources of renewable power, e.g. wind, solar and hydro. Due to the distances involved in Western Europe, for primarily an under-ground and underwater cable system, HVDC will be the preferred technology. As an asynchronous means of interconnection, with precise controllable power flow and the ability to improve stability at the connections to the existing HVAC grid, HVDC will bring added functionality to the operation of the interconnected European grid. At the same time, it will need more controllability. The development of Voltage Sourced Converter (VSC) HVDC technology, with its smaller substation footprint (50 – 60% of conventional HVDC technology), the ability to control reactive power consumption/production at the converter stations, and the very limited harmonic distortion, has created an ideal technology for the connection of off-shore wind farms.

Possible Technologies for such Smart and Super grids are:

- HVDC Smart Grid Solutions with VSC (voltage sourced converters)
  - Modular Multilevel Converters
- HVDC Super Grid Solutions with FACTS and HVDC Classic and Bulk
- HVAC Super Grid Solutions with Gas Insulated Lines (GIL)

#### **Future requirements with focus on HVDC solutions**

Some limitations for a Supergrid are already known: fault currents; HVDC voltage drops in extended HVDC networks; load flow control in meshed HVDC networks; reliability and security standards for Supergrid; N-1; etc. The solutions for future networks will have to overcome them.

At present (2011), technologies have converged to a common solution, which is the Modular Multi-level Con-

verter (MMC). This technology creates a controllable output voltage waveform by switching in (and out) many individual HVDC capacitors in the correct sequence. The resultant waveform is virtually a perfect sine-wave and is controllable in both magnitude and phase angle, allowing the converter to control active and reactive power flow. The latter function is critical for connection to weak HVAC systems, e.g. wind farms.

When Multi-terminal HVDC networks or HVDC Grids are to be developed, interoperability of the equipment provided by different manufacturers becomes important. In a first step, agreement on some fundamental operating principles of HVDC networks is needed, such as:

- Fault behavior
  - Short circuit currents of converter stations,
  - Location of fault clearing devices (at each converter station or at each HVDC feeder)
  - Handling HVDC faults of VSC links (or grids).
- Power system protection
  - Separation of normal transients from fault relays and communication to selectively detect faults
  - Fault clearing mechanisms (fault current and overvoltage limitation)
  - Converter control and protection: sequences for start-up and shut-down of converter stations; HVDC grid controls.

To ensure optimized development of the future integrated grid it is critical to agree on basic principles for the technologies.

Additional innovative products and apparatus will be needed to propose a thorough solution for a wide area HVDC grid:

- HVDC circuit breakers are key for the SmartGrids 2035. A fault in one cable section will need to be detected and cleared within “ms” to ensure that the rest of the grid remains in operation.
- Rapid detection (1 – 2 ms) and discrimination of the fault and fast acting protection system.
- HVDC – HVDC converter and HVDC “transformer”. Such technology is widely available at low voltage and in some cases at medium voltage, but not at the high HVDC voltages (320 – 500 kV) and power ratings (1000 – 3000 MW) which would be required by a future HVDC grid.

Finally, additional key features of the future HVDC grid will be standardization and inter-operability. The former will require the use of a common HVDC voltage throughout the grid, to allow interconnection of the disparate sections as the grid evolves. The latter will require coordination on control and protection issues as discussed above.

These issues are being addressed in various technical bodies, such as CIGRE and CENELEC, and reports being prepared by individual TSOs, the EU.

### **TASK T.3: System technologies and incentives for flexible electricity consumption of large scale consumers**

It is expected that also large scale industrial consumers wish and need to contribute to the security of the electricity system. Research is needed on which incentives, monitoring and control means large consumers need to get more involved in the processes of electric grid operators contributing to an all-time secure operation of electricity grids.

#### **SmartGrids 2035 Research Topics in research area T (Smart Transmission)**

The SRA 2035 defines the following research topics with sub-topics for research area T:

| <b>T01</b> | <b>Transmission Grid Infrastructures</b>   |
|------------|--|
| a          | Transmission infrastructure in the sea and densely populated areas with cables, gas insulated lines, overhead lines and super conductive links.  |
| b          | Transmission Grid Infrastructure Research for <ul style="list-style-type: none"> <li>• Capacity: long distance links with much more capacity compared to today’s 400 kV overhead lines</li> <li>• Cost expressed in €/GW.km driven down, depending on the technology</li> <li>• Reduced relative losses</li> </ul> |



|             |  |
|-------------|--|
| <b>T02</b>  | <b>HVDC Grid based system</b>  |
| a           | HVDC models, combined HVDC and HVAC system models and algorithms   |
| b           | HVDC Systems Research for <ul style="list-style-type: none"> <li>• Handling much more wind and PV</li> <li>• Designing the DC offshore grid</li> <li>• Meshed overlay grid</li> <li>• Improved interoperability between suppliers</li> <li>• New grid codes</li> <li>• New architectures of the transmission HVDC grid and effects on the distribution grid including voltage, flow and cable temperature control</li> </ul> |
| <b>T03a</b> | <b>Bulk Energy Storage infrastructure, planning, integration, operation</b>  |
| <b>T04</b>  | <b>Long distance electricity wheeling</b>  |
| a           | Control / flatten the variability of transmission grid flows by connecting uncorrelated renewable energy sources   |
| <b>T05</b>  | <b>Energy carrier technologies for the energy service consumer</b>   |
| a           | Hybrid consumer flexibility to choose between different energy carriers (heat, electricity, gas). Technologies to obtain an integral view and a hybrid optimization method and convergent control.   |
| <b>T06a</b> | <b>Incentives, monitoring and controls for large scale consumers, actively contributing to an all-time secure operation of the (transmission) grids</b>  |

