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European smart grid prospects, policies, and challenges

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ABSTRACT

A smart grid (SG) is developed to overcome grid congestion and to meet the demand for and sustain the supply of electricity. The European SG is supported by European Union (EU) policies and the joint EU Energy and Climate Package. This study reviews the prospects, progress, policies, and challenges faced by EU countries, electricity networks, and their relevant stakeholders. European SG prospects were initiated through the EU's Strategic Energy Technologies plan and continue with the strategic research agenda that has been road-mapped for 2007–2035. The EU, with its Directorates-General, agencies, and commissions, has established directives and policies to promote SG among member states. The factors that stimulate the innovation and implementation of SG require the need to generate electricity optimally (i.e., low greenhouse gas emission and renewable or sustainable source) and to secure its supply while ensuring reliability and quality. Despite the challenges, the European SG continues to develop and progress, fulfilling renewable energy targets and customer satisfaction and addressing environmental concerns.

Contents

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1. Introduction

Europe's electricity power networks are evolving from conventional grid to smart grid (SG) to meet 21st-century demands. Future grids are envisioned to be environment friendly, sophisticated, and capable of bi-directional power flow. In 2005, the European Commission (EC) launched an expert group called the Smart Grid European Technology Platform (Smart Grid ETP) to develop a joint vision and research program for the European SG, with a focus on making future grids more flexible, accessible, reliable, and economical. Furthermore, the European Union (EU) Energy and Climate Package particularly conveys a clear message to improve and actualize the vision, target the increase of the use of renewable energy sources by 20% by 2020, reduce greenhouse gases (GHGs) by 20% from 1990 levels, and improve energy efficiency by 20% [1]. Energy demand, environmental concerns, and better technological solutions are the motivations behind the innovations to use future grids. Global energy resources are mainly dependent on fossil fuels, and the use of fossil fuels is the main reason for the global increase in GHGs [2–4]. To meet energy demands and address the problems of climate change and depletion of fossil fuel sources, renewable energy resources are tapped as the energy source with the most potential [4–7]. SGs are necessary to meet energy demands and manage supply to provide consumer satisfaction in terms of the security, reliability, and quality of electricity supply. SG emphasizes managing issues in energy supply and demand through its low-carbon technology and meeting demand through secure and optimized electrical consumption on the part of the end user. Its implementation is envisioned to be crucial to the future supply of electricity.

The literature shows that SG has great potential, and policies are essential for the commercial establishment of the relevant technologies. This study reviews the technologies, prospects, policies, and challenges of SG in Europe for the benefit of the industries, policymakers, energy users, and researchers.

2. European electricity grid

Traditionally, the European electricity grid was managed separately at the national level. All of its operation, investment, cost, knowledge, and issues were overseen by individual transmission system operators (TSO). The response to any contingencies was slow because of the insufficient flow of information exchange [8]. However, the increased loading of existing power systems amplified the necessity to overcome the present limits of existing topologies and grids through significant transformation. Such transformation should include planning, developing, and financing grids and disseminating the technology among the EU member states. The EU has made the European blackout of November 2006 and 2003 as the root point of its ambitious plan to provide a secure supply to consumers. It has learned the importance of having adequate real-time data and sharing or communicating these data among TSOs [8,9]. The European Network of Transmission System Operators for Electricity (ENTSO-E) and the Coordination of Electricity System Operators (CORESO) are the agencies that presently coordinate system interconnection and operation among TSOs.

A comparison between “aged” electric grid and “smart/modern” grid is shown in Table 1. The old electricity grids were built 30–50 years ago when electricity was distributed to consumers in generalized form. Given the great demand for electricity, the old grids were subjected to high stresses and contributed to compelling electric losses (between 2% and 4% for the European Transmission System and between 4% and 9% for the European Distribution

Table 1
Comparison between the present and smart grids [12,13].

	Present grid	Smart grid
System topology	Radial topology (electricity generated from the power plant, transmitted through the transmission line, and distributed at the distribution level)	Decentralized topology (electricity generated and transmitted in multiple ways at the transmission and distribution levels)
Communication	Single way (not based on real time)	Bi-directional way (based on real time)
Disturbance rehabilitate	Manual. The protection of assets from faults is the main priority.	Self-healing, prevents rapid deterioration, and minimizes effect
Power flow control	Limited	Fully automated
Consumers' engagement	No participation	Extensive participation and option of being a prosumer
Metering	Electromechanical (not based on real time)	Digital (real-time metering is enabled)
Reliability	Susceptible to failure and outage	Automated Pro-active protection and outage prevention Power quality is the main concern.

System) [10]. The many disadvantages of traditional electric grids were discovered, such as inefficient communication between electric supply and demand, which may lead to unused electricity, and quality and grid management issues, when the intermittent Renewable Energy Sources (RES) were connected. The modernization of the grid was envisioned to facilitate major innovation and opportunities, which have been identified as system topology and communication, disturbance rehabilitation, power flow control, consumer engagement, metering, and reliable electric power systems. In terms of bi-directional communication, the electricity grid management will become more efficient, providing convenience to both utility providers and consumers. An essential evolvement is in the area of signal processing technologies [11]. Over the years, signal processing technologies have had significant functions from the innovation and evolution of wireless telecommunication to Internet technologies. With the ability to make decisions, control actions, and filter signals by timely eliminating noise from relevant information, the evolution of advanced signal processing has become a vital element in SG technologies. The benefits include facilitating visualized communication and computing and controlling full integration with the diversity of energy sources and current electricity systems. Examples of the new development initiated from SG innovation are the plugin hybrid electric vehicles (PHEVs) and plugin electric vehicles (PEVs). These technologies have raised awareness of the challenges of emerging signal processing and their future influence on electric grids and charging system managements.

Some of the technologies must evolve and mature to realize the capacity of future grids or SG, as shown in Table 1. The technologies used should be able to make the electricity grid observable, controllable up to its optimization, capable of automated healing during disturbance, and highly efficient in terms of integration with the existing system and miscellaneous energy sources. The maturity of these technologies as SG enabler is one of the key challenges addressed in this study because the readiness of all the technologies in one place is essential. The maturity of these technologies is further explained in Section 5.

2.1. ENTSO-E

The ENTSO-E is the main regulatory body that coordinates the operation of the European electrical grid network and provides a reliable market. It began its operation in July 2009 with five member associations: Nordic Electricity (NORDEL), United Kingdom Transmission System Operators Association (UKTSOA), Union for the Coordination of the Transmission of Electricity (UCTE), Association of the Transmission System Operators of Ireland (ATSOI) and Baltic Transmission System Operators (BALTSO). Conceived through the EU's third legislative package on gas and electricity markets, it aims to actualize a single market for electricity and gas to ensure an effective energy market [14,15] and to maintain minimum prices for gas and electricity, enhance standards, and ensure secure supply [14]. About 41 TSOs from 34 European countries are members of ENTSO-E [15], which is the largest interconnected electricity system in the world, with more than 220,000 km of 400 and 200 kV lines supplying electricity throughout the EU's interconnected transmission grid. ENTSO-E sources generate approximately 3000 TWh of electricity yearly [15–17]. The system has achieved power exchange through alternate current (AC) (i.e., flexible AC transmission system (FACTS)) and high voltage direct current (HVDC) links. ENTSO-E initiated the UCTE Operation Handbook (OH), Compliance Monitoring and Enforcement Process (CMEP), and Multilateral Agreement (MLA) to ensure continuous interoperability and support technical operation, policies, monitoring, reporting, and security of principle among TSOs, thereby ensuring system data security [18]. However, ENTSO-E is facing dissimilarities in the electricity landscape pattern because of the increased cross-border power flows between member states (especially in the power market) and the large penetration of RES. The intermittent nature of RES affects the power quality (PQ) through the elements of harmonics, flicker, and transients. The ENTSO-E interconnected system is therefore operating near its maximum level. ENTSO-E members are working closely in coordinating the system effectively and through variations in the generation pattern, primarily influencing network design and control and challenging and obstructing SG implementation. However, smarter coordination, management, and transmission infrastructure can overcome these challenges and obstructions.

2.2. CORESCO

The high penetration of RES in the electricity grid, the objective of secure supply, and the rapid development of the European electricity market are the main factors of the establishment of CORESO in February 2009. Given the present grid congestion, CORESO is accountable for coordinating, strengthening, and closely monitoring the inter-operation of the TSOs to improve security, reliability, and efficiency of power supply among the Central–Western European countries and of data exchange among its members. In December 2011, CORESO improved its operation by upgrading to a demand-based monitoring system. This system can receive real-time data every minute from relevant TSOs under CORESO. It is a data acquisition and display system (DADS) tool that allows easy data collection and analysis. It allows CORESO to notify a particular TSO of any inconsistencies in the data received and suggests remedial actions [19,20]. After more than three years of service, CORESO has become a reliable organization and has improved the security of electricity supply. It plans to expand its coverage to all the EU 12 and EU 15 countries, while increasing shareholding among EU countries.

