# Smart Grids Innovation Challenge Country Report 2019

MI Smart Grids

**S**trategies, **T**rends and **A**ctivities on Jointly Identified **R**esearch **T**opics (START)

MISSION INNOVATION
accelerating the clean energy revolution

MAY 2019

SMART GRIDS

# INNOVATION

CHALLENGE

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Dr. Sanjay Bajpai has over 30 years of industrial and R&D management experience in the area of Management of Technology Development, Demonstration and Commercialisation Programmes as well as socio-economic programmes requiring application of Science & Technology. He is currently Associate Head of Technology Missions Programme leading Research Development and Demonstration Programmes on energy and water technologies of Department of Science and Technology, Ministry of Science and Technology, Government of India. Besides fulfilling the promotional role expected of the above programmes, he has developed several innovative model for national, bilateral and multi-lateral research.

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She is active in Mission Innovation IC1 on smart grids since its launch in Beijing and has been appointed as IC1 contact point to the BIE sub-group (Business and Investor Engagement).

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Josef Ayoub has been working in the Innovation and Energy Technology Sector at Natural Resources Canada (NRCan) since 1999, attached to the CanmetENERGY at the Varennes research center, currently in the position of Senior Science Advisor to the Director General. He has been representing Canada as official delegate to the executive committees of several international multilateral programs including the IEA ISGAN and IEA PVPS TCPs coordinating and facilitating R&D collaborative arrangements between Canadian and international research centers. Mr. Ayoub was also the Operating Agent of the IEA SHC Task 40/ECBCS Annex 52 R&D group investigating net-zero energy buildings. From October 2011 – October 2013 Josef was seconded by the Government to be the Network Manager the Smart Net-Zero Energy Buildings Strategic Network, a major Canadian research effort of 15 universities headquartered at Concordia University in Montreal, Canada. Prior to joining NRCan, from 1984 to 1999, Josef was a research scientist at the Brace Research Institute at McGill University in Montreal, conducting applied research in appropriate renewable energy technologies for the developing areas of the world. He also consulted on renewable energy projects funded by Canadian aid agencies, the United Nations University, the World Bank and other multi- and bilateral-financing entities, traveling extensively for long periods at a time in Africa, Latin America and Southeast Asia.

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# FOREWORD

Smart grids constitute an essential enabler for the deployment of clean energy technologies. The adoption of smart grids functionalities such as observability, controllability, self-diagnosis and healing open the way to a wider integration of renewable energy sources, a more active participation of the users, the adoption of energy efficiency measures and the consequent potential reduction of GHG emissions. At least 30 nations around the world have adopted policies favoring renewable energy sources and have reached outstanding results with more than 20% of electricity supply covered by renewable energy sources. In addition, several countries have set the goal to reach 100% renewable energy supply from centralized and distributed sources in the future. This target has been proven to be technically and economically feasible, provided that an effective new approach to grid management is adopted, making full use of "smart grids" and their technologies.

While deployment of smart grids solutions is currently underway in many countries, this report identifies and collects the main research, development and innovation topics that will form the basis for the future joint work within Mission Innovation Challenge 1 (IC1) on Smart Grids. Most of the MI IC1 members have ongoing research programs, initiatives and activities on smart grids; their present knowledge and experience together with their commitment towards significantly higher R&D smart grids investments, will act as a catalyst to accelerate the roll-out of smart grids technology in the near future. This report, therefore, is a worldwide reference regarding the most recent global smart grids achievements and applications as well as their development programs.

It is important to acknowledge that this report is a collaborative achievement, and the Editors express here their appreciation to all those who have contributed to its production. This report is only possible because of the hard work and dedication of all MI IC1 members, and we are indebted to organizations and national and international agencies for the data they have provided as well.

This report is designed to be informative, strategically focused to serve the policy audience, and sufficiently detailed to meet the needs of researchers, stakeholders and investors. Whatever the perspective is, we hope that this work will increase the reader's understanding of the global smart grids R&D status quo, development, and trends.

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CONTENTS

# EXECUTIVE SUMMARY

Mission Innovation (MI) is a global initiative presently involving 23 countries and the European Union to dramatically accelerate global clean energy innovation. The power of innovation – driven by sustained public investment coupled with business leadership – can make clean energy widely affordable and bring fledgling ideas into the mainstream.

As part of the initiative, the participating countries committed to doubling their governments' clean energy research and development (R&D) investments over five years, while encouraging greater levels of private sector investment in transformative clean energy technologies. These additional resources will allow a strong acceleration to the availability of the advanced technologies that will lead to a clean, affordable, and reliable energy mix.

Mission Innovation was announced on November 30th 2015, as world leaders came together in Paris to undertake ambitious efforts to combat climate change and it is organized in 8 Innovation Challenges:

1. Smart Grids
2. Off-Grid Access to Electricity
3. Carbon Capture, utilization and storage
4. Sustainable Biofuels
5. Converting Sunlight
6. Clean Energy Materials
7. Affordable Heating and Cooling of Buildings .
8. Renewable and Clean Hydrogen

Focusing on IC1 on Smart Grids, it is noteworthy to say that a transformation of the energy system is taking place in many countries across the world. This transformation features the surge of renewable energy share in many countries, and makes the energy system prone to a dramatic reduction in greenhouse gas (GHG) emissions, higher energy and economic efficiency, fostering a wider independence from fossil fuels.

Renewable energy sources (RES) integration and advanced technological solutions related to power systems (e.g., storage, HVDC connections, smart meters etc.) are among the key solutions needed to reduce greenhouse gas emissions and tackle climate change. In this view smart grids are an essential enabler for the deployment of clean energy technologies, paving the way for massive RES integration.

In 2016, for the first time, the increase of renewable energy (RE) capacity exceeded the increase of fossil fuel power capacity. Many countries have set the goal to reach 100% of RES in the future. However, the intermittent nature of variable RE raises concerns about their integration in today's power systems due to potential stability and reliability issues.

There is a worldwide interest in smart grids and storage in order to optimally balance supply and demand in the context of a high-penetration of RES. Research and development in the field of smart grids is needed to develop technology solutions and enable a seamless integration of up to 100% renewable generation. Business and Investors Engagement (BIE) is important in order to accelerate innovation, commercialization and deployment of smart grids and renewable energy.

The Smart Grids Innovation Challenge (IC1) is co-led by China, India and Italy and the member countries include: Australia, Austria, Brazil, Canada, China, Denmark, Finland, France, Germany, India, Indonesia, Italy, Mexico, Norway, Saudi Arabia, South Korea, Sweden, the Netherlands, United Kingdom, United States of America and the European Union.

The main objective of IC1 is to accelerate the development and demonstration of smart grids technologies in a variety of grid applications, including the robust, efficient, and reliable operation of regional grids and distribution grids as well as micro-grids in diverse geographic conditions, to facilitate the cost effective uptake of renewable energy. IC1 aims at developing an improved and shared understanding of main Research and Development (R&D) needs and gaps, fostering national research towards jointly identified R&D priorities thus promoting opportunities to researchers, innovators and investors from around the world and strengthening and expanding collaboration between key partners, leveraging on their complementarities and synergies.

Top R&D priorities in the field of smart grids have been identified by IC1 members and six joint R&D Tasks have been selected in order to concentrate the collaborative effort (see

Appendix I). The Program of Work (PoW) for these six R&D Tasks was released on November 2018 at the 4th deep-dive workshop in Rome.

The present IC1 document represents a new release of the previous Country Report 2017 and contains information updated till 2018 about strategies, trends, ongoing activities and case studies from sixteen countries of MI IC1 and the European Union. In this Country Report 2019 edition a special focus is made on the activities and initiatives ongoing at national level supporting the jointly identified R&D topics and IC1 activity at large.

Many R&D projects covering specific innovation challenges in the field of smart grids have been launched worldwide. Several, among the most important ones, are reported as Case Studies in this report.

Moreover, a short recap of the most relevant information for each contributing IC1 member is reported.

# GENERAL REMARKS

In general terms, the rapid deployment of renewable energy sources (RES) and smart grids is fostering a significant increase of the energy system sustainability, affordability, resiliency and security and hence the mitigation of climate change and a range of economic benefits. Renewable energy markets are expected to continue to grow considerably in the coming decade and beyond and there is a tremendous economic opportunity for the countries that are engaged in the roll out of clean energy technologies. As stated above, each IC1 member contributing to this Report provided information on its own energy strategy, RES and smart grids trends and projects, sharing experience in R&D activities to assist governmental investment and to enable private sector and investor engagement. Please read the corresponding section to access to the detailed country information.


# 1. AUSTRALIA

## 1.1 General Framework and Implementation

Australia has a population of around 25 million, an area of 7,692,024 $km^2$, and is experiencing a rapid uptake of renewable energy generation technologies – with the installed capacity of large-scale PV currently doubling around each six months. In 2018, total electrical consumption was around 261 TWh (an increase of about 1% from 2017). Of this, approximately 49 TWh were from renewable generation sources, an increase of about 25% from 2017 (39 TWh).

A transformation of the Australian energy sector is in progress, substantially led by consumers through the installation of world-leading amounts of solar energy at their homes and businesses. New technologies are being embraced as consumers more proactively manage their energy use and support action on climate change.

This consumer side action has resulted in very high levels of renewables, particularly PV, installed within low voltage distribution networks – small scale systems account for around 85% of PV capacity. Consequently, improving utilisation of existing electricity distribution assets, while maintaining system reliability and power quality continues to be a key challenge for Australia.

The Australian electricity system is also importantly characterised by its sparsity. Rather than a single interconnected system, there are multiple separate systems:

- the National Energy Market (NEM), which covers the majority of the eastern and southern part of Australia, extending from upper parts of Queensland, down through New South Wales (including the Australian Capital Territory), Victoria and Tasmania, and part way across South Australia;
- the South West Interconnected System (SWIS), covering the southwest of Westerns Australia
- the North West Interconnected System (NWIS), which primarily covers the mining areas in the Pilbara region of Western Australia;
- the Darwin-Katherine, Alice Springs and Tennant Creek networks in the Northern Territory; and
- a number of mini-grid systems in remote communities, particularly throughout Western Australia and the Northern Territory.

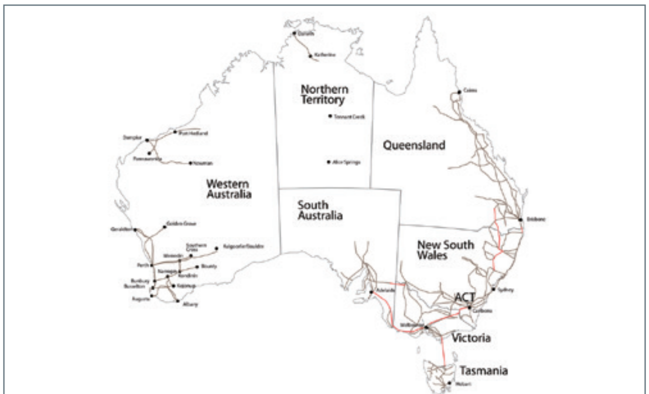


Figure 1-1. Transmission Networks in Australia

In joining Mission Innovation, Australia pledged to double government clean energy research and development expenditure to approximately $216 million by 2020 to accelerate clean energy technological breakthroughs and reduce emissions. At the same time, Australia is working to encourage greater levels of private sector investment in transformative clean energy technologies. This work is being funded, delivered, and coordinated through a number of agencies, such as the Australian Renewable Energy Agency (ARENA), the Australian Research Council, and Australia's national science and research agency, the CSIRO.

National consultation programs have been undertaken to inform Australia's transitional pathways in the electricity sector, including the:

- Electricity Network Transformation Roadmap[1-1]- which identified a pathway to decarbonisation of the Australian electricity sector by 2050; and
- Independent Review into the Future Security of the National Electricity Market - Blueprint for the Future[1-2] (Finkel Review).

The Blueprint for the Future Security of the National Electricity Market sets out a vision for the future electricity system and identified four key required outcomes:

- increased security;
- future reliability;
- rewarding consumers; and
- lower emissions.

Responding to this, and specifically relevant to the IC1 Smart Grids Challenge are the Distributed Energy Resources (DER) focused program funding initiatives by ARENA. This is supporting R&D, demonstrations and deployments for network hosting capacity, virtual power plants and microgrids. To date, ARENA has committed $113M ($80M USD) to DER projects, with total project value of $304M ($215M USD).

[1-1] http://www.energynetworks.com.au/electricity-network-transformation-roadmap

[1-2] https://www.energy.gov.au/government-priorities/energy-markets/independent-review-future-security-national-electricity-market

### 1.1.1 Data sources

Data and information contained in this report are primarily sourced from:

- The Australian Bureau of Statistics http://www.abs.gov.au
- Geosciences Australia http://www.ga.gov.au
- The Australian Energy Regulator https://www.aer.gov.au
- The Clean Energy Regulator http://www.cleanenergyregulator.gov.au
- The Department of the Environment & Energy (DoEE) - https://www.energy.gov.au
  Information in this report has been adapted from that published by the DoEE, which is provided under Creative Commons Attribution 4.0 International licence https://creativecommons.org/licenses/by/4.0/
- The Australian Renewable Energy Agency (ARENA) https://arena.gov.au
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- The Australian Energy Market Operator https://www.aemo.com.au
- The Commonwealth Scientific and Industrial Research Organisation (CSIRO) - http://www.csiro.au

## 1.2 Status of Renewable Energy and Smart Grids

With low population density and multiple population clusters separated by thousands of kilometers, Australia does not have a single interconnected electricity system. The two largest electricity systems in Australia are the National Electricity Market (NEM) and South West Interconnected System (SWIS).

The NEM covers the majority of the eastern and southern part of Australia, extending from upper parts of Queensland, down through New South Wales (including the Australian Capital Territory), Victoria and Tasmania, and part way across South Australia. Regions within the NEM are connected through a number of High Voltage transmission lines, including 3 HVDC links (Basslink, between Victoria and Tasmania; Murraylink, between Victoria and South Australia; and Directlink (Terranova), between NSW and Queensland).

The NEM coordinates the wholesale electricity generation and high voltage transmission to five interconnected regional market jurisdictions (QLD, NSW (& ACT), Vic, Tas, SA), where it supplies large industrial users or connects to local distribution networks. Generation is scheduled through a spot market with 5-minute dispatch intervals, based on lowest cost from a 'pool' of available generators, subject to network and generation constraints.[1-3]

The SWIS covers an area of around 255000 km² in the southwest of Western Australia. The Wholesale Electricity Market (WEM) for the SWIS coordinates operation with the aim of facilitating investment and providing flexibility on how electricity is traded. It includes market mechanisms for: generation & demand-side capacity; a day-ahead and short term energy market; a balancing market; and load-following ancillary services.[1-4]

Both the NEM and WEM (for the SWIS) are operated by the Australian Energy Market Operator (AEMO).

In addition to the NEM and SWIS, there are:

- the North West Interconnected System (NWIS), which primarily covers the mining areas in the Pilbara region of Western Australia;
- the Darwin-Katherine, Alice Springs and Tennant Creek networks in the Northern Territory;
- a number of mini-grid systems in remote communities, particularly throughout Western Australia and the Northern Territory.

In 2018, renewable generation contributed around 19% of Australia's electricity generation mix. Of this, hydroelectricity is the largest single source (around 35%) of renewable energy within Australia, followed by wind (around 33%) and solar (around 24%). Approximate generation capacities and outputs for 2018 are shown in Figure 1-2, derived using data from AEMO (NEM & SWIS), Territory Generation (NT), Clean Energy Regulator (renewable generation installations) & the DoEE (generation totals).

Trends in the uptake of renewable generation are shown in Figure 1-3. Both wind and small-scale solar installations have been growing steadily, at around 500MW and 1GW per year respectively. Small-scale solar had reached 8.1GW by the end 2018, installed across more than 2 million households.

Of particular note is the strong growth in large-scale PV over the last two years, with multiple new solar farms being commissioned and installed capacities approximately doubling every 6 months – from 0.4 GW in mid 2017, to 3.1 GW by the end 2018.

Figure 1-4 shows distribution network line length information by state/territory in Australia, totaling around 850,000 km. This data highlights an important aspect of the network management challenge in Australia – long line lengths coupled with very low population densities in parts of the country. As an example, Horizon Power in WA has around 1 customer per 47 km². For this reason, optimizing existing assets and using new technologies to avoid requirements for network augmentation is an important consideration.

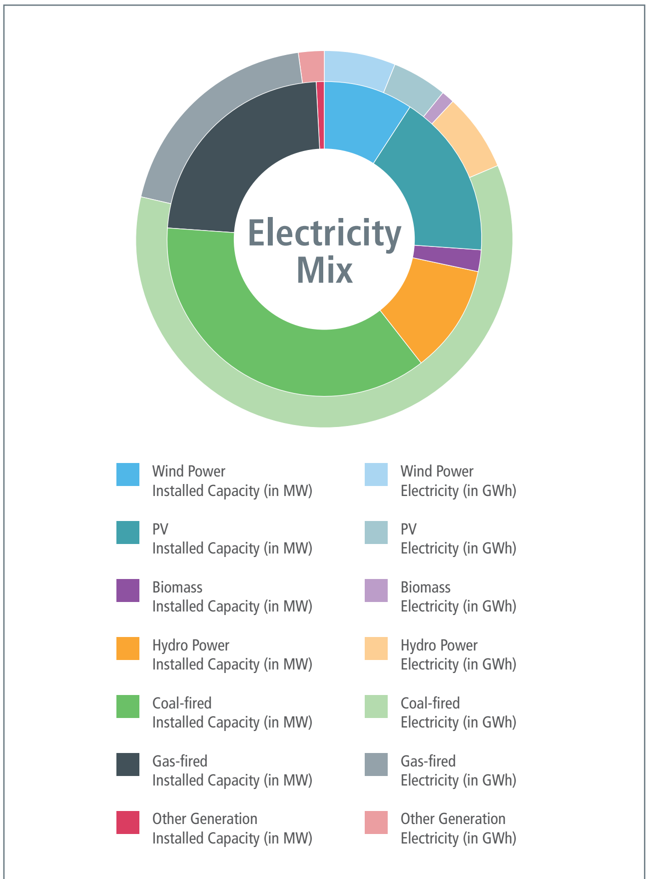



Figure 1-2. Electricity Mix by the End of 2018

[1-3] More information on the NEM can be found at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM

[1-4] More information on the WEM can be found are: https://www.aemo.com.au/Electricity/Wholesale-Electricity-Market-WEM

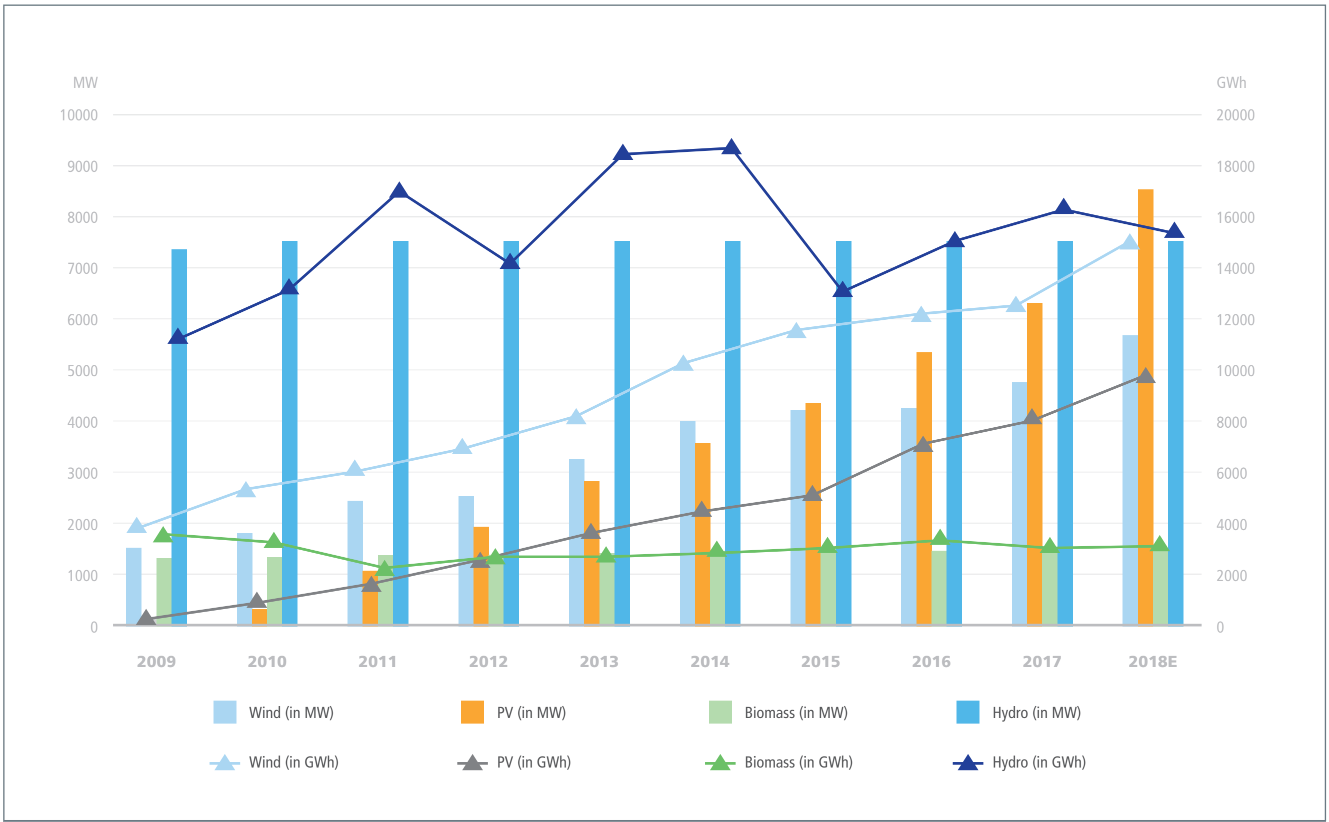



Figure 1-3. Trends on Renewable Energy Generation

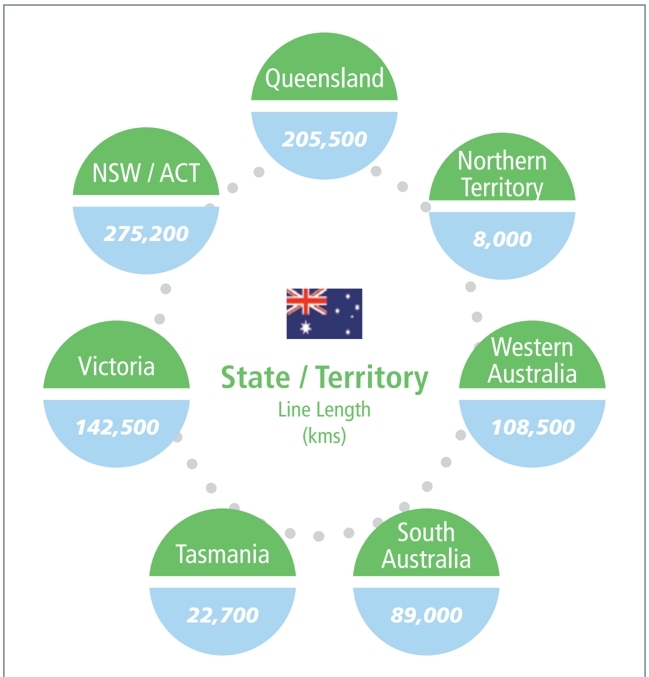



Figure 1-4. Distribution Line Lengths by State/Territory

## 1.3 National Programs in Fields of Smart Grids and Renewable Energy

Following a national consultative process, the Blueprint for the Future Security of the National Electricity Market sets out a vision for the future electricity system and identified four key required outcomes:

- increased security;
- future reliability;
- rewarding consumers; and
- lower emissions.

ARENA has run a number of targeted funding programs to stimulate the required R&D, demonstrations and deployments to deliver these outcomes. To date, this has included:

- **Power System Services** – a $7M program focused on innovative methods and technologies to provide power system security and strength services, applicable to enabling high amounts of renewable energy within the electricity system;
- **Demand Response** – a $35.7M initiative in conjunction with the Australian Energy Market Operator (AEMO) to deliver 200MW demand response capacity by 2020;

- **Distributed Energy Resources** – a $12.5M program supporting both studies and demonstration projects to address the challenges – technical, regulatory & commercial – of increasing amounts of distributed energy resources within the electricity grid.
- **Short Term Forecasting** – a $10M program focused on improving 5-minute ahead forecasting of the output of large scale solar and wind farms and integrating this into the dispatch systems of AEMO.

Through ARENA and the Clean Energy Finance Corporation (CEFC), the Australian Government has already provided significant support for large-scale energy storage projects and research, for example:

- A study by the Australian National University (ANU) to develop a map of potential sites for off-river pumped hydro projects, and (with the CEFC) assisting Genex Power to investigate the feasibility of a pumped storage hydro power plant at the disused Kidston Gold Mine in North Queensland.
- In South Australia, ARENA is supporting the deployment of up to 1,000 centrally controlled batteries in homes and businesses. Together, these will form the largest battery storage 'virtual power plant' in the world, with a combined 7 MWh storage capacity.
- Direct funding of energy storage research, including for the development of advanced lithium-sulphur batteries with the University of Technology, Sydney, the establishment of a mobile energy storage test facility at the University of Adelaide, and a range of research around the use of CSIRO's patented UltraBattery.

Australia also has a relatively large off-grid market for electricity, with energy storage a key enabling technology for projects in remote or fringe-of-grid areas. For example, on King Island in the Bass Straight, ARENA has provided $6 million to a Hydro Tasmania project that includes the installation of the largest battery-based energy storage system in the country. The project has reduced diesel use by 1.9 million litres per year.

**National Smart Grid R&D Activities in Line with POWs Tasks and Sub Tasks**

In joining Mission Innovation Challenge #1: Smart Grids, Australia sought to specifically contribute to activities on:

- Storage Integration;
- Demand Response; and
- New Grid Control Architectures.

Specific national programmes aligned to these task include:

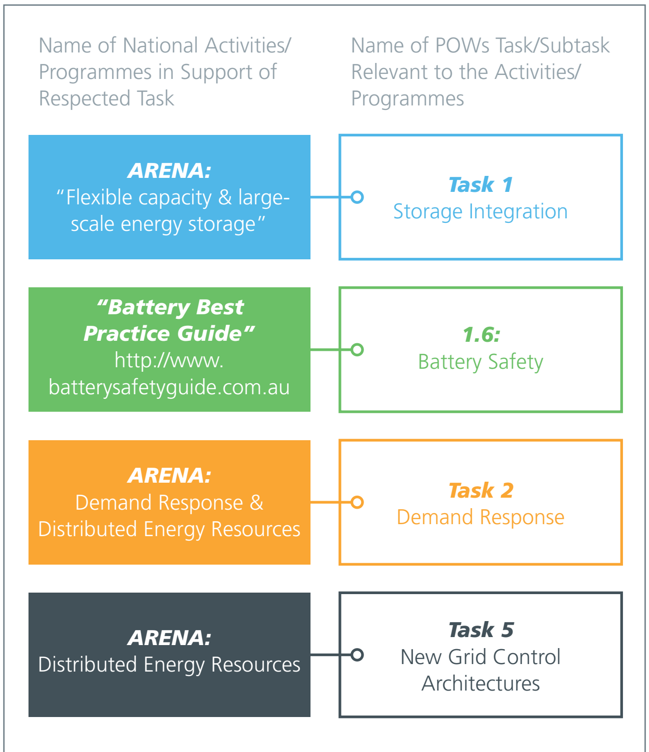



Figure 1-5

## 1.4 International Programme Related to Smart Grids and Renewable Energy

Australia participates in multiple International Energy Agency (IEA) technology collaboration programs (TCP). Specific to the Mission Innovation Smart Grids challenge is participation in both the ISGAN (Smart Grids) and PVPS (Photovoltaics) programs. Within the ISGAN TCP, Australia is particularly active within ISGAN Annex 5, Smart Grid International Research Facility Network (SIRFN) – which facilitates collaboration and development of common test protocols between international laboratories. This work is carried out in the CSIRO Renewable Energy Integration Facility (REIF) in Newcastle, Australia.

Australia is also a strong participant in the Mission Innovation Challenge #7 (Affordable Heating and Cooling), which included collaboration with IC1 on the electricity network impacts of air-conditioning systems.

## 1.5 Case Studies

PROJECT CASE #1
**AEMO and ARENA Demand Response Trial**

**Related Sub-challenge of IC1**
Distribution grid innovation

**Type of Project**
Demonstration

**Topic**
Demand Response

**Objective**
To provide 200MW of emergency reserves for extreme peaks by 2020.

**Contractors**
Energy Australia, EnerNOC, Zen Ecosystems, Powershop, United Energy, Intercast & Forge, AGL

**Period**
2017-2020

**Ongoing and Achieved Key Findings**
Although it only happens a few times each year, when Australia's summers sizzle, households and businesses send electricity demand sky high by simultaneously switching on their air conditioners. When this happens, consumption increases by around 50% more than average.

The challenge for the Australian Electricity Market Operator (AEMO) is to find the most cost-effective way of meeting the occasional spike in the demand for electricity.

A cost effective way to reduce demand during peak periods, and relatively quick to implement, is to pay some energy consumers to voluntarily cut or shift their use of power to better match supply.

This demand response approach lowers the amount of electricity required from the grid during peak periods to reduce the likelihood of a blackout, and can ramp up demand during off- peak periods, or when renewable energy output is high, to use excess electricity more efficiently.

Through this project, Businesses, large companies and individual householders participating in the projects have the opportunity to receive incentives in exchange for limiting or shifting their electricity use during peak demand times such as heatwaves, when the grid is under stress and at risk of blackouts. The economy overall will also benefit from a more efficient electricity system that has avoided the cost of having to build unnecessary new infrastructure.

Trial information is available from ARENA (https://arena.gov.au), and specifically:https://arena.gov.au/assets/2019/03/demand-response-rert-trial-year-1-report.pdf

PROJECT CASE #2
**ARENA Distributed Energy Resources Programme**

**Related Sub-challenge of IC1**
Distribution grid innovation, micro grid innovation

**Type of Project**
Technology development, demonstration.

**Topic**
Distributed Energy Resources

**Objective**
Investigate & trial novel approaches to increasing network hosting capacity with the objective of allowing the system to operate securely whilst maximising the ability of distributed energy, such as solar PV, to provide energy to the grid.

**Contractors**
Zeppelin Bend, Jemena, SA Power Networks, Solar Analytics, RACV, CitiPower & Powercor, Dynamic Limits, University of Tasmania, CSIRO, Oakley Greenwood, the Australian National University and the University of Melbourne.

**Period**
2019-2022

**Ongoing and Achieved Key Findings**
There are 12 individual projects that contribute to this programme of research and demonstration. Two examples are:

**SA Power Networks - Advanced VPP Grid Integration -**
The advanced VPP grid integration project aims to show how higher levels of energy exports to the grid from customer solar and battery systems can be enabled through dynamic, rather than fixed, export limits, and to test the value this can create for customers and Virtual Power Plant (VPP) operators.

The project will introduce an interface Application Program

Interface (API) to exchange real-time and locational data on distribution network constraints between SA Power Networks and the Tesla South Australian Virtual Power Plant (VPP), enabling the VPP to optimise its output to make use of available network capacity. This concept will be tested in a field trial over 12-months.

Recent work by the Australian Energy Market Commission, and the joint Energy Networks Australia/Australian Energy Market Operator Open Energy Networks project has recognised the dynamic management of distribution network capacity is a key requirement to unlock the full value of VPPs and other distributed energy resources. This project will be the first to demonstrate this concept in operation with a real VPP that is actively participating in the market, and to seek to measure the real-world costs and benefits of this approach.

The intention is to enable the VPP to operate at higher levels of export power than would otherwise be allowed under normal fixed per-site export limits. In principle, this could double the VPP's maximum export capacity at certain times, enabling the VPP to provide greater market and system-wide benefits. The learnings from this project could help develop a consistent national approach, and potentially a standard API, for VPP aggregators to access advanced network integration services from distribution networks across the National Electricity Market.

See: https://arena.gov.au/projects/advanced-vpp-grid-integration/

**CSIRO - National Low-Voltage Feeder Taxonomy Study -** The National Low-Voltage Feeder Taxonomy Study aims to produce the first national low-voltage network taxonomy that outlines the real-world characteristics of the distribution system. Depicting how low voltage power flows through the system will help with the design and assessment of the technologies and systems that can maximise the hosting capacity of distributed energy resources (DER) across Australia. It will also enable users to test the value proposition of innovative technological solutions by highlighting how they contribute to the stability, reliability and performance of networks across Australia.

The CSIRO will work with Energy Networks Australia and distributed network service providers across Australia to collect data and information on the state of the low-voltage network. The CSIRO will coordinate the data and develop a standard representation of low-voltage network characteristics for Australia, and a distributed energy resources model. The project will result in the publication of the final low-voltage taxonomy power-flow models for use by the energy sector through the Energy Use Data Model (EUDM).

The project identifies ways to reduce barriers to renewable energy uptake by providing the dataset and tools to move towards evidence-based hosting capacity limits. By providing rich low-voltage network data for free to the wider community, the project grows the capacity for industry, researchers and decision makers to explore the relationship between emerging distributed renewable energy technologies and the operation and performance of Australia's electricity distribution system.

This project will produce the first national low-voltage network taxonomy that clearly articulates the real-world characteristics of the distribution system in relation to the impact of higher levels of solar PV penetration. The grid stands to benefit from efficiently deployed demand response and distributed storage. It also provides the ability for industry to test how their distributed energy technologies interact with, improve and add value to Australia's low voltage networks.

See: https://arena.gov.au/projects/national-low-voltage-feeder-taxonomy-study/

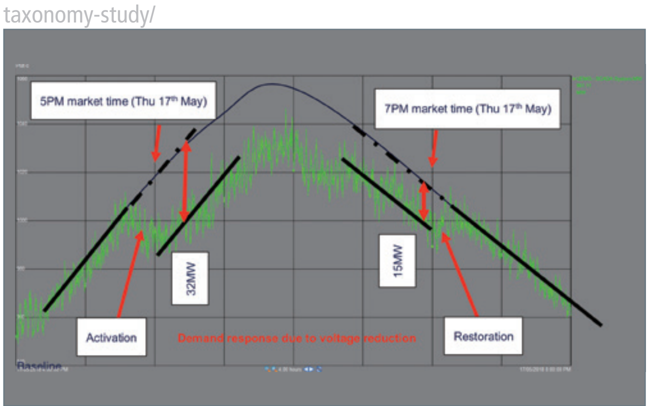



Figure 1-6. Example Results from Voltage Control Based Demand Response Trial by United Energy[1-5] as Part of the AEMO and ARENA Demand Response Trial

[1-5] See: https://arena.gov.au/projects/united-energy-distribution-demand-response/


# 2. AUSTRIA

The Smart Grids Innovation Challenge (IC1) aims to develop and demonstrate the use of smart grid technologies and storage in a variety of grid applications. These applications include robust, efficient, and reliable operation of regional and distribution grids as well as microgrids in diverse geographic conditions. By 2030, the objective is to develop technology solutions that can accommodate renewable based power plants in large scale across the globe. The main sub-Challenges for IC1 have been already defined as regional grid innovation, distribution grid innovation, microgrid innovation and cross innovation.

## 2.1 General Framework and Implementation

"Innovative Energy Future and Clean Mobility" is a high priority in the Austrian governmental programme for 2017-2022 (published at the end of 2017). The commitment to Mission Innovation is explicitly anchored in the governmental programme. It includes a declaration to increase the research budget during the period and to start an "Energy Research Offensive".

The Austrian Energy Research and Innovation Strategy[1-1] pursues this vision and has set itself the following goals:

- Energy research and innovation will result in economic growth, create new jobs and will contribute to decarbonisation of the energy system;
- Energy research funds will be successively increased;
- Austria will be an innovation and technology leader in selected energy related areas;
- Austria will improve its contact to international markets and innovation networks;
- Austria will have an increased presence at a global level.

In 2018 the Austrian government presented "#mission2030[1-2]", the Austrian Climate and Energy Strategy. The key objective of the Federal Government's climate policy is to reduce greenhouse gases by 36% by 2030 compared with 2005.