With the research defined by this SmartGrids research area T the following technologies shall be provided:

### **Research Area T (Smart Transmission Systems): Key Technology, Hard- and Software**

#### **SmartGrids Electro-Technology**

- HVDC Smart Grid Solutions with VSC (voltage sourced converters) and Modular Multi-level Converter (MMC)
- HVDC Classic Super Grid Solutions
- HVAC Super Grid Solutions with FACTS and
- HVAC Super Grid Solutions with Gas Insulated Lines (GIL)
- Fault clearing devices
- Power system protection (including converter control & protection) devices
- HVDC circuit breakers
- HVDC – HVDC converter and HVDC “transformer” at high HVDC voltages and power ratings
- Other technologies: UHV AC (Ultra High Voltage AC), UHV DC, gas insulated lines, UHV XLPE cables

#### **SmartGrids Software**

- Tools for long distance grid supervision and control (organised along the actual structures but complemented with a global structure able to deal with management of transnational flows and contingencies)
- Tools for the operation of hybrid HVAC/HVDC transmission grids
- Tools for truly meshed overlay transmission grids

### **Research area TD “Smart Electricity Transmission & Distribution Systems”**

Some issues are common to both the Transmission and the Distribution systems. The research area for these issues is called T&D (Research Area “Transmission & Distribution”).

We define the following task for this research area T&D:

## TASK TD.1 Network Asset Management

**Purpose: "Minimizing grid assets investments and maintenance costs while keeping asset health as high as possible"**

Any advanced asset management system has to take into account expected lifetime and the expected time to failure of the assets. Such a system has not only to evaluate these parameters according to forecasting models, but it has also to measure a sound number of parameters in order to improve forecast techniques. This system will steer investments driven by reduction of network losses or overall expected time to failure.

An asset management system for a network operator has to keep updated information on the equipment deployed by taking into account:

- a) commissioning and decommissioning of the devices
- b) historical information of the device operations
- c) aging of the devices due to time and weather conditions.

This information should be fed into forecasting models in order to evaluate devices' expected time to failure as well as devices' efficacy and efficiency. Research activities shall focus on improving forecasting models as well as the devices, e.g., new devices have to be designed allowing measurement of the parameters forecasting models are more sensitive to.

Furthermore research activities as well as applied research shall focus on designing back-compatible solutions in order to improve asset management of already deployed devices (particularly focusing on long lasting devices like power devices).

On top of monitoring devices and forecasting models, advanced tools have to be designed in order to optimize network operations, particularly focusing on optimizing a given benefit with respect to the invested amount. The asset management systems have to steer investments in order to meet different requirements like the reduction of network losses or the improvement of network reliability and quality of service. Given network topology, operation conditions and the deployed assets, these tools have to be able to perform a sensitivity analysis addressing the equipment that are mostly impacting network efficiency, efficacy and reliability. Furthermore, the tools shall also be able to depict a temporal evolution of the network identifying current bottlenecks or possible points of failure as well as future ones.

### SmartGrids 2035 Research Topics in research area TD (Smart Transmission & Distribution Systems)

The SRA 2035 defines the following **research topics** with sub-topics for research area TD:

| TD01 | Grid Asset System Planning (life cycle)  |
|------|--|
| a    | Decision support for grid planning: Asset management tools to support decisions related to network design and planning taking into account the deployed grid but also the available technological solutions  |
| b    | Risk Based Asset Management: Stochastic models and methods for operation, based on the reliability of each component to decide the safest network topology and operation scheme  |
| c    | Economics of Asset Management: designed solutions and proposed equipment as possible compatible, interoperable and standardized  |
| d    | Models for physical ageing phenomena: To be able to predict expected lifetime and over load capabilities of critical components in the grid, better models for physical ageing phenomena on components and materials are needed. The models should take into account input from existing and future sensors installed in the smart grid. |

## Research area RC “Smart Retail and Consumer Technologies”

**Definition:** The term “consumer” is used in this SRA 2035 for the one who consumes the goods/products and services supplied by an energy or electricity system. The aggregation of (small) consumers or the collective effects of many consumers has a strong effect on the economy of the energy and electricity system.

Often consumer and customer are used in an interchangeable way. In this SRA 2035, however, a customer is the recipient of a good, service, product, or idea, obtained from a seller, vendor, or supplier for a monetary or other valuable consideration. Clearly, in the new SmartGrids system, also DSOs, TSOs, balancing groups, wholesale traders are customer of many others. “Customer” is a general term for participants in a market based environment.

In the SRA 2035, in this research area RC, we talk about “consumers” in the role of energy products and services customers.

The research area RC concentrates on necessary new developments on the consumer premises.

**Retail**<sup>5</sup> includes subordinated services, such as delivery to consumers as customers. Purchasers may be individuals or businesses. In commerce, a “retailer” buys goods or products in large quantities from manufacturers or importers, either directly or through a wholesaler, and then sells smaller quantities to the end-user. Retailers are at the end of the supply chain. Retailing is often seen as a necessary part of the overall distribution strategy. The term “retailer” is also applied where a service provider services the needs of a large number of individuals, such as a public utility, like electric power.

**Purpose:** “SmartGrids for the Integration of Retail and Consumer Requirements by 2035”

**Triggers:** Research in area RC is triggered by changes expected between 2020 and 2035.

- The needs of consumers and those that provide services for them directly for
  - Designing, building, operating and maintaining the grid for a secure, sustainable and economical Electricity System by 2035 ... 2050
  - Integrating electricity, gas and heat and other utility (-like) services - as the consumer does not think in terms of the e- or g-grid, but only in what is needed to sustain a certain lifestyle
- The needs for a more transitional, step-by-step approach in which consumers, industry and government collectively develop the possibilities and needs of our future energy system.