3. Overview of European SG trends

SG is considered necessary to support sustainable growth and modernize the operation of the power system operation, both of which are important to meet the world's presently high demand for electricity and future development. In developing systems of energy transmission and distribution, it is a good option for the integration of renewable energy sources in electricity production [21]. The European Energy Agency (EEA) and ENTSO-E report that, as of December 2014, nearly 3210 TWh of electricity have been generated annually for the EU-27 sectors (i.e., transportation, household, industry, services, etc.) [22]. The need for SG is obviously a response to the present climate change, rapid increase of oil prices, depletion of fossil fuel sources, aging of the infrastructure of the present electricity grid, and significant benefits of its implementation [23,24] Furthermore, consumers nowadays want a more intelligent system to manage their electricity consumption and a sustainable, reliable, and secure supply from their power provider [25]. SG is a decentralized electricity network whose operation is shared between the central and distribution sides. The Distributed Generation (DG), RES, Demand Response (DR), Energy Storage, and Demand Side Management (DSM) are envisioned to replace the activities and functions of conventional power plants. SG offers large benefits in terms of real-time pricing to customers, self-healing technology, pervasive control over power flow, high reliability, and significant improvements to the environment [25–28].

3.1. Building the SG system

The EU 2020 climate change and energy policy aims to increase renewable-sourced energy by 20%, reduce GHG emissions by 20% from 1990 levels, and improve energy efficiency by 20%. Serving electricity to 34 member states in Europe with more than 450 million people obviously requires a major paradigm shift in the innovation of the present topology of the electricity network [17,29]. The innovation and development of future energy infrastructure must reflect effective and sustainable use of natural resources, improved grid security, and effective energy savings. Furthermore, the energy lost in transmission and distribution has become a main efficiency issue concerning the capability of providers. In general, up to 8% energy losses from generation to consumption through transmission and distribution have been reported worldwide [30]. The aging infrastructure of existing grids seems to be insufficient in serving future energy demand. The key potentials of SG systems are safe integration and aggregation of RES, DR, and distributed energy resources (DER) [31,32]. SG is not a completely new grid, where the grid itself will prosper to be a smarter and intelligent grid instead of an electric power provider [33].

3.2. SG landscape in Europe

In 2014, the European Commission Joint Report Centre (EC-JRC) produced a comprehensive and detailed inventory report on the data of the 30 European countries (i.e., EU28, Switzerland, and Norway) involved in SG activities from 2002 to 2014 [34,35]. Surveys and analyses started from SG Research and Development (R&D) to Demonstration and Deployment (D&D) throughout Europe. The data consisted of the R&D (first subset) and D&D (second subset). The R&D and D&D phases consisted of 459 SG projects (e.g., smart network management, integration of DER, integration of large-scale RES, smart customer and smart home, EV, information and communication technology (ICT), and storage), including 287 national projects and 172 multinational projects with an average project duration of approximately 33 months. A total of 220 SG projects were still under construction as of 2013, accounting for 101 projects that were started in 2012, as illustrated in Fig. 1. Between 2005 and 2015, the average number of projects completed was 32 [36]. As recorded, the total investment made was € 3.15 billion, with the largest investments coming from France, Spain, and the United Kingdom (UK) [34]. The inventory report that summarizes SG projects throughout Europe is shown in Table 2.

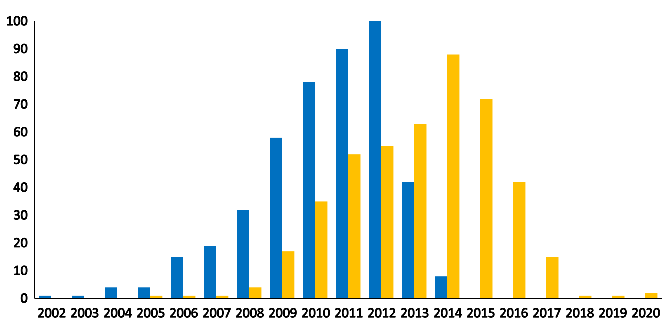

Fig. 1. Starting year and year of completion/expected completion of SG projects [36].

In 2014, eight additional SG projects were commissioned with a total investment of € 60 million. The same year listed a huge figure of project completion, with 89 completed projects. The projects involving D&D were actively progressing and recorded 400 new companies that penetrated SG activities, with an annual investment reaching ca. € 475 million between 2013 and 2014. However, details on the investment were not incorporated in the inventory because the information involved was promoted late by the respective participants. The following are examples of the projects: Flexible Urban Network–Low Voltage (period: 2014–2015), Eta: Creating Efficient Distribution Networks (period: 2014–2017), and Vulnerable Customers and Energy Efficiency (period: 2014–2017).

Figs. 2 and 3 show the total number of SG R&D and D&D projects across Europe and their total budget allocation. A total of 211 projects in the R&D phase are worth approximately € 820 million, and 248 projects under D&D have a total budget of around € 2320 million. Out of 459 SG projects, 172 projects are focused on the multinational level, where the average number of countries per project is 6. The list of national projects acquired shows that a total of 214 SG projects were implemented by a single country. Nevertheless, the total budget of € 3150 million excludes 37 projects from the original total 459 SG projects because the participants are yet to promote their information.

Fig. 4 shows the geographical inventory of the conducted SG projects, the majority of which are focused at Germany, Denmark, and Italy [34]. Denmark and Germany are the countries that are known to have established R&D and D&D phases, respectively. The vigorous encouragement of the participation of stakeholders is a reason for their highest number of R&D and D&D projects. The majority of the projects are concentrated in the EU 15 countries, such as Germany, Denmark, Italy, Spain, France, the UK, and Netherlands. The database clearly indicates that the geographical distribution of the SG projects between the EU 15 and EU 12 countries is not uniform. The contribution and involvement of the EU 12 countries still lag, with less than 20 projects from the start of SG. Different factors contribute to this pattern, including economic, social, technological, and other factors.

3.2.1. R&D phase

At the micro perspective of the R&D phase, the distribution of the number of projects versus their application have been scrutinized, as illustrated in Fig. 5. Obviously, 2012 saw the most R&D projects piloted (exceeding 70 projects), and each project shown may have had more than one application. Since 2006, projects

Table 2
Recent summary of SG projects [34].

NUMBER	BUDGET	ORGANIZATIONS	IMPLEMENTATION SITES
Total: 459 projects in 47 countries (excluding 8 projects in 2014)	Total: € 3.15 billion (excluding 60 million budget in 2014 for 8 projects)	Total: 1670 organizations	Total: 578 sites
287 national projects (73 projects with more than one partner)	221 ongoing projects: € 2 billion (with an average of 9 million € per project)	2900 participants (1350 in R&D and 1550 in D&D)	33 countries
172 multinational projects (with an average of 6 countries per project)	238 completed projects: 1.15 billion € (with an average of 5 million € per project)	Most active organization types: universities/ research centers/ consultancies and DSOs	Most sites: Germany (77) and Italy (75)
Average project duration: 33 months	Largest investment: UK and France	Most active company: 45 projects (from Denmark)	Largest number of sites per project: 30 sites

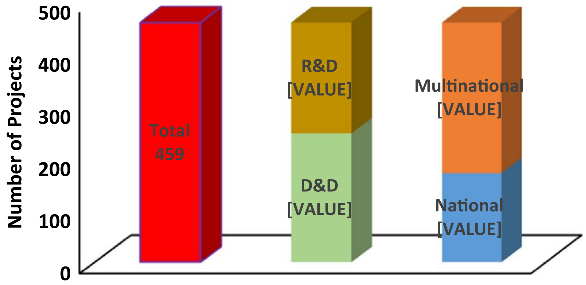

Fig. 2. Number of SG R&D and D&D projects across Europe (including 2014) [34].

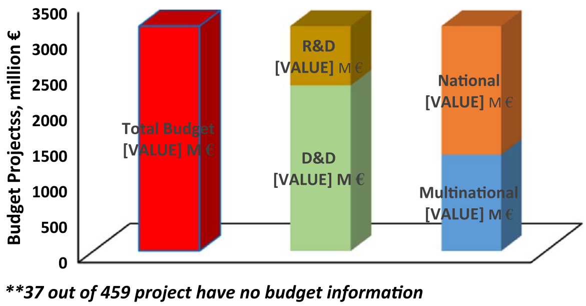

Fig. 3. Total budget of SG R&D and D&D projects across Europe (including 2014) [34].