Renewable energy currently accounts for around 33.5% of the produced energy. Around 72% of electricity generation already comes from renewable energy sources (RES). Of all European countries, Austria has achieved the largest contribution from RES to electricity generation. The federal government has

[1-1] Energy Research and Innovation Strategy – Summary, Federal Ministry for Transport Innovation and Technology, Vienna, March 2017, https://nachhaltigwirtschaften.at/resources/e2050_pdf/E-Forschung_Kurzfassung_englisch_v2.pdf

[1-2] #mission2030 – Austrian Climate and Energy Stragegy, Federal Ministry for Sustainability and Tourism and Federal Ministry for Transport, Innovation and Technology, Vienna, September 2018, www.mission2030.bmnt.gv.at

therefore set itself the objective of covering 100% of total national electricity consumption (national balance) from renewable energy sources by 2030. This will mean developing all renewable energy vectors, infrastructure, storage facilities along with investments in energy efficiency. The focus in coming years will need to shift to the transport and space heating sectors, to maximize the returns from the investment. These two sectors have the greatest potential for savings and reductions.

Due to its mountainous, central European location around 60% of the electricity in Austria is produced by hydro power and another 10% by other renewable resources (Wind, PV and Biomass). There is a significant share of large hydro power plants (e.g. along the river Danube) and pump storage (located in the Alps region) as well as a lot of small and medium scale hydro plants in the mountains. The share of renewable based electricity generation in Austria is currently very high. Nevertheless, it is expected that additional renewables (mainly wind, photovoltaics and small hydro) need to be integrated into the networks as "distributed generation" in order to reach the national objective of 100% electricity from RES by 2030 (see Figure 2-1).

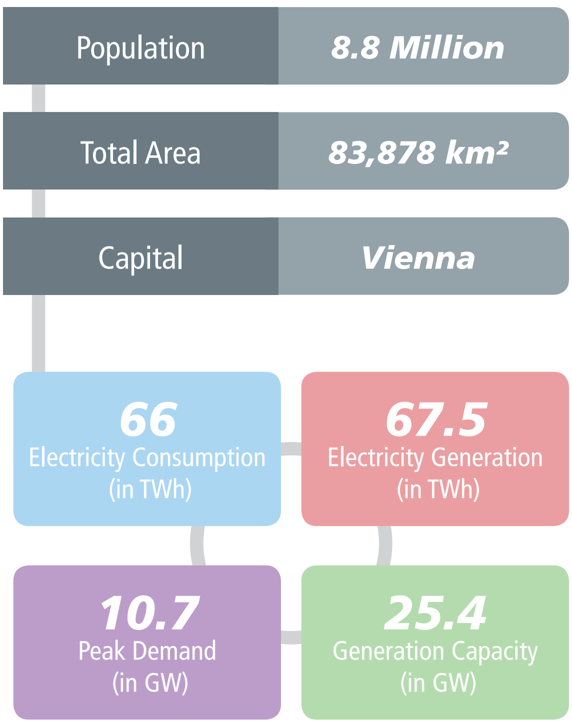



Figure 2-1. Key Figures of Austria by End of 2018

In 2018 the overall electricity consumption in Austria was around 66 TWh with a peak demand of 10.7 GW compared to an overall generation capacity of 25.2 GW.

## 2.2 Status of Renewable Energy and Smart Grids

Austria's objective is to increase the share of renewable energy to to 45-50% by 2030 starting from a current 33.5%. Another objective is to cover 100% of total electricity consumption (national balance) from national renewable energy sources by 2030. This increase considers the anticipated increase in electricity consumption, as electricity from renewable sources in Austria will be used in the mobility, building and production sectors to replace imported fossil fuels. This goal relies on future trends in digitalization, decentralization and participation. **Balancing energy and control energy to stabilise network operations are disregarded for the purpose of calculating the 100% renewable energy supply.** At present around 72% of electricity generation is already RES based.

To reach a 100% RES based power system Austria expects to increase the annual RES generation by around 35 TWh. This means an increase in PV capacity from 1.2 GW in 2017 to around 12 GW in 2030 (a factor of 10) and wind capacity from 2.8 GW to around 7 GW (a factor of approximately ~2.5).

There is one transmission system operator in Austria operating the power system at 220 kV and 380 kV. There are around 120 distribution network operators (including a high number of municipal utilities and small local network operators). The Austrian power grid is divided into four voltage levels:

- Extra-high voltage 380 kV and 220 kV
- High voltage 110 kV
- Medium voltage: 30 kV, 20kV, and 10 kV (mainly urban)
- Low voltage: 0.4 kV

The main driver for the Austrian Smart Grid research and related projects is the massive integration of renewable-based distributed generation into the distribution system level. The focus of the related smart grid projects has been to increase the hosting capacity of the existing medium and low voltage distribution networks for distributed energy resources (DER), including distributed generation (DG), demand response (DR), storage and e-vehicles as well as the interaction of transmission and distribution networks. Additionally, there is a strong focus on how to integrate new actors, roles and service providers (such as prosumers, active consumers and aggregators) in the future power system in order to support the above mentioned energy transition in Austria. In the last

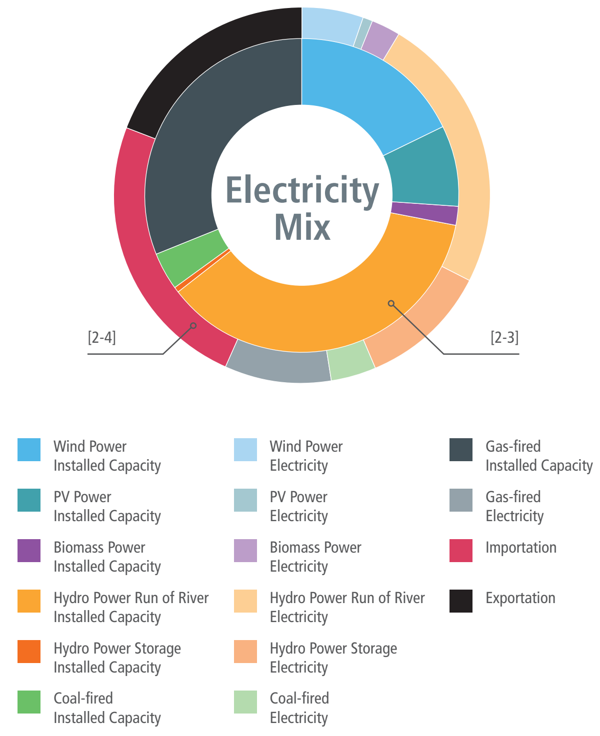



Figure 2-2. Electricity Mix by the End of 2017

two years the focus has been extended towards dynamic grid support of RES to investigate and develop solutions for inertia and enhanced frequency support by converter-based distributed energy resources.

With the support of the Ministry for Transport, Innovation and Technology as well as the Climate and Energy Fund (known as KLIEN and described further below), individual Austrian projects have been strategically pooled in recent years to generate a critical mass. This has increased European and international visibility of projects and strengthened Austria's position in the implementation of the European Commission's Strategic Energy Technology Plan (SET-Plan). The focus is on an integrated approach for planning and operating distribution grids and the effect on the transmission system, which can be divided into three major sub-aspects:

- Distribution grid planning, design, and operation to optimise integration of distributed electricity generation;
- Integration of customers into a smart grid and electricity markets;
- Power system service provision by distributed energy resources including transmission and distribution system interaction.

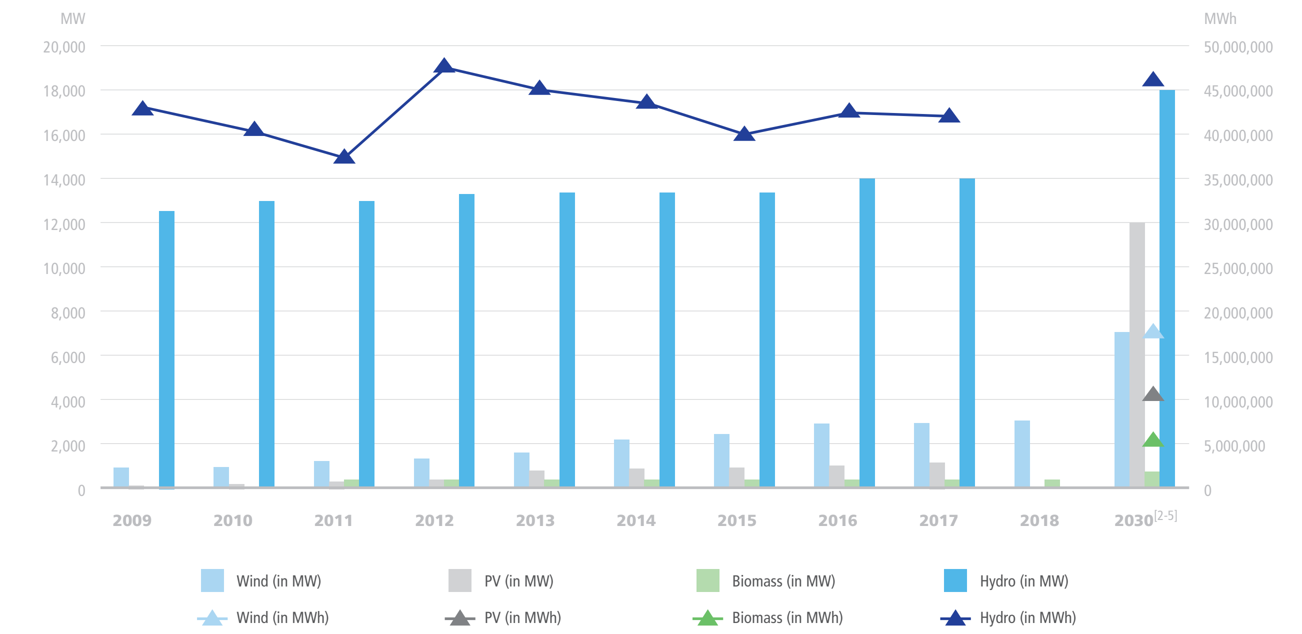



Figure 2-3. Trends on Renewable Energy Generation

[2-3] Innovative Energietechnologien in Österreich Marktentwicklung 2017, bmvit, Berichte aus Energie- und Umweltforschung, 4/2018, https://www.pvaustria.at/wp-content/uploads/marktstatistik-2017-endbericht.pdf (only summary in English)

[2-4] -control Statistikbroschüre 2018, https://www.e-control.at/publikationen/statistik-bericht (german only)

[2-5] https://www.eeg.tuwien.ac.at/eeg.tuwien.ac.at_pages/research/downloads/PR_464_final_report_Stromzukunft_Oesterreich_2030_(TU_Wien_-_EEG_Mai_2017-final).pdf (table14)

## 2.3 National Programs in Fields of Smart Grids and Renewable Energy

The Climate and Energy Fund of the Austrian Federal Government is focused on advancing the mobility and energy transitions. Additionally, it subsidises measures for the reduction of greenhouse gas emissions. From 2007 until 2017 a total subsidy of 1.1 billion Euro has been assisted in implementing  more than 110,000 projects funded in 195 separate funding calls. The fund is a motor of innovation at all steps of the development chain from research to market and offers 23 different programmes in the areas of research and development, mobility, market penetration and raising awareness. The Federal Ministry of Transport, Innovation and Technology (bmvit) has been running several thematic programmes in the field of energy following a top down approach with clear strategies, goals and objectives. Furthermore, energy research projects can be conducted in the Basic Programmes and in the Competence Centre Programme of the Austrian Research Promotion Agency (FFG) based on a bottom-up approach. Public R&D is undertaken by the 9 federal provinces with own programmes too.

The main focus of the Energy Research Programme of the Climate and Energy Fund is on research, development and market introduction of new materials as well as innovative technologies, processes and system solutions. The bmvit programme City of Tomorrow is focused on future cities to create and empower intelligent energy solutions on a building- as well as a district level. Smart Grids play a key role in management of this type of energy system. Based on the existing research projects and pilot regions (Model Regions) in the field of Smart Grids, in 2013 bmvit initiated a strategy process called Smart Grid 2.0, which was finalised in 2016. The bmvit's Smart Grids 2.0 strategy process was a platform for creating foundations for decision-making and implementation components on which a consensus can be reached – based on findings of Research, Technology and Innovation (RTI) initiatives and with the broad-based involvement of stakeholders. The results are included in the Austrian Energy Research and Innovation Strategy with priorities in six areas shown in Figure 2-4.

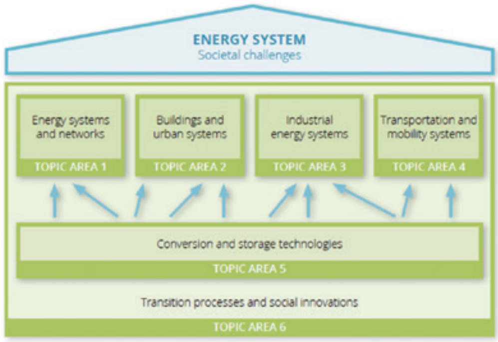



Figure 2-4. Topic Areas for Energy Research

Topic area 1 on **Energy systems and networks** focuses on development of the electricity systems, transformation of heat and gas networks and the creation of an innovative environment for user integration. Coupling the interactions in different sectors is a significant priority, i.e. linking electricity, heating and mobility systems so that renewable energy can be used as effectively as possible in an integrated way. To demonstrate this in realistic scenarios, numerous Smart Grid Model Regions have been established in Austria.

While research funding is offered for the whole development chain, the funding instrument for flagship projects is particularly important:

- Flagship projects are R&D projects that are strategically and scientifically defined and are of substantial size when measured in terms of their scientific and financial investment (>EUR 2 mill.) and the number of project partners;
- Flagship projects address the horizontal and/or vertical integration of the value chain and address the technological feasibility of systems solutions with a long-term potential for growth;
- Flagship projects serve to strengthen a sector or branch or to generate model solutions to important challenges faced by society. They support national and international visibility for Austrian technology.

In the past, numerous flagship projects have been funded within the portfolio of the national programmes for energy research referred to previously. In 2017 a new program was started, which bundles a number of flagship-type projects in "Flagship Regions for Energy".

**Programme "Flagship Region Energy"**

Studying system aspects of the energy systems, dealing with complex questions of integration of numerous technologies, different energy infrastructures, digital services, etc, requires new methods of piloting technologies and systems which they interact with in a real-life environment. From 2018 to 2021 the Climate and Energy Fund will invest up to 120 million Euros in 3 flagship regions (see section 5). Each model region will bring new technologies and applications to market maturity by joining research, development and innovation (RDI) tasks of the Austrian research and innovation community. Significant additional funding will be raised from the private sector. Over 200 project partners from business, science and research are so far involved in the projects. The following are focus areas of the FTI-initiative "Flagship Region Energy":

- Exemplary implemented solutions which enable up to 100% renewable energy: innovative energy technologies "made in Austria" should demonstrate that a region can supply itself with up to 100% regional renewable energy. The clear goal is an optimised overall system for all market participants with a perfect interaction of production, demand, system management and storage;
- Focus on research to establish a holistic energy system by sector coupling. Realistic test-beds will be established to demonstrate this approach;
- Strengthening Austria as a leading market for innovative energy technologies;
- Involvement and active participation by users and operators is a central element of the FTI-initiative "flagship regions". People will experience first-hand the large-scale application of innovative energy technologies.

## 2.4 International Programme Related to Smart Grids and Renewable Energy

**Transnational Joint Programming Platform Energy Systems**

Within the successor of the "ERA-Net Smart Grids Plus" programme begun in 2014, the Austrian Ministry of Transport, Innovation and Technology coordinates a network of 27 national and regional RDI funding programmes in 23 European and associated countries. The focus initiatives are smart & digital networks and integrated regional energy systems. The goal of this initiative is to initiate and fund transnational RDI projects in co-creation with regional stakeholders and innovation ecosystems in the participating countries. This platform enables national and regional funds to support transnational projects close to implementation needs and at the same time paves the way for national and regional innovation stakeholders to team up with partners from other countries and regions as well as with international entrepreneurs. Moreover, the cooperation of the funding agencies with associated partners such as market uptake programmes, private investors, regional business clusters and start-up networks is foreseen. The platform is financed by participating countries with support of the European Commission.

With its focus initiatives the network develops and supports projects according to Mission Innovation challenges 1 (Smart Grids) and 7 (Heating and Cooling in Buildings). Whilst it is currently a European network, countries and regions as well as funding and supporting partners from outside Europe could be taken on board to create an increasing impact on Mission Innovation goals.

**International Activities in Context of MI Innovation Challenges:**

Austria has started a national process to map its current international activities and research priorities with the Mission Innovation priority areas. As a first step, the current international activities related to the MI innovation challenges were identified. To be highlighted is the participation of Austrian public or private sector entities in 17 IEA Technology Collaboration Programmes (TCPs). Among these the following are Smart Grid related:

- International Smart Grid Action Network;
- Demand-Side-Management;
- Energy in Buildings and Communities;
- Heat Pump Technologies;
- Energy Efficient End-Use Equipment;
- Bioenergy;
- Photovoltaic Power Systems;
- Concentrated Solar Power.

Other Smart Grid related Austrian contributions to European networks are the European Energy Research Alliance (EERA) and ERA-NET Smart Energy Systems.

## 2.5 Case Studies – General Overview

Several model regions have been established in Austria during the research projects currently being conducted. The smart grid technologies that have been developed were field tested in these regions. Current model regions and demonstration projects in Austria are:

- Smart Grids Model Region Salzburg;
- Smart Grids Pioneer Region Upper Austria;
- Smart Grids Pioneer Region Vorarlberg;
- Smart Services for the Greater Linz Area;
- Smart Grids Pioneer Region Styria.

Details about the individual model regions and demonstration projects can be found in the Technology Roadmap Smart Grids Austria, published in May 2015 [1].

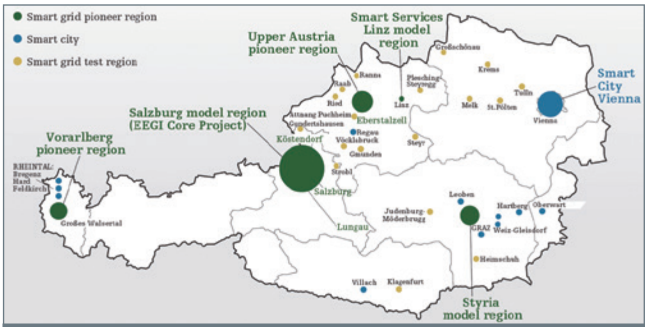



Figure 2-5. Smart Grid and Smart City Model Regions in Austria

As mentioned above the Climate and Energy Fund of the Austrian government is about to invest into 3 flagship regions (started in autumn 2018), which are listed here below.

The flagship region **"Green Energy Lab"** in the eastern part of Austria is expected to become a living lab for energy systems of tomorrow with a significant high share of renewables. The approach focuses on flexibility and system integration by digitalisation of networks, infrastructures and end-users. Thus addressing particularly, the topics of Mission IC 1 (Smart Grids) and 7 (Heating and Cooling of buildings).

**"New Energy for Industry"** will showcase the renewable supply of industry facilities, including electrification of industrial processes and power system flexibility provision (IC1 smart grids) and aspects of biofuels in industrial processes as targeted by IC 4.

The **"Flagship Power and Gas"** will showcase the change to a hydrogen-based energy system, focussing on renewable production, storage, distribution and appliance in energy, industry and mobility. This is applicable to aspects of power to gas addressed in Mission Innovation (IC 1) as well as Mission Innovation IC 8 on hydrogen.

**PROJECT CASE #1**

**LEAFS - Integration of Loads and Electric Storage Systems into Advanced Flexibility Schemes for LV Networks**

### Related Sub-challenge of IC1

Distribution grid innovation

### Type of Project

Technology development, demonstration

### Keywords

Flexible Demand, Battery Energy Storage Systems, Grd Friendly Flexibility, Low Voltage Grid, Scalability

### Objective

Leafs evaluates the effects of increased customer and energy market driven utilisation of energy storage and load flexibility on power distribution grids. Technologies and operational strategies are developed that enable optimal use of distribution grid infrastructure by activating flexibilities using direct or indirect control also by the local grid operator or even incentives.

### Contractors

AIT – Austrian Institute of Technology, Fronius International GmbH, Siemens AG Österreich, Salzburg Netz, Netz Oberösterreich GmbH, Stromnetz Steiermark GmbH, Energieinstitut an der JKU Linz, University of Technology Vienna, Moosmoar Energies OG.

### Period

01.11.2015 - 31.03.2019

Figure 2-6. Inauguration of the LEAFS Field Trial – Autumn 2017

### Key Findings

Extensive analysis of a large number of low voltage grids has shown that activating market-driven flexibility significantly increases grid loading and reinforcement requirements due to increased coincidence of peak loads.

Different intelligent measures such as active power control with P(U), limiting power feed in to the grid, or central storage systems reduce grid reinforcement requirements visibly.

Activating flexibility via market services in a "gridfriendly" way is technically possible. However, the effort to integrate battery energy storage systems and flexible loads at low voltage level in a corresponding grid control scheme is high.

## PROJECT CASE #2
## ABS4TSO - Advanced Balancing Services for Transmission System Operators

### Related Sub-challenge of IC1
Regional grids, distribution grid innovation

### Type of Project
Technology development, demonstration

### Keywords
Synthetic Inertia, Enhanced Frequency Response, Frequency Stability, Dynamic System Services, Battery Systems.

### Objective
Within the scope of ABS4TSO, the characteristics of highly dynamic system services, supporting future system stability and security will be analysed. A proof of concept for the applicability of dynamic frequency support by converter-based systems will be performed. A battery storage system will be installed within the scope of the project as a reference implementation in order to assess the defined applications and services.

### Contractors
Austrian Power Grid AG, Verbund Hydro Power GmbH, Verbund Trading GmbH, Verbund Solutions GmbH, AIT – Austrian Institute of Technology, University of Technology Vienna.

### Period
01.05.2018 - 30.04.2021

### Key Findings
After the first project period the following key conclusions can be drawn:

Inverter-based generation can provide significant flexibility in terms of frequency response, combining different services at different time scales.

It is possible and recommended to go beyond replicating standard frequency response services such as synthetic inertia and implement non-linear responses that take into account frequency deviations and derivatives of the frequency.

Nonetheless, delays in all control loops need to be kept small, otherwise oscillations might appear in the grid.

Functionality aimed at reducing deterministic frequency deviations may need to take into account seasonal effects and time of the day.

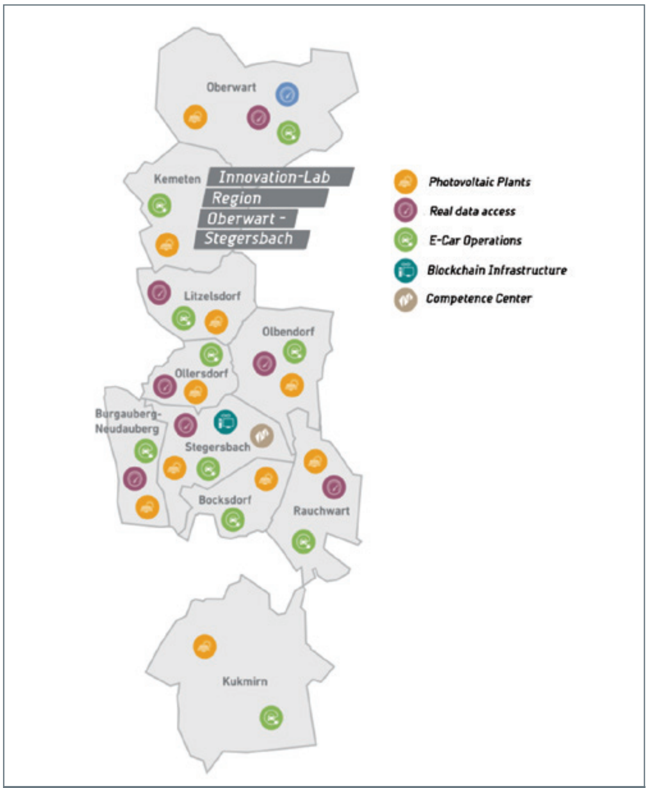



Figure 2-7. Advanced Balancing Services for Transmission System Operators

After installing the battery system in the grid and implementing all functionalities of the defined system services the following project results will be reached:

- Proof-of-concept of dynamic frequency support by converter-based systems and technology-neutral formulation of possible future, high dynamic system services;
- Specification of technical requirements and sizing of assets providing such services;
- Economic potential of future market products;
- System impact of such new system services assuming an upscaled implementation;
- Concept development for testing, monitoring and evaluating of the correct provision of services;
- Development of suitable environment for the provision of the analysed services.

PROJECT CASE #3
**Act4.energy - Innovation Lab Energy Community Stegerbach**

### Related Sub-challenge of IC1
Distribution grid innovation, microgrid innovation

### Type of Project
Demonstration

### Keywords
PV – self consumption, Local Energy Communities, Digital, Renewable Energy Systems, Regional Energy Cells

### Objective
The Innovation Lab act4.energy is positioned to be an open innovation community. Its goal is to link the population, social organisations, the representatives of economy and municipalities and the so called "inner network" of the open innovation community, with each other.

The aspired solutions and concepts of the project aim to stabilize the energy production of renewable energy sources, with the underlying objective of easing their breakthrough, thus allowing a smooth energy system transition.

### Contractors
Energie Kompass GmbH and 10 Municipalities.

### Period
01.01.2018 – 31.12.2022

### Key Findings
**Access:** So that the target group of organisations can undertake research and innovation projects, a fair opportunity has been created to contribute and benefit from the open innovation community.

**Know-how transfer:** Experience gathered from the co-creation processes which are being deployed, as well as expertise from economy, science, municipalities and administration are freely available to follow up projects and the energy innovation community in general.

**Business opportunities:** Providers of products/services related to energy logistics find a corresponding market, which leads to the benefit of all actors. Access to know-how, involvement in projects, opportunities of business deals and network expansions have been made available.

The Innovation Lab provides a living lab test region for the testing and demonstration of solutions and business models for renewable energy communities. It has the explicit goal to achieve scalable results that can be rolled out to a broader, European wide, public.

## 2.6 References

[1] Technology Platform Smart Grid Austira. Smart Grids Austria Technology Roadmap - Implementation Steps for the Transformation of the Power System up to 2020, Vienna, April 2015

# 3. CANADA

## 3.1 General Framework and Implementation

Canada's energy system is entering a period of significant change, driven by its commitment to a low carbon economy and the Paris Agreement pledging to reduce carbon emissions 30 percent below 2005 levels by 2030. The electricity sector will play a key role in the transition to a cleaner economy. To achieve this goal, federal, territorial and the majority of provincial governments all agreed to the Pan-Canadian Framework (PCF) on Clean Growth and Climate Change.[3-1] The PCF identified four key areas of transition for the electricity sector: growth in renewables and low-emitting sources, increasing interconnections to allow the flow of clean power, modernizing the electricity system, and reducing diesel reliance in remote communities.[3-2] Following the PCF, in 2017, Canada launched an open and inclusive nation-wide dialogue with stakeholders, experts and the public to "envision what a low carbon future would look like for Canada over a course of a generation."[3-3] The result of this dialogue summarized in the Generation Energy (GE) Council Report, released later that year, shared the collective vision of an affordable, reliable and clean energy future (i.e. electricity produced from renewable energy such as wind, solar, hydro, geothermal, as well as energy efficiency solutions). The PCF and GE Council reports are guiding Canada's pathways to transition to a decarbonized energy future through wasting less energy, switching to clean power, using more renewable fuels and producing cleaner oil and gas.

The National Energy Board (NEB) of Canada reported that in 2016, Canada's electricity generation was 66.4% renewable and 80.6% non-emitting in operation.[3-4] The Canadian energy industry generated approximately 648.4 terawatt-hours (TWh) of electricity in 2016 (Figure 3-1). Hydro is Canada's

[3-1] The Pan Canadian Framework on Clean Growth Climate Change - a federal, provincial and territorial policy engagement. https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework.html.

[3-2] Ibid, pp: 11.

[3-3] Canada's Energy Transition: Getting to our Energy Future, Generation Energy Council Report - the result of an open and inclusive Canada-wide dialogue with stakeholders, experts and individual Canadians to envision a low-carbon future: https://www.nrcan.gc.ca/20093.

[3-4] National Energy Board of Canada, Canada's Renewable Power Landscape: Energy Market 2017. https://www.neb-one.gc.ca/nrg/sttstc/lctrct/rprt/2017cndrnwblpwr/index-eng.html.

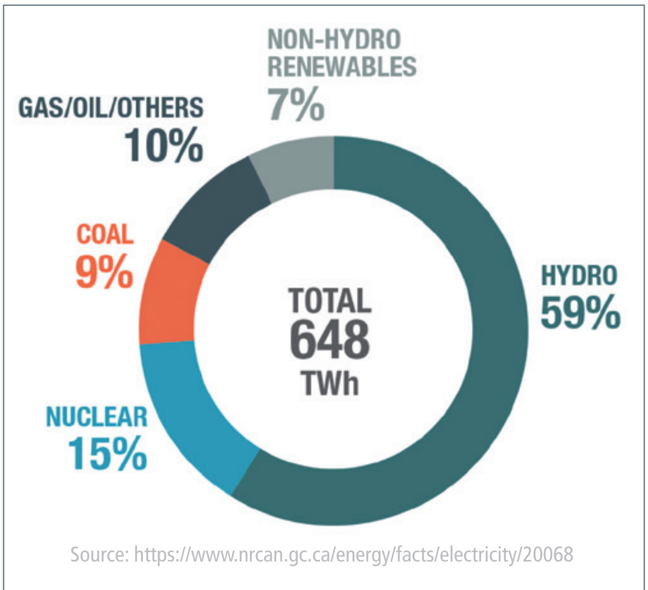



Figure 3-1. The Canadian Energy Industry Generated 648.4 Terawatt-hours (TWh) of Electricity in 2016.

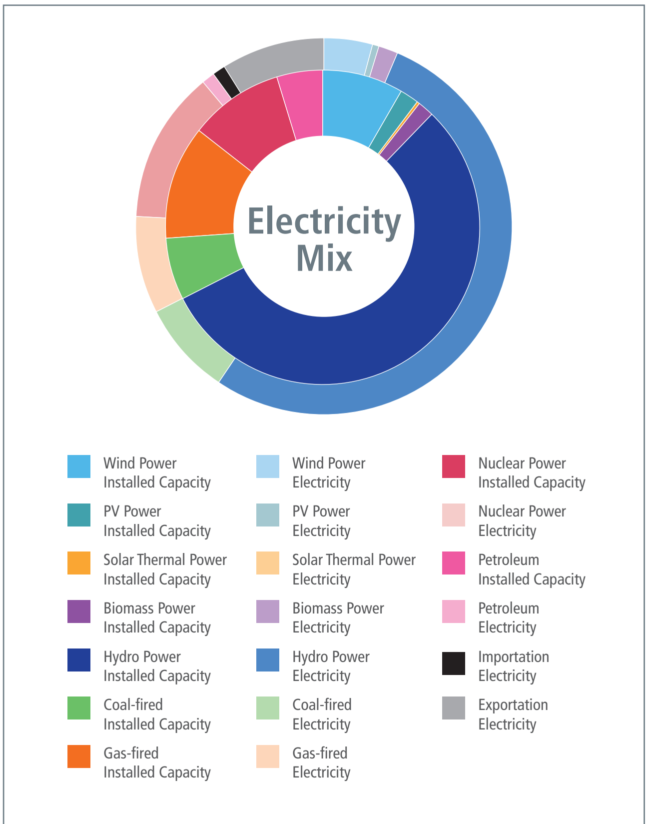



Figure 3-2. Electricity Mix by the End of 2016 and 2017 in Canada

largest source of electricity, averaging about 59.6% of total generation from 2005 to 2016. Hydroelectricity generation is primarily in the provinces of Manitoba, British Columbia, Quebec and Newfoundland, Labrador, and in the northern Yukon Territory. Nuclear energy, located exclusively in the provinces of Ontario and New Brunswick supplied on average 15.7% of Canada's electricity during the same period and was the second largest source of total generation.[3-5] Non-hydro renewable generation has grown in 2016 to 7.2% of total generation, with wind, biomass, and solar representing 4.7%, 2.0% and 0.5% of total generation respectively. Solar growth was exclusively in the province of Ontario because of a feed-in-tariff program implemented by the provincial Ministry of Energy.[3-6]

The NEB also released another report in 2018 examining Canada's long-term energy outlook exploring the role of electricity in Canadian end-use demand.[3-7] In the residential sector, electricity currently accounts for 40% of total energy demand. NEB forecasts that by 2040, this share will grow to 42% for the Reference Case[3-8], and 51% in the Technology Case[3-9]. In the commercial sector, electricity presently accounts 33% of the demand. By 2040, the forecast is for this share to grow to 37% in the Reference Case and to 49% in the Technology Case. Electrification of space and water heating in those sectors drives the growth of the electricity demand. Figure 3-2 shows electricity mix in Canada by source at the end 2016 and 2017.

[3-5] Ibid.

[3-6] The Independent Electricity System Operator (ISO) of Ontario: http://www.ieso.ca/en/Sector-Participants/Feed-in-Tariff-Program/Overview.

[3-7] National Energy Board of Canada, Canada's Energy Future 2018: An Energy Market Assessment, https://www.neb-one.gc.ca/nrg/ntgrtd/ftr/index-eng.html.

[3-8] Ibid, Reference Case is based on a "current economic outlook, a moderate view if energy prices and technology development, and climate and energy policies announced at the time of the analysis."

[3-9] Ibid, Technology Case "assumes greater global climate policy action and low carbon technology adoption than in the Reference Case. It provides one potential view of what faster energy transition would look like for Canada's energy future.)

## 3.2 Status of Renewable Energy and Smart Grids

Renewable generation is playing an important role in transitioning Canada to a low-carbon future (Figure 3-3). Total generating capacity in Canada increased to 66.4% renewable in 2016 – a 1% increase over the previous year. Hydro is the largest source of renewable electricity, accounting for 59.6% of capacity in 2016. Non-hydro renewables comprised the remaining 6.8% of Canada's total capacity in the same period. Non-hydro renewable power capacity grew by 8.2% with an added 1,293 MW of solar, biomass, and wind.[3-10] The latter was the dominant source of new renewable capacity in Canada in 2016.

Renewable electricity generation varies between provinces and territories. In the provinces of Ontario, Quebec and Nova Scotia, wind comprised over 50% of net capacity additions. In Quebec, a province that generates 95.2% of its electricity from hydro, wind capacity additions surpassed those of hydro by 104 MW. The province of Ontario led Canada in total wind (467 MW), biomass (188 MW) and solar photovoltaic (1,782 MW).[3-11] Natural gas generation decreased by 5.4% in 2016 across Canada, particularly in the provinces of British Columbia, Manitoba, Ontario, Quebec and Newfoundland, Labrador and in the Northwest Territories. In the provinces where coal is a large source of electricity, natural gas generation increased to 9.6% in 2016 as part of the provinces of Alberta, Saskatchewan, New Brunswick and Nova Scotia long-term plan to transition towards less GHG-emitting sources.