### Lead Stakeholders:

Consumers, distributed electricity generators owners, electric vehicle owners, distributed storage owners, retailers, aggregators

### Tasks:

RC.1: Retail and Consumer Information and Communication Technology Infrastructures

RC.2: Retail and Consumer Energy Services & Management

RC.3: Consumer Interfacing Technologies

RC.4: Consumer Driven markets

RC.5: Active Consumer Programs

**All tasks of research area IS (Integrated Systems) and of area SE (Socio-Economical and Ecosystem research) have a strong effect of how the retail and consumer systems by 2035 must function. In addition, we define special tasks dedicated to the retail and consumers.**

## Introduction

New mechanisms are needed to match supply and demand at all times. Active participation of the users connected to the grid is of crucial importance to keep the system balance between generation and demand and considering at the same time grid inherent constraints.

<sup>5</sup> Partially taken from Wikipedia



Consumers are the key stakeholders on the electricity demand side, and can play a role on the electricity supply side too (prosumers). New markets will emerge where services are offered by multiple parties, giving the consumers a choice in whether and how to co-operate in the system. New services to consumers will emerge requiring the consumer to be actively involved.

New solutions are needed to increase the flexibility in the system. The solutions must be heterogeneous in terms of technology and implementation and able to co-exist without limiting the free choice by consumers how they would like to participate.

Since active participation is crucial, the Research Area RC focusses on how to enable new balancing mechanisms that involve consumer participation. The research will address the opportunities and barriers for existing and new players in the market to offer services that support the new "active" balancing mechanisms. One important barrier to overcome is how to make consumers aware, willing and able to actively participate and adapt their behaviour.

Research Area RC together with Research Area SE aims at defining the technological, psychological, sociological and economical preconditions and requirements for "Active consumer participation".

A transition approach for getting consumers to become more active and involved is very challenging:

- Predicting future (long term) consumer needs in a constantly changing world is nearly impossible, also, since technological, legal and political aspects of our future energy systems are still evolving.
- Three dimensions to change behavior and create involvement are awareness, motivation, and ability. The way to approach these dimensions changes over time.
- Energy use of consumers is based on routines and habits, both complicated and difficult to change.
- Behaviour can be changed or influenced by values and attitudes, other people's behaviours, and various economic incentives and constraints (Consumer psychology), behaviour, loyalty, value and profitability.

These topics are outside of the core technology oriented research of the SRA 2035. They are, however, subject to Socio-Economical and Ecosystem research described in area SE.

## **TASK RC.1 Retail and Consumer Information and Communication Technology Infrastructures**

**Purpose: "Creation and enhancement of enabling ICT architectures (smart living, energy internet)"**

This research task addresses the information and communication architectures that allow the energy resources to be connected to the ICT infrastructure in a generic manner. The communication infrastructure is by nature heterogeneous (Home networks, Local Area Networks, Wide Area Networks, Fixed line, Mobile). Abstraction of heterogeneous physical communication infrastructures to a generic level is an essential part of the research topics. The infrastructure will have basic functions and services, such as device handling and management, zero configuration capabilities, automatic service discovery and resilience capabilities. It is important to leverage results from projects on topics such as future Internet, Internet of things and smart living into the energy domain.

Today (2011), several other industrial branches are well ahead of the energy business in this respect (e.g. home entertainment, security systems and mobile Internet applications). Whenever standards and research are available in these areas they should be incorporated in the roadmap of the energy industry.

Research in this task is focussed on:

- Uniform communication architectures in heterogeneous implementations: Uniform in the sense that clear, well defined services/interfaces are offered to the service and management layer
- Addressing the different communication architectures: home, local, regional, global and the fact that they may be used for more than just energy management services (also known as the smart living concept).
- Information modelling of energy resources and information infrastructure capabilities: Express characteristics of energy resources and information infrastructure in a standardized manner
- Basic infrastructure services such as device management, service discovery and resilience functions.

## **TASK RC.2 Retail and Consumer Energy Services & Management**

**Purpose: “Alignment of Retail and Consumer energy service platforms and service management frameworks”**

Various technologies for e.g. demand and supply matching, dynamic pricing, energy feedback and others are under development; technologies which will underpin smart energy service offerings from utilities, aggregators or other (new) actors in the energy market. In such a heterogeneous ecosystem, inefficiencies may be introduced due to a fragmented technology landscape. Consumers may be limited in their selection of energy service providers due to technology lock-in; also in turn energy service providers may suffer from the same technological lock-in. SmartGrids technologies will most likely continue to evolve for the next decades; also new business models for smart energy services are just emerging and won't stabilize anytime soon.

The main objective and purpose of this task is to resolve this impasse through the research and development of platforms enabling the integration of heterogeneous SmartGrids technologies and energy services and allowing new business models to emerge. These platforms enhance innovation both in technologies as well as smart energy services. This requires research into and development of the interoperation between SmartGrids technologies as well as between these technologies and the services built upon them. Furthermore operational management challenges of such large scale distributed systems must be addressed to support the full lifecycle of services in terms of fulfilment, assurance, billing and accounting.

The research in this task is focussed on:

- Enabling consumer choice: The consumer should be able to choose how to participate in the energy system. Choices could be which service provider, which type of service, with or without local generation.
- Proving service platforms and management: Frameworks to create and deploy energy services. E.g. composition using service building blocks, information sharing mechanisms using information already available by other services (separation of hardware, sensor information, existing home energy management systems) and applications.
- Managing heterogeneity: There is no single solution for energy services and no single supplier of services. Solutions need to co-exist and co-operate. Agreements on standards to use, levels of interoperability need to be defined. Components should be replaceable without changing the system (modularity)
- Handling the varying requirements of consumers of different size: Management challenges and service platform requirements will be different depending on the demand side program involved and also the size of the consumers involved. This is especially true for commercial and industrial consumers.