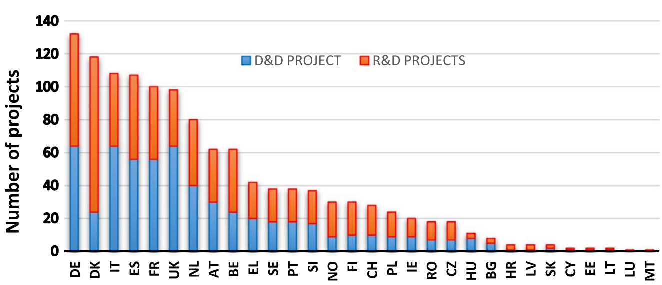

Fig. 4. Number of projects per stage of development and country [34].

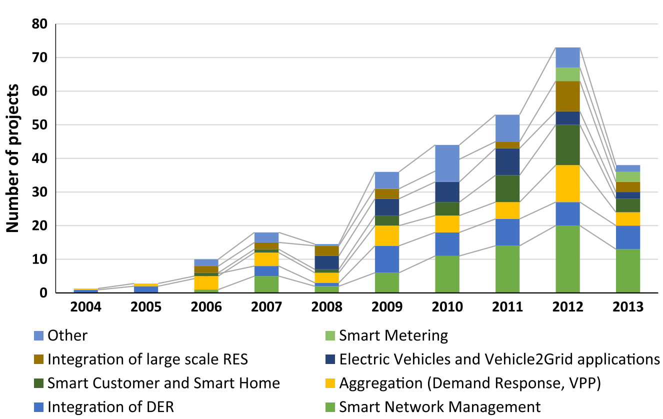

Fig. 5. Distribution of R&D project by year and application (2004–2014) [34].

involving Smart Network Management steadily increased until 2012, when its main focus was oriented toward enhancing network controllability and observability. The data obtained by [34] exclude the rolled out smart metering projects.

The analysis indicated that ten organizations or stakeholders were directly involved in SG innovation, with universities managing the lion's share of the total budget (see Fig. 6). This new percentage exceeded the total budget received by the DSO/utility/energy providers, as recorded in 2011 by [25]. Indeed, the first

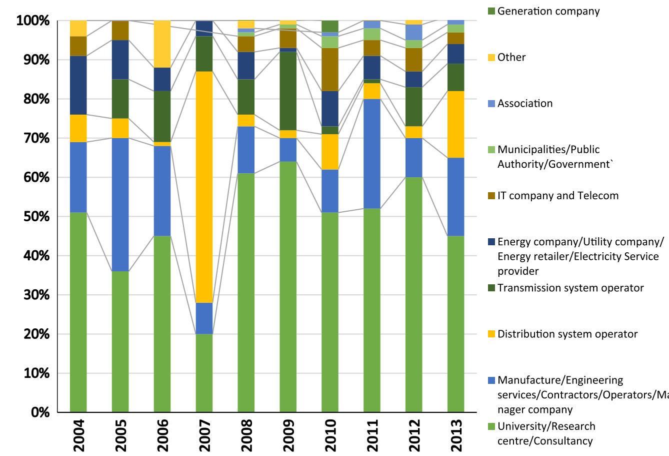

Fig. 6. Percentage of stakeholder participation of R&D based on total investment [34].

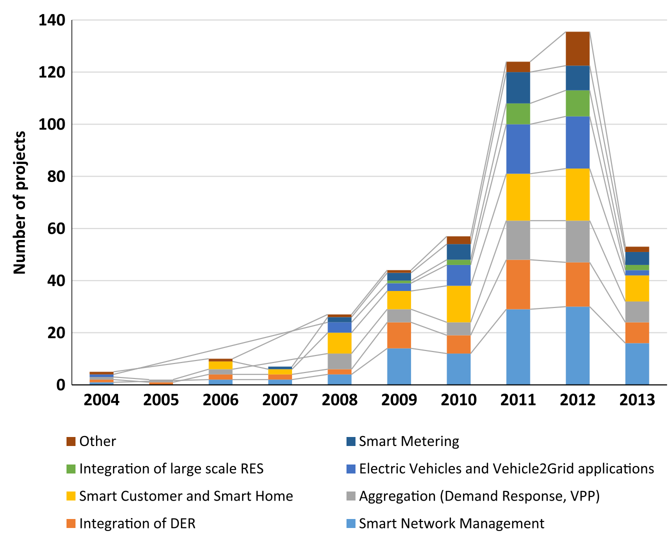

Fig. 7. Distribution of R&D project by year and application (2004–2014) [34].

stage of the commencement of any new activity begins with the R&D phase. However, the statement made by [28] is inevitable because the root cause of the issues of power systems is normally found at the distribution level. The generation sector contributes a smaller total investment in SG, where the investment made was only for the years 2008 and 2010.

3.2.2. D&D phase

The year 2012 recorded the highest involvement in the D&D phase, with 60 new SG projects and with smart network management constituting the most active applications (see Fig. 7). The number of projects shown is the total of ongoing and new projects for SG. Until now, smart metering activities constitute the most noteworthy activities and progress that contribute to the acceleration of D&D progress. However, Fig. 7 displays only the total number of smart metering projects that are part of a subset of the SG sector. In 2009, the European parliament under the directive 2009/72/EC instructed member states to reach 80% smart meter installations at the consumer side in each region by 2020 [37]. The implementation of smart metering should benefit all consumers, according to the Cost Benefit Analysis (CBA) underlined by the EU Third Energy Package [38]. The directive and package accelerate EU smart meter deployment. To date, Finland, Italy, and Sweden are the countries that have finished installing their nationwide

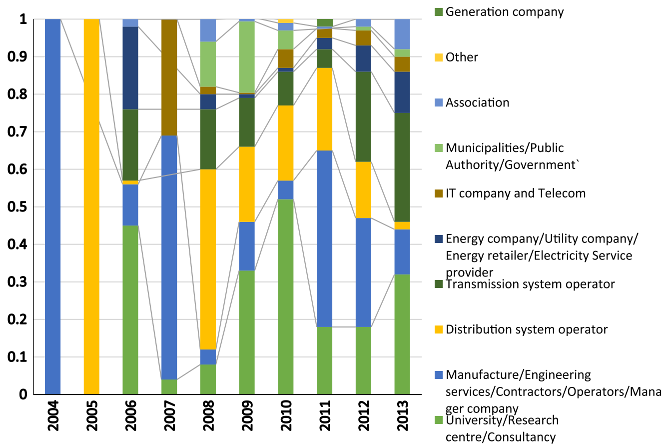

Fig. 8. Percentage of stakeholder participation of D&D based on total investment [34].

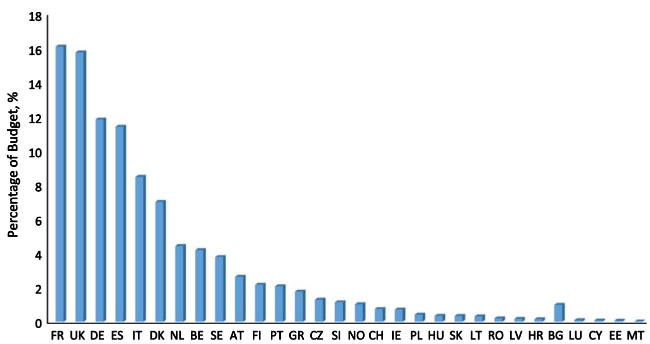

Fig. 9. Distribution of total budget per country [34].

smart metering systems. The total number of EU SG D&D projects is presented in Fig. 7. D&D projects apparently received the largest budget, with € 2320 million for 248 projects.

Fig. 8 shows that the pattern of the participation of stakeholders has not changed significantly from year to year, with the DSO and universities being the most dynamic participants, followed by manufacturing. Indeed, the backbones for SG implementation exist from R&D until deployment.

3.2.3. Project categories and budget distribution across Europe

The projects are divided into two phases: R&D and D&D, where the data presented exclude roll out smart metering projects. As of 2013, the total investment in overall SG activities was USD 3.42 billion (€3.15 billion), with an average of USD 902 million (€ 830 million) in the R&D phase and USD 2521 billion (€2320 million) in the D&D phase. Until 2013, around 220 SG projects were still under construction and yet to be completed. In early 2014, eight additional projects entered the SG sector, with a total investment of approximately 60 million. Hence, with new information and data, the total investment and projects for 2013 and 2014 reached € 475 million, with 50 new projects commencing in both years. Fig. 7 shows the distribution of the total budget per country among EU member states. The largest percentage of the budget went to France and the UK, which received 16.1% and 15.76%, respectively. The correlation between Figs. 4 and 9 shows solid agreement with [39], which states that EU 15 countries (i.e., located in Western and Southern Europe) received larger budgets than EU 13 countries (i.e., located in Eastern Europe), which received a budget of no more than 1%. Countries with substantial expansion of renewable energy expressed their massive concern and progress in the SG sector, such as France, the UK, Germany, Italy, Denmark, and other countries. Reference [40] states that, within two years, France succeeded in increasing its generated electricity using renewable energy from 71,623 GWh in 2011 to 103,666 GWh in 2013, with the main elements of renewable energy being biomass and hydro.