The power grid is getting smarter with the ascendency of distributed generation (DG), variable renewable energy, and other distributed energy resources (DER) with 2-way communication capabilities (Table 3-3). Further to the growing trend of variable RE deployment in Canada over the years, storage is also experiencing a parallel growth. In addition to traditional energy storage technologies, like pumped hydro plants and batteries, DERs comprise distributed generation and controllable loads as well. Controllable loads have the potential to provide the grid with added flexibility like systems managing space heating loads (e.g. smart thermostats) or water heating loads (e.g. smart electric water heater controls). The Canadian flexibility potential in space and water heating in a residential setting is estimated to be the same as a 39

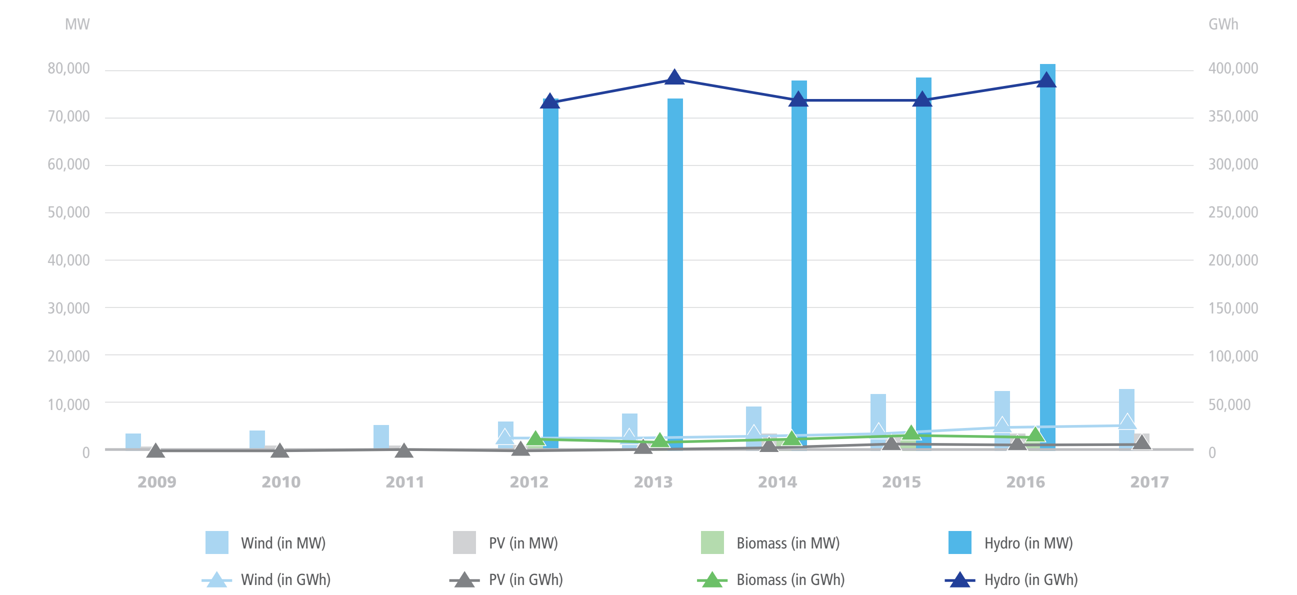



Figure 3-3. Trends on Renewable Energy Generation

[3-10] NEB, Canada's Renewable Power Landscape: Energy Market 2017. https://www.neb-one.gc.ca/nrg/sttstc/lctrct/rprt/2017cndrnwblpwr/index-eng.html.

[3-11] Ibid.

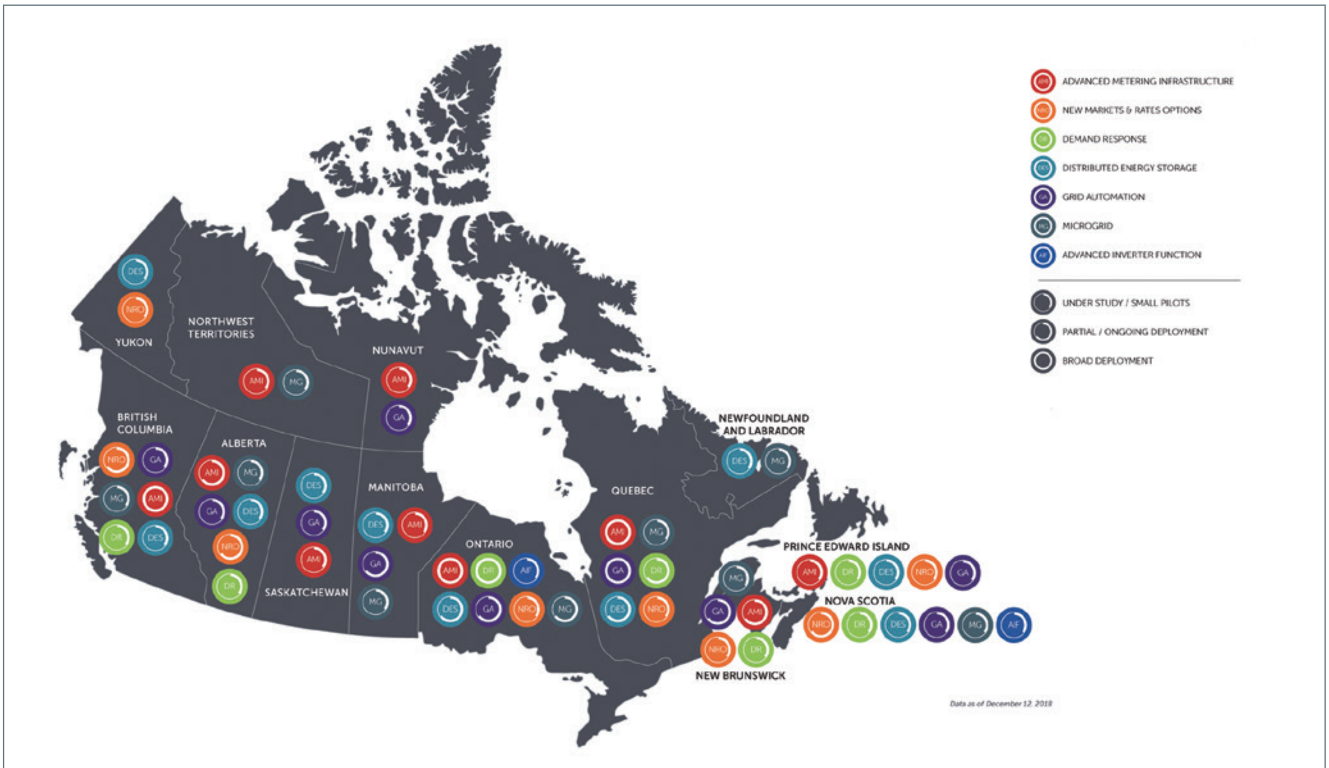



Figure 3-3. Canadian Deployment Levels of Different Smart Grid Applications. Source: Smart Grid in Canada 2018 Report.

GW capacity battery with 85 GWh of storage, which only represents a fraction of the controllable load potential across various sectors.[3-12] Additional controllable load potential exists in various applications including industrial processes, commercial buildings and the electrification of transport.

Electric vehicles (EVs) have seen a massive uptake in the last few years and seen as another controllable load with significant flexibility potential.[3-13] With access to a clean grid, EVs can be the transportation sector's means of reducing GHG emissions. With over 87,000 Battery and Plug-in Hybrid EVs (BEV and PHEV respectively) that require electricity from the power grid as fuel, there is a massive impact on the grid.

Without including residential and privately owned charging locations, there are more than 850 Level-3 public EV chargers and over 5,800 Level-2 public EV chargers.[3-14] They draw a maximum output per charger of 150 kW and 19.2 kW respectively.[3-15]

Given that over 82 % of meters in Canada are smart meters, there is an opportunity to gain access to this data not only for active customer consumption monitoring but also to make better use of flexible loads. Smart meters can be a gateway for information exchange between the customers and the utility.

Efforts are well underway to integrate effectively the increasing levels of variable renewable energy within a smart grid context. The deployment levels of smart grid applications across Canada varies, but all provinces and territories have piloted some type of smart grid applications (Figure 3-3). Completion of the inner circle indicates the level of deployment of each application: 1/3 circle indicates under study or small pilots, 2/3 circle indicates partial or ongoing deployments and a full circle indicates broad deployment. Regions of Canada that are most active in deploying smart grid and developing innovative solutions receive their support through provincial and territorial programs and policies.

[3-12] S. Wong, "CanmetENERGY Research Brief: Summary Report on Canadian Residential Demand Response and Ancillary Service Market Opportunities," Natural Resources Canada, 2015.

[3-13] Electric Mobility Canada, "Electric Vehicle Sale in Canada in 2018," [Online]. Available: https://emc-mec.ca/new/electric-vehicle-sales-in-canada-in-2018/?platform=hootsuite. [Accessed January 2019].

[3-14] Natural Resources Canada, "Electric Charging and Alternative Fuelling Stations Locator," [Online]. Available: https://www.nrcan.gc.ca/energy/transportation/personal/20487#/analyze?fuel=ELEC&ev_levels=all . [Accessed February 2019].

[3-15] Hydro Québec, "Electric Vehicle Charging Stations Technical Installation Guide," 2015.

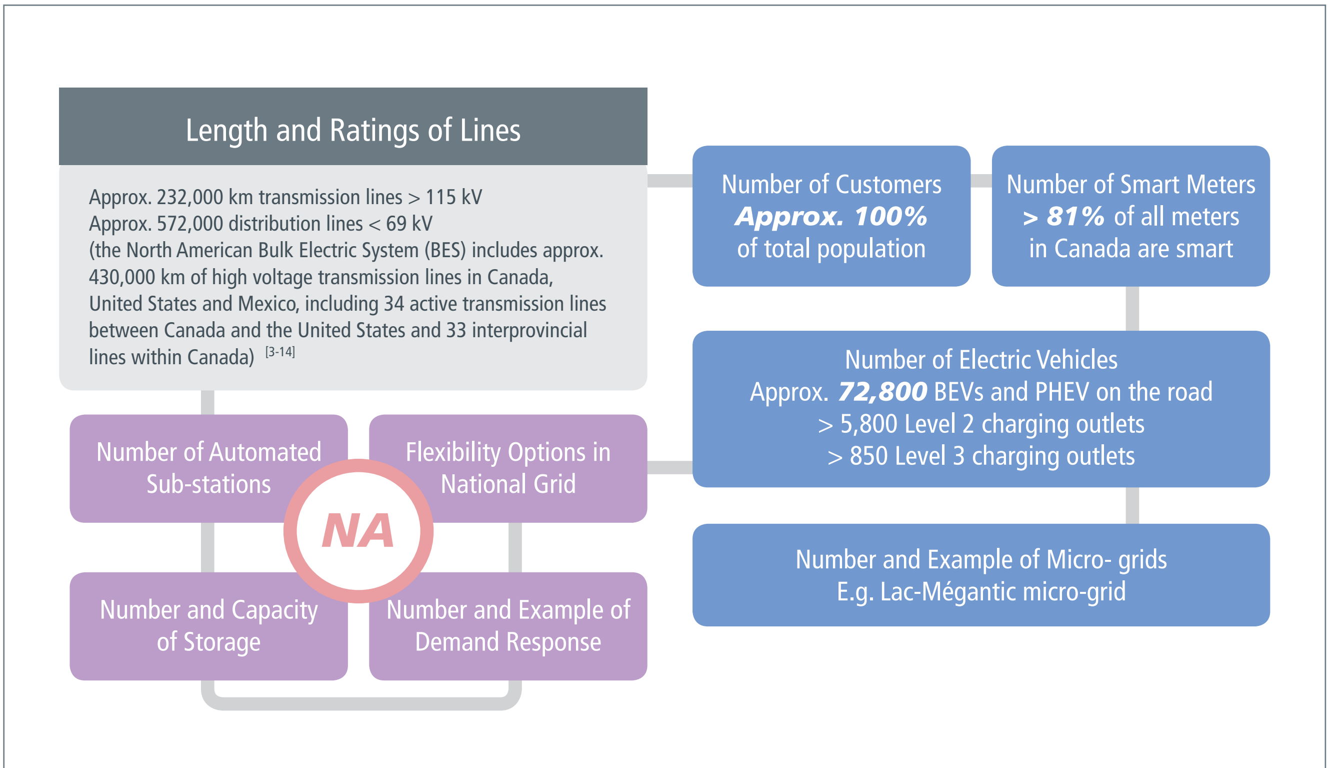



Figure 3-4. Key Smart Grids Data by the End of 2018.

## 3.3 National Programs in Fields of Smart Grids and Renewable Energy

All federal, provincial and territorial governments across Canada have policies related to clean energy, and activities related to grid modernization and smart grid. Several federal, provincial and territorial funding programmes support research, development, demonstration and employment investments in renewable energy and smart grid. The public sector has invested over CAN $261 million to represent a total project value of CAN $785 million across 135 smart grid RDD&D projects (Fig.3-5). Due to commercial sensitivity, the Ontario Ministry of Energy's Smart Grid Fund is not included in Figure 3-5 but the province of Ontario has invested CAN $200 million in smart grid deployment activities within its jurisdiction.

Several federal organizations including Natural Resources Canada (NRCan), Sustainable Development Technology Canada (SDTC), Innovation Science and Economic Development Canada (ISED), and Natural Sciences and Engineering Research Council (NSERC) facilitate collaborations with industry, government and academic partners to enable the integration of renewable energy with smart grid. The Green Infrastructure Phase 2 programme fund administered by NRCan allocated CAN $812 million for dedicated programs related to smart grid, emerging renewable energy, EV infrastructure, energy efficient buildings, and clean energy for rural and remote communities. This fund targets accelerating deployment and market entry of next-generation clean energy infrastructure. Other programs funded by NRCan include the Energy Innovation Program for clean energy technology R&D for internal and external funding, the Program of Energy Research and Development for internal energy R&D, and the Clean Growth Program for clean technology RD&D in specific natural resource sectors including energy. SDTC SD Tech Fund and ISED Strategic Innovation Fund both invest in various types of innovation projects including those related to renewable energy and smart grid. The NSERC Energy Storage Technology Network (NESTNet) develops, tests, demonstrates and commercializes innovative energy storage technologies, products, processes and services. NESTNet, established in 2015 for a five-year funding period, brings together universities, industry, utilities and government to address various technical, economic and policy topics relevant to energy storage uptake.

Since each province and territory govern their respective electricity systems, programs and policies vary according to the provincial or territorial priorities in energy infrastructure, environmental policies and economic development. Provincial and territorial governments and authorities hold significant

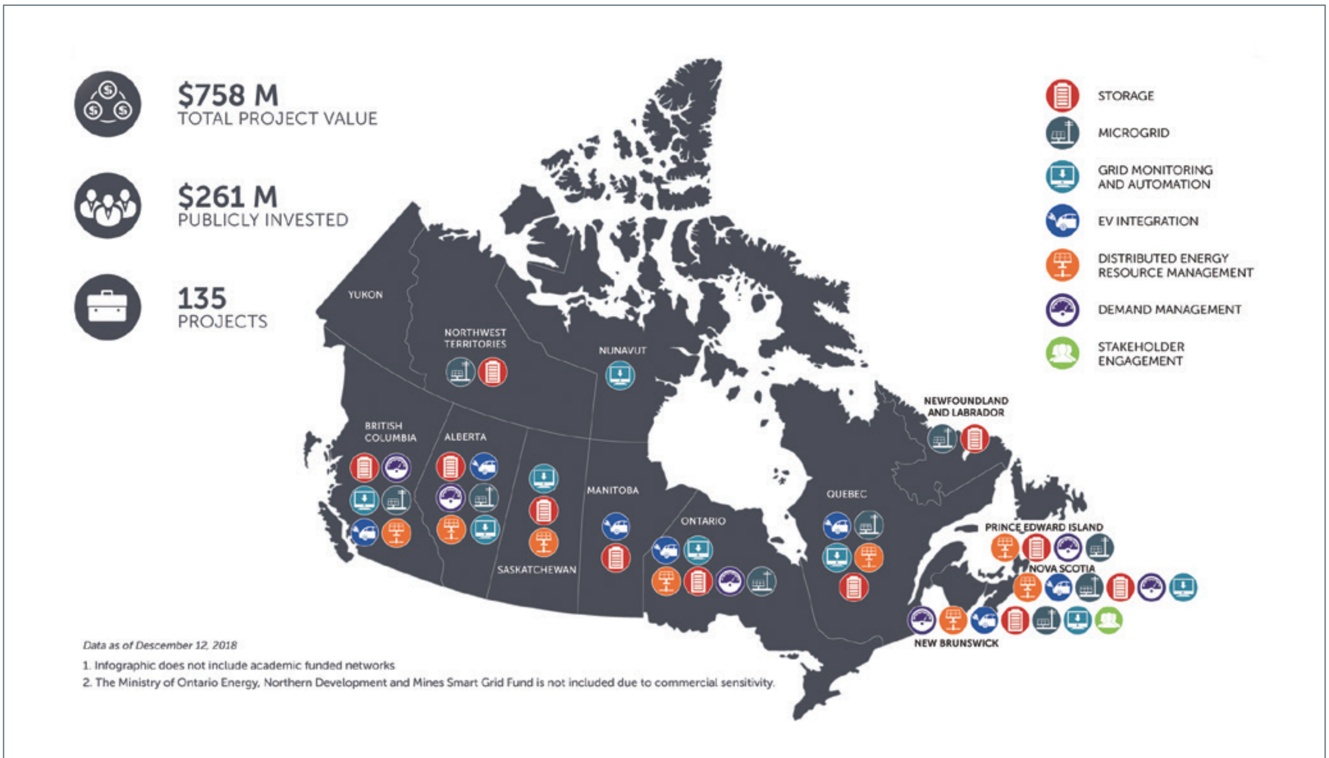



Figure 3-5. Canadian Public Investments in Smart Grid RDD&D Since 2003. Source: Smart Grid in Canada 2018 report.

power in determining both how the current electric system operates and how to plan and develop the systems of the future. In spring 2016, the provincial government of Alberta announced plans to phase out coal-fired electricity generation and the development of 5,000 MW of renewables by 2030. Alongside, the Alberta Electricity System Operators (AESO) completed the first round of a competitive and transparent Renewable Electricity Program where the record was set for the lowest renewable energy prices in Canada at 3.7¢ CAD per kWh for a 600 MW wind procurement. The territory of Nunavut has also piloted its first solar project. Jurisdictions are also evaluating energy storage capabilities to understand how to use these resources to support grid services. The Independent Electricity System Operator in Ontario procured over 50 MW of energy storage through 2 competitive phases; 11 facilities from Phase 1 are or will soon be providing a total of 32.8 MW of regulation services or reactive support and voltage control.[3-16] Other smart grid enabling technologies like smart meters continue to deploy despite 82% of meters in Canada being smart meters. Nova Scotia Power has received approval from regulators for a smart meter roll out to start in 2019.

## 3.4 International Programme Related to Smart Grids and Renewable Energy

Canada is an active member of several International Energy Agency Technology collaboration programmes in renewable energy and end-use, including the International Smart Grid Actions Network, Photovoltaic Power Systems, Solar Heating and Cooling, Energy Storage Systems, Wind, and Energy in Buildings and Communities. Canadian researchers are collaborating on R&D Tasks and Annexes with experts from the international community to advance the deployment of renewable energy and energy efficiency in the built environment and power systems.

NRCan, the Secretaría de Energía of Mexico and the U.S. Department of Energy are collaborating on the North American Renewable Integration Study (NARIS). It aims to inform decision makers about the opportunities of adding more RE on the North American power grid. NARIS will develop state-of-the-art methods, scenarios, and datasets for NARIS and future analysis purposes in addition to assess coordinated grid planning and operations, cross-border transmission, grid flexibility, and other strategies and technologies to enable high penetration of renewables.

[3-16] http://www.ieso.ca/Sector-Participants/Energy-Procurement-Programs-and-Contracts/Energy-Storage

Canada is also collaborating with the United States and Mexico on two activities related to removing barriers to the high penetration of renewables into the grid. The first collaboration is with the Department of Energy and the National Renewable Energy Laboratory (NREL) in the US, and with the Secretaría de Energía de México and Instituto Nacional de Electricidad y Energías Limpias (INEEL) in Mexico, on a North American deep decarbonisation and electrification study (NADDES). The study will focus on informing decision makers of the opportunities available to meet long-term (2050) goals for deep decarbonisation (i.e., meeting 90% of energy needs through clean and renewable energy), and to develop and make publically available an open source domain to give countries and their citizens the capacity to conduct their own studies. The initial phase of the collaboration was to establish a dialogue to develop an open source modelling platform. The second collaboration is with INEEL, NREL, Sandia National Laboratory and CYME International on a R&D knowledge exchange program in advanced inverter functions testing protocols. The intention is to develop platform for Canadian, American and Mexican scientists to exchange information and conduct research and development activities related to smart inverter in high renewable penetration scenarios. In the initial stage of this collaboration, NRCan hosted a workshop to establish a working group to harmonize hosting capacity, calculation methods considering, but not limited to, the capabilities of advanced inverter functions. Both projects are very much in the early stages of implementation.

Canada and the United Kingdom are advancing the clean growth and climate change agendas by partnering on the Power Forward Challenge.[3-17] The Challenge seeks to develop consortium-based partnerships between innovators from Canada and the UK to develop end-to-end solutions integrating DERs. Led by NRCan as an Impact Canada Initiative and the Department for Business, Energy and Industrial Strategy in the UK, the initiative aims to demonstrate how to integrate disruptive, modular, scalable and interoperable energy resources in a smart grid that provides value. The Challenge launched in fall 2018 will announce the semi-finalists in mid-2019, and the final award winning team in March 2021.

[3-17] Power Forward Challenge: https://impact.canada.ca/en/challenges/power-forward.

## 3.5 Case Studies

**PROJECT CASE #1**
**The Lac-Mégantic Microgrid**

### Related Sub-challenge of IC1

Microgrid Innovation

### Type of Project

Demonstration

### Topic

Ville de Lac-Mégantic, in the province of Quebec, teamed with the Canadian public utility Hydro-Québec to build a solar plus storage microgrid in a new downtown area. The most advanced energy technologies will be deployed in the coming years, making the neighborhood a cutting-edge technological showcase. The project will make it possible to determine how new technologies may contribute to the creation of new services for customers and help them reduce their energy consumption, increase their comfort and help maintain service to certain buildings during outages. The Lac-Mégantic microgrid will include about thirty residential and commercial buildings. It will feature:

- up to 3,000 solar panels (300 kW installed capacity) to generate electricity;
- batteries able to store maximum 1,200 kWh of energy;
- smart homes and buildings equipped with consumption management systems;
- charging stations for electric vehicles; and
- total surface area of 170,000 m².

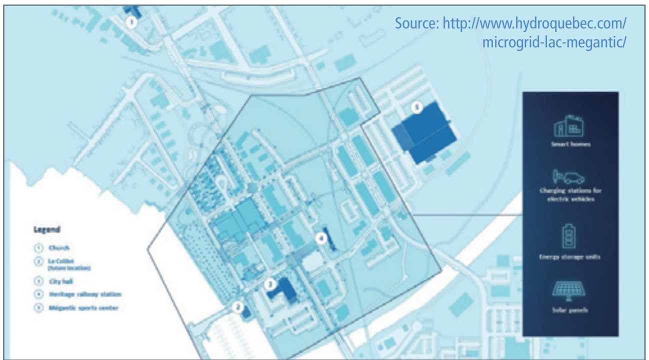



Figure 3-6. The Canadian Energy Industry Generated 648.4 Terawatt-hours (TWh) of Electricity in 2016.

### Objectives

- Implement the first microgrid in the province of Québec.
- Assess DER technologies in a real-life situation.
- Transpose the microgrid model to off-grid systems thus reducing reliance on fossil fuels.
- Manage the microgrid's power demand during winter

peak periods by using DERs and load control.

- Make Lac-Mégantic's vision of a smart city a reality.
- Help increase the city's appeal as a hub for economic and technological innovation.

### Contractors

Hydro-Québec | Ville de Lac- Mégantic | Transition énergétique Québec | Green Municipal Fund (Federation of Canadian Municipalities)

### Period

Q1 2018 – Q4 2019 (expected).

### Ongoing and Achieved Key Findings

The project is currently in the realization and construction phase, and all indications are that it is on target to commence progressive deployment by December 2019.

### Added Value for IC1 Objective

This project presents an opportunity for the utility to identify ways to reduce its electricity purchases in peak periods and avoid costly network investments, and provide reliable back-up power during grid outages, while maintaining customer comfort.

## PROJECT CASE #2
## TIntegrating Distributed Generation into Secondary Networks in Large Urban Centres

### Related Sub-challenge of IC1

Distribution

### Type of Project

Demonstration

### Topic

In the City of Calgary, generators are not allowed to export energy onto secondary or spot networks. This physical limitation adds significant hurdles to the already challenging financial business case for installing distributed generation in the province of Alberta. Secondary and spot networks are typically encountered in dense urban centres and are designed to have a high-level of reliability with complex protection systems. Other North American cities that contain these networks experience the same physical constraints as Calgary. With no technical solution to ensure distributed generation can be fully integrated and optimized, their integration into the distribution grid has been severely limited. An untapped potential for renewable and distributed energy exists in Calgary, particularly from rooftop solar PV, and combined heat and power (CHP), that could significantly reduce GHGs and result in many ancillary benefits.

### Objective

To develop and demonstrate a new solution to accommodate bi-directional power flows on urban electrical grids

### Contractors

ENMAX Power Corporation (public utility) | Alberta Smart Grid Consortium

### Period

2018 - 2022

### Ongoing and Achieved Key Findings

The project was awarded Government of Canada funding under the Green Infrastructure Smart Grid Demonstration and Deployment Program in August 2018. It is too early in the implementation phase to extract achieved key findings, but the project aims to benefit Canadian stakeholders in a variety of ways including but not limited to:

- A demonstration of smart grid technology for the integration of renewable distributed generation into secondary and spot networks to generate a solution that allows for their integration to the grid. This will lower the economic barrier for customers to invest in more renewable energy generation, proliferate clean energy in the city of Calgary, lower GHGs, and increase grid resiliency;
- Disseminating project lessons learned through the Alberta Smart Grid Consortium and to other municipalities across Canada and North America, magnifying the impact that will be experienced in Calgary;
- Permitting real-time local control of customer-owned DER generation and having significant promise for optimizing generator and grid utilization including providing a foundation for future implementation of Demand Response;
- Addressing policies on DER value to the grid, demand response, aggregation, and how the current markets and systems must evolve to address these changes.

### Added Value for IC1 Objective

Using a combination of advanced monitoring and controls as well as protective relay configuration changes that allow for export, the proposed project will demonstrate how solar PV, and ultimately other forms of distributed generation and energy resources, can be safely integrated into secondary and spot networks.

## PROJECT CASE #3
## Transactive Energy Network for Clean Generation, Energy Storage, Electric Vehicle Charging and Microgrid Integration

### Related Sub-challenge of IC1
Cross-cutting innovation

### Type of Project
Demonstration

### Topic
In recent years, there has been significant progress made on the development of distributed energy resource (DER) technologies like solar photovoltaic, small-scale renewable and non-renewable generation, energy storage, controllable loads and grid-connected micro-grids. What is missing, however, is a platform that allows the integration of these DER technologies into aging, congested, and largely unmonitored electric power distribution systems. This demonstration links three widely dispersed micro-grids in the city of Toronto, Nova Scotia and upstate Main (in northeast USA) into a transactive energy network. It is designed to demonstrate a smart and integrated transactive energy (TE) network that will allow DERs to be integrated technical and financially into electric power systems. This is accomplished by developing a suite of software tools, referred to as GridOS that efficiently and optimally connect the various components of the grid together, creating a TE network that uses technical and economic signals to manage the exchange of electricity within an electric power system.

### Objective
To demonstrate a smart and integrated transactive energy (TE) network that will allow the financial and technical integration of DERs into electric power systems.

### Contractors
Opus One Solutions Energy Corporation (Lead)

Consortium members include: Advanced Microgrid Solutions | Emera Maine | Nova Scotia Power Inc. | Ryerson CUE-Toronto Hydro | Smarter Grid Solutions | Toronto Hydro

### Period
2016 – ongoing

### Ongoing and Achieved Key Findings
The Government of Canada provided funding to this project through SDTC in September 2016, as a demonstration of a micro-grid of micro-grids. It is too early in the implementation phase to extract achieved key findings, but the project aims to benefits Canadian stakeholders in a variety of ways including but not limited to:

- Using the whole customer load as grid resource for the operator by optimizing DER to control load on the customer side of the meter;
- Demonstrating different ways of interacting with the grid: Emera Main is combining solar , batteries and backup diesel generators; Nova Scotia Power manages utility-scale and behind-the –meter residential energy storage to balance the variability in wind generation, as part of the PowerShift Atlantic work; and Toronto Hydro is working on a set of micro-grid projects to see how DERs can support local grid controls.

### Added Value for IC1 Objective
Demonstrations of electrical storage and renewable generation to develop the ability to service the load or harness it for the wholesale market – generators give it resiliency.

## PROJECT CASE #4
## Charge the North

### Related Sub-challenge of IC1
Cross-cutting innovation

### Type of Project
Demonstration

### Topic
Canada is a global leader in clean electricity generation with 66% of our electricity coming from renewable sources. To meet its GHG emission reduction targets, the Government of Canada supports the electrification of transportation and has invested in green infrastructure and clean technologies to increase the number of zero-emission vehicles.

The increasing electric vehicle (EV) adoption creates concerns from utilities and EV owners across Canada and this project aims to address some of these challenges. The demonstration project is divided into three sections, which all utilize the capabilities of FleetCarma's vehicle data logger combined with centralized data collection and control.

1. FleetCarma will monitor and capture data on driving and charging habits from 1000 EVs in Canada. The analysis will provide an overview of the EV drivers' behavior, as well as aid the optimal planning of new EV charging station installations across the country.
2. Led by Alectra Utilities, a distribution company, eleven

utilities will analyse real-world data from smart-chargers installed in the workplace to minimize EV and grid integration issues. The smart-charger controls the power rate at which EVs are charged to support efficient grid operation, while ensuring EVs are fully charged as specified by the owner. This smart system will include integration of solar power and energy storage in the workplace's building management system.

3. A new charge reimbursement system will be tested in multi-unit dwellings that is more cost efficient and does not require installing a sub-meter.

#### Objective

By collecting EV data from 1000 EV owners across Canada to better understand their behaviour and habits, FleetCarma aims to influence better grid planning in addition to supporting optimal EV charging deployment and demonstrating charging solutions for workplaces and multi-unit dwellings.

#### Contractors

FleetCarma. Partners: Alectra Utilities and 11 other regional utilities

#### Period

2017- ongoing

#### Ongoing and Achieved Key Findings

The Government of Canada provided funding to this project under the Energy Innovation Program in June 2017. The project is currently monitoring the 1000 EV owners that sign up for the trial. The FleetCarma device is tracking their EV usage until March 2019. It is still too early in the process to extract achieved key findings, but the project aims to benefit Canadian stakeholders in a variety of ways including but not limited to identifying where grid and charging infrastructure upgrades are required, and demonstrating effective smart-charging solutions for workplace and multi-unit dwellings. These demonstrations will address EV adoption barriers regarding a need for grid and resource management and a lack of enabling technologies, and will result in GHG emissions reduction.

#### Added value for IC1 objective

A better understanding of the disruption EVs bring to the grid because of the data gathered from several EV owners. This will allow innovators to prepare solutions and methodologies to address the limits EVs bring to the grid.

## 3.6 References


[1] The Pan Canadian Framework on Clean Growth Climate Change - a federal, provincial and territorial policy engagement. https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework.html.

[2] Ibid, pp: 11.

[3] Canada's Energy Transition: Getting to our Energy Future, Generation Energy Council Report - the result of an open and inclusive Canada-wide dialogue with stakeholders, experts and individual Canadians to envision a low-carbon future: https://www.nrcan.gc.ca/20093.

[4] National Energy Board of Canada, Canada's Renewable Power Landscape: Energy Market 2017. https://www.neb-one.gc.ca/nrg/sttstc/lctrct/rprt/2017cndrnwblpwr/index-eng.html.

[5] Ibid.

[6] The Independent Electricity System Operator (ISO) of Ontario: http://www.ieso.ca/en/Sector-Participants/Feed-in-Tariff-Program/Overview.

[7] National Energy Board of Canada, Canada's Energy Future 2018: An Energy Market Assessment, https://www.neb-one.gc.ca/nrg/ntgrtd/ftr/index-eng.html.

[8] Ibid, Reference Case is based on a "current economic outlook, a moderate view if energy prices and technology development, and climate and energy policies announced at the time of the analysis."

[9] Ibid, Technology Case "assumes greater global climate policy action and low carbon technology adoption than in the Reference Case. It provides one potential view of what faster energy transition would look like for Canada's energy future.)

[10] NEB, Canada's Renewable Power Landscape: Energy Market 2017. https://www.neb-one.gc.ca/nrg/sttstc/lctrct/rprt/2017cndrnwblpwr/index-eng.html.

[11] Ibid.

[12] S. Wong, "CanmetENERGY Research Brief: Summary Report on Canadian Residential Demand Response and Ancillary Service Market Opportunities," Natural Resources Canada, 2015.

[13] Electric Mobility Canada, "Electric Vehicle Sale in Canada in 2018," [Online]. Available: https://emc-mec.ca/new/electric-vehicle-sales-in-canada-in-2018/?platform=hootsuite. [Accessed January 2019].

[14] https://www.nrcan.gc.ca/energy/electricity-infrastructure/18792

[15] Natural Resources Canada, "Electric Charging and Alternative Fuelling Stations Locator," [Online]. Available: https://www.nrcan.gc.ca/energy/transportation/personal/20487#/analyze?fuel=ELEC&ev_levels=all . [Accessed February 2019].

[16] Hydro Québec, "Electric Vehicle Charging Stations Technical Installation Guide," 2015.

[17] http://www.ieso.ca/Sector-Participants/Energy-Procurement-Programs-and-Contracts/Energy-Storage

[18] Power Forward Challenge: https://impact.canada.ca/en/challenges/power-forward.

A 100% solar-energized community in the Sun and Moon County, Qinghai.

The energy system, including 100kW PV, 220 kWh battery, air-source heat pump and heat storage, has been implemented in 2018 and supplied electricity and heat for 24 rural houses. (Photo Lidong Guo)

# 4.CHINA

## 4.1 General Framework and Implementation

**Geography:** The People's Republic of China is located in East Asia. It is the fourth largest country in the world with the area of 9,562,911 km$^2$.

**Population:** The total Population was 1,395,380,000 at the end of 2018.

In 2018, the energy consumption of China reached a new high level of 4,640 Mtce, with an increase of 3.3% compared with 2017 (see Figure 4-1). The energy production of China is estimated to be 3,770 Mtce. In the mix of energy production, the main contributions are 66.1% from raw coal, 7.0% from raw oil, 5.1% from natural gas, and 21.8% of electricity China strongly prompts the development of clean coal-fired generation. By the end of 2018, 700 GW of coal-fired installation was upgraded with ultra-low emission technology, and 600 GW with energy-saving technology (see Figure 4-2).

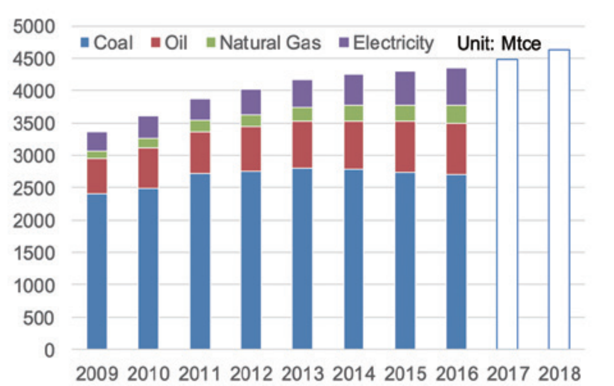



Figure 4-1. The Energy Consumption of China. In 2017 and 2018, the Total Energy Consumption are Available.[4-1]

The Central Committee of CPC and the State Council of China have released a series of documents in order to fulfill the pledge of the Paris Agreement on Climate Change and further the Energy Reform, including four revolutions: Energy Consumption, Energy Supply, Energy Technology and Energy Administrative System, and comprehensive international cooperation. A mixed energy structure driven by coal, oil, gas, nuclear, new energy and renewable energy is proposed to meet the targets of non-fossil energy share in the primary energy consumption to 15% by 2020 and 20% by 2030[4-2]. According to the 13th Five-Year Energy Development Plan and the 13th Five-Year Renewable Energy Development Plan, the renewable share in electricity consumption of 2020 is targeted to 27%.

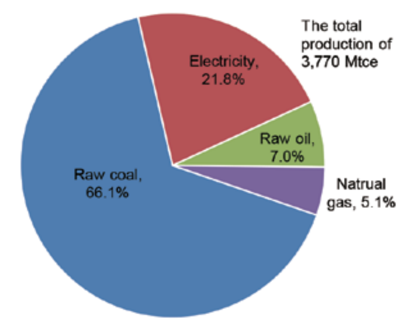



Figure 4-2. The Energy Production of China in 2018.[4-3]

[4-1] National Bureau of Statistics of China (NBoS). http://www.stats.gov.cn.

[4-3] Revolutionary Strategy of Energy Production and Consumption (2016-2030). National Development and Reform Commission of China. http://www.ndrc.gov.cn.