This task addresses the issues related to the layer of service platforms for energy services and the related operational management challenges. Service platforms will be used to create or orchestrate service components for energy services to consumers. Services will be offered by multiple service providers. The platform needs to be able to support new market and business models. Management services are required to manage the lifecycle of the service in terms of fulfilment, assurance, billing and accounting.

## **TASK RC.3 Consumer Interfacing Technologies**

**Purpose: “Enabling (human) interactions”**

This research task addresses the layer above the service layer concerning interface technologies required and desired at the consumer premises. It is mainly concerned with the possible human interactions with the demand side management system on the consumers' premises, and the interaction of this system with the energy services and energy markets.

Research in this task is focussed on:

- Service management by the consumer: Offering human interfaces that will allow the consumer to make decisions on his planned demand or generation.
- Level of automation of demand response (including load management): The control decisions are based on agreements between stakeholders (service providers, suppliers, consumers, DSO), but constraints may apply (availability of generation, intermittence, price, grid constraints)
- Home Energy Management Systems.

## **TASK RC.4 Consumer Driven markets**

### **Purpose: “Developing Market Models for Energy Services, developing a Platform for consumer services”**

The research area focuses on wholesale market structures, consumer access to these markets and the influence on demand side development and third party competition.

- Enabling new energy market propositions by providing the proper technologies and standards for supporting these propositions
- Consumers are needed to play a more active role in future energy systems. This consequently requires a higher level of involvement. In addition, it sets the need for a technological and legal framework in which roles are defined and data can be exchanged between appropriate parties in a secure and safe manner.
- Some new and existent roles (e.g. aggregator) and responsibilities will have to be open to new entrants in order to stimulate market innovation.
- A transparent technological and legal framework will provide the opportunity for new business models to emerge.
- Demand response and wind/solar integration, and consumer’s ability to replace or cooperate with balancing generation.
- Market creation and an analysis of the opening of wholesale market structures appropriate for demand side products.
- Access to wholesale markets by suppliers, aggregators, ESCOs and end-consumers and their influence on competition.
- The influence of capacity markets, reserves margin requirements and reserves markets on demand side ability to lower the cost of wind integration.
- The impact of wholesale market structures on other SmartGrids applications such as prosumers, EVs and residential program development.

## **TASK RC.5 Active Consumer Programs**

### **Purpose: “Increase consumer involvement and mechanisms to change behaviour”**

The objective of this task is to create an enabling environment where the available SmartGrids related technologies, services, policies, infrastructures and social issues not only encourage but facilitate increased consumer involvement/engagement in both creation/development and the implementation/operation of these technologies, services etc.

This consumer engagement will result in a system that will invite and sustain the behavioural changes necessary (including acceptance of technologies, services and other issues) to ensure the successful implementation and operation of SmartGrids and the related assets.

These behavioural changes are twofold. They involve both changes in the daily routine of consumers (e.g. turning down the thermostat, switching off lights, reducing showering time); and they involve investment behaviour (e.g. investing in energy efficient technologies and/or smart and efficient appliances or enabling technologies such as smart meters and accompanying displays). Changing routine is more difficult than changing investment behaviour, but routine behaviour is key to create an optimal balance between demand and supply.

Three dimensions are known to change behaviour and create involvement: awareness, motivation and ability. Being aware includes understanding the general importance and need for a behavioural change and the specific knowledge on how to contribute to that personally. Motivation can be driven by more intrinsic beliefs, values and norms, but can also be motivation from the social context. Ability is the way in which technical, legal and personal capabilities are in place. The way to approach these three dimensions changes over time and with context. Setting in place these dimensions will be not enough for a long-lasting behavioural change if there are barriers experienced.

There is no such thing as “the consumer”. The consumer can be an individual or a household, but also an SME or a community. These consumers can not only react differently to involvement but also to technologies, services and policies in different cultural, national and climatic contexts. Even the same “consumer” can react differently at different times of day or moments in life or in different places. The behaviour of the consumer is highly context dependent. Observing how challenging changing behaviour is, the opportunities of smart technology and appliances need to be fully explored: the ability to personalize information or make it context/location dependent and to provide relevant feedback; the opportunity to use persuasive technology, i.e.



technology designed to change attitudes or behaviours of users through persuasion and social influence. Or the most extreme option: the ability to automate the desired behaviour.

There are also strong and as yet largely unexplored differences between consumers of differing sizes. For example, small industrial and commercial consumers have a high potential to lower and/or shift load, yet their behaviour can be influenced by business type, existing energy management infrastructure as well as human and cultural aspects. All factors decide which demand side programs might be most appropriate and also the content, delivery method and corresponding feedback methods which will be most effective. Part of the research will concentrate on the particular needs of these consumer groups, what types of communication techniques are most effective and what types of support they require.

The purpose of this task is to create a short- mid- and long-term roadmap where the interrelated technological, behavioural and legal, entrepreneurial, social and political aspects and needs of a transition to a SmartGrids enabled energy system will be addressed and possible facilitating interventions and mechanisms will be identified. In this roadmap the different roles and active engagement of relevant stakeholders, and the necessary technologies, services and interventions will be highlighted for the different moments in time. It is important to address that some system choices inherently enable more consumer participation and active engagement than others. This roadmap shall be designed in co-creation with the consumers targeted. In addition this roadmap needs to be designed so that it can be constantly adapted to emerging and evolving knowledge and (mutual) learning on consumer, industry, societal and government needs and (technological) system demands.

Special attention shall be paid to identifying both the consumer value and industry and government value of such an approach.