3.2.4. Sources of funding

Theoretical ideas for SG alone without sources of funding are not sufficient for its implementation. The sources should be varied to enable effective results. The EU funds are derived from five active sources: (1) private funding, (2) EC funding, (3) national funding, (4) regulatory funding, and (5) unclassified funding. The EC has several funding programs for SG projects, such as the plan's 6th and 7th Framework Program (FP). In some European countries, the SG projects are financed by their own energy ministries (national funding) to stimulate SG development (e.g., the E-Energy program in Germany funded by the Federal Ministry of Economics and Technology). Investments are larger in EU 15 countries than in EU 12 countries, following the SG project distribution pattern. Analysis shows that Denmark leads in R&D innovation through their small-scale projects funded by the Forskel program [25]. However, government funds seem insufficient. Funding is therefore needed from private sectors and stakeholders to accelerate SG projects [41]. Private funding refers to funding by an individual or specific organization, which contributes the highest percentage of the total budget, mostly for R&D and D&D implementation. Fig. 10 shows the distribution of investment among the abovementioned funders. Of the € 3.15 billion (100%) total investment, € 1500 million (49%) was funded by the private sector as the starting capital for SG projects, followed by around € 693 million (22%), € 567 million (18%), and € 284 million (9%) funded by EC, national, and regulatory funds, respectively. The gap in funding occurred because the stakeholders were concerned about the effect of CBA. Indeed, the progress of SG projects in EU highly depends on the funders.

4. Prospect of SG in Europe

The SG prospect was initiated from the SET plan of 2005 and continued with the ambitious plans formulated in 2007 for strategic research and the roadmap to 2035. The vision is to transform the European electricity network such that it is more flexible, reliable, and accessible and to obtain higher economic value [42–44]. With the vision formulated toward 2020 and beyond, the EU has taken initiatives in the form of packages and policies to make it more tangible. The EU Climate and Energy Package particularly aims to improve and actualize SG prospects that correspond to SG objectives for sustainable development, reliable power supply, and market competitiveness. The package is committed to reach the

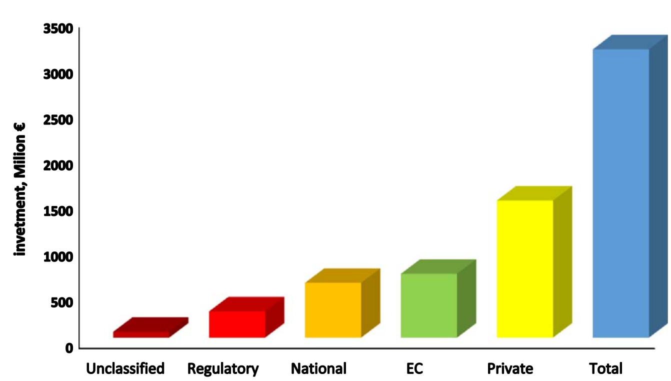

Fig. 10. Distribution of investment among the funders [34].

target of 20% more renewable-energy generation, 20% less GHG emission from 1990 levels, and 20% improved energy efficiency by 2020. With an outlook of revolutionizing the traditional grid into a sophisticated and healthier pan-European grid capable of bi-directional power flow, future grids are envisioned to be smarter [17,42,45,46].

4.1. High capabilities to coordinate demand and supply in the energy network

SG is seen as necessary to support sustainable future growth and the modernization of the operation of power systems. For massive power generation from RES, the generation and distribution systems need to deliberately coordinate demand and supply. For future electricity networks, Europe is forecasted to be analogous to the Internet model, involving bi-directional flow of power and massive distribution of decision making at each node of the system. This model can lead to a better interconnection of systems and controllable power flow [45]. Developing and implementing this model require technology availability, maturity (e.g., ICT system, telecommunication, and power electronics), and efficient management coordination by unions and governments.

The EU's 2020 vision states that all future system operations will be shared among transmission, distribution, communication, and control systems [42]. The energy policy defines the nature of the unbundling of future electricity networks as the key element toward the application of DG in SG [47]. DG can be connected closely to the consumer's end. In this context, virtual power plants (VPP) act as an aggregator that controls DG activities (i.e., RES, DSM, DR, energy storage) in terms of the market and the physical system. The EU's 2020 SG vision illustrates the main role of renewable energy in SG activities and the EU's energy policy goals for these activities, aside from control systems, telecommunications, and ICT technologies. DG allows consumers to manage and reduce their energy consumption through the DR mechanism. The new term “prosumer” refers to producer–consumers able to supply energy while consuming it, thereby optimizing SG activities. Prosumers are allowed to re-sell or re-supply their surplus energy produced by rooftop solar panels or small-scale wind farms to utility providers [48]. SG is envisioned to coordinate and balance the demand and supply for operational efficiency. This vision alludes to the flexibility of the future European electricity network (by 2020), enabling responses to changes and challenges, as envisaged by the EU.

4.2. Sustainable and secure power supply

Sustainable energy development can be realized through RES and with reduced GHG emission. While the electricity supply security is guaranteed, the demands of the digital infrastructure must be consistent and competent to tackle the challenges to the integration of DG, high-tech cyber security, and data protection [49]. Since 2006, the EU has started boosting the growth of RES sources, such as onshore and offshore wind, concentrated solar panel (CSP), and photovoltaics (PV), as alternatives to conventional fossil fuel. These plans contribute to the opportunities and benefits available to stakeholders. Countries, such as Finland, Sweden, Spain, and Germany, are forecasted to increase their renewable-sourced energy, exceeding the EU's 2020 climate target. Wind and solar power are the most popular potential sources able to cover almost the entire electricity consumption of Europe. The UK plans major growth for offshore wind, whereas Germany has increased its solar and wind power generation. Fig. 11 shows the positive increment in the use of RES for electricity production.

Fig. 12 shows a report produced by the Environmental Data Services (ENDS) on National Renewable Energy Action Plans

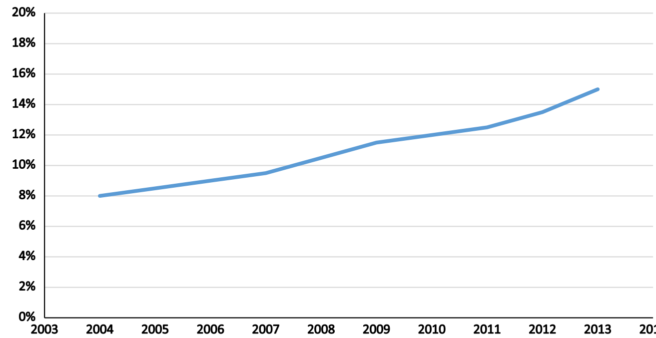

Fig. 11. Share of RES for electricity production in EU countries [50].

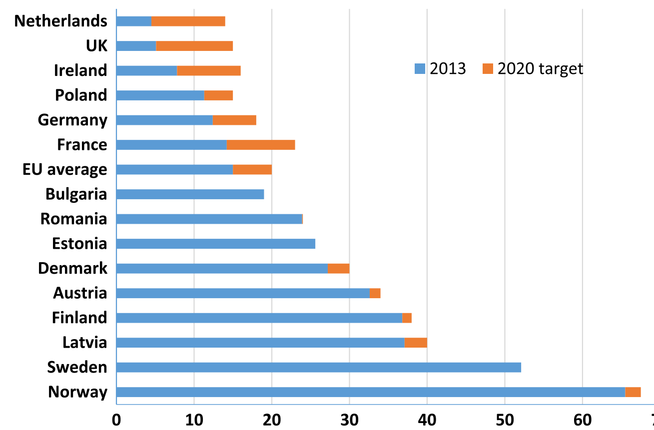

Fig. 12. Shares of renewable energy by EU countries [50].

comparing the final energy generated by member states through RES from 2008 to 2020 [50,51]. As expected, RES is predicted to increase tremendously as an option in electricity supply, in conjunction with EU countries striving for SG implementation. Each country has its particular RES according to geography. Germany leads in solar technology and is developing biomass technology. By 2020, Germany's renewable energy is expected to rise gradually to 18.2%. Sweden and Finland depend on the wood of their forests to produce their share of more than 35%. However, the sustainability issue of wood is expected to arise in the future.