[4-3] Source of the total energy production is the 2018 Statistical Bulletin on National Economic and Social Development of China. The composition of energy production is estimated from monthly production data published by NBoS.

In the Government Work Report 2019 of the State Council, it was proposed to deepen the reform in the fields of electricity, oil and gas, and emphasized to accelerate the accommodation of wind, solar and hydropower. In order to decrease the curtailment of renewables, the National Development and Reform Commission (NRDC) and the National Energy Administration (NEA) have promulgated policies such as the Implementation Plan for Reducing the Curtailment of Wind, Solar and Hydropower, and the Action Plan for Clean Energy Accommodation (2018-2020). These documents have assigned a series of tasks related to smart grid, including topics to optimize the layout of electricity generation, to release the potential of load saving at the generation side, and to prompt the interaction among generation, load, grid and storage. A target set for 2020 is to reach 95% of the average utilization of wind power and to exceed 95% of the utilization of photovoltaic power. In the next years, it should be an important guidance of energy policies to promote high-quality development of energy in China.

## 4.2 Status of Renewable Energy and Smart Grids

**Status of Renewable Energy**

According to the NEA, by the end of 2018, the accumulated installation of renewable energy reached 728 GW, which accounts for 38.3% of the China's generation installation. The installed capacity of hydro, wind, photovoltaic and biomass are respectively 352 GW, 184 GW, 174 GW and 17.81 GW (see Figure 4-3).

In 2018, the electricity generation of renewable energy is 1,867 TWh, which accounts for 26.7% of the total generation. The generation of hydro, wind, photovoltaic and biomass are respectively 1,233 TWh, 366 TWh, 177.5 TWh and 90.6 TWh.

In the past ten years, the installation of renewable energy has increased at the high rate of 14.6% in annual-averaged base. This is mostly due to the dramatic increment of photovoltaic and wind power, respectively, at rates of 104% and 30% in annual-averaged base.

China targets to install 680 GW of renewable energy, which has been realized in advance, and contribute 27% of electricity generation from renewable energy by 2020. An aggressive envision by 2050 is proposed to be 2,959 GW installation of renewable energy and 68% generation contribution from renewable energy. It implies that the annual installation of renewable energy should increase stably at a rate of 4.5% in the next 32 years, and the great effort should be paid to accommodate the large amount of renewable electricity.

**Status of Smart Grids**

China's power grid is composed of six large-area AC synchronous grids in North China, Northeast China, Central China, East China, Northwest China and South China. Most of the grids are operated by the State Grid Corp. of China (SGCC) and the China Southern Power Grid Corp (CSPG). In 2020, the regional grids will be interconnected by DC transmission lines.

There are five major power generation groups in China, including the China Huaneng Group, the China Datang Corp., the China Huadian Corp., CHN ENERGY, and State Power Investment Corp. The 70% of China's power generation is provided by these companies.

The next-generation power grid, which accepts large-scale renewable energy power and intelligence as its main features, is the trend of China's future power grid. The two major characteristics of future power grid development are the centralized and decentralized access of large-scale renewable energy power, as well as the comprehensive intelligence of power grid operation control and power consumption. The years between 2020 and 2050 will represent the transition period of China's power grid transformation. From now to the mid-term of 2030, China's transmission network will still maintain the ultra/UHV AC-DC transmission network mode. Future power technologies such as multi-terminal

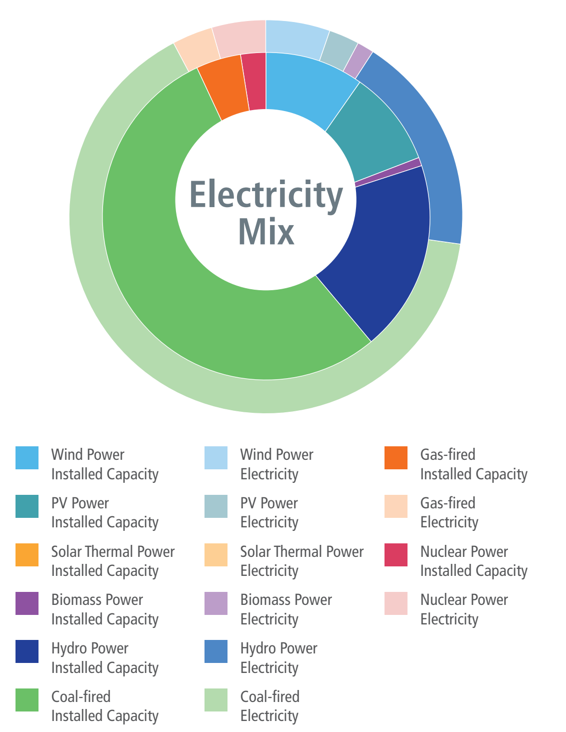



Figure 4-3. Electricity Mix by the End of 2018

DC transmission technology, FACTS and VSC-HVDC will be widely deployed, and energy storage technology is likely to make great progress, laying a technical foundation for the transformation of the power grid. In coordination with the transformation of power supply, the power grids in China will generally be a combination of national transmission grids, local transmission and distribution networks, and microgrids which can adapt to large-scale renewable energy such as hydro, wind and solar power generation. They will be able to meet the needs of large-scale renewable energy power such as hydropower, wind power, solar power generation, and power transmission, optimization and intermittent power mutual compensation for centralized power generation bases such as coal-fired power and nuclear power.

With the rapid development and upgrading of China's electric power sector, the power grid continues to expand. The voltage level is continuously improved, the large-capacity and high-parameter generator sets are increasing, and the new energy power generation is concentrated on a large-scale grid. The power system configuration and operation characteristics become more and more complex. The application of new technologies, such as information technology, has increased the number of non-traditional hidden dangers, and put forward higher requirements for system support, transfer and adjustment capabilities, which has brought severe challenges to the safe and stable operation of the power system.

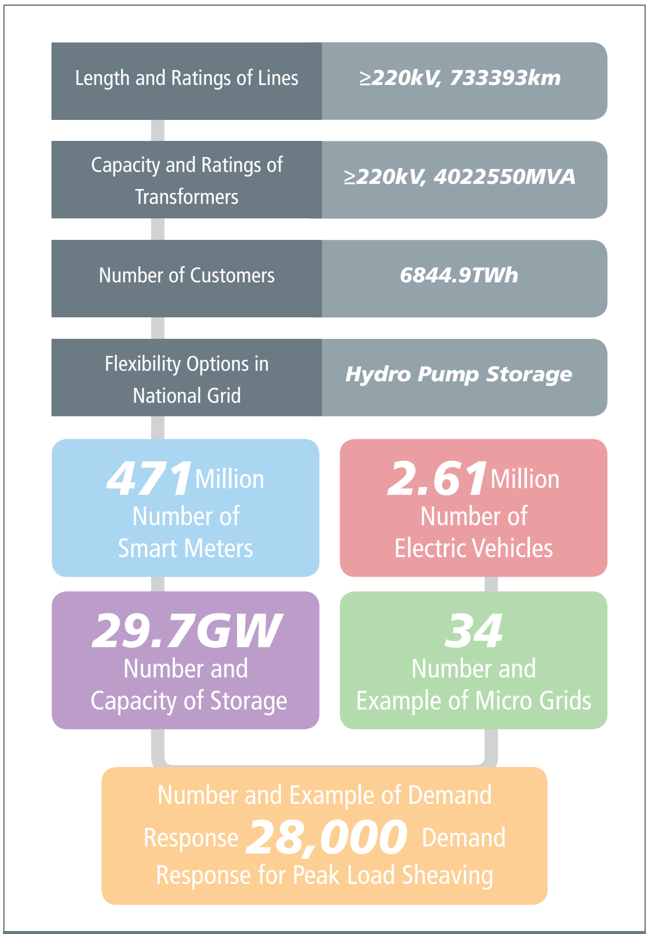



Figure 4-4. Key Smart Grids Facts and Figures by the End of 2018

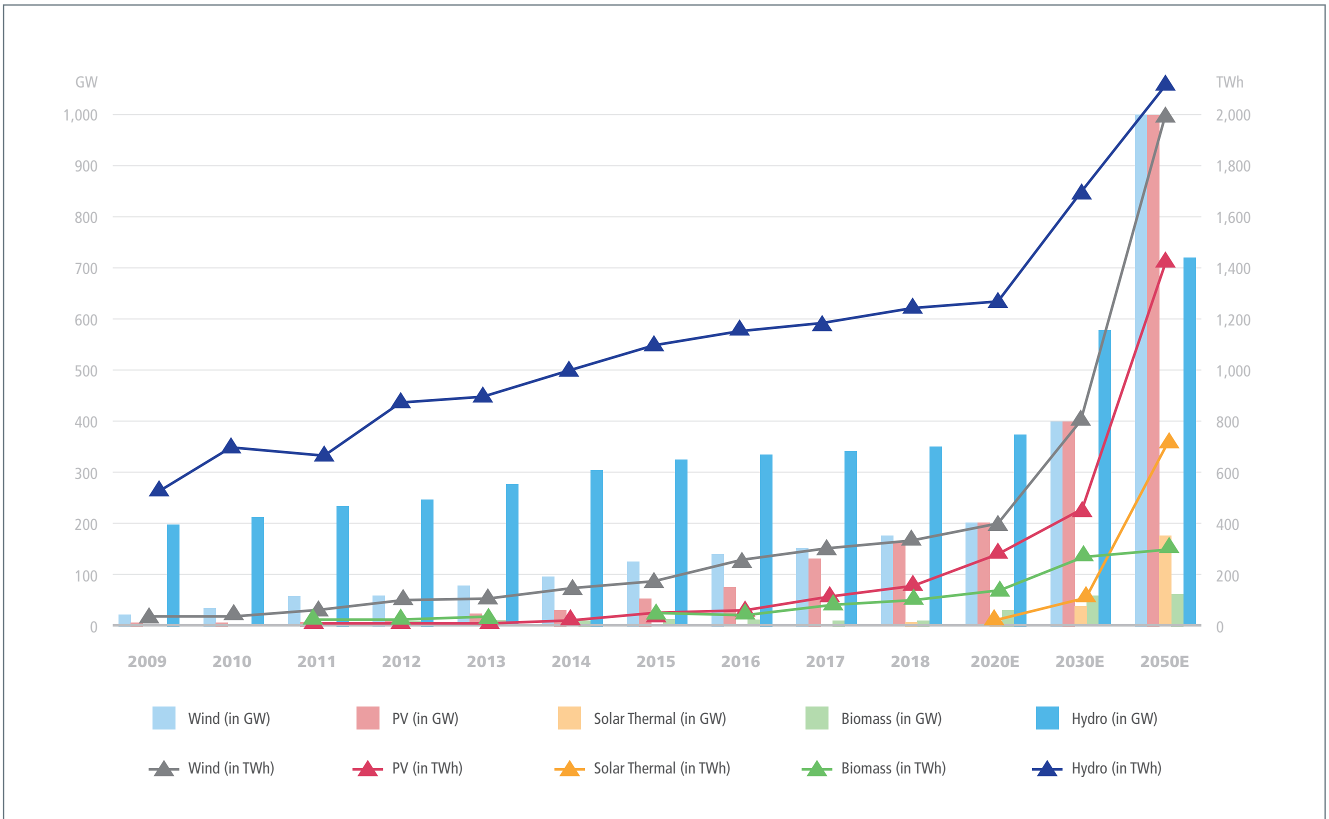



Figure 4-5. Trends on Renewable Energy Generation

## 4.3 National Programs in Fields of Smart Grids and Renewable Energy

In China, the national investment on RDD of smart grids and renewable energy is mainly allocated by the Ministry of Science and Technology (MoST), the National Science Foundation of China (NSFC), and the Chinese Academy of Science (CAS). The science and technology department of local governments also invests on these fields according to the development of local industry and energy system. The SGCC and the CSPG are two important funding organization from the aspect of state-owned enterprise.

**National Programme**

The National Key Research and Development Program of China launched at the beginning of the 13th Five-Year Plan. It aims to the major topics of science and technologies related to the national economy, the people's livelihood, and the national security. Industry, research institutes and universities are involved in collaborative innovation. The Program is administrated by MoST, and replaces former programs such as the National Key Fundamental Research Program, the National High-tech R&D Program and the National Science and Technology Support Program. The Program is composed of Key Special Projects, in which Projects on Smart Grids Technology and Equipment and Projects on Renewable Energy and Hydrogen have been launched.

The Strategic Pioneer Science and Technology Program was launched in 2011. The Program was proposed on the basis of the strategic study of the scientific and technological roadmap towards 2050, and targeted to major scientific and technological issues concerning the long-term and overall development of China. The Program is administrated by CAS, and is divided into two categories: the prospective and strategic research (Category A) and the fundamental and cross-cutting frontier research (Category B). In 2018, the Category A project of Clean Energy has been launched. It supports 13 institutes of CAS to research in eight fields including renewable energy, storage, hydrogen and etc. A 100% renewable powered demonstration in Zhangjiakou city is ongoing under the support of the project.

The NSFC supports the theoretical and frontier research. It encourages the applicant to freely propose the project and make the discoveries. These projects are divided into the General Project, the Key Project, the Major Project, and many others. The research related to smart grid and renewable energy are important topics supported constantly by the NSFC. In 2017, the Smart Grids Joint Fund of NSFC and SGCC was launched. The Joint Fund supports fundamental research in the fields of smart grids, ultra-high voltage, new energy, electrical materials, and energy storage in line with the global trend of energy and electric technology.

**Programme in Highlights**

The objective is to promote innovation in smart grid technologies, support the transformation towards a clean energy structure and an energy consumption revolution. Five technological directions, including the grid-integration of renewable energy, the flexible interconnection of grids, the interaction of supply and demand, the distributed generation and hybrid energy, and the fundamental technologies of smart grids, are supported in the Projects. The guideline of the Projects is released once per year during 2016 to 2018. Research institutes, universities and companies could jointly participate by submitting their project according to the guideline.

The Projects of Renewable Energy and Hydrogen (2018-2022) is another of the Key Special Projects in the framework of The National Key Research and Development Program of China. The objective is to prompt the healthy and sustainable development of renewable energy and hydrogen industry, to support the industrial upgrade and the scaled deployment, and to accelerate the replacement of fossil fuel–based energy in electricity, thermal and transportation sectors. Seven technological directions, including solar, wind, biomass, geothermal, marine, hydrogen and integration of renewable energies, are supported in the Projects. The guideline of the Projects is released once per year during 2018 to 2020.

**National Smart Grid R&D Activities in Line with POWs Tasks and Sub Tasks**

In National Key R&D Program of China, The "Smart Grid and Equipment" Projects support all the 6 POWs tasks and are the most important for smart grid R&D. Besides, "Renewable Energy and Hydrogen Energy technology" Projects and "Science and Technology for 2022 Winter Olympics" Projects of National Key R&D Program also support some POWs tasks. The Strategic Pioneer Science and Technology Project for Clean Energy funded by CAS focusing on the demonstration and application of clear energy has also a close relationship with some POWs tasks of IC 1.

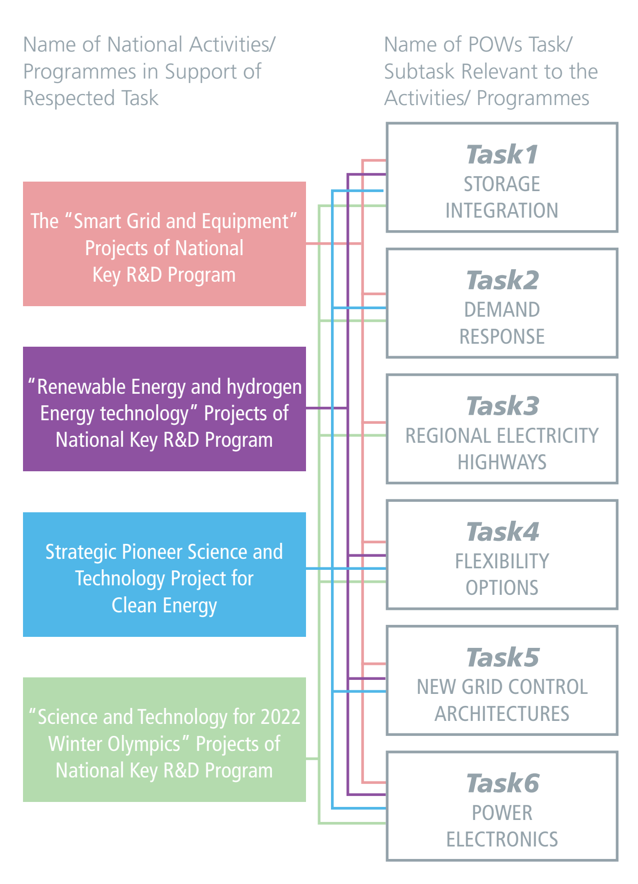



Figure 4-6

## 4.4 International Programme Related to Smart Grids and Renewable Energy

MoST, CAS and NSFC are main funding agencies for international programme at national level. The science and technology department of local government will call for proposals on international collaboration projects.

In MoST, the Intergovernmental Cooperation Program on Science and Technology Innovation (ICP) and the Strategic International Cooperation Key Program on Science and Technology (SICP) are two important programmes for an international collaboration. The ICP focuses on science, technology and engineering issues of common concern and supports projects according bilateral or multilateral intergovernmental scientific and technological collaboration agreements. In 2018 the collaboration with US, Finland, European Union, Czech Republic, Republic of Belarus, Japan, Korea, Pakistan, Philippines, Brazil, India, and etc., in fields of smart grids and renewable energy, are supported in ICP. The SICP supports the non-governmental international Science and Technology (ST) cooperation. The energy technology is the priority in SICP. In 2018, SICP supported an international cooperation project between China and 3 countries in the Smart Grids field.

In CAS, there are series of international programs, such as the International Partnership Program, the ST Collaboration Action of the Belt and the Road, bilateral collaboration programs, and the International Talent Program. In most of these program, smart grids and renewable energy are prior topics to be supported.

## 4.5 Case Studies

**PROJECT CASE #1**
**Research on Key Technologies of Microgrid System Concerning Comprehensive Utilization of Multi-Renewable Energy Resources Based on Solar Energy**

### Related Sub-challenge of IC1

Task 2.4, Task 5.7.

### Type of Project

National High Technology Research and Development Program (863 Program) of China (2015AA050402).

### Topic

Energy management system, multi-energy supplement, combined heat and power (CHP), integrated energy applications.

### Objective

In view of the important demand of energy supply guarantee and eco-environmental friendliness in the process of new urbanization in China, the research and demonstration of a new type of multi-energy integrated utilization micro-grid system based on solar energy are carried out. The key technologies such as system planning and design, intelligent control/inversion, energy efficiency management and demand response are mastered to form renewable energy with energy permeability of more than 60%, heat storage and storage. The implementation scheme of megawatt-level CCHP new rural community micro-grid will form a set of strategies suitable for the promotion and application of urbanization in western provinces and regions of China, promote the comprehensive utilization of renewable energy, and the construction of intensive, intelligent, green and low-carbon urbanization in China.

### Contractors

Institute of Electrical Engineering CAS, China Southwest Architecture Design and Research Institute Corp.Ltd; China Academy of Building Research; Zhejiang University; Ningbo Ruikai Solar Power Technology Corp.Ltd.

### Period

Mar 2015 – Mar 2018.

### Ongoing and Achieved Key Findings

The first kW-level combined heat and power system based on solar thermal power was established in Yanqing, Beijing. It realized cascade utilization of solar energy by recycling thermal energy from the solar thermal power station. In Tuergan and Zhulu the application demonstrations of CCHP are completed. Another experimental system was built in Qinghai Province, including 1MW PV power and 1.5MW load, to verify the village-level microgrid planning, design and operation control technology.

### Added Value of IC1 Objective

Advanced models, mechanism and related policies of multi-energy complementary integrated application systems have been studied.

Figure 4-7. The Application Demonstrations of CCHP in Tuergan, Qinghai, China.

## PROJECT CASE #2
## Coordinated Control Technology for Trans-regional AC-DC Interconnected Power Grid

### Related Sub-challenge of IC1

Task 5.5 Impact of new control architectures on regional grids.

### Type of Project

This project was supported by the National High Technology Research and Development Program of China (863 Program) under Grant 2011AA05A119, and the project belonged to the Program of the Key Technology Research and Development of Smart Grids

### Topic

Coordinated control of AC-DC system, head-swing impact, low frequency oscillation, control equipment, demonstration project.

### Objective

The project aimed at the stability of certain key and weak tie-lines as well as the control of power oscillation. Based on multi-information from power system and some controllable DCs, the sensitive control points of multiple DCs were identified. What's more, coordinating different targets constrained by regional and provincial tie-lines, the demonstration of trans-regional AC-DC interconnected power grid that used local substations and wide-area coordinated control was constructed. The demonstration was located in the central China grid and was the largest project in the world.

### Contractors

China Electric Power Research Institute Co., Ltd., SGCC Central China Branch State, State Grid Henan Electric Power Co., Ltd., State Grid Hubei Electric Power Co.,Ltd., NARI Group Corporation, State Grid Sichuan Electric Power Co., Ltd., State Grid Chongqing Electric Power Company, Grid Operation Branch of State Grid Corporation of China, Huazhong University, Zhejiang University, Sichuan University

### Period

2010.11–2015.03

### Ongoing and Achieved Key Findings

The project coordinated analog quantity of DC polar control and AC safety control and designed single DC controller that could satisfy multiple targets. Besides, a coordinated controller which could suppress the head swing of UHVAC tie-lines was researched. The scheme of the control system containing two levels, named coordinated station and DC/AC sub-station, was proposed. The demonstration contained nine DCs that had the functions of emergent control, power modulation as well as damping control. After the operation of demonstration, the transfer capabilities of important AC or DC lines could be increased to 119% or above. In a word, the whole project transferred the traditional single control to multi-input and multi-output as well as multi-target response control, and greatly smoothed the contradiction between safety and efficiency of trans-regional AC-DC Interconnected Power Grid (Figure 4-8).

### Added Value of IC1 Objective

The project provided a coordinated control scheme of trans-regional AC-DC interconnected power grid to enhance the intelligent level of power system and promote the consumption of clean energy, including suppressing the random fluctuation, adapting the complex operating manners and multiple fault types, ensuring the safety of the DC system that transfers new energy power.

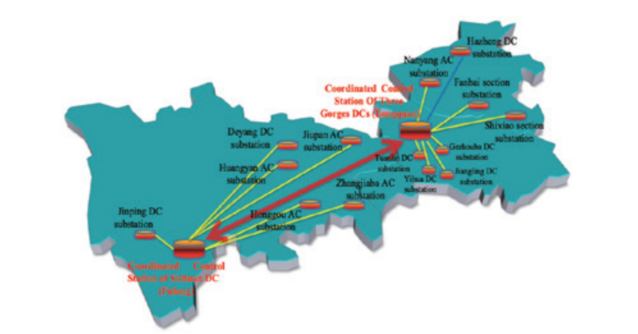



Figure 4-8. The Coordinated Control System for Trans-regional AC-DC Interconnected Power Grid with the Largest Scale and Most Functions

Figure 4-9. The Coordinated Control Station Of Three Gorges DCs

## PROJECT CASE #3
## Multi-terminal VSC-HVDC System R&D for Large-scale Wind Farm Integration

### Related Sub-challenge of IC1
Regional grid innovation.

### Type of Project
Technology development, demonstration, and commercialization.

### Topic
Large-scale renewable energy integration, multi-terminal voltage sourced converter based high voltage direct current (VSC-MTDC), high-end equipment manufacturing.

### Objective
The project aims at solving large-scale wind farm integration problem based on the VSC-HVDC technology. A framework of a multi-terminal HVDC system and its multi-functional control strategy are developed. Here, the first architecture for the VSC-MTDC system is proposed. Its control & protection system offers functionalities such as various operation modes, start-up and shut down, DC voltage and station-online rec-connection. The framework is not only being evaluated in real-time simulation but also implemented on-site as the world's first VSC-MTDC project in the Nan'ao wind farm of Guangdong province (cf. Figure 4-10, Figure 4-11).

### Contractors
RXHK, NR ELECTRIC CHINA XD

### Period
Jan. 2012 - Dec. 2014

### Ongoing and Achieved Key Findings
The project successfully built the world's first VSC-MTDC system and solved the key technologies regarding both design and system integration. The core equipment for engineering application, such as high-voltage large-capacity converter and valve control system, was successfully developed and manufactured, which achieved a breakthrough in voltage and capacity level in the industrial area. A control and protection (C&P) system that can realize rapid coordinated control in a multi-terminal HVDC system was developed and validated in practice. A testing platform was established for both high-voltage large-capacity converter and C&P system, which can support the industrial development of the core equipment.

### Added Value of IC1 Objective
The project promotes the use of VSC-HVDC technology for large-scale renewable energy integration to scale up the ratio of renewable energy in smart grids. It also offers the experience regarding the design, testing, and operation stage of the multi-terminal VSC-HVDC system.

Figure 4-10. Site View of Converter Valve in Jinniu Converter Station

Figure 4-11. Site View of Suchen Converter Station

## PROJECT CASE #4
## Development of Photovoltaic Medium Voltage DC Grid-connected Converter

### Related Sub-challenge of IC1

Regional grid innovation, distribution grid innovation, micro grid innovation.

### Type of Project

Technology development, demonstration.

### Topic

Modular design, high power, high efficiency, MV DC

### Objective

With the increasing application of DC high-voltage transmission, the number of photovoltaic power plants has increased rapidly. The integration of photovoltaic power into high-voltage DC grids will become an important form of grid connection for photovoltaic power generation in the future. Relying on the design and key technology research of photovoltaic comprehensive research demonstration base, the exploration and the overall solution of large-scale photovoltaic high-voltage DC grid connection technology is carried out. The development of 100-kilowatt DC grid-connected equipment will be directly converted into the DC power grid through the photovoltaic DC grid-connected converter for high-ratio boosting, which will provide technical support for the promotion and application of DC grid-connected technology of photovoltaic power plants in China.

### Period

May 2013- May 2015.

### Ongoing and Achieved Key Findings

This converter is the first 200kW photovoltaic DC grid-connected converter with complete independent intellectual property rights in China, providing the technical support for the popularization and application of photovoltaic DC grid-connected. By researching and comparing a variety of DC/DC topology schemes, a new kind of high-power, high-efficiency, high-variation ratio topology and a control strategy suitable for photovoltaic are proposed. The modular design of photovoltaic high-voltage DC grid-connected converters is mastered. A ±10kV/200kW photovoltaic DC grid-connected physical test platform is established. The test platform simulates the true DC grid to the maximum extent. The developed photovoltaic high-voltage DC grid-connected converter can be tested on this platform to simulate the photovoltaic power generation through high-voltage DC. The integration of the grid-connected converter into the DC grid has great practical significance and reference value for the next step of PV high-voltage DC research and demonstration.

### Added Value of IC1 Objective

The developed photovoltaic high-voltage DC converter adopts modular design. It is easy to expand and combine serial-parallel combination control. With high working range and high efficiency, it can be used in various large, medium and small-sized photovoltaic power stations, which can effectively solve the problem of local consumption and external transportation of the photovoltaic power generation.

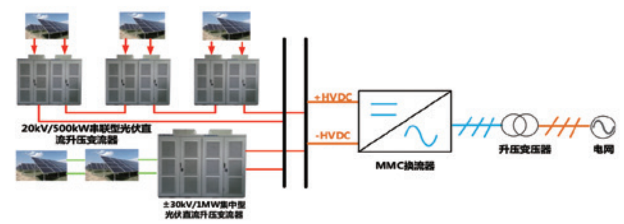



Figure 4-12. Large-scale Photovoltaic Power Plant DC Boosting Convergence Access System

Figure 4-13. ±10kV/200kW Photovoltaic DC Grid-connected Converter

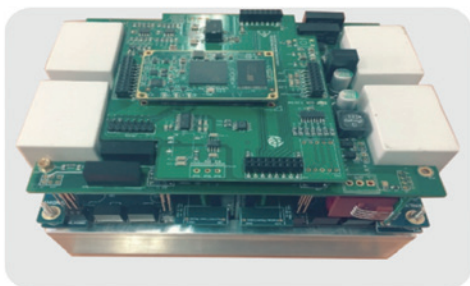


Figure 4-14. New Photovoltaic DC Boost Module Based on GaN HEMT

## PROJECT CASE #5
## Fundamental Theory of Planning and Operation for Power Systems with High Share of Renewable Energy Generations

### Related Sub-challenge of IC1

High penetration and  integration of renewable energy.

### Type of Project

National Key R&D Program of China
 (Grant No. 2016YFB0900100).

### Topic

Fundamental theory of power system planning and operation, standard test system, stability analysis under high penetration of renewable energy and high penetration of power electronics.

### Objective

The project aims at studying the basic theory and method of future planning and operation of high-proportion renewable energy power systems in China and to provide a standardized system for high-proportion renewable energy scenarios. The project aims to solve the following key scientific issues: 1) power system planning and operation under high penetration of uncertainty and 2) Stability mechanism of power system under high share of power electronic devices.

### Contractors

China Electric Power Research Institute Co., Ltd., Tsinghua University, Shanghai Jiao Tong University, Huazhong University of Science and Technology, Tianjin University, etc.

### Period

Jul. 2016 - Dec. 2020

### Ongoing and Achieved Key Findings

The project proposes an efficient panoramic operation simulation method for AC-DC hybrid complex power system with high renewable penetration. A new power system flexibility theory is proposed and used in the evolution planning of energy-electricity-grid coordination. A security region theory is proposed for the distribution grid and applied to the distribution grid planning under high renewable penetration. A multi-scale dynamic interaction analysis method is proposed to reveal the power system stability mechanism under high penetration of power electronics. The project releases standardized test cases for both transmission and distribution systems with high penetration of renewable energy. The project is developing a series of software platforms based on the proposed theories and methodology.

### Added value of IC#1 objective

The project provided in-depth understandings of the evolution mechanisms of power system configuration and behavior under high penetration of renewable energy. A series of novel theories, methods and technologies are carried out for the planning and operation of future high renewables-penetrated power system, including forecasting, planning and operation technology under uncertainty, and stability analysis under high penetration of power electronics.

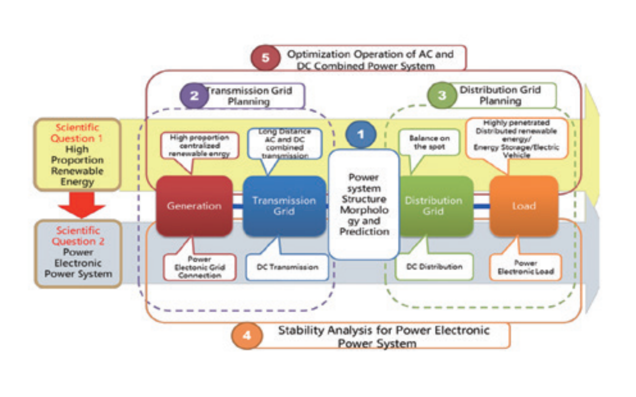



Figure 4-15. Project Research Framework

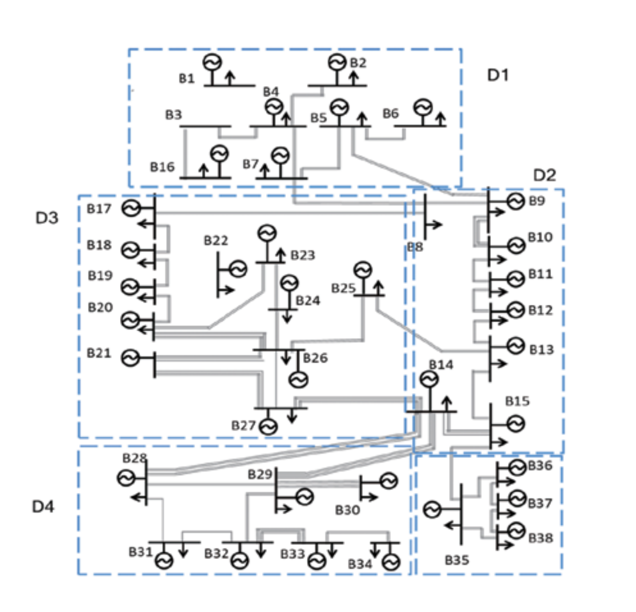



Figure 4-16.Standardized Test System for Transmission System with High Penetration of Renewable Energy

## 4.6 References

[1] Yang, Zilong, et al. "Topology and control of transformerless high voltage grid-connected PV systems with a cascade step-up structure." IECON 2017-43rd Annual Conference of the IEEE Industrial Electronics Society. IEEE, 2017.

[2] Guo, Li-dong, et al. "Research on control strategy of the energy storage system for photovoltaic and storage combined system." IECON 2017-43rd Annual Conference of the IEEE Industrial Electronics Society. IEEE, 2017.

[3] Huang X, Wang H, Guo L, et al. Large-scale photovoltaic generation system connected to HVDC grid with centralized high voltage and high power DC/DC converter[C]//2017 20th International Conference on Electrical Machines and Systems (ICEMS). IEEE, 2017: 1-6.

[4] Chongqing Kang, Liangzhong Yao. Key scientific issues and theoretical research framework for power systems with high proportion of renewable energy[J]. Automation of Electric Power Systems, 2017, 41(9):2-11.

[5] Zongxiang. Lu, Haibo. Li and Ying. Qiao, Probabilistic Flexibility Evaluation for Power System Planning Considering Its Association With Renewable Power Curtailment, in IEEE Transactions on Power Systems, 2018, 33(3): 3285-3295.

[16] Jingkun Liu, Ning Zhang, Chongqing Kang, Daniel S. Kirschen and Qing Xia. Decision-making models for the participants in cloud energy storage, IEEE Transactions on Smart Grid, 2018, 9(6): 5512-5521.

# 5. DENMARK

## 5.1 General Framework and Implementation

Country overview, energy generation and consumption by the end of 2018, and future outlook (e.g. by 2020, 2030 and/or 2050).