### SmartGrids 2035 Research Topics in research area RC (Smart Retail and Consumer Systems)

The SRA 2035 defines the following **research topics** with sub-topics for research areas RC:

| <b>RC01</b> | <b>Consumer Driven local services, markets considering distribution grid constraints</b>  |
|-------------|---|
| a           | Advanced demand response and demand side management techniques and technologies for low-cost, secure and sustainable distribution system operation  |
| b           | Electronic Energy Market places to enhance small consumer and local generator participation in the distribution constrained power   |
| c           | Centrally Controlled or Distributed/Federated energy markets, Command & Control or Peer-2Peer "everything?": The new energy service company – local for local   |
| d           | Potential of consumer demand to interact and support DER generation in various markets: The ability of wind to bid into high priced markets in cooperation with Demand Response aggregators                                 |
| e           | Local and national Demand Response programs: Possible conflicts between requirements to lower peak demand and network capacity issues   |
| f           | Capacity and reserves Markets: What consumer types and demand response programs types are most appropriate for each market and how could these best be integrated.  |
| g           | Residential and small commercial consumers and consumer based Ancillary Services Markets: How can this become a reality? What impact would such access have on the cost/benefit of residential programs and home automation |

| <b>RC02</b> | <b>ICT for Smart Consumers</b>   |
|-------------|--|
| a           | Consumer Energy Cloud ICT: The Energy Cloud is the virtual solution for the collection and distribution (at any time and at any place) of meter and control data from all nodes in the smart energy system (like the future internet of things).   |
| b           | ICT systems for Consumers Demand side participation (DSP): Autonomous ICT system solutions required of existing and potential future demand side participation applications for enabling ease of adaptability from existing dedicated solutions for seamlessly interfacing with ICT systems for the distribution and transmission networks |
| c           | Consumer opportunities with ICT: New consumer opportunities arising from modern ICT technologies   |

|   |   |
|---|---|
| d | Consumer information handling: Security, Privacy and Data Protection, Handling of huge amounts of data, Central vs Decentral management |
| e | Consumer Service Architecture: Service Oriented Architectures to integration and standardization  |
| f | User Interface: Simple, accurate, reliable, and intuitive displays and interfaces for the consumers                                     |

| RC03 | EV for Smart Consumers   |
|------|--|
| a    | Standardization for EV integration and harmonization of ICT interfaces to EV (connected to distribution grids) within national boundaries as well as across Europe |
| b    | Cyber security of the EV data including: storage, transmission, retrieval and the privacy  |

With the research defined by this SmartGrids research area C the following technologies shall be provided:

### **Research Area RC (Smart Retail and Consumer Systems): Key Technology, Hard- and Software**

#### **SmartGrids ICT**

- Smart heat, mobility and electricity service meters and the necessary communication and control infrastructure and technology; Communication gateways, data concentrators; home communication infrastructure

#### **SmartGrids Software**

- Energy Cloud: a solution for the collection and distribution of meter and control data from all energy nodes in the smart energy system; service platforms for any energy services
- Market platform tool for distributed users with market compatible input, monitoring, matching, grid and other constraint handling optimization algorithm (including compatibility check with higher level/wholesale market in hierarchical market process structures)

#### **SmartGrids ICT HW at consumer side**

- Smart Grid Box at grid users premises allowing interaction with the grid constrained market.

#### **SmartGrids ICT SW at consumer side**

- Tools for price based market participation of small users satisfying at the same time grid constraints

### **Research area SE "Socio-Economical and Ecosystem SmartGrids barriers and opportunities"**

**Purpose:** Socio-Economical and Ecosystem oriented issues such as social, legal, economics, environmental and business model research questions, barriers and opportunities to enable a wide use of SmartGrids technology by 2035.

**Triggers:** Research in area SE is triggered by changes expected between 2020 and 2035:

- Electricity grid regulation will move from grid cost-incentive based only towards combined grid-cost-incentive, operational quality-incentive and sustainability- incentive based
- Electricity grid regulation will become a (key) subset of an overall energy system regulation
- Energy regulation will also include new city topics such as roles and duties in mobility, space heating/cooling.
- The legal framework will give new responsibilities and duties to new SmartGrids businesses with associated social, legal, environmental, economic and business model research questions.

#### **Tasks:**

- SE.1 SmartGrids Business Models
- SE.2 Economic SmartGrids Models
- SE.3 New legislation for markets, grids, energy carriers and involved stakeholders
- SE.4 Compatibility of SmartGrids and SmartCity Evolution
- SE.5 SmartGrids Evolution and Transition



SE.6 Opposition and Support to Proposed Power Line Projects  
 SE.7 Interactions between Industry, Regulatory Authorities and NGOs

**Lead Stakeholders:**

Consumers, Energy Policy Legislators, Communities and Cities

The following tasks complement those of mainly research area S (Systems Integration), D (Distribution) and RC (Retail and Consumer).

**TASK SE.1 SmartGrids Business Models**

**Purpose: "Business models for new SmartGrids stakeholders and goals"**

**TASK SE.2 Economic SmartGrids Models**

**Purpose: "Economic models for models for new SmartGrids stakeholders and goals"**

**TASK SE.3 New legislation for markets, grids, energy carriers and involved stakeholders**

**Purpose: "Legislation models for new SmartGrids stakeholders and goals"**

**TASK SE.4 Compatibility of SmartGrids and SmartCity Evolution**

**Purpose: "Achieving compatibility between the evolution of Cities towards SmartCities and the SmartGrids"**

**TASK SE.5 SmartGrids Evolution and Transition**

**Purpose: "Analysis of the transition risks and chances of SmartGrids towards the future"**

**TASK SE.6 Opposition and Support to Proposed Power Line Projects**

**Purpose: "Explore the role of NGOs and social networks play in organizing local opposition/support to proposed power line projects"**