Through EU initiatives, other sources are being exported to countries and regions, such as North Africa, the Middle East, and Norway, to fulfill Europe's future electricity demand. Desertec and North Sea Super Grid Project are contributing to achieve EU's goals for climate, energy, GHG emission, RES, and energy efficiency. The Desertec project is a collaboration between the EU and North Africa conducted to supply solar-powered electricity through HVDC cables. It is expected to serve almost half of Europe, North Africa, and the Middle East within 40 years, in a mission to achieve sustainable development. The North Sea Super Grid Project focuses on balancing supply and demand between nine European countries through offshore grids integrated in wind farms and other RES across the North Sea. With the mandate given to the EC, the elements of environment, security of supply, PQ, and cost are being closely monitored for all the projects involving SG. These elements are the most essential factors in designing future models of electricity networks and turning the SG mission and vision into reality, while benefiting stakeholders.

4.3. Competitive and open markets

The recent development of SG has made the EU the world leader of this technology, its policies, and the market. This development is projected to continue with EU's ambitious plans for Europe. The platform for SG has been built for existing companies and newcomers to form a more innovative, privatized, and liberal market, parallel with an efficient regulatory framework [49]. The transition to a liberal market can change the conventional monopoly of electricity supply, with the consumer given the freedom to choose his electricity supplier and empowered through his/her role, such as prosumer. The security of supply during transmission and distribution is also foreseen to be detached from generation in a future system shared between central and DG. VPP controls DG operation in the context of the integration of the physical system into the market, which has high potential in stimulating an open and efficient power market [52,53]. In terms of the role of the academe in accelerating SG activities, the University of Manchester, in collaboration with the Electricity North West (ENW), Joule Centre, and North West Regional Development Agency (NWDA), has established the Smart Grid Development Centre (SGDC), which provides services to small to medium enterprises (SME) and major corporations to deploy, test, and demonstrate their SG products at a low cost and in a practical environment [54].

4.4. Government and regulatory body

Along the path of European energy policy goals, SG seems to be the most valuable element that can expedite the achievement of such goals. Encouraging the use of RES, DER, EV, and other smart appliances will directly contribute to energy savings, reduced carbon emission, and enhanced energy efficiency.

4.5. Utilities and consumers

The self-healing, two-way communication, decentralization, and predictive reliability of SG makes electricity network operation and maintenance more manageable and easy. Consumers are able to monitor their electricity consumption through smart meters and to choose a suitable time to use electricity (e.g., off-peak periods) to save energy and reduce carbon emission.

4.6. Academic research infrastructure

Over the years, EU and stakeholders have worked closely for the innovation and development of SG technologies. The academic research on SG involves representatives from universities and research centers (see Fig. 4). According to [25], the diversity of the stakeholders can significantly boost the level of SG projects, reduce the encountered R&D challenges, and encourage the development of innovative SG products and new services produced by universities and research centers. To produce relevant and accurate research on SG, Ireland has a very sophisticated level of smart academic research infrastructure that collaborates with industry partners, such as the Electricity Research Centre (ERC), Irish Software Engineering Research Centre (University of Limerick), and United Technologies Research Centre (UTRC) [55]. Berlin University of Technology has its own SG laboratory to develop models related to SG (i.e., integrating eMobility into the SG system), which are beneficial to power, energy industries, economy, and carbon footprint until 2030. The revenue obtained from the developed products can finance and promote SG development in Europe. These steps will leverage the right balance in sharing benefits, costs, and risks among the stakeholders [56]. The monitoring of SG demonstration projects in some countries in Europe are under the responsibilities of the National Regulatory Authority for Energy (NRA), government, DSOs, funding institutions, universities, and others. For example, in Belgium, monitoring is performed by universities, whereas in Norway, monitoring is performed by the Norwegian Smart Grid Centre [57].

5. Challenges to the deployment of SG in Europe

A total of 459 SG projects across 30 countries in Europe from 2001 to September 2014 were reviewed, covering the phases from R&D to D&D. Table 3 summarizes the challenges encountered by these projects. These challenges are highlighted as points of reference, sharing, and learning for upcoming projects [25]. Several challenges have been emphasized by the researchers at the earliest stage to enable the SG and interconnected core. The key challenges to SG development are system integration from various disciplines, regulatory barriers, technology maturity, and consumer engagement in SG projects [25,27,41,58,59].

5.1. System integration

Cooperation, combination, and integration are required for multidisciplinary players with different interests, businesses, regulations, and technologies to ensure the interoperability of SG systems [30]. Despite significant investment in SG projects, stakeholders still face obstacles in integrating newly developed technologies into SG systems. According to the interview conducted among stakeholders, DSO, and academics, the time estimated for the completion of SG pilot projects that generate results is about two to three years. The processes involved are the program setup and design, roll out of equipment, testing, analysis of data, and dissemination of lessons learned [60]. The accountability of different stakeholders for different industrial disciplines has contributed to the most common technical problem in interoperability, especially in integrating ICT systems and other elements (e.g., RES, DER, and DSM) into the network. The failure of interoperability is the most reported incompatibility among the different IT protocols and their components, in addition to the lack of a communication standard for EVs and the different communication standards for SG devices [25]. Setting up an SG platform requires integrating the physical and market layers, in addition to advanced ICT capabilities.

5.1.1. Physical layer

This layer is specifically used to secure and optimize the infrastructure for power or data flow between producers and consumers. Investments from system operators (TSO/DSO) are crucial to it. TSOs invest in the development of HVDC, FACTS, device monitoring and controlling, and RES integration. DSOs invest in

Table 3
Summary of various barriers to the deployment of SG technologies.

Barriers	Description
1. System integration	• Integration between the physical and market layer for the interoperability of SG implementation
2. Regulatory barriers	• The aging regulatory barriers need to be revised according to SG development. • Implement several incentives for consumers to encourage SG
3. Maturity of technologies	• The technologies involved in emerging and developed SG are ICT, storage, power electronics, and others.
4. Consumer awareness and participation	• Consumers still lack SG knowledge and benefits gained.

smart meters, DER integration (distributed generator, storage, and EV), and response to demand. The integration of RES and DER into the grid introduces new challenges for grid stability, requiring intensive case studies.

5.1.2. Market layer

The market layer refers to an efficient mechanism capable of coordinating transactions among operators, prosumers, and aggregators. Aggregators act as the middle party to producers, consumers, and the market. They are able to procure and sell load flexibilities in the electricity market on behalf of consumers. Most SG projects in Europe contribute a physical layer, a market layer, or both. Managing the system integration of and interoperability among the elements is important in maintaining the SG concept, technology, and success.

5.2. Regulatory barriers

The government is generally the policymaker, whereas regulators supervise the implementation to maintain stakeholders' interest, protect their benefits, and prevent market abuse [52]. Existing policies and regulatory frameworks are designed to deal with the standard operation of electricity networks and not SG networks. Thus, new policies are important to ensure that the numerous benefits are enjoyed by all stakeholders. Since the last decade, almost USD 406 million (€ 300 million) in funds has been invested by the EU in European SG projects. The funding was about USD 9.2 billion (€ 6.8 billion) for R&D, innovation, and deployment of 300 SG projects in Europe in September 2012 [25]. Compared with other stakeholders, DSOs also play a major part in coordinating SG deployment throughout Europe. The overall investment by DSO was nearly 67% for about 115 projects [25,27] Moreover, as mentioned by [58], the EU's current regulation prefers that member states be encouraged with cost efficiency through reduced operation costs rather than upgraded smarter systems. Immediate amendment and revision will be performed on the current regulation to ensure SG investment potential. The proposed new regulation should emphasize fair cost sharing among the DSOs, TSOs, suppliers, private sectors, and end users to prevent some players from benefiting from SG at the expense of others. The main concern with many stakeholders is whether or not the benefits overweigh the cost because the cost of modernizing networks is extremely high. In enabling SG deployment in Europe, these challenges depend on the EC's proposal of policy initiatives, such as the development of a common EU SG standard, addressing data privacy and security issues, regulatory incentives for SG deployment, guarantee of an open and competitive retail market in the interest of consumers, and continuous support of innovation in SG technology and systems.

5.3. Technology maturity, security, and quality of supply

In conceptual terms, SG operation is envisioned to integrate the use of ICT, storage technologies, and power electronics to ensure the production and consumption of electricity to balance all the levels. Changing the electricity generation landscape requires changing the network design and control. It also requires system integration. Moreover, the synchronization of new technologies and the capability to eliminate PQ problems must be ensured. Simoes et al. [41] explained the great importance of technology maturity and availability to ensure operational security. The level of maturity is accessed through the development and application of DER, power electronics, control, automation and monitoring, demand side management, distribution automation, and protection and communication systems. SG is defined in several ways, depending on its application; Table 4 summarizes the most demanding activities and technologies for SG in Europe.