Country overview 2018:
Population: 5.8 million people
Total area (in km2): 42,934
GDP per capita: 54,337 USD

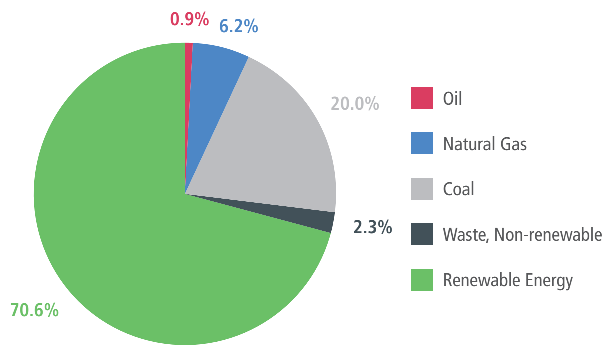
Energy production: 658 PJ
Energy consumption: 747 PJ

Denmark has a broad and sustained political support for lowcarbon transition of the Danish energy sector. Approximately every five years a broad coalition in the parliament forms a new energy agreement to determine the energy policy for the coming years. Last agreement was made in 2018. Some of the goals of the energy agreement are that by 2030:

- At least 55 pct. of the Danish energy consumption will be covered by renewable energy
- Danish electricity consumption will be covered by renewable energy
- Use of coal will be phased out

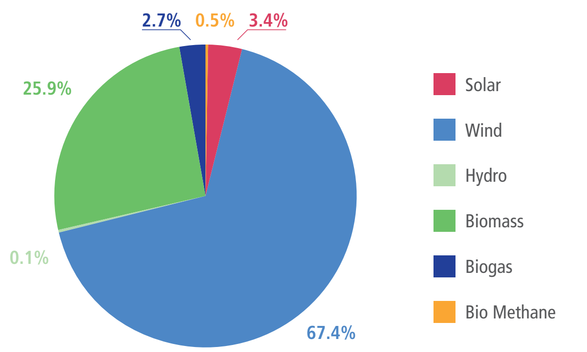
## 5.2 Status of Renewable Energy and Smart Grids

Electric capacity (in kW) and generation mix (in kWh) by the end of 2018 is shown in Figure 5-1;




Source: https://ens.dk/sites/ens.dk/files/Statistik/tabeller2017_-_tables2017.xlsx

Figure 5-1. Energy Mix in Production of Electricity in 2017




Source: https://ens.dk/sites/ens.dk/files/Statistik/tabeller2017_-_tables2017.xlsx

Figure 5-2. Renewable Energy in Electricity Production (2017)

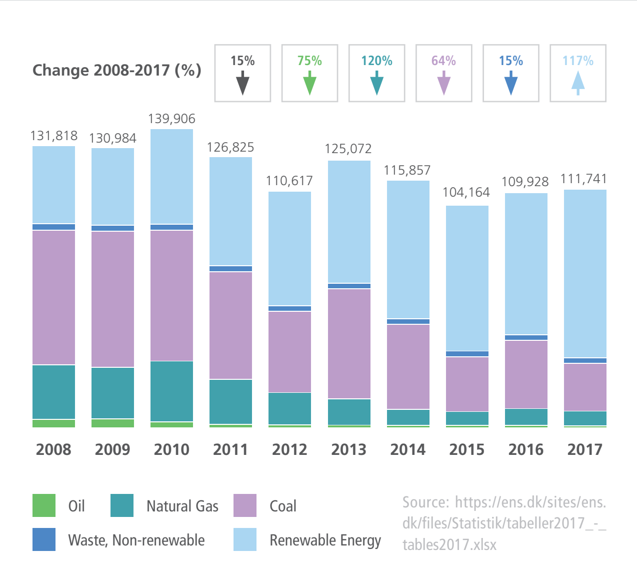



Figure 5-3. Electricity Production by Fuel 2017

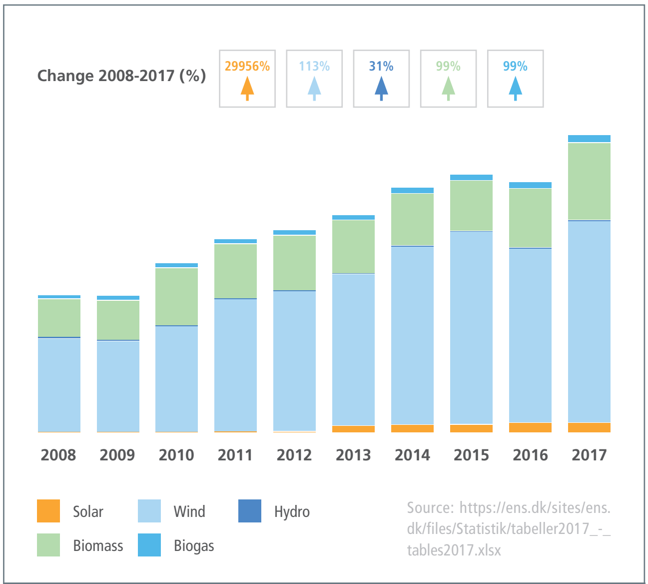



Figure 5-4. Electricity Production from Renewables 2017

- Trends on renewable energy illuminated by historic capacity (in kW) and generation (in kWh) in past 10 yrs; and the national goal(s) in near future (e.g. 2020, 2030 and/or 2050) on basis of capacity and generation;

The numbers in above Figures and tables clearly show that an increasingly amount of electricity is being produced from renewables. In 2017 renewables accounted for more than 70 percent of the energy mix in energy production.

Out of the renewables it is clear that wind is the largest producer accounting for 67.4 percent or 53,208 TJ. Wind production has increased by 113 percent comparing data from 2008 and 2017 which is the latest data available. Wind is expected to play a major role in the Danish energy supply and as part of the latest Danish energy agreement three offshore wind farms with a total of 2400 MW have been suggested. If the wind farms were realized they could cover the entire energy consumption for all Danish households.

- Introduction of national grids including the geographic layout and statistics of regional/transmission grid, distribution grid, and micro-grid; electricity market and its operation; top stakeholders in category of grid corp., RE owner, manufacturer, and etc.;

The Danish electricity sector is thoroughly unbundled. Currently in the system, there are the following roles:

- TSO – System operator and transmission network operator, owner of transmission network
- DSO- Distribution system operator, owner of distribution network, consumption metering
- BRP – balance responsible for a portfolio consumption or generation units
- Aggregators – managing flexibility
- End users
- Producers
- Market operators

The network is divided in two. On part is synchronous with the continental European network and the other part is synchronous with the Nordic area. Denmark is part of the Nordpool market. The part of the network above 100kV is transmission level.

- Technological progress of smart grids, especially in 6 prior topics of smart grids: storage, demand response, regional electricity highway, flexibility options, new grid control architecture, and power electronics;

There is a big potential for batteries connected to the system. Due to the network unbundling, owners are only allowed to own batteries if they use them for network operation only. At the moment several Danish research projects develop and demonstrate solutions integrating batteries in the grid. As part of a new project funded by EUDP the largest battery in Denmark will be installed in the Danish Island Bornholm. Learnings will add to the Danish palette of green energy technology.

Several projects on demand response have been carried out in recent years. They include EVs, domestic heating, energy management of commercial buildings and plants. These projects have demonstrated the technical potential for such schemes. Many of the projects have also studied or demonstrated market integration of demand response at system as well as distribution level. Currently there are efforts for taking these initiatives a step further introduce real market operation of demand response. The network has been strengthened and expanded to integrate in particular large offshore wind farms.

International interconnectors have been built or are in the planning phase to further enable long distance transmission of energy and share control resources. The growth in renewable energy has resulted in many conventional power plants mainly supplying system services since it is no longer feasible for them to sell electricity. It also means that they have improved their controllability and that there has been a substantial effort to improve the system service capabilities of renewable energy plants. This work is towards enabling them to participate in frequency control, power balancing and similar markets. Another result of the reduced conventional capacity is the introduction of synchronous condensers and HVDC technologies with good control capabilities. At the distribution level, the DSOs are improving the observability of the networks to reduce the time customers are not supplied and to enable the introduction of more active management of the distribution network exploiting e.g. demand response for grid reinforcement deferral. The excellent controllability of power electronics is being investigated to improve the network operation in view of the reduced system inertia.

- Key issues and/or innovation challenges of smart grids towards high-share of RE.

The main challenges in the Danish power system are to maintain the long term stability, economically ensure availability of domestic flexibility sources and operation during periods with low renewable energy production.

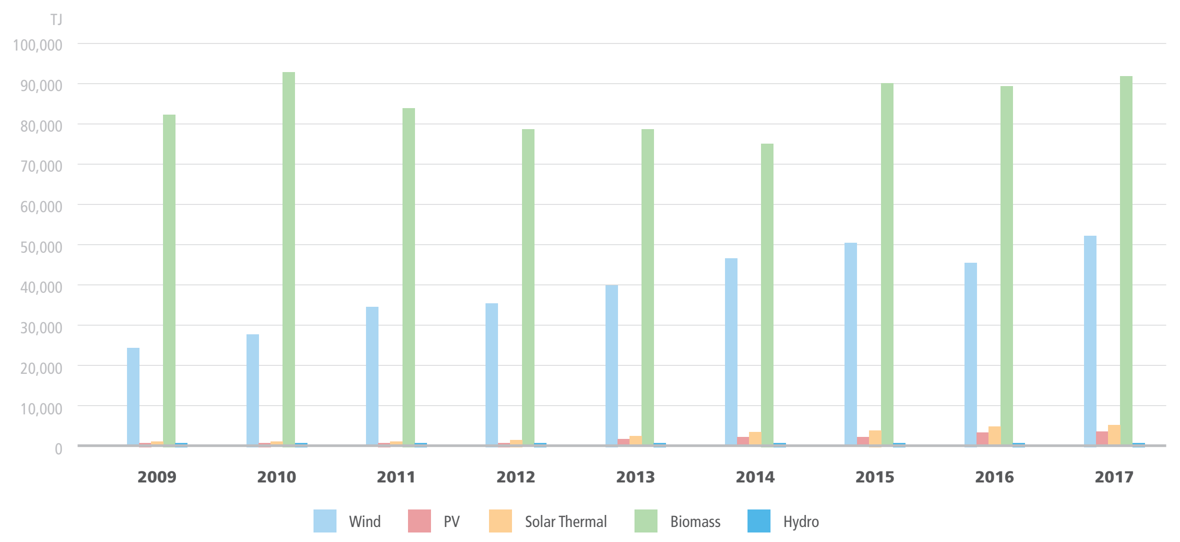



Figure 5-5. Trends on Renewable Energy Generation

## 5.3 National Programs in Fields of Smart Grids and Renewable Energy

Framework of governmental RD&D investment - programme, goals, strategy, activities, department in charge.

Denmark has two large national funding schemes supporting R&D in energy, EUDP and Innovation Fund Denmark.

**EUDP (Energy Technology Development and Demonstration Program)**

EUDP is a Danish public funding scheme supporting new energy technology contributing to fulfilling Danish objectives within energy and climate. EUDP supports private companies and universities to develop and demonstrate new energy technologies. EUDP can support energy technologies widely such as renewable energy technologies, energy efficiency technologies, conversion technologies such as fuel cells and hydrogen, integration of energy systems including storage. EUDP creates jobs and growth, increases the security of supply and helps Denmark to become independent of fossil fuels.

**Innovation Fund Denmark**
Innovation Fund Denmark invests in cultivating and translating ideas, knowledge and technology for the benefit of Danish Society. The Innovation Fund Denmark's investments should stimulate. Growth and employment and Solutions to key societal challenges

The objectives are achieved by means of:

- Innovation and technological advances
- Interdisciplinary alliances
- Thriving entrepreneurship
- Research excellence
- A dynamic international outlook

**Grants**
The total grants in energy R&D in 2017 from the two Danish public funding schemes amounted to 499 MDKK. However, as part of the latest Danish Energy agreement energy and climate R&D will receive a cash injection with a target of DKK 1 billion (EUR 134 million) by 2024.

**Source:**
https://innovationsfonden.dk/sites/default/files/2018-08/energi18-arsrapport-om-de-danske-energiforskningsprogrammer.pdf
https://efkm.dk/ministeriet/aftaler-og-politiske-udspil/energiaftalen/

**National smart grid R&D activities in line with POWs tasks and sub tasks-** Country specific smart grids R&D activities that best support the POW tasks/subtasks so that a collective framework for the future strategies and expectations can be developed for the same.

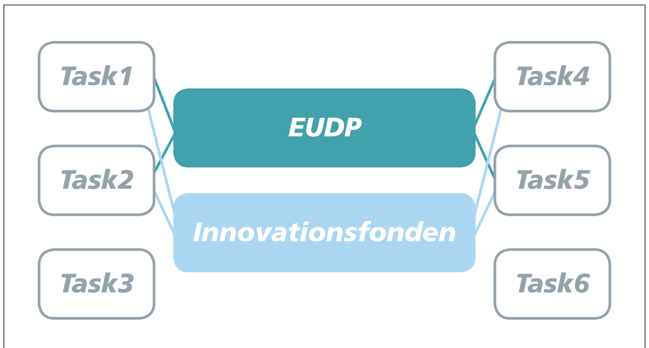



Figure 5-6

## 5.4 International Programme Related to Smart Grids and Renewable Energy

The Danish public funding scheme supports activities related to ERA-Net Smart Grids Plus - a European initiative supporting development and demonstration of innovative technologies, markets and societies contributing to a smarter system thinking and transnational knowledge sharing.

EUDP has recently included Mission Innovation activities in their funding scheme. There are two options:

- Danish participation in the Innovation Challenge working groups as example the Smart Grid Challenge.
- Technology development with international project participants from Mission Innovation member countries.

The research collaboration SDC (Sino Danish Center), which the Technical University of Denmark is part of, has a new theme on ‘Sustainable Energy’. The collaboration supports PhD-scholarships and the purpose is to achieve international excellence in research and education in sustainable energy systems and deliver high quality candidates to the energy sector. Similar research collaboration exists between India and Denmark research institutions.

## 5.5 Case Study

- The case(s) should be selected according the objective of IC#1 to highlight the national exertion from RD&D projects, such as technological solution for accommodating high-share of RE, international S&T collaboration, BIE, and etc.
- Defined format for case study is as following.

**PROJECT CASE #1**
**EnergyLab Nordhavn**

**Related Sub-challenge of IC1**
Cross innovation.

**Type of Project**
Technology development, Demonstration

**Topic**
Integrated Energy systems, energy flexibility, triple Helix

**Objective**
To develop new methods and solutions for the design and operation of the future integrated energy system based on Nordhavn as a globally visible real life laboratory.

### Contractors

Technical University of Denmark, City of Copenhagen, Copenhagen City and Port Development, Radius, HOFOR, ABB, Danfoss, Balslev, Metrotherm, Glen Dimplex, Nerve Smart Systems

### Period

2015-2019

### Ongoing and Achieved Key Findings

Established a shared data management system for energy data across the energy infrastructures, historic and real time. Demonstrated the use of a grid connected battery for peak shaving and frequency support application. Demonstrated the operation of an 800 kW heat pump delivering ancillary services to the power grid – with / without pre-starving of the connected DH system, which is a significant contribution to the frequency market. The result is an operational flexibility product, and the technical implementation is expected to entail that the DSO sends an order to the asset manager, who will be offered an availability and an activation fee. Preliminary analysis shows that this may be significant for the business case for a heat pump connected to a district heating grid.

### Added Value of IC1 Objective

The main contribution here is the unlocking of the flexibility potential in the heat network and in the buildings, through the physical coupling of the networks through heat pumps. This increases the possible wind power penetration, which is already high (2018: 42%)

Figure 5-7

## 5.6 Reference

[1] J. Marcos, O. Storkel, L. Marroyo, et al. Storage requirements for PV power ramp-rate control[J]. Solar Energy 99 (2014): 28–35.

[2] B. M. Mazumdar, M. Saquib, A. K. Das. An empirical model for ramp analysis of utility-scale solar PV power[J]. Solar Energy 107 (2014): 44–49.

[3] D. Connolly, H. Lund, B.V. Mathiesen, et.al. The technical and economic implications of integrating fluctuating renewable energy using energy storage[J]. Renewable Energy 43 (2012) :47-60.

[4] M. Jannati, S.H.Hosseinian, B.Vahidi, et al. A survey on energy storage resources configurations in order to propose an optimum configuration for smoothing fluctuations of future large wind power plants[J]. Renewable and Sustainable Energy Reviews 29(2014): 158–172.

# 6. FINLAND

## 6.1 General Framework and Implementation

Finland is situated in northern Europe. It has an area of 338,432 square kilometres of which 72% is forest, 10% is water and 8% is cultivated land. The population of Finland is 5.5 million, which corresponds to an average density of 18 persons per square kilometre. More than two-thirds of the population reside in the southern third of the country. Productive forests are the most valuable natural resource in Finland. The main domestic energy resources are hydro power, wood and peat. Finland also has some rich deposits of metallic ores of which the most significant are copper, zinc, and nickel.

Total energy consumption in 2016 was 1,348 PJ (32.2 Mtoe[6-1]) which corresponds to 245.0 GJ/capita (5.9 toe/capita). Electricity consumption in 2018 was 87 TWh. Figure 6-1 presents the recent development in total electricity consumption.

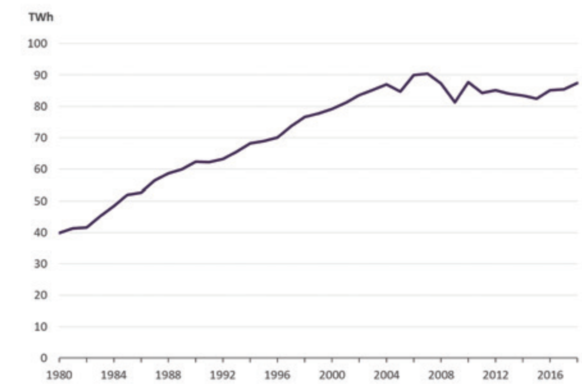



Figure 6-1.Total Electricity Consumption Development in Finland[6-1].

Finnish electricity consumption has, to a certain extent, followed changes in Gross Domestic Product (GDP). Figure 6-2 presents the recent year-on-year changes in total consumption.

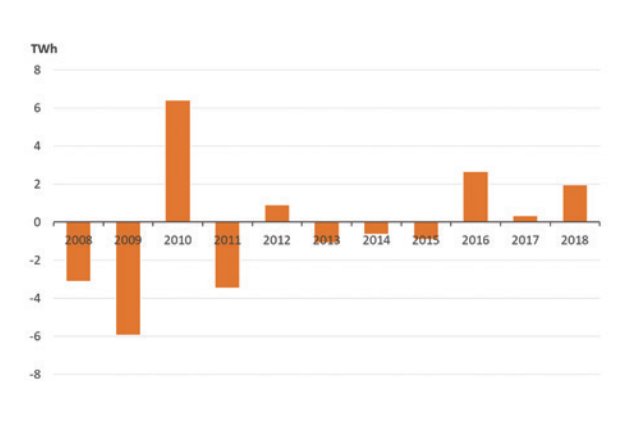



Figure 6-2. Year-on-year Changes in Electricity Consumption.[6-1]

Generally, industry uses roughly half of Finnish electricity. The other half is consumed by housing, buildings, agriculture and various services. Figure 6-4 shows the profile of electricity consumption.

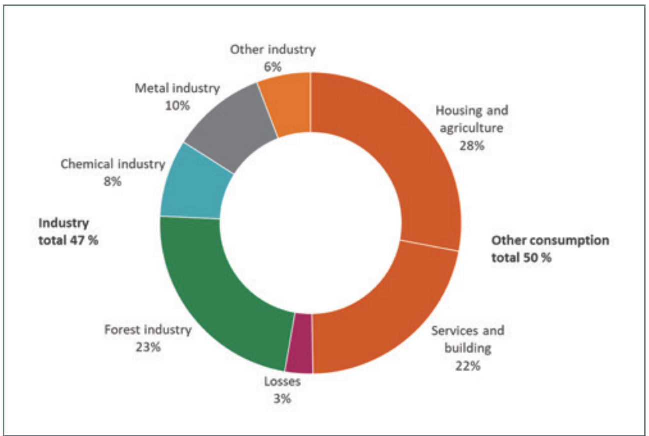



Figure 6-4. Electricity Consumption in 2018.[6-1]

Peak avoidance has been one recent trend in the development of the energy system. Finland typically faces the peak load hours during cold winter days when there is most need for heating and lighting. Figure 6-3 illustrates the development of peak loads. To date, the development in peak loads has been very similar to the development in overall consumption figures.

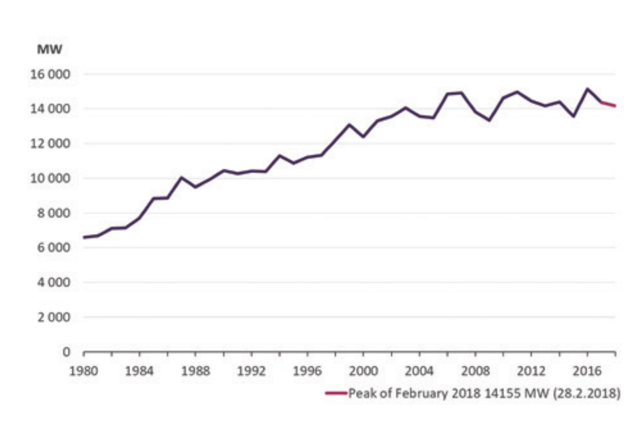



Figure 6-3. Development of Peak Loads.[6-1]

## 6.2 Status of Renewable Energy and Smart Grids

The share of renewable energy in Finnish total consumption is currently almost 40% (37 % during 2017). The national energy and climate strategy addressing year 2030 defined the objective of increasing the share of renewable energy over 50 percent during by 2030.

Finland's long-term objective is to be a carbon-neutral society. The Parliamentary Committee on Energy and Climate Issues published in October 2014 a report **"Energy and Climate Roadmap 2050"**, which serves as a strategic level guide for the journey towards this target. The roadmap analysed the means of constructing a low-carbon society and achieving an 80–95% reduction in greenhouse gas emissions compared to a 1990 baseline.

The generation mix is rather balanced, combining nuclear power, hydro power and biomass-based generation as indicated in Figure 6-5. Net import was 23% in 2018.

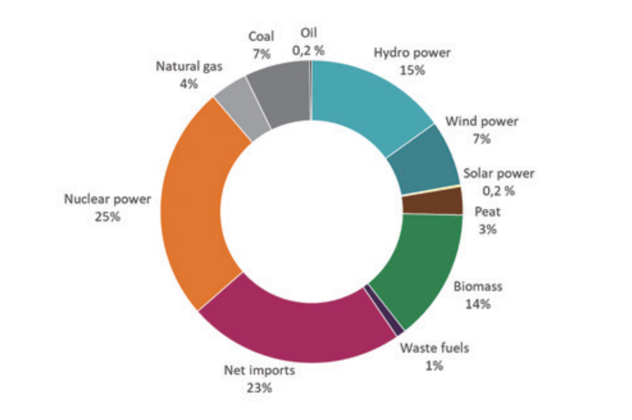



Figure 6-5. Electricity by Energy Source in 2018.[6-1]

Wind power installations has been progressing slowly during recent years, but is accelerating rapidly. Figure 6-6 presents the generation and capacity of wind power.

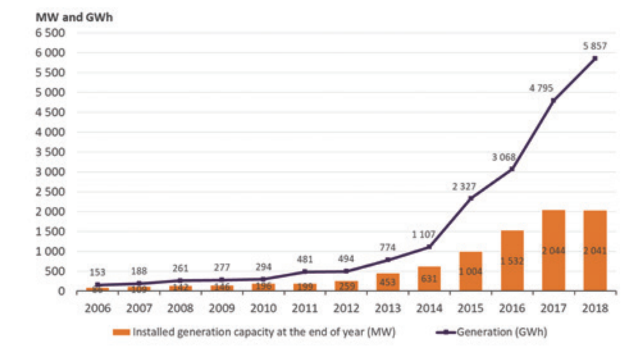



Figure 6-6. Generation and Capacity of Wind Power.[6-1]

Overall $CO_2$ emissions for power generation in Finland have been decreasing as illustrated in figure 6-7.


Figure 6-7. $CO_2$ Emissions for Power Generation.[6-1]

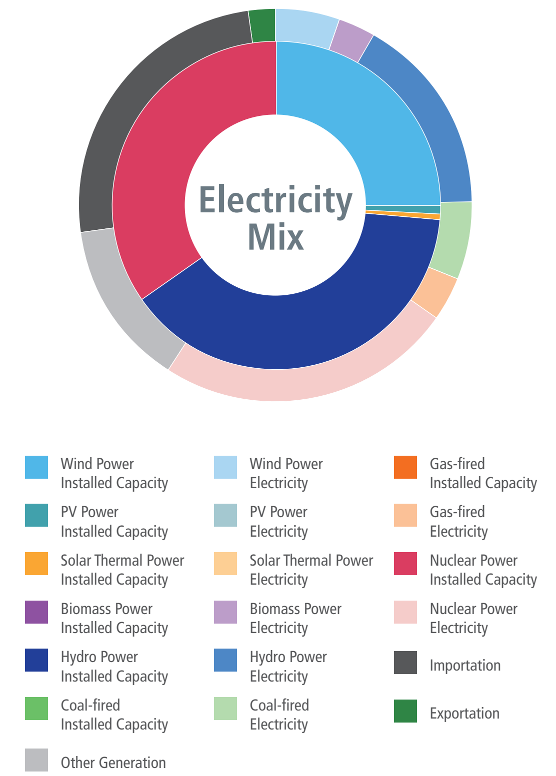



Figure 6-8. Electricity Mix by the End of 2017

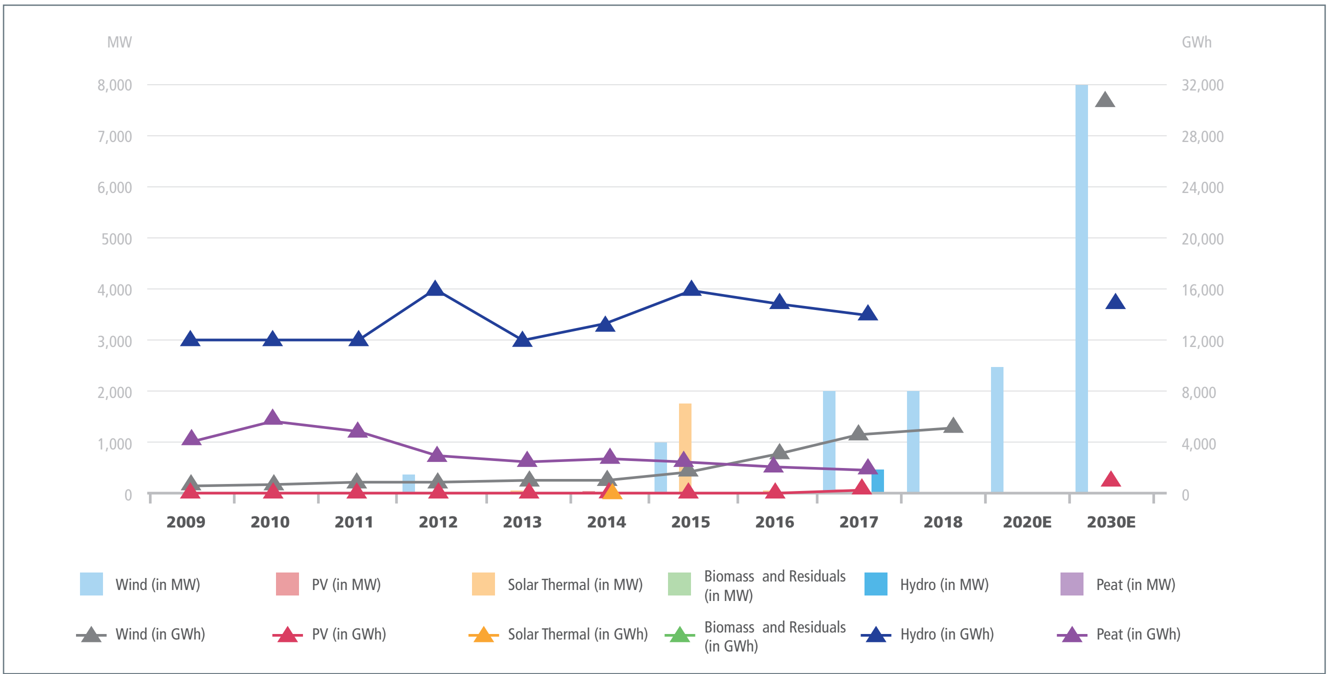



Figure 6-9. Trends on Renewable Energy Generation

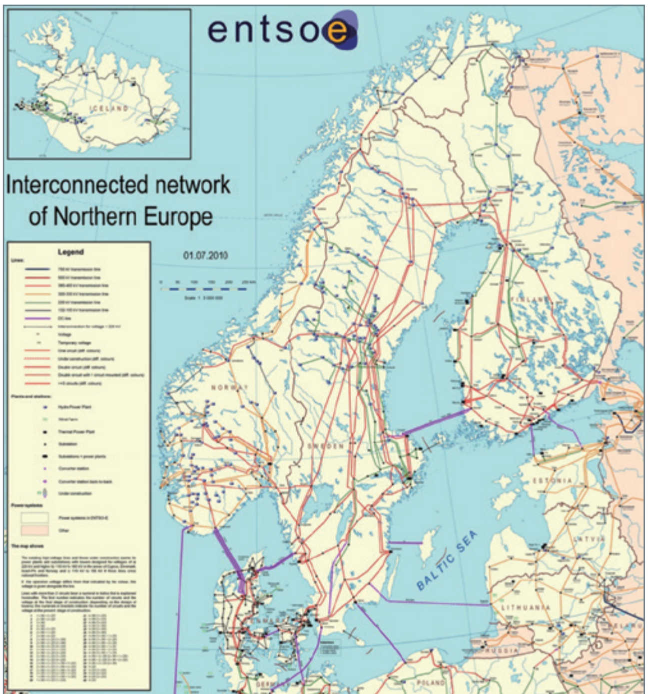



Figure 6-10. Finland is a Part of Interconnected Northern Europe Network.[6-2]

The Finnish electricity system is often referred to as Smart Grid 1.0, on the basis that it has already implemented Smart Grid functionalities into current systems. While there are different interpretations on how "smart" the current system is, it may be reasonable to state that the Finnish electricity system is for many parts among most advanced systems in Europe or even globally. The basis for this are, for example, high levels of network automation, wide use of Smart Meters, and open energy market structures.

Historically, Finnish development has been strongly driven by reliability requirements. Major investment programs are currently running to improve reliability and resilience. In addition, new factors such as the share of renewable energy or wide-scale adoption of Electric Vehicle (EV) charging are currently gaining more attention, however actual problems have been rare so far.

Finland is a part of the interconnected Northern Europe network and shares market mechanisms with Nordic countries.

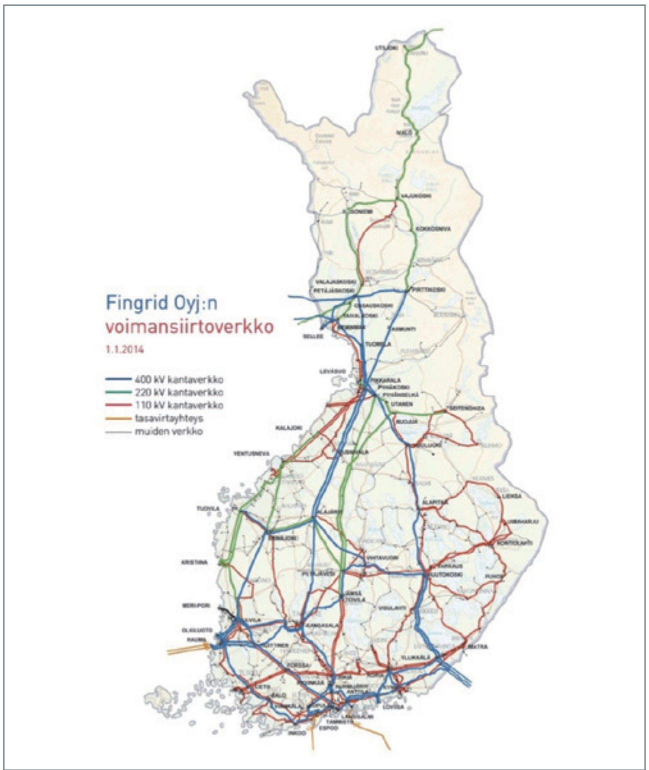



Figure 6-11. Finnish Transmission Network.[6-2]

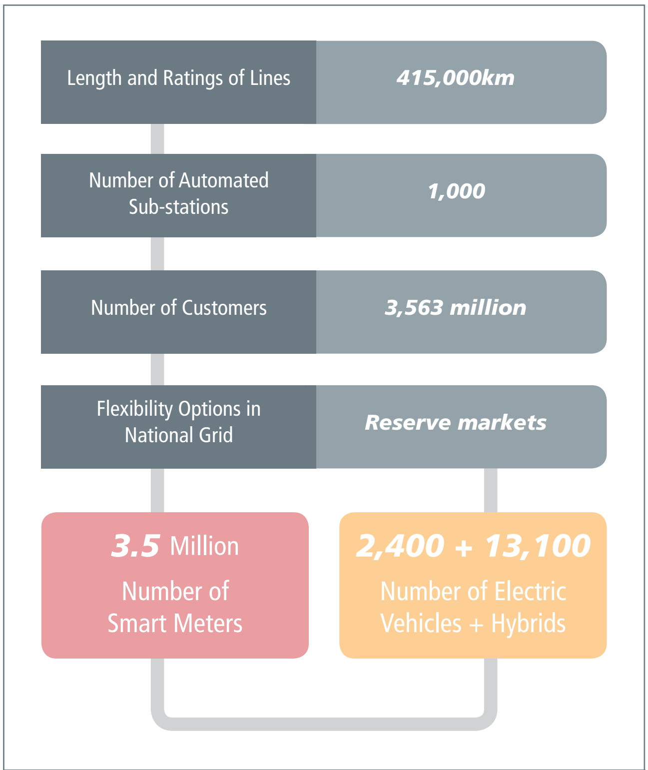



Figure 6-12. Key Smart Grids Facts and Figures by the End of 2018

## 6.3 National Programs in Fields of Smart Grids and Renewable Energy

The Smart Energy Finland Programme by Business Finland brings together the services for technical development and exports. A hundred million euros will be granted to smart energy solution innovations by the programme from 2017 to 2021. The programme will also grant support for the international expansion of growth-oriented companies that possess growth potential and feature renewable energy and smart energy solutions in their product portfolio.

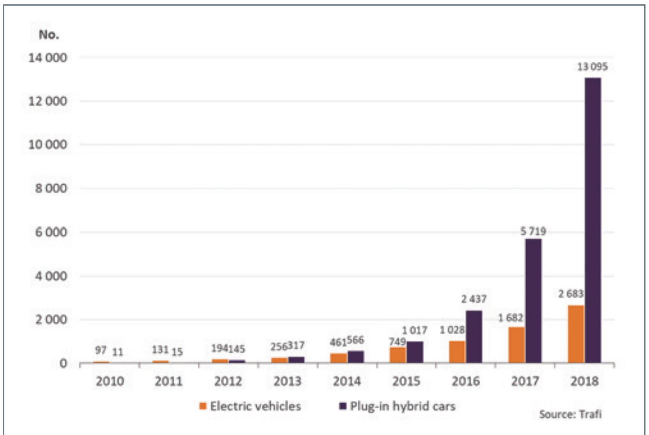



Figure 6-13. Development of EVs and Plug-in Hybrid Cars.[6-1]

The programme's objectives include:

- Support the international growth of companies;
- Contribute to the creation of a solid foundation for expertise with the development of smart energy ecosystems and test platforms;
- Challenge the energy sector into utilising digitalisation, the Internet of Things (IoT), Artificial Intelligence (AI) and the Internet of Energy;
- Introduce new business concepts in the fields of energy efficiency, renewable energy, energy storage systems, smart networks and integration of steering as well as consumer-oriented business;
- Contribute to the creation and development of new start-up companies;
- Attract international investment in Finland;
- Build an internationally competitive business ecosystem in Finland in the battery sector and to help Finland to become a leading country in the battery recycling expertise.

The focus areas of the programme include:

- The value chain of sustainable energy (bioenergy, W2E, W2V, biofuels), with emphasis on building export ecosystems in the target markets;
- Batteries from Finland campaign will contribute to creating a business ecosystem worth millions of euros in Finland. It will make Finland a business platform that will attract international companies in the battery sector and take the position of a leading technology and service provider in the global market;
- Developing and creating test platforms in smart networks (Smart Otaniemi, Åland Islands, Vaasa etc.) in Finland, and seek to build similar concepts in one or two target countries. This will be carried out with the help of global partnerships and creating solution and service concepts in the respective markets;
- In smart buildings, the focus areas will include IoT, AI digitalisation and Building Information Management (BIM);
- As a general rule, all efforts will be on taking full advantage of digitalisation.

One essential aspect for Mission Innovation challenges is utilizing developed platforms and linking them for international collaboration.

## 6.4 International Programme Related to Smart Grids and Renewable Energy

Generally, Finland is very active in international activities within the theme of Smart Grids and Smart Energy Systems. There are several levels of collaboration:

- At the EU level, Finland collaborates mainly through EU framework programmes such as Horizon2020;
- On the EU-level, ERA-NETs or similar joint initiatives are also used;
- Nordic collaboration takes place within Nordic Energy Research or other platforms;
- Bilateral project calls are organized, for instance joint calls between Finland and Germany have taken place.

## 6.5 Case Study: Smart Otaniemi

Smart Otaniemi in Finland is an innovation ecosystem that connects experts, organisations, technologies and pilot projects. It brings the building blocks of a smart energy future together. The testing platform is being built around Nokia's 5G network, utilising the opportunities it brings for fast transfer of data.

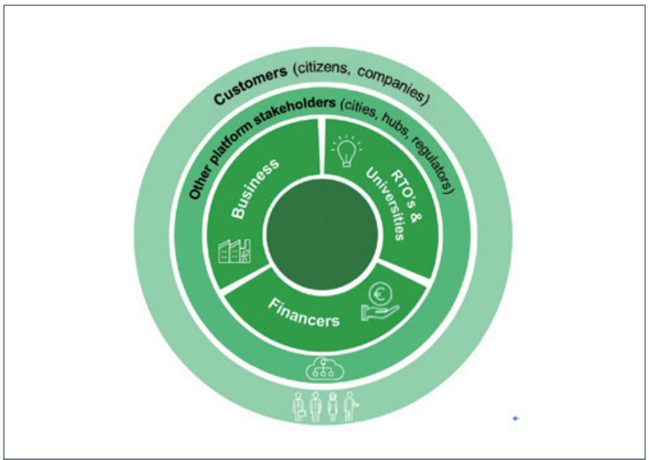



Figure 6-14. Structure and Actors of an Innovation Ecosystem.