**TASK SE.7 Interactions between Industry, Regulatory Authorities and NGOs**

**Purpose: "Understanding of social and political interactions between industrial promoters, regulatory authorities and NGOs"**

**SmartGrids 2035 Research Topics in research area SE (Socio-Economical and Ecosystem Research)**

The SRA 2035 defines **the following research topics** with sub-topics for research areas SE:

| <b>SE01</b> | <b>Sociological questions of consumer demand response and elasticity</b>  |
|-------------|---|
| a           | Analytics and decision support for consumers  |
| b           | Technology acceptance issues related to new consumer roles  |
| c           | Real time personal energy footprint and interaction with the environment  |
| d           | Bundling of services to consumers   |
| e           | Consumer lifestyle needs and impact: Marketing to integrate new 'energy and other utility options' in a consumer lifestyle / lifecycle (event driven)   |
| f           | Active demand as part of energy audits  |
| g           | Consumer segmentation (Residential, small commercial, larger commercial, industrial) and grouping of consumers (neighbourhoods, communities, villages /towns, cities and their sectors): How can technology contribute to their business differentiation? |
| h           | Consumer maturity development: learning cycle and roadmap approach  |
| i           | The interaction of Business Development Goals, and internal management and financial structures with Demand Side Program acceptance: Needs and requirements of business owners, energy management personnel.  |



|   |   |
|---|---|
| j | Consumer Interaction: Addressing consumers themselves, for residential, commercial and small industrial players |
| k | Prosumer Oriented Programs for residential, commercial and industrial players: Change scenarios                 |
| l | Consumer Experience Management, Consumer Touch-points and the Consumer: Journey / Consumer Lifecycle            |
| m | Smart City – Smart Living – Smart Grid: Integration / convergence   |
| n | Transition strategy for moving towards Energy Efficiency and Distributed Generation: The consumer side          |
| o | Social and consumer acceptance: Risk of SmartGrids rejection  |
| p | Technological, psychological, sociological, economical and pre-conditions for an active consumer participation  |
| q | How consumers really behave rather than how system designers want them to behave                                |
| r | The role of social media in influencing consumer behaviour  |
| s | Turn energy consumption into a game? (compete with the neighbours)  |
| t | Open source information on the energy system - Can this lead to a consumer revolution?                          |

|              |  |
|--------------|--|
| <b>SE02a</b> | <b>Multi-commodity and Multi-service-business for demand response and non-energy based local services for the consumer</b> |
|--------------|--|

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|-------------|--|
| <b>SE03</b> | <b>Interaction Grid - Building - Districts: Energy service consumers in Smart Communities and Cities</b>   |
| a           | Consumer lifestyle needs & impact: Integration of 'energy and other utility options' in a consumer lifestyle / lifecycle (event driven marketing approach) |

|             |  |
|-------------|--|
| <b>SE04</b> | <b>Economic questions of consumer demand response and elasticity</b>   |
| a           | Business models, market parties, value web and consumer roles  |
| b           | The potential of energy consumption information (feedback) on overall small business efficiency and best practice. |

|             |  |
|-------------|--|
| <b>SE05</b> | <b>Ancillary services, sustainable operations and low level dispatching (Smart Integration)</b>  |
| a           | Smart employment caused by new ancillary services: study the relationship between the level of smartness compared to the number of direct operational personal.  |
| b           | Few market rules and mechanisms for ancillary services: More harmonization.  |
| c           | Financial market integration of ancillary services   |
| d           | Effect of near-ZEB (Zero energy building) on ancillary services: Assumption on the way houses will be built or renovated embedding PVs or being more isolated: what impact will this have on the demand, peak demand problem,  |
| e           | Ancillary services and relationship with Smart Cities, Smart Transportation, etc.: Packaged SmartGrids technologies for a smarter city? Transition roadmap towards less net consumption, more prosumers, 100% EVs, Scheduling capacity locally. Think about a labelling program for smart cities compliant with SmartGrids requirements. |

|              |  |
|--------------|--|
| <b>SE06a</b> | <b>Knowledge Transfer of Complex Smart Grids Issues (Training)</b> |
|--------------|--|

|             |   |
|-------------|---|
| <b>SE07</b> | <b>Efficiency and cost-benefit value of SmartGrids technology</b>                                 |
| a           | Cost-benefit analyses of the efficiency of SmartGrids technology for grid model based forecasting |

| <b>SE08</b> | <b>Economic SmartGrids models</b>  |
|-------------|--|
| a           | What processes are needed for which type of economic model? What are the structural parameters of an economic model?   |
| b           | Cost/benefit analysis of solutions with different levels of complexity and different scenarios of EV deployment in a cost effective way both for the power system and the consumers. |
| c           | Research on non-economic drivers for energy storage development in domestic applications   |

| <b>SE09</b> | <b>Legislation for markets, grids, energy carriers and all involved stakeholders</b>  |
|-------------|---|
| a           | From separated regulation and tasks for TSO and DSO towards a more efficient grid structure and grid operation and generation grid-level connection with dynamic task separation  |
| b           | New energy-markets designs (e.g. dynamic automated or semi-automated transactional mechanisms) and assessment of risks and opportunities for network stability and cost effective management and options for new regulatory framework by storage. |
| c           | Development of a regulatory framework based on the coordination of different European policies to give visibility for energy storage applications and global value creation   |

| <b>SE10</b> | <b>SmartGrids evolution transition</b>  |
|-------------|---|
| a           | Risks of early SmartGrids implementation in transition to CO2 free, smart system: From risk perception of early installations towards rewarded benefits of early movers |
| b           | Pace of change of SmartGrids: From a slow, low risk, wait and see attitude towards massive change of thousands of grid users  |

| <b>SE11a</b> | <b>Compatibility of SmartGrids and SmartCity evolution: From policy making roles in city planning related to streets, communities, etc. towards an enhanced integration of energy, water communication and sustainability issues.</b> |
|--------------|---|
|--------------|---|

### **Key results provided by Research Area SE (Socio-Economical and Ecosystem research)**

The SmartGrids research area SE is not technology oriented and will not directly provide technological solutions. Research Area SE provides insights into business aspects including economic models, supported by the right legal frameworks.