5.3.1. DERs

DERs may include elements of DG, energy storage, and managed loads, such as EV. The integration of DER into the SG electricity network is intensely challenging from the perspectives of the physical and market layers. The main goal of DER in the context of SG deployment is to guarantee grid stability, online coordination of EV, adjustment of DGs or storage devices to the grid and market conditions, optimized energy resources, and provision of small players with easy access to the electricity market. The connection of DG to the grid contributes some benefits from utilities and to

Table 4
Components of the SG design concept based on the applied technologies.

Component	Applied technologies	Description
Decentralized topologies	• VPP • Micro grids RES/DER	• Configuration of a grid part, with secondary control and link interfaces • Configuration of electricity production, namely, photovoltaics, wind, and others, its primary control, and the producer interface • Configuration between storage facilities, primary control, and storage interface [61]
Bi-directional communication	• Smart metering • Distributed automated system	• Real-time control of electricity use between producers and consumers • Wide area of servicing network gateway is required to build the communication among SG elements [62].
Intelligent appliances	• DR • DSM	• Change of consumer's energy consumption to reduce peak load demand • Relevant incentives offered for energy saved [63].
Advanced control technique	• Wide-area measurement systems (WAMS) • Distribution management system (DMS) • Outage management systems (OMSs) • Intelligent electronics devices (IEDs) • Energy management systems (EMSs) • Advance Metering Infrastructure (AMI)	• Integration of RES required high efficiency control method for high performance and efficiency • Monitoring and operating devices installed to avoid disturbances or faults • Consumers are able to control their consumption, storage, onsite generation, and EV charging. • Responsible for processing, computing, and transmitting data from consumers and networks • Automated self-healing technology [64].
Consumers' participation	• Smart Home (DR, DSM)	• Fully automated system at home for electricity control and optimization • Consumer satisfaction with the electric management and usage system [65].
Interoperability framework	• Bluetooth/Wi-Fi/ 4 G range for Smart Meter interface	• Operation consists of multiple sources of electricity generation, energy distribution network, and consumer's energy. • Enabling the exchange of data and information at different levels [66].
Electric transportation	• EV • EV Supply Equipment (EVSE) • PHEVs	• SG is able to simultaneously integrate and accommodate many EVs and RES through the advanced communication and monitoring system • Standardization on the charging system in EU countries (IEC62196) [67].

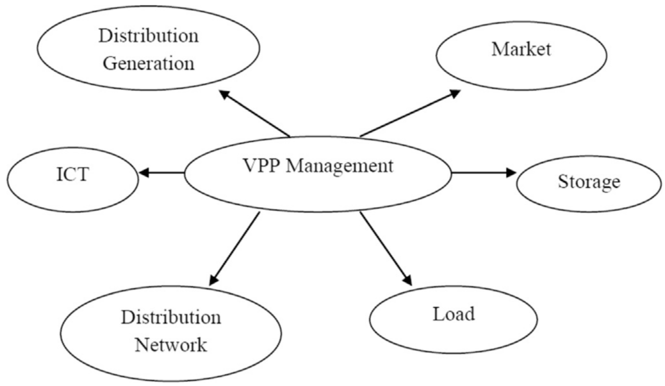

Fig. 13. VPP management diagram [69].

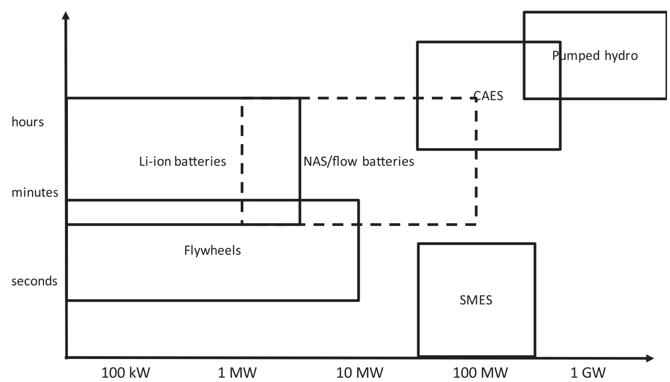

Fig. 14. Comparison of the discharge duration against the rated power of the grid energy storage technologies [41].

customers, such as improved PQ, less loss-to-system power, T&D capacity, enhanced reliability of the electrical supply, and power supply backup to residential areas. Despite these benefits, given the bidirectional flow of the electricity from the DG units and the generation side, the interconnection of DG can violate protection, control, and safety. New technologies can be adopted to overcome these problems: FACTS devices, installation of energy storage into the network, and VPP as management strategy for the DER. Several methods have been actualized to analyze and explore DER's capabilities and new technologies, but activities are still at the R&D stage and demonstration, such as VPP and Vehicle2Grid. None of the DER integration activities has reached the deployment phase [25]. As Fig. 13 illustrates, [68,69] define VPP as a new concept of aggregating the various capacities of DERs into large power plants with ratings high enough to participate in energy markets and provide ancillary services to distribution networks. Although Vehicle2Grid is defined as a vehicle (i.e., PHEVs, electric cars) that is charged from the grid, it is also able to provide or sell back the energy to the grid to maintain the reliability of the electrical system [70].

5.3.2. *Energy storage*

In SG technologies, any excessive electricity production may be transformed and stored into mechanical or electrochemical energy forms. Fig. 14 shows the comparison of the technologies for grid energy storage, in which the factors considered in the selection of storage are based on the improvement of the grid in terms of efficiency, reliability, PQ, load labeling, and peak shaving and voltage regulation. However, the appropriate energy storage must be chosen with respect to its applications [71].

5.3.3. *Power electronics*

With the high penetration of RES and other sources into the electricity grid, the use of power electronics is inevitable because the power converter is mandatory and fundamental to SG development. A power converter is a typical interface between the SG system and local power sources [59]. RES, such as PV and wind energy, are important main sources for SG and are integrated and installed in commercial and residential applications. With RES's intermittent behavior, the generator and converter output voltage, power, and frequency always deviate from the original waveform or values. Thus, the integration of RES into energy storage technology is necessary for compensation. The power electronics converter element is imperative to allow energy storage during excessive input power and to compensate during lack of input power. Fig. 15 illustrates the integration of several energy sources, storage, and power converter into the grid.

According to [41], the power electronics system in SG should be highly efficient and reliable and be capable of synchronizing the connected source to the grid, transferring optimal energy, and providing bidirectional power flow (local and/or grid), communication, and self-healing. It should also have a smart meter.

5.3.4. *Control, automation, and monitoring*

Present electricity network technologies cannot meet electricity demand peaks yet. Thus, many parties struggle to actualize SG in electrical network systems to improve system reliability and efficiency. Bi-directional power flow and information create many challenges. A sophisticated technology is required to control and monitor an SG system. Smart-meter applications can be modeled as Internet networking and two-way communication, by which customers and utilities can generate and deliver energy data, and customers can control and monitor electricity consumption according to price signals [72]. With the analysis of PQ, the deployment of smart meters on the customer's side can reduce energy use and therefore meter readings. The key benefits to utilities include lower harmonic distortion, less voltage imperfection, fewer equipment failures, and reduced operational costs (through less technical and non-technical losses). Currently, in Europe, the main investments in smart meters are made by Italy (USD 2.9 billion/€ 2.1 billion) and Sweden (USD 2 billion/€ 1.5 billion). An investment of USD 41 billion (€ 30 billion) is to be made for the installation of 170–180 million smart meters in the EU 27 countries by 2020 [25].

5.3.5. *DSM*

To achieve stability in electricity network grids, electricity supply and demand must be balanced in real time. The rising demand has conventionally been accommodated by increasing a

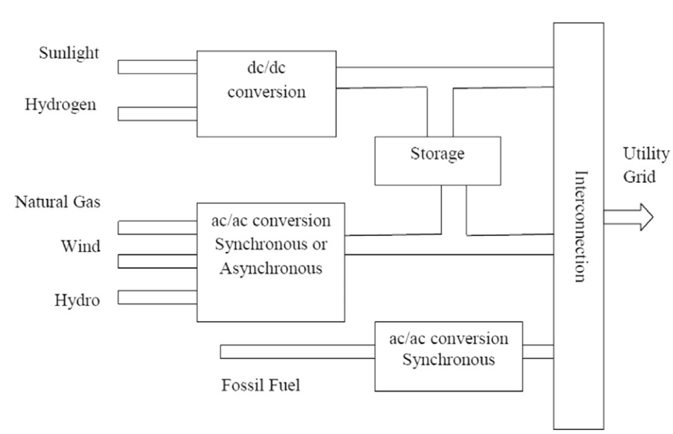

Fig. 15. Integration of several sources of energy into the grid [59].

system's power generation capacity. Simoes et al. [41] claimed that DSM is a sophisticated method capable of changing energy consumption patterns. It is a key enabler for customers to control, monitor, and adjust their electricity consumption in real time. The need for DSM penetration is due to the present aging electricity infrastructure, rapid growth in RES, and advanced ICT technologies. It is also used to equip future SG networks [73]. By applying DSM, customers are able to sell their electricity back to the utilities. The commissions offer several dynamic pricing models to encourage participation in preserving and supervising electricity consumption. The methods proposed for time-varying pricing in DSM are time of use (TOU), real-time pricing (RTP), critical-peak pricing (CPP), and peak-time rebate (PTR). TOU is the rate based on the production and investment of cost structure; it is high during peak periods and vice versa. RTP allows customers to obtain information on electricity price versus time period in advance so that they can plan their electricity consumption. CPP encourages customers not to consume electricity during peak periods to avoid paying high rates. PTR is an incentive for customers to keep their electricity consumption to a baseline [73]. DSM was taken from Spain's Active Demand Management (GAD) project, which aims to optimize electrical energy consumption and its associated costs at the domestic level, while meeting consumer needs and maintaining quality standards. [25,74] showed that customers are able to reduce energy consumption by 10–15%.