Smart Otaniemi is an ecosystem of more than 50 partners, working on seven concrete pilots, developing new ideas and creating new business. The ecosystem is open for new partners with new pilot ideas,ranging from quick testing of new solutions, to more research-oriented topics in the energy field.

The identified topics for substance roadmaps are; energy storage, flexibility market, Power-to-X, autonomous driving and future city structures. The idea is to be able to experiment new solutions on a system-level, whilst also utilising the simulation and virtual modelling potential that the research partners in Otaniemi can provide – creating next generation energy solutions for different regions.

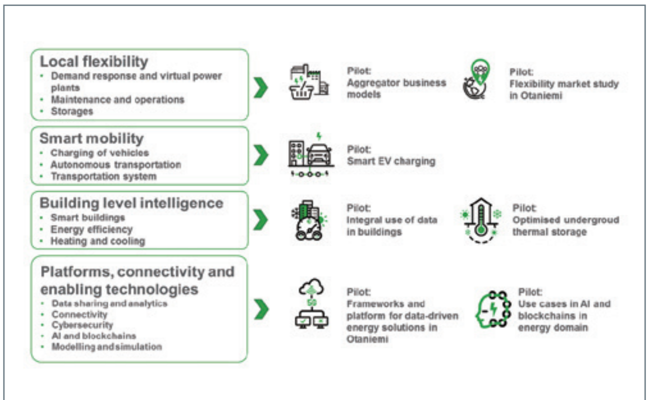



Figure 6-15. Main Themes and Current Pilots Running in Smart Otaniemi.

Figure 6-16 gives a more detailed view on a pilot in which an aggregator business is harnessing flexibility from multiple sources through a new sub-aggregator concept.

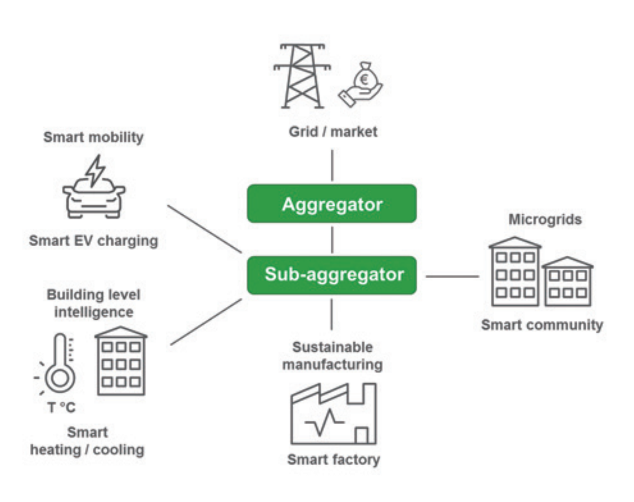


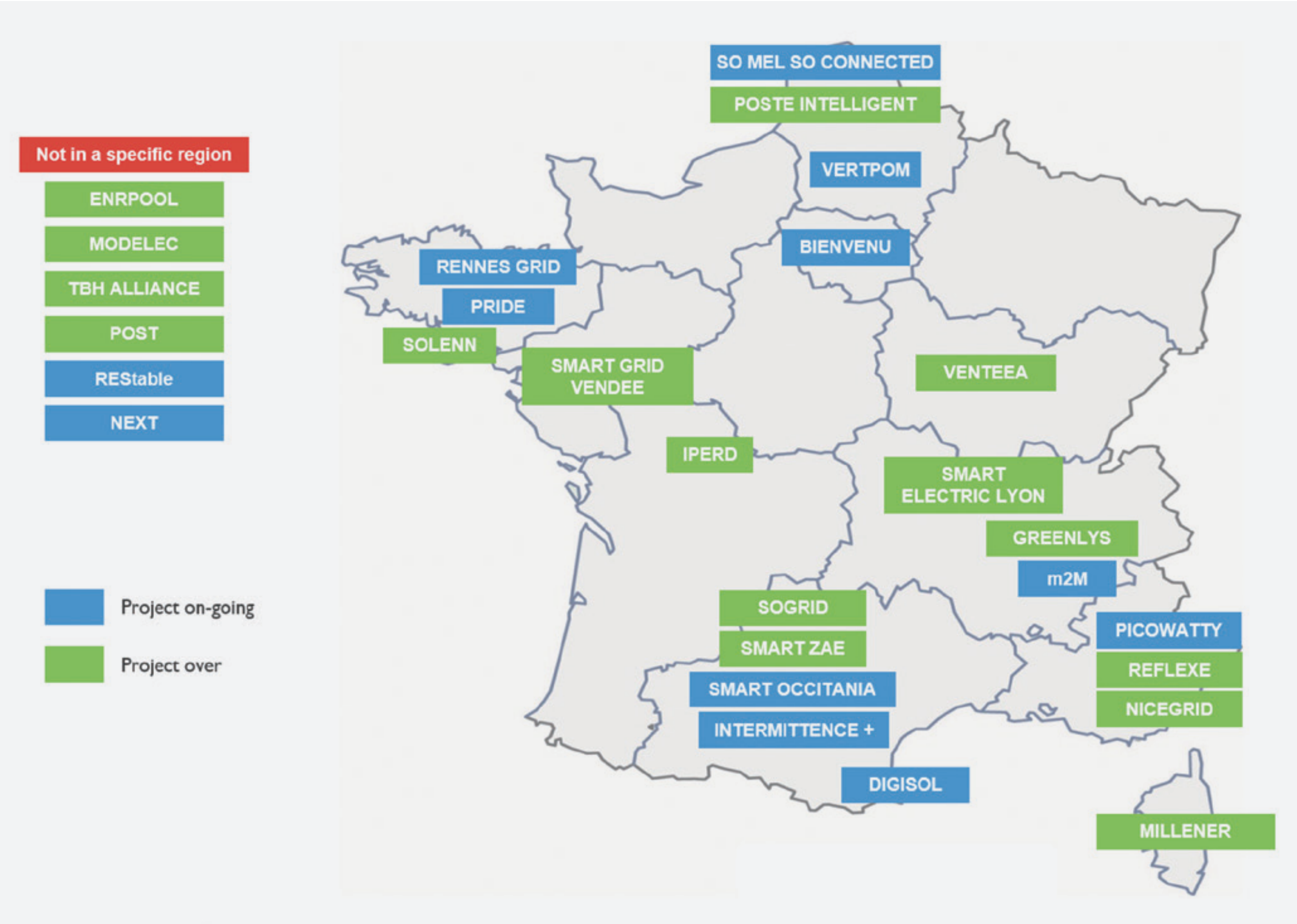

Figure 6-16. Concept of Smart Otaniemi Aggregator Business Pilot.

The current partner network represents multiple sectors from ICT to energy utilities, service providers, technology vendors and real estate owners. Companies vary from start-ups to big corporations. Everyone shares the same long-term vision: making energy smarter for the future.

## 6.6 References

[6-1] Energy Year 2018 - Electricity. Finnish Energy, 01/2019.

[6-2] Fingrid. www.fingrid.fi




# 7. FRANCE

## 7.1 General Framework and Implementation

France is deeply committed to the fight against Climate Change. The Energy Transition Act (2015) has set ambitious targets to reach over several different timescales. By 2030, the greenhouse gas emissions should be reduced by 40% compared with 1990 and shall be reduced to a quarter of their 1990 levels by 2050. Renewables should contribute 32% of final energy consumption by 2030 (40% for electricity) and nuclear will be capped at 50% of electricity generation by 2035. Final energy consumption should be reduced by 20% in 2030 compared to 2012 and by 50% in 2050.

Those targets, set in the law, are translated into actions via programmes of work spanning multiple years known PPE. The second PPE which covers the 2019-2028 period is currently under consultation and should be adopted during summer 2019. It defines trajectories and means of reaching national targets (such as financial incentives, new regulation to be implemented and identifying cross sector approaches). The PPE is strongly linked to other national policy documents: the low-carbon strategy, the sustainable mobility plan, the national plan for air pollution emission reduction, and the national energy research strategy.

The French islands and non-interconnected territories have a separate PPE and are pilots for the energy transition. By 2030, each of these territories shall reach energy independence using only renewables. The demonstrations and large scale deployment ongoing overseas will be used to accelerate the energy transition in continental France.

## 7.2 Status of Renewable Energy and Smart Grids

Electricity transmission is operated by the national Transmission System Operator (TSO) RTE, except overseas where there is no separation between generation, transmission and distribution.

RTE operates over 100,000km of lines with 5 voltage levels: very high voltage lines (400kV, 225kV) representing 45,000km and around 55,000km of high voltage lines (150kV, 90kV, 63kV). The voltage levels below this are operated by the corresponding Distribution System Operator (DSO). France has over 130 DSOs but, the largest, ENEDIS, operates 95% of the total distribution network (1,300,000km of lines).

France is part of the European electricity market. The interconnections with six European countries have an influence on the national market prices since France export capacity is 17.5 GW and import capacity 12.5 GW. Market coupling between different European countries is already effective and provides a single trading zone when the interconnections are not saturated.

The transport and distribution prices are regulated at a national level with the principle of equalisation: every consumer pays the same price for T&D regardless of their location.

The power system is overall not yet heavily constrained in continental France for the moment, due to a reliable and well sized network, and a relatively low share of variable renewable electricity sources. Flexibility is ensured by pumped storage hydro (5 GW). The continuous growth in interconnections is shown in the following Figure 7-1:


Figure 7-1

The current electricity mix is dominated by nuclear, which provided 72% of national production in 2018 (549 TWh). Net exports were 60 TWh in 2018, France being the largest electricity exporter in Europe in 2018.

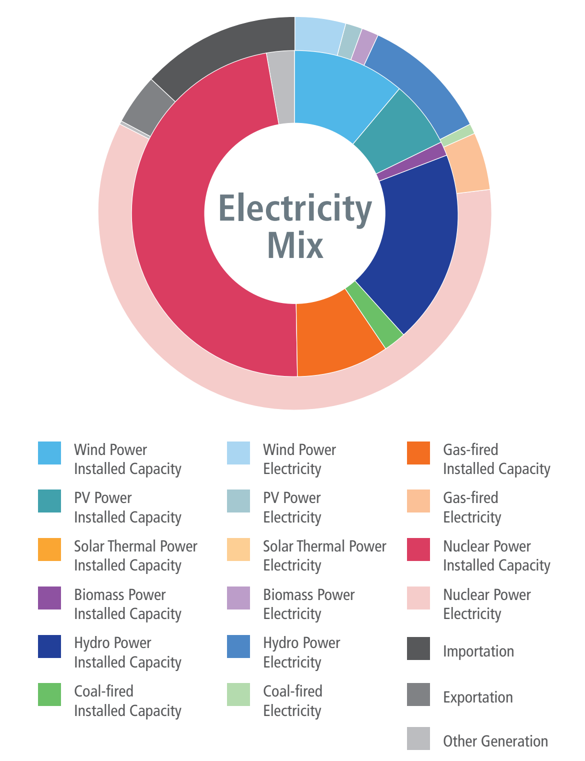



Figure 7-2. Electricity Mix by the End of 2018

The electricity generation mix (Figure 7-2) will change dramatically in the years to come. The share of generation from Renewable Energy Sources (RES) will rise from 21% in 2018 to 40% in 2030, most of the additional capacity being based on solar PV, onshore and offshore wind. Plants running on coal will be shut down in 2023, and the nuclear share will decrease to 50% of the mix by 2035. All these changes are decentralizing power system management, with most of the new production sites connected on the distribution network, which increase the need for flexibility.

The RES recent past and objectives set by the law and the PPE are summarized in the following table.

Smart grid solutions aim to facilitate distributed generation and integration of RES; support Demand Response activities to balance supply & demand with limited environmental impacts and adapt the grid to changes in consumption (such as Electric Vehicles) in the most efficient ways.

The transmission network is already well equipped with sensors and supervision centers to ensure real time balance of supply and demand. New equipment is being progressively tested and deployed: smart substations capable of self-adapting when necessary, dynamic line rating to collect real time data at several locations on the status of a line.


Figure 7-3. Trends on Renewable Energy Generation

The distribution network is facing new issues: a large amount of renewables connected on low voltage levels, the integration of electric vehicles, and the adoption of residential Demand Response. New equipment is rolled-out progressively. Distribution automation already enables electricity to be restored to 70% of customers within a few minutes. More than 150,000 of the 780,000 medium and low voltage substations are equipped with sensors. Some of the new equipment being rolled out are listed here below.

- 35million Smart Meters by 2021. The deployment of the Linky smart meter commenced at the end of 2015 and over 17million are already installed. Linky meters are connected to the feeding substation through powerline communication. They enable the collection of data for grid management, resolution of incidents without physical intervention, remote measuring of consumption, coupling with devices directly plugged into the meter (e.g. for Demand Response), customer access to a free website to visualize its consumption and a half-hourly load curve. Linky facilitates Photovoltaic (PV) self-consumption and allows the ability to refine the tariffs for distribution and supply to facilitate energy consumption behavior;
- Exchange of information with the local electricity producers and possibility of disconnection in case of an incident;
- Consumption and generation forecast software on the local scale and new solutions for grid planning;
- New control systems on the low voltage network.

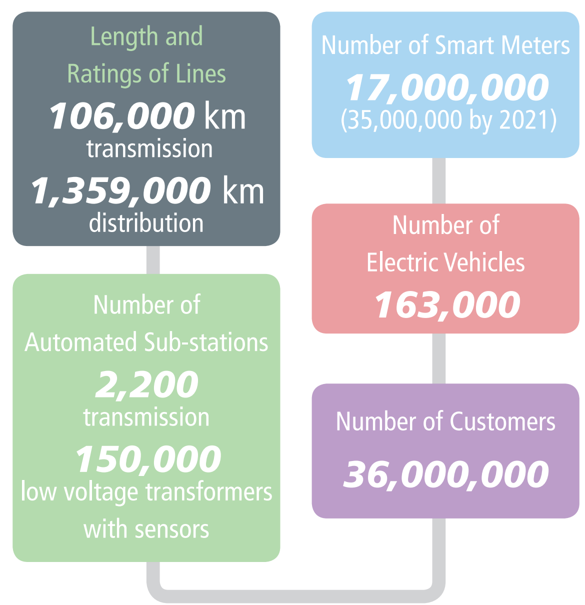



Figure 7-4. Key Smart Grids Facts and Figures by the End of 2018

## 7.3 National Programs in Fields of Smart Grids and Renewable Energy

France is supporting both Research, Development and Innovation (RDI) and deployment of the first mature solutions.

RDI projects are funded by the National Research Agency (ANR) or the National Innovation Fund ("Programme des Investissements d'Avenir" or PIA). Since 2011, the PIA through its operator, the energy agency ADEME, has funded 28 demonstrators. The demonstrators involve more than 120 private and public partners, and correspond to 120 M€ expenditure.

Another important investment is the SuperGrid Institute, a collaborative research platform which develops new technologies for electricity transmission networks, including high-voltage direct current lines (HVDC), with public and private investment. Supergrid benefits from more than 80M€ public support.

Overall, research is very active on the RDI fields covered by the Mission Innovation Smart Grid Challenge Program of Work, with major French public research institutions such as CEA and CNRS involved.

Beyond specific technological issues, particular attention is currently being paid at a national level to the economic cost and benefit assessment of smart grids solution, and to multi-vector energy systems modeling, with the aim to define optimal public policies.

## 7.4 International Programs Related to Smart Grids and Renewable Energy

France is involved in 17 technology collaboration programs (TCP) hosted by the International Energy Agency. Amongst these, the ISGAN TCP is dedicated to smart grids.

France is also part of the Clean Energy Ministerial and is involved in most Mission Innovation Challenges. France co-leads the Off-grid Access to Electricity Challenge (IC2) with India.

Many French public and private organizations regularly participate in European smart grids and smart energy related programs.

## 7.5 Case Studies

PROJECT CASE #1
**Smart Grid Vendée**
http://smartgridvendee.fr

### Related Sub-challenge of IC1
Distribution grid innovation

### Type of Project
Demonstration

### Topic
Flexibility management, integration of RES, tension regulation

### Objective
Optimize electricity production, distribution and consumption at intermediate scale.

### Contractors
Sydev, Actility, GE, Cofely Ineo, CNAM, Legrand, Enedis, RTE

### Period
2013-2018

### Key Findings / Added Value
After a large instrumentation campaign, including real time measurements, at several sites of production and consumption and several points on the network (see table below), programs were developed to optimize network exploitation such as Demand Response with public and industrial sites, optimised connection costs for production sites (with limited capping), real time feeder optimisation.

**Production**

**5 Wind Farms** (50 MW) **48 PV Sites** (2MW)

**Consumption**

**120** Public buildings
**1,000** Public lighting points
**7** Industrial sites

**Network**

**5** Substations (90 kV to 20 kV)
**100** Substations (20 kV to 400 V)
**73** 20 kV lines

Figure 7-5

PROJECT CASE #2
**Smart substation (poste intelligent)**

### Related Sub-challenge of IC1
Regional grid innovation

### Type of Project
Demonstration

### Topic
Digital control management, real time data exchange, cybersecurity

### Objective
Digitalisation of control-command systems and advanced features in 2 substations (225kV and 90kV) allowing higher integration of RES

### Contractors
RTE, Alcatel-Lucent, GE, Enedis, Schneider Electric, Neelogy

### Period
2013-2018

### Key Findings / Added Value
Development of new sensors and hypervision software; control-command systems including self-analyze and dynamic reconfiguration.costs for production sites (with limited capping), real time feeder optimisation.

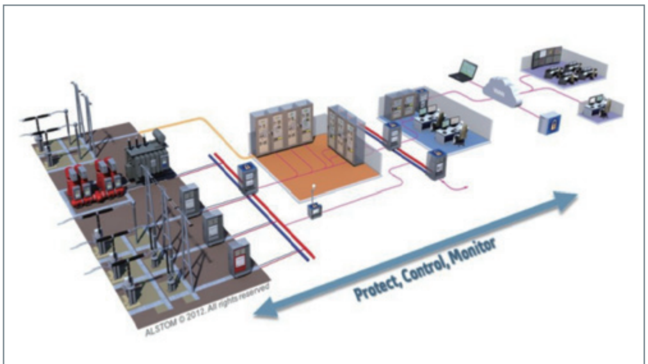



Figure 7-6

## 7.6 Further Information

- A summary of the 2019-2028 energy plan (PPE) can be found on https://www.ecologique-solidaire.gouv.fr/programmations-pluriannuelles-lenergie-ppe

- The Think Smart Grids association website (https://www.thinksmartgrids.fr) provides information in English about the smart grids solutions provided by French industrials and overview of the French implementations.

- First results from smart grids demonstrators, by the energy and environment funding agency ADEME : https://www.ademe.fr/smart-grids-first-results-from-french-demonstrators

  This study will be updated in 2019.

- A repository of the demonstration and research projects is available online (in French) on the website of the French energy regulator (CRE) : http://www.smartgrids-cre.fr

Figure 8-1. Brandenburger Tor, Berlin

# 8. GERMANY

## 8.1 General Framework and Implementation

The Federal Republic of Germany lies in Central and Western Europe, between the Baltic and North Seas to the north, and the Alps to the south with nine neighbouring countries (without sea border).

By the end of 2018, Germany has a population of about 82,877M inhabitants and achieves a gross domestic product of 3,388 billion €, i.e. 40,883 € per capita. Germany's area comprises 357,385 km² with an average population density of 230 inhabitants per km² (69 – 3,948) and 41,304M households [1].

Germany emitted 895 Mt CO2 equivalents greenhouse gas in 2016, 332 Mt from fossil energy and 167 Mt from transportation.

The installed generation capacity is about 207 GW (2018), of which more than 50 % (118 GW) is referred to renewables (RES). In total, 540 TWh (net) were generated in 2018 from that capacity, mainly used by industrial customers and private households. The maximum load is about 80 GW with an average of 65 – 70 GW during a working day [2].

In November 2016, the German government adopted the Climate Action Plan 2050 [3], making Germany one of the first countries to submit the long-term low greenhouse gas emission development strategy to the UN as required under the Paris Agreement. The Climate Action Plan 2050 confirms and specifies the German government's ambitious climate targets. Germany's long-term goal is to become extensively greenhouse gas-neutral by 2050.

The quantitative goals of Germany's Climate Action Plan 2050 [3] foresee a reduction of greenhouse gas emissions of 40 % by 2020, 55% by 2030 and at least 80 % by 2050 (in comparison to 1990).

A monitoring system for the energy transition is in place to review progress and take corrective actions if targets are at risk of being missed.

The central element of the monitoring system consists of an annual monitoring report [4]. Every three years, the monitoring report is supplemented by a strategic progress report.

The energy transition is one of the greatest challenges facing society today. It is an enormous task that can be mastered better and more effectively through the use of innovation and new technologies. Therefore, the federal government supports basic and applied research and demonstration projects, as well as large pilot installations (living labs).

## 8.2 Status of Renewable Energy and Smart Grids

The peak load in Germany is around 80 GW, whereas 65 – 70 GW is the typical load in Germany at day time. In total, by the end of 2018, an installed capacity of about 210 GW ensures a reliable electricity supply, from which more than 50 percent (~120 GW) is based on RES [2].

In 2018 about 540 TWh were generated from all installed resources. In total, RES produced around 219 TWh in 2018, 4.3 percent more than in 2017. Consequently, they accounted for more than 40 percent of net electricity generation.

Photovoltaic systems fed approx. 45.7 TWh (net) into the grid in 2018. Their generation increased by approx. 6.3 TWh or 16 % compared to the previous year. The installed PV capacity at the end of November was approx. 45.5 GW. The increase in 2018 amounted to approx. 3.2 GW.

Wind energy produced approx. 111 TWh (net) in 2018 and its production was approx. 5.4 % higher than generation in 2017. Wind energy is thus the second largest energy supply after brown coal (131 TWh), but ahead of hard coal (73 TWh) and nuclear (72 TWh). In ten months, wind power generation exceeded generation from hard coal and nuclear energy. The share of onshore wind was approx. 89.5 TWh, 2 TWh more than in 2017. Offshore wind increased its production from 17.4 TWh in 2017 to more than 19 TWh in 2018. Approximately 16.6 TWh were generated in the North Sea. Offshore production in the Baltic Sea was approx. 2.3 TWh.

In 2018, solar and wind energy plants jointly produced approx. 157 TWh. This puts them ahead of lignite, hard coal and nuclear energy.

Regarding the trend of RES, the expected increase of RES is mainly determined by Germany's Energy Concept [5]. With respect to gross electricity production, the share of RES shall be increased to 35 % in 2020, to 50 % in 2030 and to 80 % in 2050, respectively.

The length of the transmission grid is approximately 36,000 kilometres, using voltages of 220 kilovolts (kV) or 380 kV for AC and up to 525 kV for the planned new high-voltage DC transmission lines. The transmission grid is operated by four transmission grid operators (TSO). The regulated transmission grid expansions bases on a scenario framework, which describes the probable developments in Germany's energy supply, especially in the next decade up to 2030. Based on this framework, necessary grid optimization (e.g. higher voltage levels, high temperature conductors, dynamic ratings) or grid expansion is determined for the next ten to fifteen years. This contains a list of the required expansions projects and new construction projects. The Federal Government receives such a draft on a regular basis. It starts the legislative process, which leads to a legally established necessity of those projects at the end of the day.

A major role in the transmission grid expansion will be played by the ultra-high-voltage DC transmission lines (up to 500 kV), the electricity highways like "SuedLink" and "SuedOstLink". The upgrading of the interconnectors to Germany's European neighbours is also becoming more and more important, because the energy transition needs a European approach. This allows, for example, combining hydroelectric power from Scandinavia and the Alpine countries with wind power and photovoltaics from Germany.

At the distribution grid level, electricity is transmitted in high, medium and low voltage (400 V – 110 kV). A large number of regional and municipal grid operators (DSO) are active in this area (890 DSO) [6]. The Energy Concept affected several grid-related acts[8-1] and ordinances, which were issued in order to

[8-1] The Act to Change Provisions of Law on Energy Cable Construction, the Act on the Digitalisation of the Energy Transition, and the revision of the Incentive Regulation Ordinance

establish improved policies to stipulate the expansion of the transmission and distribution grid.

Since the beginning of smart grid research funding in 2008, significant process has been achieved in various technical areas. Storage and its grid integration were supported by a large funding call (> 184M €) in 2011, in which different storage technologies are addressed, e.g. electrical, chemical and thermal storage. Several results have been integrated in existing products, e.g. PV home storage based on RedoxFlow batteries.

For the regional and trans-regional electricity highway new components, installation techniques and monitoring equipment have been developed, e.g. DC gas isolated lines, enhanced drilling techniques or power quality monitoring. Flexibility options in the distribution grid have been enabled by non-discriminatory smart market platforms or enhancements in (regional) virtual power plants. New grid control architectures have been developed for transmission and distribution grids, e.g. control rooms for AC/DC-systems or big data analyses in the distribution grid. Improvements in power electronics were achieved at high and low voltage, e.g. new HVDC converter architectures, usage of new IGBTs or DC integration in industrial fabrication processes.

Especially, integration of DC links in the existing AC infrastructure and the penetration of information and communication technology (ICT) in distributions grids are additional improvements over the recent years.

In addition to technical developments, important and central aspects of enabling smart grids with high share of RES also include questions of acceptance and standardisation. When it comes to acceptance, both the customer and the network operator have to adopt technical solutions in the long term.

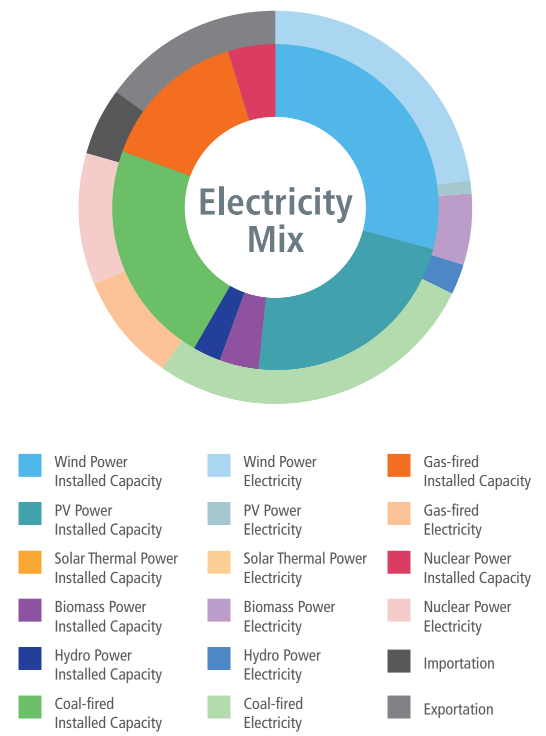



Figure 8-1. Electricity Mix by the End of 2018

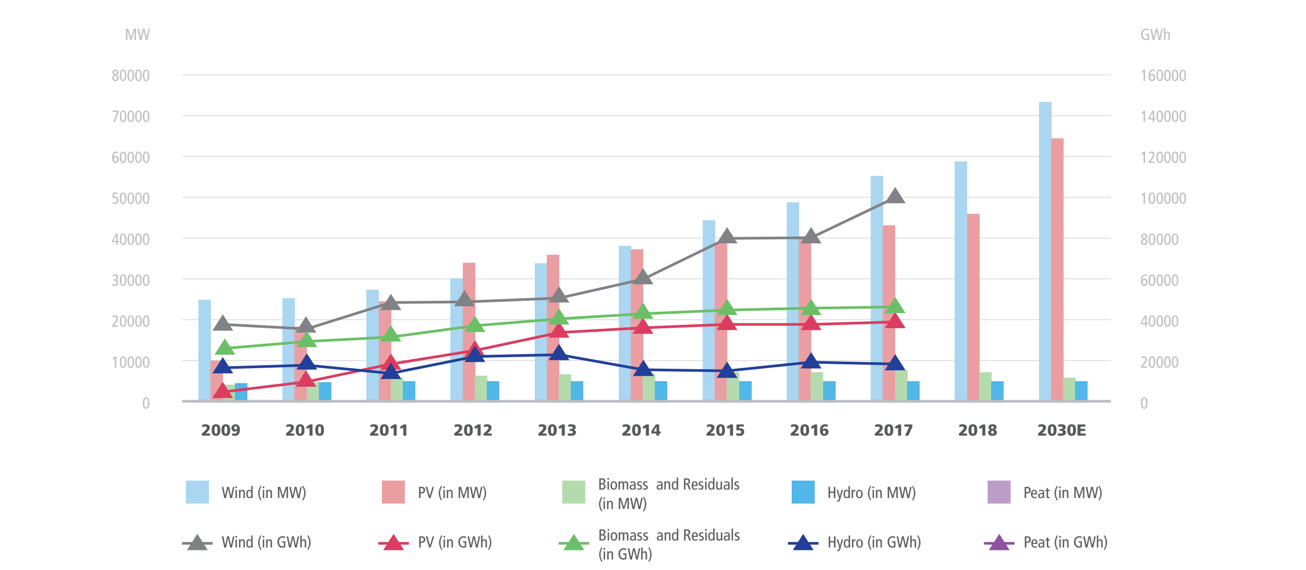



Figure 8-2. Trends on Renewable Energy Generation

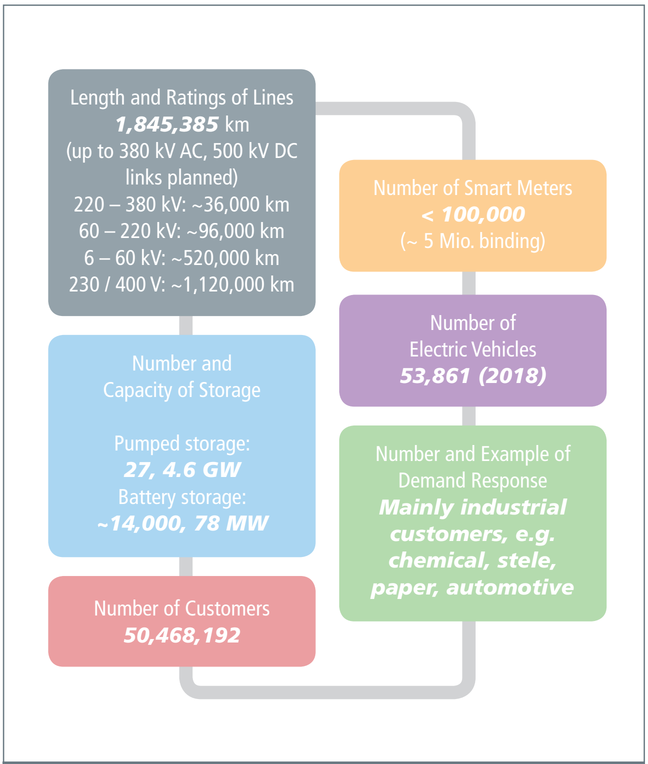



Figure 8-3. Key Smart Grids Facts and Figures by the End of 2018

## 8.3 National Programs in Fields of Smart Grids and Renewable Energy

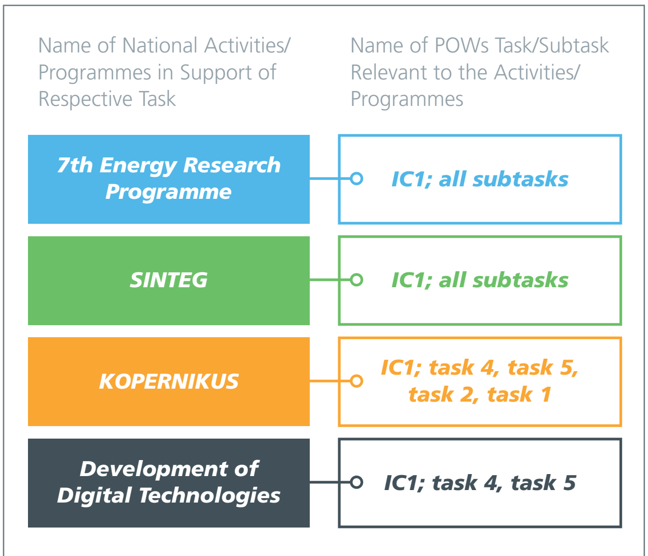



Figure 8-4

The Federal Government promotes research and development in the field of innovative energy technologies.

In September 2018, the Federal Cabinet adopted the 7th Energy Research Programme entitled "Innovations for the Energy Transition" [9].

The 7th Energy Research Programme supports companies and research / academic institutions in research, development and demonstration for innovative energy technologies. The Energy Research Programme is a strategic element of the Federal Government's energy policy to support a continuous research and innovation process.

The research programme defines the current funding priorities of the Federal Government as 'efficiency first'. Thus, project funding will focus on the efficient use of energy and the reduction of consumption. In addition, the aim will be to step up the integration of renewables, primarily in the buildings sector. Energy-efficient and low-carbon industrial processes and carbon recycling will play a key role in the industrial sector. The programme also addresses the transport sector by promoting modern energy technologies, such as batteries and fuel cells, the production of biogenic and synthetic fuels and the analysis of the repercussions of new mobility schemes on the energy sector.

Research funding in power generation will address the entire range of renewable energies and thermal power stations. Research work on electricity grids, energy storage and sector coupling will be assigned to the thematic cluster of system integration.

In addition the programme addresses intersystem research topics, comprising energy system analysis, energy-related aspects of digitisation, resource efficiency, $CO_2$ technologies, materials research and societal aspects of the energy transition.

Furthermore, the Federal Government sees expediting technology and innovation transfer as a prerequisite for the efficient, intersectoral implementation of the energy transition and an urgent task for energy research policy. This is why it is introducing "Living Labs for the Energy Transition" as a new programme pillar and will support the innovation process from the development to the commercialisation of technologies in an integral approach. The Federal Government will also make it easier for young enterprises with high innovation transfer ability and innovative power to benefit from the programme.

In the past, the first smart grid developments in Germany were funded in the national government initiative "E-energy - IT-based energy system of the future", which was announced in 2008.

This dedicated funding call, "E-energy", was declared to be a landmark project of the German government, and up to 2013 the government provided total subsidies of about 140 million euros for six pilot projects, in which the use of ICT in the energy sector was explored and tested. In addition, cross-sectional topics, such as the legal framework (including data protection) and standardization, were also studied.

The gained results and insight were continued in a follow-up programme "Smart Energy Showcases - Digital Agenda for the Energy Transition" (SINTEG). The new funding programme aims to develop and demonstrate in showcase regions new approaches to ensure reliable and secure grid operation with high shares of RES generation on the basis of wind and solar energy. The programme places a clear focus on building smart networks linking up the energy supply and demand sides, and on the use of innovative grid technology and operating strategies. It thus addresses key challenges of the energy transition including the integration of renewables into the system, flexibility, digitisation, system security, energy efficiency and the establishment of smart energy systems and market structures. The project makes an important contribution to moving forward the digital transformation and the energy transition.

The Federal Ministry for Economic Affairs and Energy is providing more than 200 M € in funding for five showcase regions. The projects seek to develop blueprints for a smart renewables-based electricity supply that can then be rolled out on a wider scale. The showcase regions are to pool knowledge, experience, undertake joint activities, and address the technical, economic and regulatory challenges posed by the energy transition over the coming decades and deliver model solutions which have been tried out in practice.

## 8.4 International Programme Related to Smart Grids and Renewable Energy

Successful innovation resulting from research and development is an important objective for the Federal Government for strengthening international competitiveness and securing jobs. Increased international cooperation can help considerably to achieve this goal. International cooperation supports the implementation and compliance of the European and global climate protection goals and the transformation of energy systems agreed upon e.g. within the framework of the Paris Climate Change Conference (COP21) in 2015, the UN Sustainable Development Goals (Goal 7: affordable and clean energy) and the G7 process. The Federal Government is emphasising its commitment through its wide-ranging international engagement. In addition to bilateral and multi-lateral initiatives focusing on different topics, it is first and foremost supporting cooperation at European level in the EU Framework Programme on Research and Innovation and its participation in funding initiatives of the International Energy Agency (IEA).