This research area SE is not at the core of this SmartGrids Strategic Research Agenda 2035 which concentrates on technologies. The research of all questions mentioned in this research area SE is, however, fundamentally linked to all systems questions of the other technology-related research areas.





# EXPERTS PROVIDING INPUT TO SRA 2035

## **SG ETP - Lead of processes towards SRA 2035**

Ronnie Belmans - K.U.Leuven / EnergyVille  
Rainer Bacher - BACHER ENERGY LTD

## **SG ETP - Secretariat**

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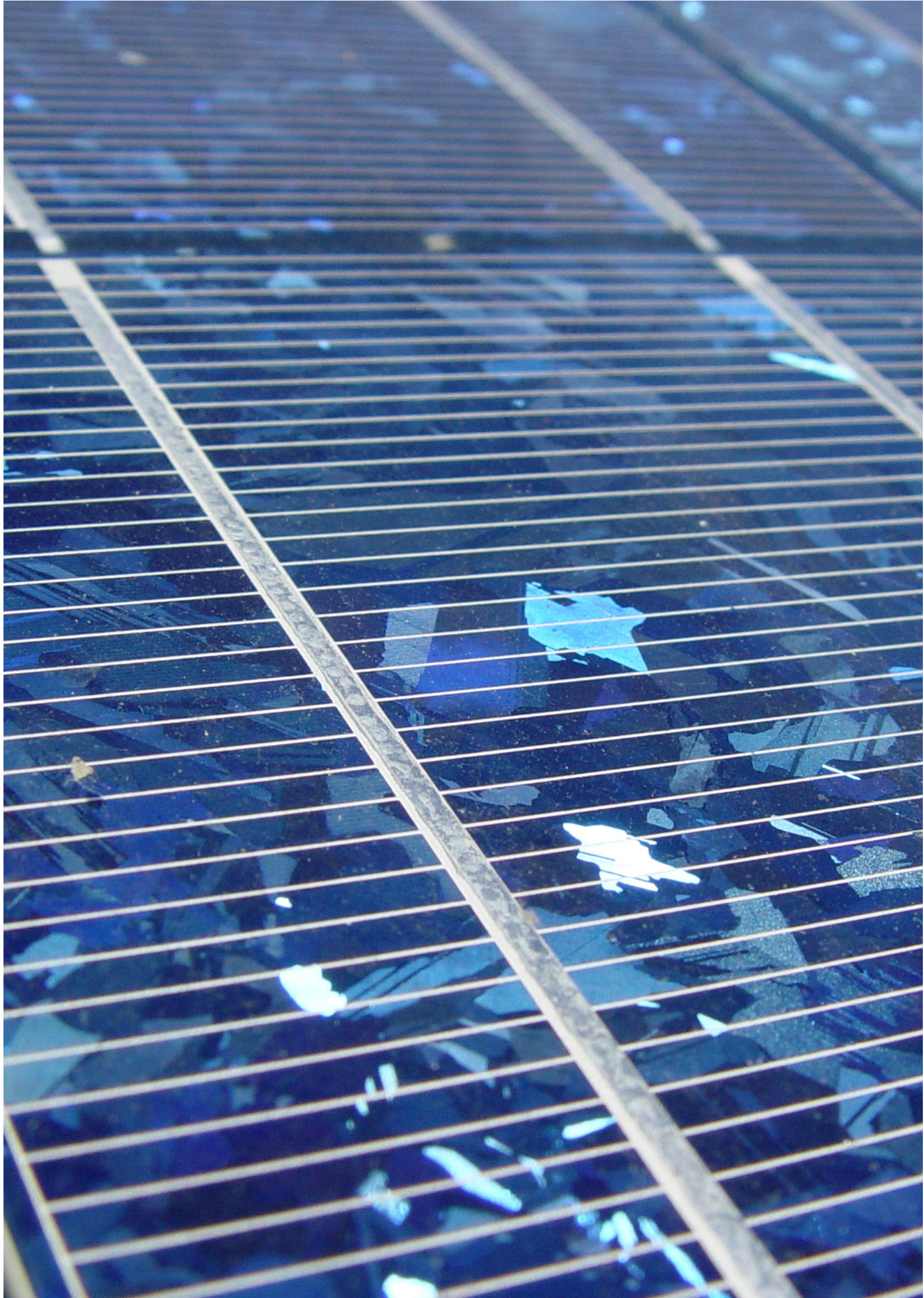


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**European Commission**

Patrick Van Hove (EC – DG Research and innovation)  
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## SG ETP (SMARTGRIDS EUROPEAN TECHNOLOGY PLATFORM) – MEMBERSHIP MARCH 2012

Chairman of the European SmartGrids Platform: Ronnie Belmans, Professor - K.U.Leuven, Honorary chairman of Elia

The current structure of the SmartGrids ETP steering committee is an executive group of individuals representing key groups of SmartGrids stakeholders.