5.3.6. ICT systems

ICT is the backbone in transforming conventional grids into SG. ICT is required for fast response, lightning-speed flow, decentralized management, and accessible paths from generator to load [75]. ICT systems concentrate more on the integration of DER, storage, consumer participation, and home energy management for the targeted smart customers, smart homes, and aggregated applications [30]. A common architecture for ICT systems is highly important to guarantee equilibrium between bandwidth and latency. Utilities and ICT companies are still struggling to meet this requirement [52]. Various options exist for wireless communication technologies that can meet the standard of SG, such as Wi-Fi, 4 G, 3 G, Zigbee, and GSM, each with its own bandwidth, transmission range, and characteristics (see Fig. 10) [41]. The common architecture should meet SG requirements, and the technology based on 4 G is appropriate to reach the goal of SG.

The participation of ICT companies increases to accelerate flexible production, such as DER integration, storage, VPP, demand response, and home energy management, aiming for innovations and changes in the electricity sector [76]. Collaborations with system operators (DSO/TSO) are expected to strengthen the ICT competency of system operators (Fig. 16).

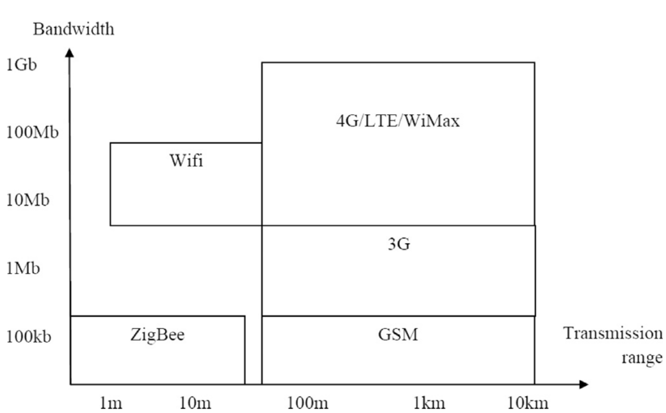

Fig. 16. Wireless communication characteristics [41].

5.4. Consumer awareness and participation

Obtaining consumer trust and involvement, especially in the early stages of SG development, is essential to ensure project success. Of the 459 SG projects, more than 145 projects known as smart customers are concentrated in the consumer's side or residential areas. Consumers always have the right to choose their participation level, guaranteeing data protection and privacy. Thus, energy providers should develop a product that is user friendly and close to consumers to ensure good response. An example is the encouragement from the regulatory body in the implementation of the feed-in tariff scheme. This scheme inspires consumers and industrial companies to reduce their CO_2 emission by alternatively using renewable energy for electricity production [77]. Surveys and studies have been conducted to observe and better understand consumer acceptance and perception of SG development. They are also conducted to ensure readiness for SG development. The results show that some consumers still lack confidence in SG technologies because of misconceptions and misinformation [78–80]. Lack of consumer confidence may result in failure to acquire benefits, such as energy savings, reduced widespread outages, optimized efficiency, transparent power supply reliability, and frequent billing information. In addition to the studies and surveys, the EC pointed out the necessity to strive for and realize consumer participation and awareness, to establish SG development in a competitive retail market, and to educate and change consumer behavior in daily energy consumption within the new smart-energy pattern. JRC questionnaires gathered information from project coordinators and consumers about consumer engagement in projects [25,34]. In 2013, major projects were initiated, focusing on smart customers. These projects include Building Energy Decision Support System for Smart Cities (BESOS) and Collaborating Smart Solar Powered Micro Grid (CoSSic). Both projects were developed by 11 partners with Spain and Norway as the leader [81,82]. Consumer participation was observed through the number of engagements in SG activities, participation in leading organizations, and geographical distribution of the SG projects.

The projects and years in Fig. 17 show a tremendous increase in consumer participation, especially in 2011 and 2012. The data for 2013 were gathered up to July only, but significant positive attitude was shown by consumers toward project engagement. Basically, the consumer refers to the residential sector, which has a high potential for energy saving. To gain consumer acceptance, DSOs need to ensure system integration with RES and DER to provide continued supply, security, efficiency, and dynamic pricing. Fig. 18 shows approximately 29% consumer engagement and investment by DSOs in their respective projects. The DSO is known as the key enabler of smart customers and home projects.

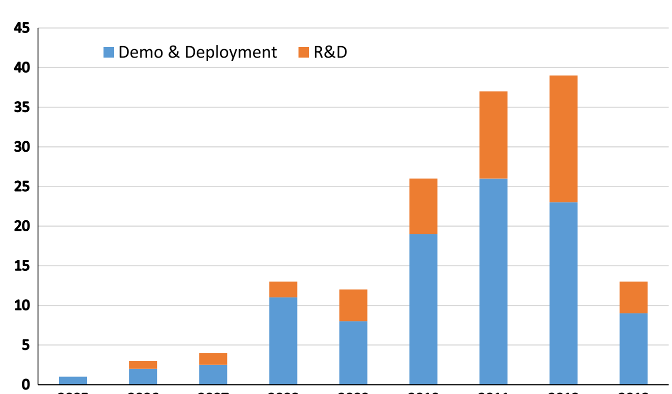

Fig. 17. Number of projects with consumer engagement [34].

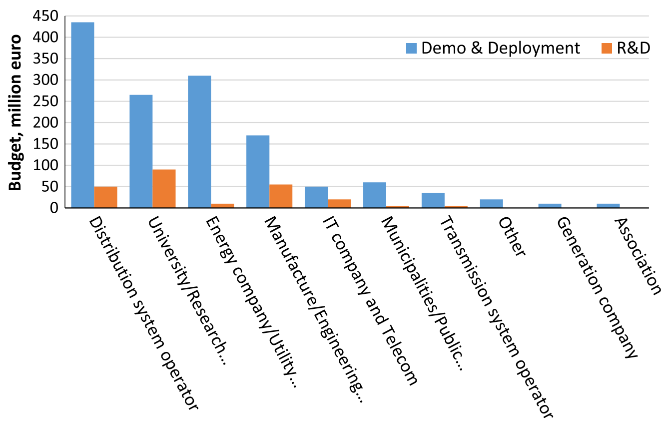

Fig. 18. Leading organizations with consumer engagement based on investment [25,34].

Universities show a positive attitude in encouraging consumers to the SG projects. TSOs and generation companies are the smaller contributors to the smart customer's projects in the EU because only a few of the SG applications are concentrated in the transmission and generation side (i.e., integration of RES and VPP). Some motivational factors are also used to accelerate SG projects, such as environmental concern among consumers, opportunities to reduce consumer electricity bills, and better comfort of the new technologies to develop a daily energy consumption pattern [34,83]. Another important factor in improving consumer engagement is raised by [84,85] regarding the policy objectives of SG that consider consumer acceptance.

6. SG development policies of the EU

Policies and technologies run in parallel. As an executive branch of the EU, the EC is accountable for SG innovation and implementation policies. Outstanding cooperation is needed among EC, regulatory bodies, stakeholders, and other working groups for a joint vision that will determine a mission for the European network of 2020.

6.1. EU policy drivers for SG

The energy sector has faced many challenges in changing the landscape of electricity generation of Europe. The existing grid has served well for many years but is becoming more congested with the increased demand from consumers, which may be inadequately served by future grids. The SG electricity network is more flexible, reliable, and assessable. The factors that determine the restructuring of existing grids include climate change, depletion of fossil fuel, aging infrastructure of electricity network, and internal European energy market [42]. In the context of EU policies, the drivers for SG transactions are inspired by the EU's climate and energy package, energy policy goals, and third energy package.