On the European level, Germany participates in strategic projects (key actions) on non-nuclear energy topics within the SET-Plan framework. For European and international cooperation, German project partners can also participate in network initiatives such as EUREKA/EUROGIA or COST. Moreover, within the framework of the ERA (European Research Area)-Net, topic-specific cooperation, coordination and joint calls for proposals between national funding organisations are also supported and coordinated on a European level.

Within the IEA Energy Technology Network, Germany currently participates in 22 of the 38 current Technology Collaborations Programmes and contributes its national expertise to the international exchange.

Within Mission Innovation, Germany has committed itself to double public investment in research and development for clean energies within five years. At the moment, Germany is engaged in 6 out of 8 Innovation Challenges, in particular co-leading IC5 (Converting Sunlight Innovation Challenge) and IC8 (Hydrogen). Germany commits its active contribution in IC1 to two tasks, task 1 (storage integration) and task 4 (flexibility options). However, all remaining tasks are also of high relevance for Germany, investigating further its further engagement. In any case, Germany will actively participate in the design of the individual tasks, foster the implementation of the PoW and participate in joint international activities within selected tasks.

## 8.5 Case Study

**PROJECT CASE #1**
**Proaktives Verteilnetz**

### Related Sub-challenge of IC1

Regional grid innovation, distribution grid innovation.

### Type of Project

Technology development, demonstration

### Topic

Smart market platform, flexibility options, enhanced grid control, ICT integration

### Objective

With the increasing application of DC high-voltage transmission, the number of photovoltaic power plants has increased rapidly. The integration of photovoltaic power into high-voltage DC grids will become an important form of grid connection for photovoltaic power generation in the future. Relying on the design and key technology research of photovoltaic comprehensive research demonstration base, the exploration and the overall solution of large-scale photovoltaic high-voltage DC grid connection technology is carried out. The development of 100-kilowatt DC grid-connected equipment will be directly converted into the DC power grid through the photovoltaic DC grid-connected converter for high-ratio boosting, which will provide technical support for the promotion and application of DC grid-connected technology of photovoltaic power plants in China.

### Period

May 2013- May 2015.

### Ongoing and Achieved Key Findings

The project developed a smart market platform for flexibility options in the distribution grid and integrated the required communication infrastructure and services in the grid operation (cf. Figure 8-5). The smart market concept bases on a flexibility traffic light idea, which describes the interaction between the market and the grid (cf. Figure 8-6). During regular operation, all services and products are traded through the platform without any restriction. In the case of congestion, the required flexibility services are traded as a priority, whereas in emergency situation the grid control is fully taken over by the DSO.

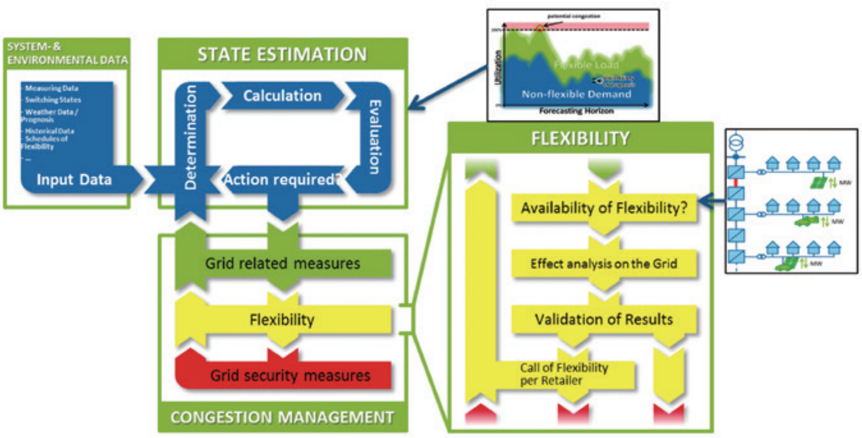



Figure 8-5. The Traffic Light Concept Enhances Current Grid Operation Concepts on Various Levels

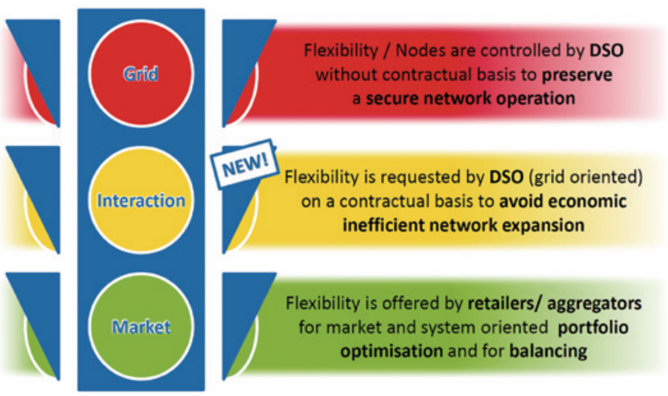



Figure 8-6. Interaction of Market & Grid - Traffic Light Concept Enables a Flexible Market Environment

### Contractors

Innogy SE, BTC AG, Venios GmbH, TU Dortmund, RWTH Aachen, OFFIS e.V.

### Period

Dec. 2014 – Apr. 2018.

### Ongoing and Achieved Key Findings

The project achieved and successfully demonstrated secure and non-discriminatory coordination of network and market players at regional level. The market is only minimally restricted and network stability is guaranteed by a suitable a customised communication and service platform. Concepts were developed, that use flexibility options for the distribution grid as well as rules for interactions between grid and the market. The performed field test brought numerous findings regarding the behaviour of decentralised generation and consumers with respect to their control behaviour for flexibility options. The determination of an individual, non-discriminatory power range per retail company is facilitating an optimal congestion management as each retailer is able to select suitable schedules of flexibility within his portfolio. E.g. the costs can be reduced by 80 % using market-based flexibility provision in comparison to the conventional grid expansion. Even in comparison with the regulated curtailment of RES, saving potentials up to 50 % are possible.

Added value of IC1 objective. The project provided a significant progress to scale up ratio of renewable energy in smart grids without exceeding investment costs.

## PROJECT CASE #2
## DC-Industry

### Related Sub-challenge of IC1

Micro grid innovation.

### Type of Project

Technology development, demonstration.

### Topic

DC micro grid, industrial grid, new DC grid architecture, enhanced protection and control architecture.

### Objective

DC-INDUSTRY aims at redesigning the power supply of industrial production facilities and factory halls via a smart, open and standardized DC micro grid and digitising the industrial power supply architecture. Here, new intelligent grid control is developed, storage is integrated to react flexibly and robustly to fluctuating power supply, and additional RES are integrated. Moreover, specific objectives consist of developing standardised interfaces, increasing the power density within the electrical drives and eliminating decentralized AC/DC conversion in the inverters.

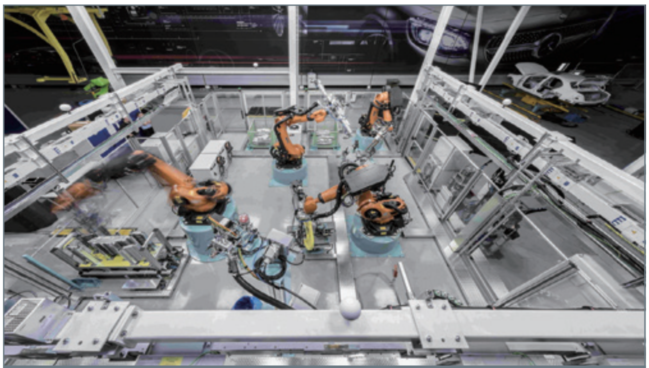


Figure 8-7. DC micro grid demo cell AREUS
(Automation and Robotics for European Sustainable Manufacturing)

Figure 8-8. DC micro grid demo cell AREUS
(Automation and Robotics for European Sustainable Manufacturing)

### Contractors

Siemens AG, Bosch Rexroth AG, Bauer Gear Motor GmbH, Baumüller Nürnberg GmbH, Danfoss GmbH, Lenze SE, LTI Motion GmbH, Daimler AG, KHS GmbH, Eaton Industries GmbH, Weidmüller Interface GmbH & Co. KG, Universität Stuttgart, Hochschule Ostwestfalen-Lippe, Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.

### Period

Jul 2016 – Jun 2019

### Ongoing and Achieved Key Findings

The project developed an open industrial DC grid system concept for a secure and reliable DC micro grid operation in industrial production and factory halls. With respect to grid management, a real time decentralised grid and power management concept for highly dynamic and efficient industrial DC micro grids was successfully defined. The concept was successfully validated in a multi-vendor industrial DC grid as demonstration plant (cf. Figure 8-7, Figure 8-8).

Added value of IC1 objective. Standardised concept for a DC grid in industrial production; new components, protections schemes and control techniques for DC micro grids; flexible production supports industry 4.0

## 8.6 Reference

[1] Federal Statistical Office. https://www.destatis.de/EN/. (2019)

[2] Fraunhofer Institute for Solar Energy Systems ISE. Energy Charts. [online] Available at: https://www.energy-charts.de/ [Accessed 13 Feb. 2019]. (2019)

[3] Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). Climate Action Plan 2050 – Germany's long-term emission development strategy. (2016)

[4] Federal Ministry for Economic Affairs and Energy (BMWi). Sixth "Energy Transition" Monitoring Report, The Energy of the Future, Reporting Year 2016 – Summary. (2018)

[5] Federal Ministry of Economics and Technology (BMWi), Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply. (2010)

[6] Bundesnetzagentur, Bundeskartellamt. Monitoringbericht 2018. (2018)

[7]Bundesnetzagentur. Genehmigung des Szenariorahmens 2019-2030, Szenario B 2030. (2018)

[8] Federal Ministry of Economics and Technology (BMWi). Energy Data: Complete Edition. https://www.bmwi.de/Redaktion/EN/Artikel/Energy/energy-data.html. (2018)

[9] Federal Ministry for Economic Affairs and Energy (BMWi). Innovations for the Energy Transition, 7th Energy Research Programme of the Federal Government. (2018)

### Figures

**Figure 8-1:** "Brandenburger Tor, Berlin"; https://www.flickr.com/photos/dangrothe/38841451751 by DanGrothe / CC BY 2.0

**Figure 8-5:** "The traffic light concept enhances current grid operation concepts on various levels" by innogy SE

**Figure 8-6:** "Interaction of Market & Grid - Traffic light concept enables a flexible market environment" by innogy SE

**Figure 8-7:** "DC micro grid demo cell AREUS (Automation and Robotics for European Sustainable Manufacturing)" copyright Siemens AG

**Figure 8-8:** "DC micro grid demo cell AREUS (Automation and Robotics for European Sustainable Manufacturing)" copyright Siemens AG


# 9.INDIA

## 9.1 General Framework and Implementation

India; a fast-developing economy is poised to advance at a high growth rate which will trigger a major escalation in energy demand because of demographic expansion, increasing urbanization and rising energy demands. After registering a GDP growth of over 7% for the third year in succession in 2016-17, Indian economy headed for somewhat slower growth, estimated to be 6.7% in 2017-18 while the world GDP growth was 3.8% during the year. The economy in its first estimates is expected to grow at 7.2% in 2018-19, a tad higher from the previous year growth. By the end of the 2018, India has a population of about 1.35 billion (estimated) and achieved a GDP of 2.948 trillion USD i.e. 2,134 USD per capita. With a total area of 3,287,263 km², average population density of India is 409 inhabitants per km² [1]. The Intended Nationally Determined Contribution (INDC), which is a part of the Paris Agreement (UNFCCC, 2015), will affect India's future energy and emissions scenarios. It has been speculated that by increasing the installed capacity of Renewable Energy Sources (RES) to 175GW by 2022, India will be able to surpass its INDC target of achieving 40% non-fossil capacity by 2022. With a 45% installed generation capacity from non-fossil sources by 2030, power sector emissions will consequently decline by 11% (375Mt$CO_2$).[2]

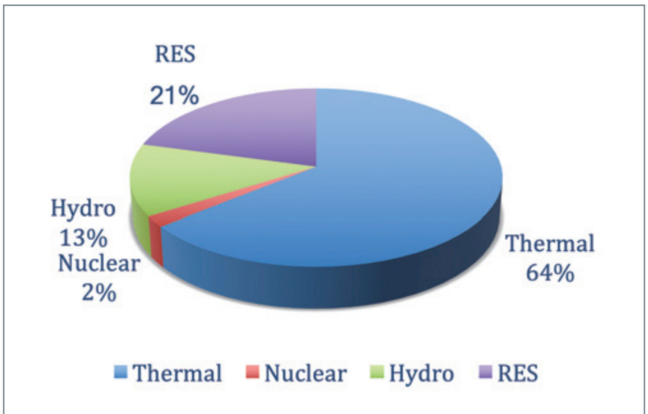



Figure 9-1. Total Installed Generation Mix as on 31-12-2018

India's power sector is one of the most diversified in the world, reconciling conventional sources (coal, lignite, natural gas, oil, hydro and nuclear power) and viable unconventional sources (wind, solar, agricultural and domestic waste). The total installed generation capacity in India by Dec 2018 is 349.288 GW. During the FY 2017-18, the per capita energy consumption was 1,148 KWh (units) and total generation from all the sources was 1303.37 Billion Units (BUs), wherein the share of renewable energy generated units is 101.83 BUs which is about 7.81% of total generated units. India's total energy consumption is projected to reach 18,635 TWh in 2047 from 6,078 TWh in 2017 due to significant growth in buildings, industry and transport sectors [3].

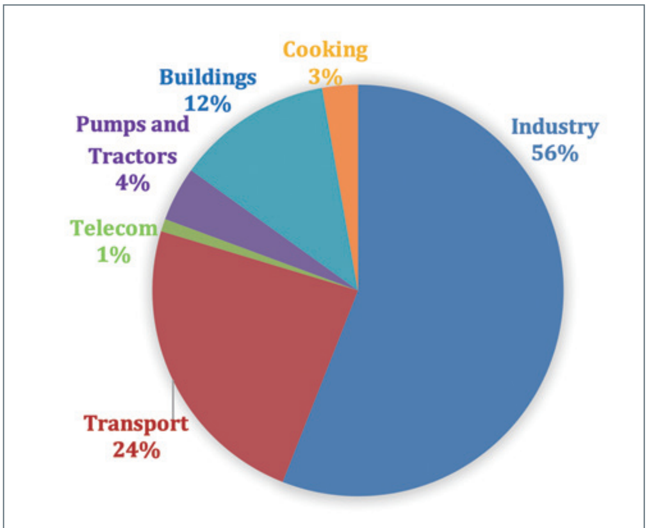



Figure 9-2. Energy Demand Distribution 2047 – 18635 TWh/yr

In India, electricity is a concurrent subject where the Central Government frames overall regulations and each state government frame their policies within that regulatory framework. There are distinct utilities owning generation, transmission and distribution. Ministry of Power (MoP), Government of India (GoI) deals with perspective planning, policy formulation, processing of projects for investment decisions, monitoring and implementation of power projects, training & manpower development, administration & enactment of legislation in regard to the power generation, transmission and distribution. Central Electricity Authority (CEA) of India advises the government on matters relating to the National Electricity Policy (NEP) and formulates short-term and vision-plans for the development of electricity systems. Central Electricity Regulation Commission (CERC) and State Electricity Regulation Commission (SERC) regulate tariff, formulate policies regarding subsidies, promote efficient and environmental benign policies at central and state level respectively. Central Transmission Utility (CTU) and State Transmission Utility (STU) ensure development of an efficient, coordinated and economical system of inter-state and intra-state transmission systems respectively. The central transmission utility of GoI, Power Grid Corporation of India Ltd (PGCIL) is responsible for national and regional power transmission planning, while the state sectors have their distinct state transmission utilities. Private sector participation is increasing in generation, distribution sectors following the ***Electricity Act 2003***, allowing increased competition.

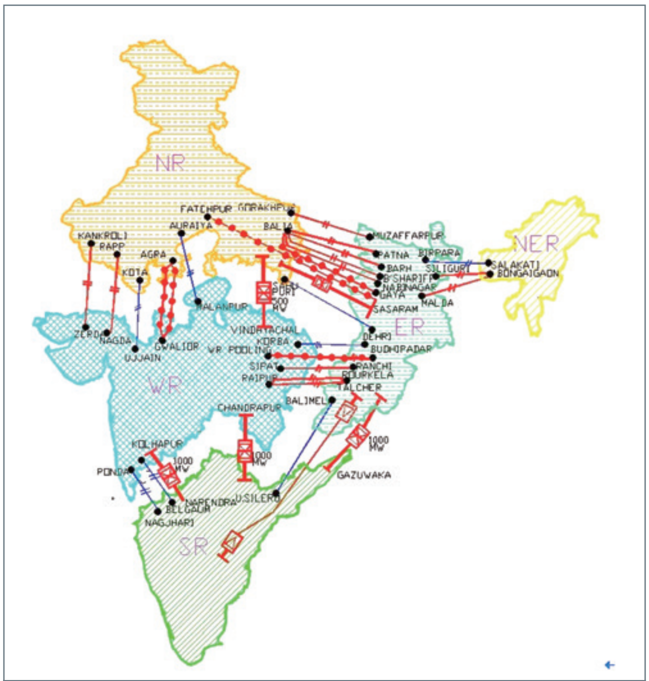



Figure 9-3. Interconnection of Five Indian Regional Grids

India is truculent towards 'one nation, one grid' policy, as individual state grids were interconnected to form 5 regional grids covering mainland of India. The five regional grids are known as Northern Region (NR), Eastern Region (ER), Western Region (WR), North-Eastern Region (NER) and Southern Region (SR). On 31st December 2013, southern regional grid was connected to central grid in synchronous mode thereby achieving: one nation-one grid-one frequency. The inter-regional length of transmission lines by the end of year 2018 is 94,850 Ckms. Moreover, India emerged as a net exporter of electricity with 7203 Million Units (MUs) supplied to Nepal, Bangladesh and Myanmar in the fiscal year 2017-18 and 4628 MUs till date. The total AT&C losses reduced from 20.7% in FY 2015-16 to 18.7% in the FY 2017-18 with the target of reducing it down to 15% in 2018-2019. The tremendous pace in modernization of the generation & transmission have strengthened the Indian power grid to meet the peak demand of 176 GW in 2018. The Indian power sector is undergoing a gradual transition from a fossil fuel centric approach to an energy efficient and renewable centric approach in an indeed impressive way. The GoI has been placing significant emphasis on aspects such as: electrification of villages; power for all round-the-clock around the country.

## 9.2 Status of Renewable Energy and Smart Grids

With the cumulative installed renewable energy capacity of 74.08 GW by the end of 2018, India holds 5th position in global ranking for installed renewable generation capacity. Solar and wind generations are the key renewable resources in India along with a small share of small hydro and bio-power.

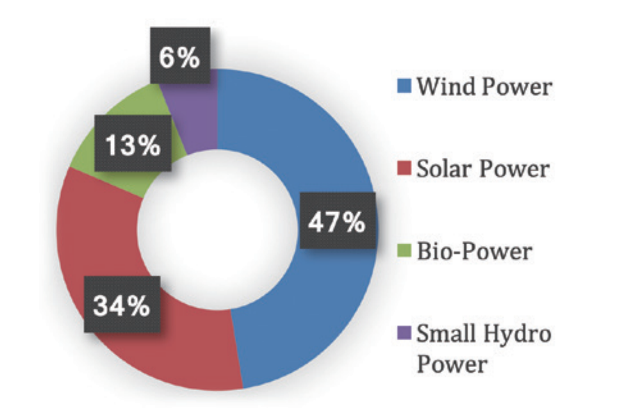



Figure 9-4. Renewable Energy Generation Mix as on 31-12-2018

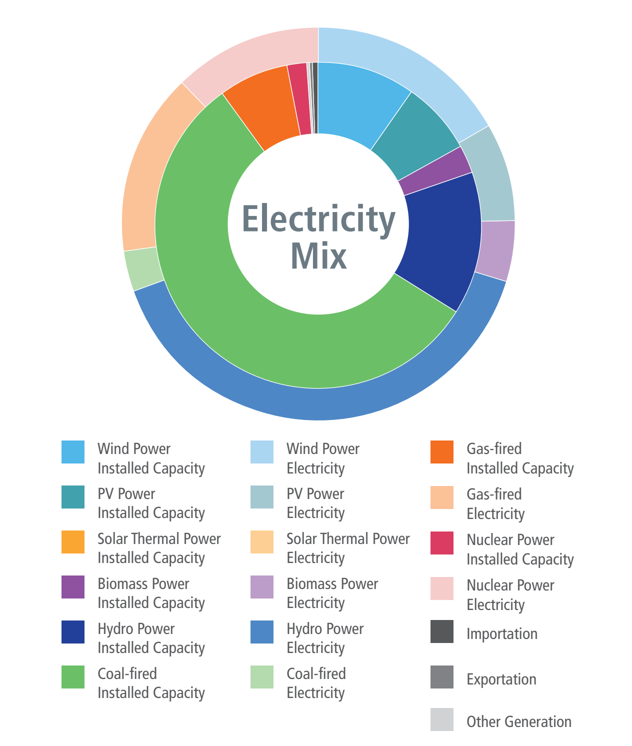



Figure 9-5. Electricity Mix by the End of 2018

India's geographical location offers it plenty of opportunity to plan for new solar power plants to enhance its renewable generation capability. India has 25.212 GW of installed solar generation capacity by Dec. 2018 from 47 solar parks scattered in 21 states. Under the National Solar Mission, Government of India planned to enhance this installation up to 100 GW by 2021-22 which includes 40 GW of rooftop solar panels in residential and commercial buildings [4]. India is blessed with 4,671 miles of coastline which provide a potential of approximately 35.14 GW of wind power generation installation at the end of 2018. Ministry of New and Renewable Energy (MNRE), Govt. of India has announced medium- and long-term goals in order to add approximately 5 GW of offshore wind power capacity by 2022 and 30 GW by 2030. Introductory observations have recommended good wind generation potential for offshore wind power both in the southern and western coastal areas in India. National Off-Shore Wind Policy was notified in October 2015 to support and accelerate the development of offshore wind facilities. India is also encouraging the idea of bio-power by generating energy of total 9.075 GW from biomass and cogeneration power plants by Dec. 2018. Approximately 138.3 MW of energy is generated by processing the agricultural, industrial and other waste materials.

**Market Mechanism and Reforms**

Indian Energy market constitutes of two power exchanges namely Indian Energy Exchange Ltd. (IEX) and Power Exchange India Ltd. (PXIL). PXIL and IEX are approved and regulated by CERC and has been operating since 27 June, 2008. The participants include 55 distribution companies, over 450 electricity generators, over 3,900 open-access consumers and 1,050 renewable energy generators and approximately 4.0% of generated power is transacted on Power Exchange in India. A total of 46,215 MUs were traded in the electricity segment of IEX, an increase of 14% over the last year trade volume of 40,528 MUs. The electricity market trading rules in India are designed over scheduling & dispatch, imbalances, congestion management and ancillary services. As smaller settlement period helps in handling the variable generation from sources, India has introduced 15-minute power bidding at power exchanges (instead of hourly bidding) w.e.f. 1st April, 2012. After amendments of forecasting, scheduling and incentivizing flexibility to Indian Electricity Grid Code (IEGC) 2010 deviation handling mechanism was introduced by CERC in 2014 to handle the imbalances in market. Ancillary services operations were launched in 2016 and it utilizes un-dispatched surplus regulated generating stations all over India. The energy exchange deals in day ahead market (DAM), Term Ahead Market (TAM) and certificate market such as Renewable Energy Certificates (REC) and Energy Saving Certificates (EScert). The disparity in prices of power purchase among regions is thinning which is evident from dynamic exchange prices in 2018. The non-discriminatory open access at inter-state level has been enabled through robust and vibrant electricity market with about 50,000 transactions totaling to over 105 BUs in short term market volumes. The competitive bidding in wind and solar power achieved lowest tariffs of Rs. 2.44/KWh in 2017 [4]. The exchange reported 93.29 Lakh REC certificates traded in 2017-18, an increase of 102% from 46.19 Lakh REC certificates traded in 2016-17. The Company commenced trading of ESCerts on September 26, 2017 and traded 12.99 Lakh energy saving certificates in 2017-18.

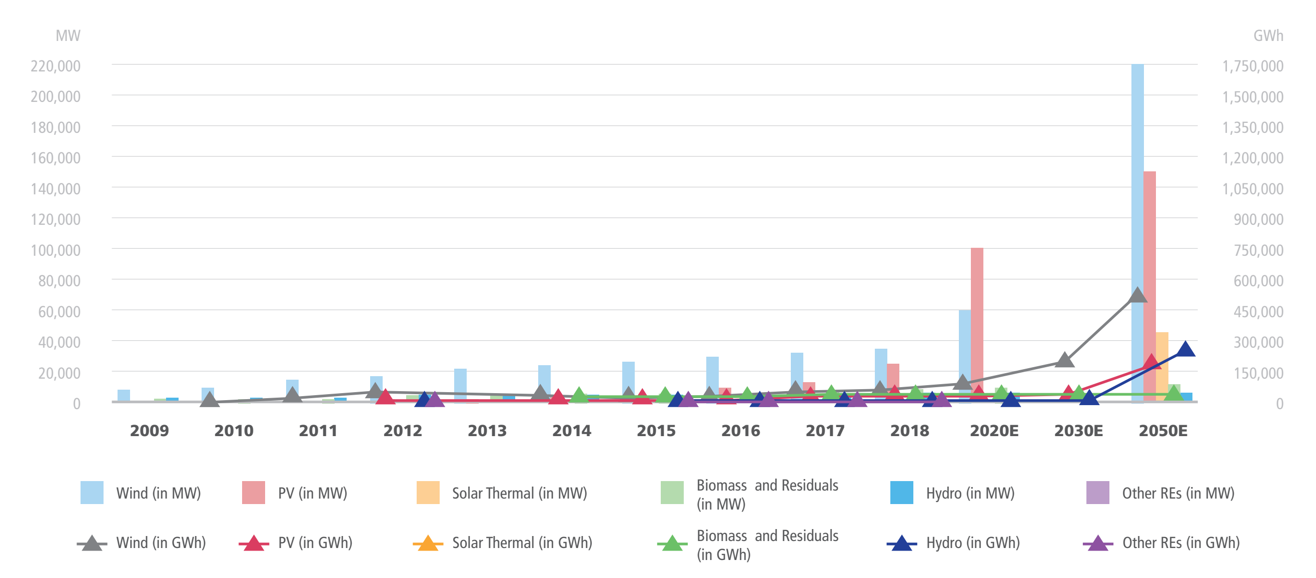



Figure 9-6. Trends on Renewable Energy Generation

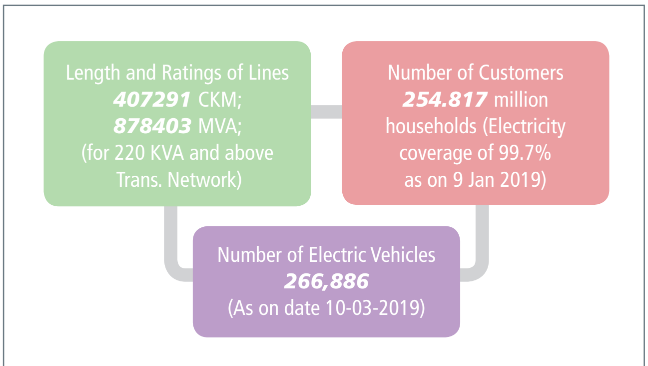



Figure 9-7. Key Smart Grids Facts and Figures by the End of 2018

## 9.3 National Programs in Fields of Smart Grids and Renewable Energy

India is undergoing the largest renewable energy capacity expansion programme in the world. The National Energy Policy (NEP) defines a trajectory to meet the government's goal to electrify every village of the country and provide uninterruptable power to everyone by 2022. Ministry of Power (MoP), Ministry of New and Renewable Energy (MNRE), Ministry of Science & Technology (MST) and Ministry of Housing and Urban Affairs (MoHUA) and their extended departments are directly involved in research, development and deployment of advanced technologies to fructify the dream of clean energy. The government is actively promoting adoption of renewable energy (RE) by offering various incentives such as Generation Based Incentives (GBIs), capital interest subsidies, viability gap funding, fiscal incentives etc. The National Solar Mission, National Wind Mission, National Electric Mobility Mission and Smart City Mission are prioritized for carrying out RD&D objectives to transform the power sector in India.

Recently, Government of India has taken several ground breaking initiatives such as electric grid modernization, building 100 smart cities and rejuvenating 500 old towns, introducing electric vehicles and bullet trains on fast track.

Some of the key initiatives taken for grid modernization are as follows –

**National Electricity Policy (NEP)**

The NITI Aayog proposed a draft of the National Energy Policy (NEP) with four key objectives: access at affordable prices, improved security and independence, greater sustainability and economic growth. The NEP proposes actions to meet the objectives in such a way that India's economy is 'energy-ready' by 2040.

**Pradhan Mantri Sahaj Bijli Har Ghar Yojana (SAUBHAGYA)**

The Saubhagya scheme was launched on 25th September 2017 to provide free electricity connections to all households (both Above Poverty Line and Below Poverty Line families) in rural areas and economically-disadvantaged families in urban areas. India has ~4 Crores un-electrified households and the Central Government has targeted to provide them electricity connections by December 2018. The Rural Electrification Corporation (REC) has been designated as the nodal agency for the Saubhagya scheme.

**National Smart Grid Mission**

Ministry of Power, Government of India, established National Smart Grid Mission (NSGM) to plan and monitor the implementation of policies and programs related to Smart Grid activities in India. NSGM is also coordinating for development of smart Grids in the smart cities under Smart Cities Mission. This promotes deployment of Smart Grid technologies like Advanced Metering Infrastructure (AMI), Substation Renovation and Modernization with deployment of Gas Insulated Substations (GIS) wherever economically feasible and grid integration of Distributed Generation in the form of Rooftop Solar PVs, Real-time monitoring and control of Distribution Transformers, Creation of Electrical Vehicle (EV) charging Infrastructure for supporting proliferation of EVs, Development of medium sized Micro-grids and provision of power quality improvement measures. Smart grid demonstration/pilot projects were sanctioned by Ministry of Power with 50% Government of India grant amounting to US$ 29.56 million and 100% funding for Smart Grid Knowledge Centre for managing research and innovation activities in 2012. Subsequently, four Smart Grid projects were also sanctioned in 2016 with 30% funding from the Ministry of Power. NSGM and Ministry of Power jointly sanctioned smart grids demonstration/pilot projects presented in Annexure-I.

**National Solar Mission and National Wind Energy Mission**

Under National Solar Mission, the target for setting up solar capacity increased from 20 GW to 100 GW by 2021-22. As on Dec, 2018 it had achieved 25.21 GW of installed solar power. Capacity of the scheme for development of solar parks and ultra-mega solar power projects has been enhanced from 20,000 MW to 40,000 MW. Seven solar parks with aggregate capacity of 26,694 MW have been approved up to November, 2018. The National Offshore Wind Energy Policy promotes deployment of offshore wind farms up to 12 nautical miles from coast. For this it had already conducted light detection and ranging (LiDAR) based offshore wind profile measurement at Gulf of Khambat, Gujrat for gathering wind resource data. On May 14th, 2018 MNRE identified the complementary nature of wind and solar energy and issued National Wind-Solar hybrid policy which provides framework for promotion of large scale grid connected wind-PV hybrid system for efficient utilization of transmission infrastructure and land. This initiative aims to achieve a hybrid wind-solar capacity of 10GW by 2022 to address renewable variability and optimal utilization of existing infrastructure.

**Smart Cities Mission**

The Smart Cities Mission is an innovative and new initiative by the Government of India to drive economic growth and improve the quality of life of people by enabling local development and harnessing technology as a means to create smart outcomes for citizens. The Mission will cover 100 cities and its duration will be five years (FY2015-16 to FY2019-20).

**Green Energy Corridor**

The integration of this planned RE generation capacity with the national grid requires expansion and modernization of the intrastate and interstate distribution as well as transmission grid. This is mainly due to the geographical distance between centers of generation and consumption as well as due to the intermittent availability of RE sources and the necessary means for grid stabilization. The requirements for efficient transport of power and strengthening of the grid has been identified in the comprehensive transmission plan called "Green Energy Corridors" prepared by PGCIL. Intra-state transmission green corridors are being implemented by eight renewable-rich States (Tamil Nadu, Rajasthan, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Himachal Pradesh, and Madhya Pradesh) with a total project cost of Rs. 10,141 crores. Seven Renewable Energy Management Centers (REMC) are proposed to work in tandem with the regional load dispatch centers and national load dispatch centers.

**National Electric Mobility Mission Plan (NEMMP)**

The NEMMP is the national mission providing vision and the roadmap for the faster adoption of xEVs (full range of hybrid and electric vehicles) and their manufacturing in the country. As a part of the National Electric Mobility Mission Plan, Department of Heavy Industries launched a scheme titled “FAME-India: Faster Adoption and manufacturing of hybrid and electrical vehicles in India”. The main aim of the scheme is to develop and support hybrid & electrical vehicles market and manufacturing eco-system till 2020 for the heavy pollution prone locations ex: major metro agglomerations, capital cities, smart cities initiatives and cities of north-east states. Technology development, demand creation, pilot projects and charging infrastructure are the main concerns with a total fund allocation of 795 crore INR. The phase 1 of the scheme started from 13th March 2015 to March 31st 2019. A total of 2,67,000 vehicles were sold and 320.5 crore INR awarded as incentives till date. FAME India Phase II scheme will be launched with total outlay of INR 10,000 crores over the period of three years that will be implemented w.e.f. 1st April 2019.

**National Storage Mission**

The key areas for energy storage application include:

- Integrating renewable energy with distribution and transmission grids;
- Setting rural microgrids with diversified loads or stand-alone systems; and
- Developing a storage component of electric mobility plans.

In line with its aspiration to achieve 100 percent electric vehicle

(EV) sales by 2030, India can rise among the top countries in the world in manufacturing batteries. India's market for EV batteries alone could be worth as much as $300 billion from 2017 to 2030. Meeting India's EV ambitions through 100 percent domestic manufacturing of batteries would require at least 3,500 GWh of batteries at a wholesale cost of $300 billion (INR 20 lakh crore) from 2017–2030—less than half the cost of the avoided oil imports. Since the battery today accounts for about one-third of the total purchase price of an EV, driving down battery costs through rapidly scaling production and standardizing battery components could be a key element of long-term success for India's automotive sector.

**Other Initiatives**

The Central Electricity Regulatory Commission (CERC) proposed several new initiatives such as draft regulations for transmission planning, connectivity & general network access, constituted task force to review framework of sharing of interstate transmission charges and losses and a report from the committee outlining CERC-recommended linking of deviation settlement rates with prices determined in day-ahead market of power exchanges. Besides these initiatives, the Central Electricity Regulatory Commission also notified amendments in its IEGC Regulations 2010 and sharing of inter-state charges and losses regulations to waive off interstate transmission charges for solar and wind projects. The Central Electricity Authority (CEA) issued a draft of Conduct of Business Rules for facilitating cross-border transactions and trade in electricity as per Ministry of Power, Government of India's Guidelines on Cross Border Trade of Electricity.

**National Smart Grid R&D Activities in Line with Program of Works (POWs) Tasks and Sub Tasks-**

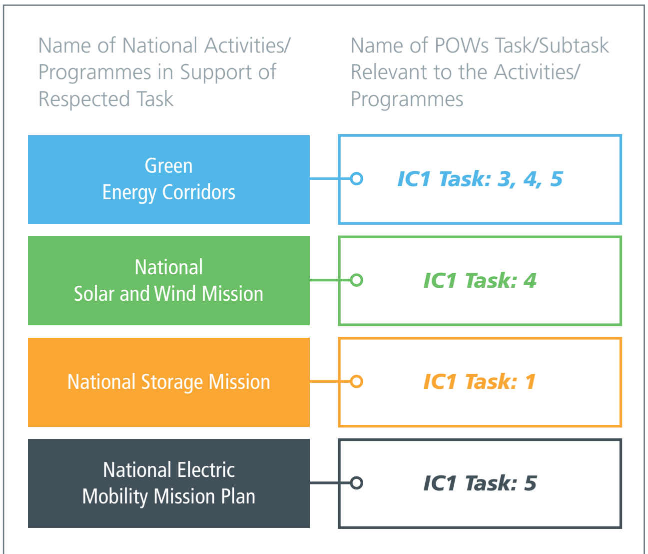



Figure 9-8

## 9.4 International Programme Related to Smart Grids and Renewable Energy

The Smart Grids challenge captured global attention in recent years and stance as a viable solution towards global climate change and energy crisis. This global challenge necessitates a transnational and trans-institutional determination. India has demonstrated its commitment to Mission Innovation in general and innovation challenge on Smart Grids in particular through several actions. India has made an investment of around 70 million USD in research activity on Smart Grids since the inception of Mission Innovation in 2015. These research activities include an Indo-US Joint Clean Energy Research and Development Centre (JCERDC) initiative UI-ASSIST, three Joint Virtual Clean Energy Centres (JVCEC) and nine research programmes partnering with 9 MI countries on smart grids. These research activities collectively brought 32 eminent national institutions, 37 international institutions, and 33 government and private industries under one platform to address the challenges in smart grids through cutting-edge technologies.