- TSO's: Represented by ENTSO-E through its Chair of the Research & Development Committee, Hubert Lemmens.
- DSOs: represented by EDSO, European Distribution System Operators for Smart Grids, Per-Olof Granström, Secretary General
- Regulators: represented by ACER, Werner Friedl (regulators were previously represented by CEER/ERGEG)
- Generation: represented by Eurelectric, and in particular by Hans Ten Berge. Gunnar Lorenz acts as Sherpa.
- Renewables: represented by the EUREC organization, and Mr. Greg Arrowsmith.
- Users: represented by IFIEC, Peter Claes (secretary general of IFIEC)
- Electrotechnology equipment manufacturers: represented by T&D Europe, Mikel Zaldunbide, ORMAZABAL
- Consumer Demand and Metering: this links to the SG ETP WG3 and to the "ICT for Energy Efficiency" groups are represented through their chair, Maher Chebbo, SAP.
- Telecommunications: represented by European Utilities Telecom Council and its chair, Miguel Ángel Sánchez Fornié, European Utilities Telecom Council EUTC Chairman
- Metering manufacturers and systems: represented by the European Smart Metering Interest Group, ES-MIG, John Harris.
- Research and development within the electricity companies: represented by Jean-François Faugeras, Head of Network R&D Programs EDF R&D
- Research institutes, governmental organizations, university institutes, education: represented by Duncan Botting, Executive Chairman Scottish European Green Energy Centre
- EERA – European Electricity Research Alliance: represented by Luciano Martini RSE leader of the Joint Programme on SmartGrids in the EERA







## LIST OF ACRONYMS

|                 |   |
|-----------------|---|
| AC              | Alternating Current                                     |
| AMM             | Automated Meter Management                              |
| CAES            | Compressed Air Energy Storage                           |
| CC              | Combined Cycle  |
| CEN             | European Committee for Standardization                  |
| CENELEC         | European Committee for Electrotechnical Standardization |
| CG              | Coordination Group                                      |
| CH <sub>4</sub> | Methane   |
| CIGRE           | International Council on Large Electric Systems         |
| CO              | Carbon Monoxide   |
| CO <sub>2</sub> | Carbon Dioxide  |
| CSP             | Concentrated Solar Power                                |
| CTE             | Coefficients of Thermal Expansion                       |
| CWA             | CEN/CENELEC Workshop Agreement                          |
| DC              | Direct Current  |
| DER             | Distributed Energy Resources                            |
| DG              | Distributed Generation                                  |
| DME             | Dimethoxyethane   |
| DR              | Demand Response   |
| DS              | Distributed Storage                                     |
| DSO             | Distribution System Operator                            |
| DSP             | Demand Side Participation                               |
| DSU             | Distributed Storage Units                               |
| EEGI            | European Electricity Grid Initiative                    |
| e-grid          | Electricity grid  |
| ESCO            | Energy Service Company                                  |
| ESD             | Energy Services Directive                               |
| ESO             | European Standardization Organization                   |
| ETP             | European Technology Platform                            |
| ETSI            | European Telecommunications Standards Institute         |
| EU              | European Union  |
| EV              | Electric Vehicle  |
| FACDS           | Flexible AC Distribution Systems                        |
| FACTS           | Flexible AC Transmission Systems                        |
| G2V             | Grid to Vehicle   |
| GaN             | Gallium Nitride   |
| g-grid          | Gas grid  |
| GHG             | Greenhouse Gas  |
| GIL             | Gas Insulated Line                                      |
| GPRS            | General Packet Radio Service                            |
| GPS             | Global Positioning System                               |
| GS              | Group Specification                                     |
| H <sub>2</sub>  | Hydrogen  |
| HSE             | Health, Safety and Environment                          |
| HTS             | High Temperature Superconductors                        |
| HV              | High Voltage  |
| HVAC            | High Voltage Alternating Current                        |
| HVDC            | High Voltage Direct Current                             |
| HW              | Hardware  |
| ICT             | Information and Communication Technology                |
| ISDN            | Integrated Services Digital Network                     |
| IT              | Information Technologies                                |
| O <sub>2</sub>  | Oxygen  |
| PLC             | Power Line Communication                                |
| PMU             | Phasor Measurement Unit                                 |
| PSTN            | Public Switched Telephone Network                       |
| PV              | Photovoltaic(s)   |
| R&D             | Research and Development                                |
| RA D            | Research Area 'Smart Electricity Distribution Systems'  |

|        |  |
|--------|--|
| RA IS  | Research Area 'Integrated Systems'   |
| RA RC  | Research Area 'Smart Retail and Consumer Technologies and Systems'                   |
| RA SE  | Research Area 'Socio-Economical and Ecosystem SmartGrids barriers and opportunities' |
| RA T   | Research Area 'Smart Electricity Transmission Systems'                               |
| RA T&D | Research Area 'Smart Electricity Transmission and Distribution Systems'              |
| RD&D   | Research, Development and Demonstration  |
| RE     | Renewable Energy   |
| RES    | Renewable Energy Sources   |
| RES-E  | Electricity from Renewable Energy Sources  |
| SCADA  | Supervisory Control and Data Acquisition   |
| SDD    | Strategic Deployment Document  |
| SET    | Strategic Energy Technology Plan   |
| SG     | Smart Grids  |
| SGIS   | Smart Grid Information Security  |
| Si     | Silicon  |
| SiC    | Silicon Carbide  |
| SME    | Small and Medium-sized Enterprises   |
| SOEC   | Solid Oxide Electrolysis Cell  |
| SRA    | Strategic Research Agenda  |
| STAIR  | Standardization, Innovation and Research   |
| SW     | Software   |
| T&D    | Transmission & Distribution  |
| TC     | Technical Committee  |
| TSO    | Transmission System Operator   |
| UHV    | Ultra-High Voltage   |
| V2G    | Vehicle to Grid  |
| VPP    | Virtual Power Plant  |
| VSC    | Voltage Source Converter   |
| WAMS   | Wide Area Measurement System   |
| XLPE   | Crosslinked Polyethylene   |
| YBCO   | Yttrium Barium Copper Oxide  |
| ZEB    | Zero Energy Building   |