6.2. EU's climate and energy package

This package focuses on the action taken by EU members against climate change and the environmental issues facing humanity. Its obvious message is for Europe to be a driving force of SG implementation. The EU is targeting the following achievements by 2020: 20% increase in the energy generated by renewable sources, 20% less GHG emitted than the 1990 levels, and 20% more efficient energy [1]. A successful track record that realized the target in the Kyoto Protocol has put higher ambitions on the EU, that is, to further the 2020 package toward a 2050 package. In achieving the goals of a secure, competitive, and decarbonized energy system by 2050, reducing GHG emission to 80% below the 1990 levels is targeted [86]. The energy policy's main objective is to develop a sustainable energy system, highly secure supply, and competiveness in developing the electricity market. The integration of RES (at the generation and distribution sides) and reduction of CO_2 pollution are the main concerns in sustainable energy development [87]. The InovGrid project has had a positive effect on Italy. Italy's Telegestore project reduced the country's "minutes of interruption per year" from 128 min to 49 min in 2001–2009 [88].

6.3. EU third energy package

To reach EU's energy policy objectives, the EU Third Energy Package was adopted in 2009 to cover security issues and actualize a single market for gas and electricity among members [14]. The Smart Grid Task Force (SGTF) is an agenda in this package that develops SG by addressing the policies to overcome the present challenges in Europe. Contribution to accelerating SG activities is an obligation imposed on member states through automation to 80% smart meters by 2020 [37]. To create a competitive and transparent SG market, the relevant technical standard established under this package was adopted, mainly in demand response and TOU pricing.

6.4. Policy initiatives for SG deployment

The Directorates-General, agencies, and commissions of EC enforce relevant policies and legislation through directives or regulations. The SGTF was established by the sub directorate of the Directorates-General Ener as a consultant adviser to the commission on policies and regulations concerning SG deployment. With the first move in policymaking in 2009, the EC addressed five policy initiatives to enable SG technologies [27]. Under the development of a common standard for European Smart Grids, several mandates have been issued by the EC to the European Standards Organizations (ESO) (i.e., CENELEC, CEN, and ETSI). The mandates seek to establish the standard for the interoperability of smart utility meters (March 2009), EV charging standard (June 2010), and high levels of SG services and operation (1st March 2011). The first European standard was set by ESO in March 2009 for smart utility meters. The proposed standard included operations involving the integration of the heterogeneous systems of smart-metered utilities (e.g., gas, electricity, heat, and water), communication protocols, and enhancement of consumer awareness on electricity consumption. Furthermore, according to the Electricity Directive (2009/72/EC) [37] and Energy End-Use Efficiency and Energy Services Directive (2006/32/EC) [89], the deployment of smart meters is necessary to realize energy efficiency, in addition to enabling demand response and authorizing consumers to control and monitor their electricity consumption.

On March 2011, the European Council issued an additional mandate to ESO to develop standards that further the high level of SG services and operation. Propitiously, the task received full support from the participating stakeholders and each ESO. The deployment of the aforesaid mandates, together with SGTF, are being closely monitored by the Commission to ensure deliverable standards. The most recent update made on January 28, 2013 was a conference held by the EC to discuss the outcome of the achievement of the said mandates. Each ESO representative presented the accomplishments of the individual organizations in developing common standards for the integration of SG systems [90]. In terms of ICT standard development, the Commission continuously assesses and reviews standards to synchronize them at the European and international levels to facilitate future European smart electricity networks. Thus, the Commission closely monitors national regulations that can potentially be applied for the specification of data protection for SG. Protecting data exchange, in particular business data, is essential and involves grid operators and stakeholders. Collaboration between ICT and the energy society is imperative to ensure network security and resilience and information on SG systems. Thus, SG data can be shared securely among companies or stakeholders.

6.5. Regulatory incentives for SG deployment

Network operators, such as DSOs, are leading in SG investments to improve network efficiency and system operation. Since SG activities started, compared with other stakeholders, DSO has invested large amounts for its deployment. A total of 27% of the investments in 2011 were made by DSO, and 67% show DSO playing a main role in SG deployment [25]. Member states are required to propose their development and implementation plans and to schedule smart-metering roll-out and SG projects. The EC also requires its members to produce action plans with targets for their SG implementation. Some member states, such as Italy and Germany, have begun regional initiatives, with incentives given to investors. Italy's Regulatory Authority for Electricity and Gas (AEEG) agrees to provide an extra 2% weighted average cost of capital (WACC) on the investment made that is relevant to energy efficiency and SG [91]. Germany has started developing incentive schemes for active players of smart-meter deployment. Nevertheless, the geographical distribution of SG projects among member states is equal, so that cooperation and trading conflicts can be avoided. Regional initiatives and EU-wide ten-year network development plans allow the discussion of issues of common interest to stakeholders and regulators of member states [92].

6.6. Competitive SG services to consumers

The use of in-home players, ICT products, and other electrical appliances encourages consumers to resort to SG services and increases transparency between producers and consumers. This trend should encourage consumers to change their behavior in energy saving and SG activities. However, the deployment of smart meters and SG can be favorable to consumers. Some consumers are anxious about database transparency, privacy, and security, as well as smart-meter capabilities in two-way communication with utilities. Thus, policy issues involving consumers should be viewed and designed holistically according to consumer need. Two basic actions have been taken by the EC through the Energy Services Directive. The first is a minimum requirement for the information format and content supplied to consumers and for consumers to have easy access to service information and demand management. The second is the development of a competitive and transparent market in SG. The EC continuously observes the fulfillment of the Third Energy Package requirements, the technical standards for the demand response, and TOU pricing.

6.7. Continuous support for SG deployment

Over the past decade, the EC has consistently launched several initiatives for SG innovation parallel to the EU 2020 targets. Large amounts of funds for FPs (i.e., FP5, FP6, and FP7) have financed demonstration and R&D. From 2001 to April 2011, FP6 and FP7 funded eight projects amounting to USD 51 million (€ 38 million) and 23 projects amounting to USD 197 million (€ 146 million), respectively. Meanwhile nearly USD 271 million (€ 200 million) was received from the European Recovery Fund, ERDF, and EERA [88,93]. In May 2005, the EC launched a group of experts called Smart Grid European Technology Platform (Smart Grid ETP) to develop a joint vision and research program for European SG. To accelerate R&D and policy implementation, the EC has initiated a joint venture between Smart Grid ETP and the European Electricity Grid Initiative (EEGI) to develop an SG roadmap and implementation plan for EC SGTF. Established in June 2010 under the Strategic Energy Technologies plan, EEGI should meet the EU 2020 target through its demonstration and R&D projects involving SG technology integration. A comprehensive implementation plan has been proposed by EEGI for 2010–2018, which identifies the need to upgrade distribution and create mutual cooperation between DSO and TSO [26]. EEGI will also assist DSO through the Smart Cities and Communities initiative to increase energy efficiency by integrating heterogeneous energy supply and use. Starting with the aforesaid SGTF, Smart Grid ETP, EEGI, and Smart Cities and Communities initiative, the EU has taken several initiatives to foster SG deployment in Europe. In the academe, the distribution of the SG funding is not limited to funds from the EC (i.e., FP6 or FP7) because universities have also been allocated budget by their respective governments [25]. Berlin University of Technology has received support from and collaborates with the German Federal Ministry of Economics and Technology to build its own SG laboratory, specifically to pursue research and develop the SG models that can help realize the goals of SG for the power and energy industries [56].

7. Conclusion

SG is being developed in an especially competitive market. The EU maintains world leadership in SG technology. Its key challenges are the system integration of various disciplines, overcoming of regulatory barriers, technology maturity, and consumer engagement. SG is a digitalized two-way communication with real-time pricing that enables consumers to achieve energy savings. Non-uniform investment in SG and its development across European countries pose challenges to trade, cross-border cooperation, and technical and social aspects of SG. Proactive initiatives and funding for SG have been established by the EU and national levels (ETP, EEGI, EERA, FP6, and FP7) to nurture and shape SG prospects beyond 2020. European SG activities began in 2001 with a smart metering project that installed 45 million smart meters in EU 12 countries; the smart meters reduced energy consumption by up to 10%. Policies for SG should be made in tandem with the technologies developed. SG promises the benefits of energy security, energy supply reliability, economic prospects, and mitigation of environmental impact. The success of future grids requires support and attention from political and regulatory quarters and the reconstitution of energy generation, market, and usage. The achievement also involves the academe, industry, and research and innovation centers. In addition to the main stakeholders, the academe or universities who are paving the way in orienting the government to SG directions should exert all their efforts to organize more conferences and consultancy groups related to SG. The continuous innovation from the industry partners, governments, regulatory and standards bodies, and professional organizations with an academic research infrastructure is highly needed to ensure the accomplishment of SG projects.

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