**UI-ASSIST: US-India collAborative for smart diStribution System wIth Storage:** The consortium is conducting collaborative research activities that will accommodate high penetration of renewable energy into our power system. Increasing adoption of Distributed Energy Resources (DER), i.e. renewable generation, storage, and demand response, poses numerous challenges to the operation of existing power system. To develop technical solutions and maintain the reliability and efficiency of the future grid with high DER penetration, this project is promoting workforce development and policy recommendations specifically relevant to US and Indian contexts.

**The India-UK collaborative research Programs:** India and UK aim to mitigate their carbon emissions and promote electrification at large scale, where the systems likely face large energy deficits. Five Smart Energy Grids and Energy Storage (SEGES) projects supported jointly by India & UK were launched. This initiative synergizes the efforts and learning of researchers from two countries to address bottlenecks such as communication infrastructure upgradation, intermittent and low inertial renewable power integration, blackouts due to peak energy demand, optimal integration of storage to the grid and designing of distribution networks for rural, urban as well as islanded communities in India and UK. The collaboration further elevated to next level with establishment of new consortiums which are Joint UK-India Clean Energy Centre (JUICE) located in UK, India-UK Centre for Education and Research in Clean Energy (IUCERCE) and the India-UK

Clean Energy Research Centre (UKICERI) in India supported DST and Research Council UK.

**Mission Innovation IC1 Projects:** India being a co-lead in IC1 launched 9 smart grids R&D projects under the umbrella of Mission Innovation in collaboration with the nine MI IC1 member countries by investing 5 million USD to financially support activities towards research, development and deployment. Figure 9-9 presents nine DST funded MI IC1 projects are mentioned. Details of nine MI IC1 member countries collaboration is given in Annexure-II.

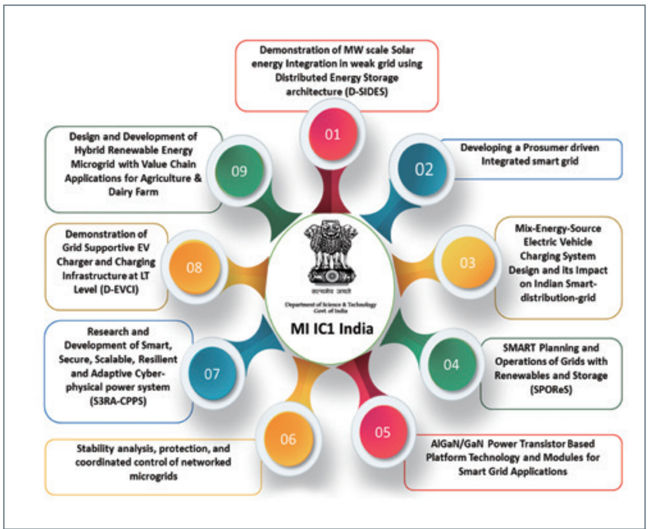



Figure 9-9. MI IC1 Projects

Besides the above-mentioned collaborations, recently India and Denmark launched a joint call for project proposal with a view to further develop and strengthen the Danish-Indian research cooperation in the areas of renewable energy. The main objective of the agreement is the development and integration of renewable energy-based solutions and energy efficiency in electricity and heating systems exploiting evolutionary algorithms. In this collaborative approach, successful projects will be funded in Denmark by IFD and in India by DST. Also, India has collaborated with Germany to establish green energy corridors to export the generated renewable power through long distances to energy demand centres. The main objective of this programme component is to improve the transmission sector framework and conditions for grid integration of renewable energies. Seven Renewable Energy Management Centres (REMCs) in renewable energy-rich states, three regional REMCs and one REMC on the national level have been conceptualized as nodal institutions for addressing operational issues on RE grid integration and will be operational in 2019.

## 9.5 Case Studies

**PROJECT CASE #1**
**Grid-Scale Energy Storage System**

### Related Sub-challenge of IC1

Distribution grid innovation

### Type of Project

Technology development, demonstration, and commercialization.

### Topic

Grid-scale energy storage, ancillary market services, effective renewable integration, power quality management, peak load management, system flexibility, grid stabilization.

### Objective

The main objective of this project is to provide grid stabilization, enhanced peak load management, added system flexibility, increased reliability for 2 million consumers.

### Contractors

The AES Corporation, Mitsubishi Corporation and TATA Power.

### Period

Inaugurated on 13 Feb 2019.

### Ongoing and Achieved Key Findings

Battery-based energy storage system enables electricity to be stored and then delivered within milliseconds, reducing instability of the electric grid and enabling more energy to be captured and delivered on demand. Further, Battery-based energy storage provides the flexibility and agility to better integrate intermittent solar and wind energy resources into India's electric grid and ensure high-quality power for consumers. Fast-ramping energy storage system provides critical flexibility to the India's grid at any point of time. This is India's first grid-scale battery-based storage system, which will address key challenges such as peak load management, system flexibility, frequency regulation and reliability of the network.

Figure 9-10. Grid-Scale Energy Storage Systems

Figure 9-11. 10 MWh Battery Storage Bank

## PROJECT CASE #2
## Smart Grid Pilot Project in Chamundeshwari Electricity Supply Corporation (CESC), Mysore

### Related Sub-challenge of IC1
Distribution grid innovation

### Type of Project
Public-Private Partnership model

### Topic
Load Curtailment, peak load management, Renewable integration, Load Forecasting/Modelling Outage Monitoring, system flexibility.

### Objective
CESC Mysore is committed towards ensuring reliable and good quality of power supply to 21,824 consumers with a good mix of residential, commercial, industrial and agricultural consumers including 512 irrigation pump sets covering over 14 feeders and 473 distribution transformers and accounting for input energy of 151.89 MU including functionality like Agriculture Demand Side Management (DSM) with community portal, consumer portal to support DSM, employee portal for knowledge sharing and benefit realization.

### Contractors
ENZEN

### Period
30-04-2014 to 20-06-2019.

### Ongoing and Achieved Key Findings
In this project total of 1813 three-phase smart meters and 19487 single-phase smart meters are installed in which 1540 and 17186 smart meters respectively are communicating. A total of 650 distribution control units are installed and communicating. 441 TMU's are installed in which 339 TMU's are communicating. The complete project is deployed successfully and working satisfactorily.

Figure 9-12. SG Control Centre (Servers) at Mysore

Figure 9-13. Communicable FPI Installations at Mysore

## PROJECT CASE #3
## SMART GRID PILOT PROJECT AT PUDUCHERRY

### Related Sub-challenge of IC1
Smart grid Implementation, Smart city development

### Type of Project
Technology deployment, commercialization.

### Topic
Advance Metering Infrastructure (AMI), outage management system, Power Quality Management (PQM), electrical vehicle charging with solar charging station.

### Objective
Deployment of smart grid with AMI, demand response, outage-management etc.

### Contractors
PGCIL

### Period
NA

### Ongoing and Achieved Key Findings
The project is a part of smart city development with AMIs of 1,650 smart meters and 32 data collector units installed which covers 9 Distribution Transformers (DT) with 9 Distribution

Transformer Monitoring Systems to monitor the healthiness of the DTs. 21 fault indicators (communicable/ non-communicable) are installed which receives alerts at smart grid control centre. The novelty includes automatic ON-OFF and intensity control of the street lightings on desired luminance and pre-determined traffic conditions. 126 lamps were implemented in smart street lighting program with energy savings of about 57%. The efficiency of metering is increased by 14% with smart meter installation that enables easy online energy audit and outage data monitoring. Grid-scale battery energy storage systems of different technologies ex: advanced lead-acid and lithium iron phosphate with 250kWh each have been connected to 22kV grid system through 2 MVA transformer.


Figure 9-14. Installation of PQM, RE integration, Electrical vehicle at Puducherry

Figure 9-15.Grid scale Battery Energy Storage System at Puducherry

## PROJECT CASE #4
## Digitalization of Substation

### Related Sub-challenge of IC1

Distribution grid innovation, digitalization of substation.

### Type of Project

Innovation, technology deployment and demonstration.

### Topic

Digitalization, fibre optic cabling communication, substation, information and operational technologies.

### Objective

Digitalization of substation using various components to understand the practical problems in control and assessment.

### Contractors

ABB

### Period

January 2018

### Ongoing and Achieved Key Findings

The first practical 110 KV digital substation of India is installed at Kerala. The key features of the substation involve integration of information and operational technologies (IT and OT), digital communication with fibre optics. The features enable the importance of power management efficiencies by turning real-time data into actionable intelligence and cost efficiencies. It comprises of IEC 61850 standards ensuring open communication architecture. The practice of Intelligent technologies will improve flexibility, availability, reliability and safety with reducing installation costs and environmental impact. The usage of optic cabling communication instead of conventional copper cables enables optimized panel design and less civil work. This substation covers the techno-park, consisting of 350 companies employing more than 50,000 people which needs continuous, reliable and round the clock power.

Figure 9-16. Techno Park – Digital Substation

**PROJECT CASE #5**
**Energy Optimization Using Microgrid Maneja Plant**

### Related Sub-challenge of IC1
Microgrid optimization

### Type of Project
Technology deployment and demonstration

### Topic
Renewable generation, battery storage, microgrid.

### Objective
To reduce the dependency on the grid, by integrating renewable generation to cater the increased demand especially during cloudy conditions. Avoiding any eventuality on account of renewable sources variation, Microgrid will aid to perform safe islanding, frequency regulation, spinning reserve to take DG Offline, load levelling and peak shifting.

### Contractors
ABB India

### Period
2018

### Ongoing and Achieved Key Findings
The first industrial microgrid with distributed control system and battery storage in the country with 400,000 sq. Meters at and shop floors. It consists of total 1.2MW is the solar capacity of the microgrid, and 1MWH is stored in the battery and used during evening and non –solar hours. These solar panels are installed on 8 buildings in the facility and will soon cover two more warehouses. The panels cover an area of almost 14,000 sq meters. The peak demand at the facility is 5,168 kW. The battery charger/inverter and battery sizing has been considered accounting for 50-60% of future capacity expansion at the manufacturing facility by 20%. It reduces carbon footprint by lowering $CO_2$ emissions by approx. 1,400 tons per year.


Figure 9-17. Rooftop solar park

Figure 9-18. Energy Storage System

**PROJECT CASE #6**
**Faster Adoption of Electric Vehicle technology in Delhi**

### Related Sub-challenge of IC1
Distribution grid innovation, cross innovation

### Type of Project
Utility Anchored E-Mobility Programme

### Topic
Electric vehicles, electric vehicle charging stations

### Objective
Gaining Experience of E-Mobility both for corporate use as well as public at large, to facilitate large scale rollout of E mobility program in Delhi.

### Contractors
EVIT, EXICOM, Zoom Car, Mahindra, Gensol, Sanya Cab.

### Period
FY 18-19 onwards

### Ongoing and Achieved Key Findings
1. Electric Vehicles – Total 9 Electric Vehicle inducted in the corporate fleet
   a) 8 No. Passenger Cars (e20 & eVerito) successfully operating since October 2018
   b) 1 No. Cargo Van (eSupro) successfully inducted since March 2019
1. Electric Vehicle Charging Infra – Total 5 Electric Chargers installed
   a) 2 No. Bharat EV DC Charger (BEVC-DC001) successfully operating since October 2018
   b) 3 No. Bharat EV AC Charger (BEVC-AC001) successfully operating since October 2018

Figure 9-19. BSES Electric Fleet

Figure 9-20. Bharat EV DC (BEVC-DC001) & AC (BEVC AC001) Charger

### PROJECT CASE #7
### Smart Grid Pilot Project in Tripura State Electricity Corporation Ltd. (TSECL), Tripura

**Related Sub-challenge of IC1**

Distribution grid innovation

**Type of Project**

Technology development, demonstration

**Topic**

AMI, Load Curtailment, peak load management

**Objective**

The TSECL, Tripura is committed to ensure reliable and good quality of power supply to its customers at competitive prices by adapting new technologies and advance management strategies for its operation, control and maintenance.

**Contractors**

Consortium of M/s Wipro and M/s JnJ Powercom

**Period**

30-09-2015 to 31-03-2019.

**Ongoing and Achieved Key Findings**

Smart Grid pilot project was put under commercial operation from 14-01-2019. In this project total 45290 (both single phase & three phase) smart meters are supplied of which 40,569 were installed. Total 280 Data Concentrator Units (DCU)/ Gateways are installed. The uniqueness of this project is that Power Line Carrier (PLC) communication has been chosen for the pilot project. The overall data availability is above 95%. The results of this project in terms of data availability and accuracy are commendable. The complete project deployed is being used by TSECL, Tripura and is working efficiently. Key benefits include increase in consumer satisfaction by accurate billing, reduction in losses, better revenue realization, consumer portal, SMS facilitation etc. In near future TSECL, Tripura is planning to implement ToU Tariff and Pre-paid functionality subject to approval from Tripura State Electricity Regulatory Commission.

Figure 9-21. AMI Installed in the Distribution System

### PROJECT CASE #8
### Smart City Pilot Project at IIT Kanpur Campus

**Related Sub-challenge of IC1**

Distribution grid innovation

**Type of Project**

Technology development, demonstration

**Topic**

AMI, Load Curtailment, peak load management, Renewable integration, Load Forecasting/Modelling, Outage Management, system, flexibility, Home automation, Grid tie Inverter, battery energy storage systems

**Objective**

Main objective of the project was to develop and implement key solutions and identify the associated challenges in implementing smart distribution system technology in Indian cities. The findings and experiences from this project will work as guidelines for smart city projects in India.

**Contractors**

Various- M/s Mindtek, M/s Sumeru Verde

**Period**

Various- M/s Mindtek, M/s Sumeru Verde

### Ongoing and Achieved Key Findings

Smart City pilot project completed on 31-03-2018. In this project total 20 households inside the IIT Kanpur Campus was chosen for implementation of Smart City functionalities. The overall communication performance is above 99%. Immediate impacts of the project will be to develop test cases for more efficient operation and control of distribution systems, savings in electricity bills, reduction in peak demand of the utilities, improvement in overall reliability of the network, and enhanced situational awareness at the control centre. The prototype in IITK will act as a test-bed for smart-city related research, development, and training activities for industries, research institutes, and academicians.


Figure 9-22. Deployment of Smart Grid Pilot Project at IIT Kanpur

Figure 9-23. Monitoring and Control System at IIT Kanpur's Smart City Pilot project.

## 9.6 Resources


[1] "World Population Prospects - Population Division - United Nations." [Online]. Available: https://population.un.org/wpp/DataQuery/.

[2] S. Thambi, A. Bhatacharya, and O. Fricko, "India's Energy and Emissions Outlook: Results from India Energy Model."

[3] "growth of electricity sector in india from 1947-2018 central electricity authority, ministry of power, government of india, new delhi."

[4] "Welcome to Government of India | Ministry of New and Renewable Energy." [Online]. Available: https://mnre.gov.in/.

- https://npp.gov.in/installedCapacityReports
- http://www.cea.nic.in/reports/monthly/renewable/2017/renewable-12.pdf
- http://erpc.gov.in/wp-content/uploads/2018/06/carbon-emissions-from-power-sector-7062018.pdf
- http://www.cea.nic.in/reports/annual/generationreview/gen_target-2018.pdf
- https://mnre.gov.in/sites/default/files/uploads/renewable_energy.pdf
- "Growth of Electricity Sector in India from 1947-2017" (PDF). CEA. Retrieved 17 February 2018.
- "Overview of renewable power generation, CEA" (PDF). Retrieved 30 April 2018.

- https://mnre.gov.in/file-manager/annual-report/2014-2015/EN/Chapter%201/chapter_1.htm
- https://mnre.gov.in/file-manager/annual-report/2015-2016/EN/Chapter%201/chapter_1.htm

- https://mnre.gov.in/file-manager/annual-report/2016-2017/EN/Chapter%201/chapter_1.htm
- https://mnre.gov.in/file-manager/annual-report/2009-2010/EN/Chapter%201/chapter_1.htm

- http://www.indiaenvironmentportal.org.in/files/file/CEA-%20renewable_energy%20gen%20report_0.pd


Note: All the above-mentioned links are accessed on 15-Mar-2019

## Annexure-I : Smart Grids Projects under Ministry of Power and NSGM

| | Utility | Smart Grid Implementing Agency | Status/ Date of Award | Sanctioned Cost | MW |
|---|---|---|---|---|---|
| Pilot Projects | CESC, Mysore | Enzen | Completed | 5.05 | 21824 |
| | UHBVN, Haryana | NEDO Japan | Completed | 5.57 | 11000 |
| | Smart grid knowledge center, Manesar | Power Grid | Completed | 0.9 | NA |
| | HPSEB, Himachal Pradesh | Alstom | Completed | 3.01 | 1554 |
| | APDCL, Assam | Phoenix IT | Under progress | 4.64 | 15083 |
| | WBSEDCL, West Bengal | Chemtrols | Completed | 1.09 | 5265 |
| | TSECL, Tripura | Wipro | Under progress | 9.83 | 45290 |
| | TSSPDCL, Telangana | ECU | Under progress | 6.48 | 11906 |
| | PED, Puducherry | Dongfang | Completed | 7.14 | 33499 |
| | UGVCL, Gujarat | - | Completed | 12.81 | 22230 |
| | IIT-K Smart City Pilot | - | Completed | 1.94 | 20 houses under RE & automation |
| | | | **Sub Total** | **58.46** | |
| Under NSGM | Chandigarh, CED (subdivision-5) | | Under Progress | 4.43 | 29433 |
| | Chandigarh, CED (complete city) | | Under progress | 37.734 | 184000 |
| | OPTCL, Odisha | | Under progress | 15.1 | 87000 |
| | JBVNL, Jharkhand | | Under progress | 35.71 | 360000 |
| | KSEB, Kerala | | Under progress | 14.1 | 90000 |
| | | | **Sub Total** | **107.074** | |

Source: http://www.nsgm.gov.in/sites/default/files/SG-Projects-Status-February-2019.pdf

## Annexure-II : MI India IC1 Programmes

| Sr. No. | Project Name | Indian Lead | MI Member Country |
|---|---|---|---|
| 1 | Demonstration of MW Scale Solar Energy Integration in Weak Grid Using Distributed Energy Storage Architecture (D-SIDES) | Dr. NP Padhy, IIT Roorkee | Dr. Luciano Martini - RSE, Italy<br>Dr. Yibo Wang - CAS, China<br>Dr. Bala Venkatesh - Rayerson University, Canada |
| 2 | Developing a Prosumer Driven Integrated Smart Grid | Dr. Amit Garg, IIM Ahmedabad | Dr. S.S. Iyengar - Florida International university, USA |
| 3 | Mix-Energy-Source Electric Vehicle Charging System Design and Its Impact on Indian Smart-Distribution-grid | Dr. Shantanu K. Mishra, IIT Kanpur | Dr. Saraju P. Mohanty - University of Texas, USA<br>Dr. Khai D. T. Ngo - Virginia Tech, USA<br>Dr. Akshay K. Rathore - Concordia University, Canada<br>Dr. Balarko Chaudhuri - Imperial College London, UK |
| 4 | SMART Planning and Operations of Grids with Renewables and Storage (SPOReS) | Dr. K. Ramamritham, IIT Bombay | Dr. Mark Dyer - University of Waikato, Newzeland<br>Dr. Prashant Shenoy - University of Massachusetts, USA<br>Dr. Samarjit Chakraborty - TU Munich, Germany |
| 5 | AlGaN/GaN Power Transistor Based Platform Technology and Modules for Smart Grid Applications | Dr. BG Fernandes, IIT Bombay | Dr. S. Madathil - University of Sheffield, UK |
| 6 | Stability Analysis, Protection, and Coordinated Control of Networked Microgrids | Dr. Saikat Chakrabarti, IIT Kanpur | Dr. Arindam Ghosh - Curtin university, Canada<br>Dr. Ramakrishna Gokaraju - University of Saskatchewan, Canada<br>Dr. Xiaodong Liang - Memorial University of Newfoundland, Canada |
| 7 | Research and Development of Smart, Secure, Scalable, Resilient and Adaptive Cyber-physical Power System(S3RA-CPPS) | Dr. BK Panigrahi | Dr. D. Dasgupta - Memphis University, USA<br>Dr. Anupam Joshi - UMBC, USA<br>Dr. M. Govindarasu - IOWA State University, USA<br>Dr. DB Rawat - Howard University, USA |
| 8 | Demonstration of Grid Supportive EV Charger and Charging Infrastructure at LT Level (D-EVCI) | Dr. Sukumar Mishra, IIT Delhi | Dr. Marta Molinas - NTNU, Norway<br>Mr. Anis Jouini - CEA-TECH, France |
| 9 | Design and Development of Hybrid Renewable Energy Microgrid with Value Chain Applications for Agriculture & Dairy Farm | Dr. Barjeev Tyagi, IIT Roorkee | Dr. Pawan Sharma - University of Tromso, Norway |

# 10. ITALY

## 10.1 General Framework and Implementation

With a surface area of 301,300 km² and a population of about 60,5 million, Italy is the fourth largest electricity market in Europe and has undergone a very significant evolution in the last 10 years, thanks to the massive deployment of renewable energy sources. In 2017 the total electric energy consumption has ranged around 321 TWh (increasing about 2% from previous year). The total installed capacity (gross efficient power) was 117.1 GW (of which 61. GW of Thermoelectric, 22.8 GW of Hydro, 19.7 GW of Solar, 9.8 GW of Wind, 0.8 GW of Geothermal, 3,6 of biofuels) and a peak load of about **53.6 GW**. The composition of the initial Italian mix (including imports) for the electricity generation is shown in Figure 10-1: renewables account for more than 31%. In terms of segmentation of electricity demand, industry accounted for 41%, tertiary, transport and other sectors for 35%, domestic sector for 22%, and the agriculture sector for less than 2%. The total technical losses ranged around **6%**.

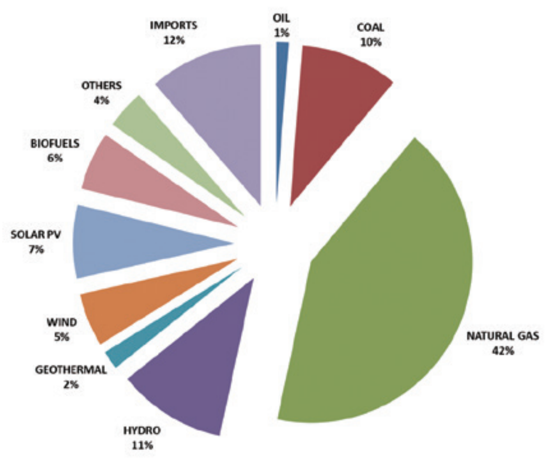



Figure 10-1. Italy Electricity Mix 2017
(Source: Elaboration from TERNA Data)

After a decade of almost continuous decline, primary energy demand started to increase again in 2017 (+2,1 % compared to 2016). The overall gross final consumption of energy in Italy in 2017 totalled around 170 Mtoe, with energy from RES totalling around 32,7 Mtoe: the share of consumption covered by RES was therefore 19,2%, higher than the 2020 target set for Italy by Directive 2009/28/EC.

Italy's national energy policy is coordinated by the Ministry of Economic Development (MiSE). The Ministry of Environment and Protection of Land and Sea (MATTM) is responsible for co-ordinating policy on climate change. Multiple government organizations are involved in renewable electricity policies: the MiSE issues the decrees that define support policies, the Italian Energy Service Provider (GSE) is responsible for managing the implementation of renewable electricity incentive programs and the Energy Market Administrator (GME) manages the trading of green certificates. Finally, the Italian Regulatory Authority for Energy, Networks and Environment (ARERA) defines procedures, imposes penalties for non-compliance with renewable electricity laws, and incentivizes network operators to continuously improve their supply quality performances. Italy's path towards sustainability beyond 2020 will follow in the tracks of the Energy Union strategy – based on five dimensions:

decarbonisation (including renewables), energy efficiency, energy security, a fully integrated energy market, research, innovation and competitiveness.

The **National Energy Strategy** (SEN), the ten-year plan published by MiSE in 2017 defined the national energy targets to drive the energy transition toward the policy targets [1]. The SEN is closely coordinated with the European Strategic Energy Technology Plan (SET Plan) and is complemented by the **Integrated National Energy and Climate Plan (PNIEC)** [2] whose final draft has been submitted by MiSE to the European Commission in December 2018. The plan sets the energy scenario towards 2030, fostering a wide-ranging transformation in which the combination of decarbonisation, circular economy, efficiency and rational and fair use of natural resources represent objectives and instruments for the future of the economy. In line with this vision, Italy plans to take an integrated approach. Some of the main general objectives sought by Italy are the following:

- Accelerate the decarbonisation process, by setting 2030 as an interim milestone towards a full decarbonisation of the energy sector by 2050;
- Put citizens and businesses (in particular SMEs) at the centre of the energy transition;
- Foster the evolution of the energy system, particularly in the electricity sector, combining centralised and distributed approaches to generation, predominantly relying on RES;
- Promote energy efficiency across all sectors and, where appropriate, electrification of energy uses;
- Guide the evolution of the energy system through research and innovation activities;
- Continue the process of integrating the national energy system with that of the entire European Energy Union.

Italy plans to pursue the target of obtaining 30% of gross final consumption of energy from renewable sources in 2030 by defining a pathway of sustainable growth for renewable sources and the full integration thereof into the system. In particular, the target for 2030 foresees a gross final consumption of energy of 111 Mtoe, with approximately 33 Mtoe of that coming from renewable sources.

The contribution of RES to meet the above target is expected to have the following distribution between the different sectors:

- 55.4% renewables share in the electricity sector;
- 33% renewables share in the heating sector (for heating and cooling);
- 21.6% as regards the incorporation of renewables in the transport sector.

In addition to the SEN and the PNIEC, there are other important documents as the National Strategy on adaptation to climate change (by decree of the Ministry of the Environment in June 2015) and the National Strategy for Sustainable Development (SNSvS), approved by the Interministerial Committee for Economic Planning (CIPE) at the end of 2017 [3].

## 10.2 Status of Renewable Energy and Smart Grids

Renewables, together with energy efficiency, are the core elements in achieving the goals of the Italian energy strategy and plans. The production from renewable electricity has seen a considerable growth in recent years, also led by generous incentives.

In the past, the Italian electricity mix was largely dependent on imported fossil fuels (mainly natural gas) generation, complemented with a significant share of hydro power. During the last decade, in order to reduce the dependence from fuel imports and the greenhouse gases emissions, the Italian government has promoted the deployment and integration of variable renewables (mainly PV and wind). Between 2009 and 2012, different mechanisms were implemented to support the deployment of renewables including feed-in tariffs, premium schemes, and "green certificate" schemes, applied depending on the type and size of renewable plants. The following figure illustrates the evolution of the Italian RES generation mix as a consequence of the adopted policy measures, and shows the important relative contribution of hydro power, the slow increase in geothermal generation, the progressive deployment of bioenergy and wind and the very steep ramp of the solar PV during the first three years of the present decade.

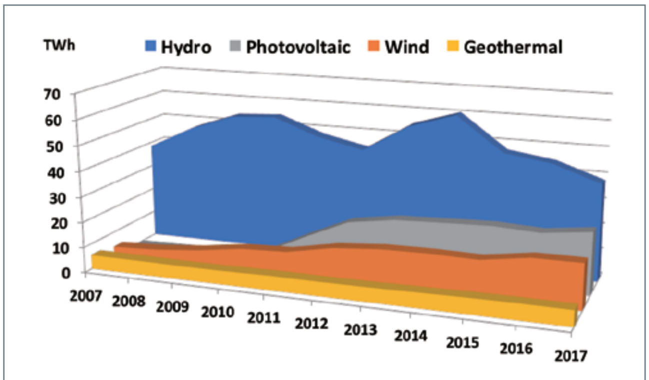



Figure 10-2. Trend of Renewable Generation (MWh) by Source
(source: Elaboration from TERNA Data)

In 2018, the total generation from renewables was about 113 TWh, characterized by a mix as illustrated in Figure 10-3, where nearly 44% of the renewable generated electricity was from hydro power, 20% from PV, and 15% from wind.

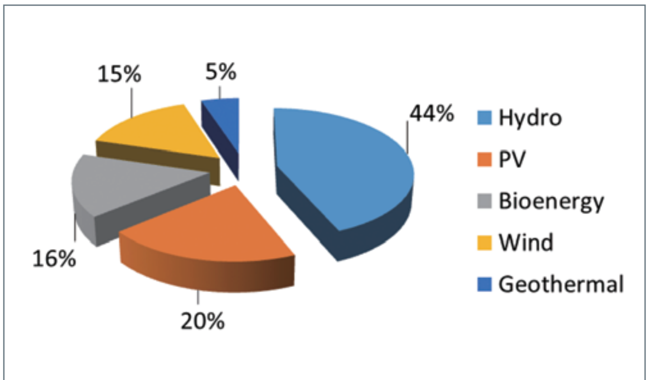



Figure 10-3. Share of Renewable Electricity Generation by Source – Italy (2018)
(Source: Elaboration from TERNA Data)

In particular, wind energy generation is composed of on land large wind farms (about 700 big plants) connected mainly to the sub-transmission (150 kV) network, while the PV plants (about 820,000 units) are mostly of medium to small size (from a few kW to MW size) and are connected to the medium or low voltage distribution networks. Appendix III reports the tables that summarize the generation mix by source in 2017 and their recent past and present contributions as well as their long-term trends.

Italy is one of the most advanced countries in the implementation of smart grid solutions and technologies, as well as energy efficiency measures and energy storage integration. Moreover, Italy has been pioneer in the development and deployment of smart meters in the European Union. In fact, under the "Telegestore" project, the Automated Meter Management (AMM) System for low-voltage (LV) concentrators and remote meter management has been deployed by the main Italian DSO (e-Distribuzione) since 2001. The implementation of the project has led to the installation of more than 32 million smart meters. A second generation (2G) of smart meters has been developed based on the requirements set by the Italian Energy Regulator, ensuring full interoperability at all levels and readings available for elaborations.

Another outstanding smart grid solution is represented by the Remote Control and Automation of the distribution network that enables a high penetration of variable renewables (distributed PV plants). Today, 100% HV/MV substations and 30% MV/LV secondary substations are remotely controlled.

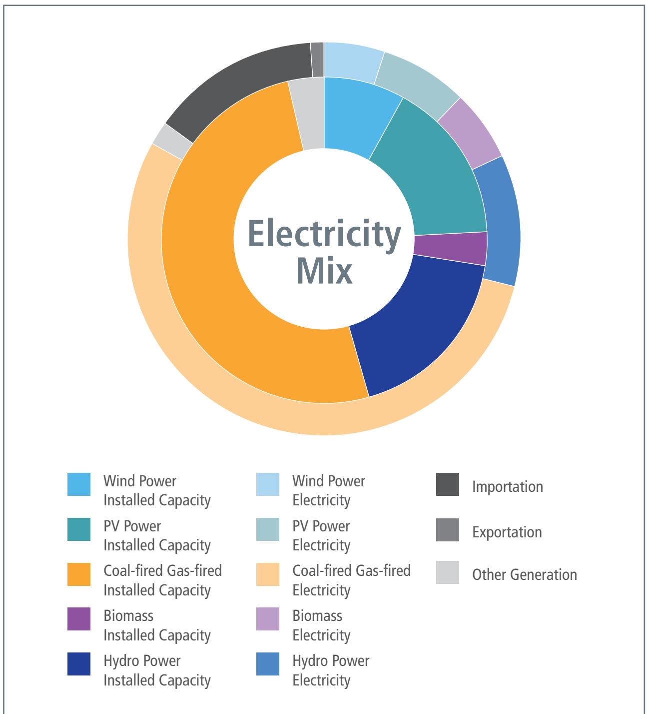



Figure 10-4. Electricity Mix by the End of 2017

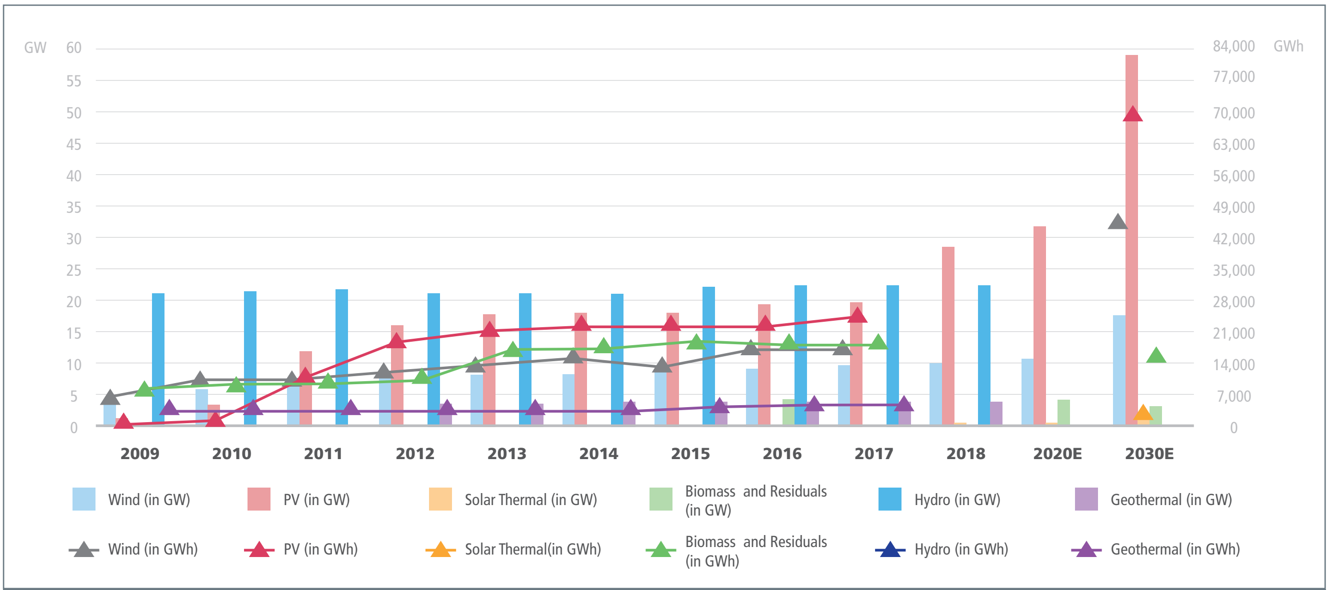



Figure 10-5. Trends on Renewable Energy Generation

The electricity network is a strategic asset for the Italian economy and its efficiency, reliability, modernization and continuous development are considered as key. Hence, demonstration projects of smart grids solution are ongoing all over Italy, with special reference to advanced network management solutions (e.g Puglia Active Network project – PAN) and storage, seen as a strategic tool for managing RES variability by providing flexibility to smart grids. Demonstration projects of advanced storage application are ongoing or already deployed and among them we mention:

- I-NEXT project, small storage on MV grid, 100 kW / 300 kWh NaNiCl2 batteries for energy balancing of a micro-grid with 100kW PV to produce, store and distribute hydrogen and electricity for a small EV and FCEV fleet;
- CNR4CAPACITY project, small storage on LV grid, 20 kW / 40 kWh for energy balancing of a micro-grid composed of 6 houses equipped with PV and storage, where an energy service company can control contracts, loads and electricity exchange with the grid, in order to maximize the income for the users and make the demand flexible.

Research plays a fundamental role in the implementation of the national energy strategies. In particular, two main research objectives have been identified in PNIEC:

- monitor and develop product and process technologies vital to the energy transition;
- promote the introduction of technologies, organizational and operational models and systems fostering security of supply.

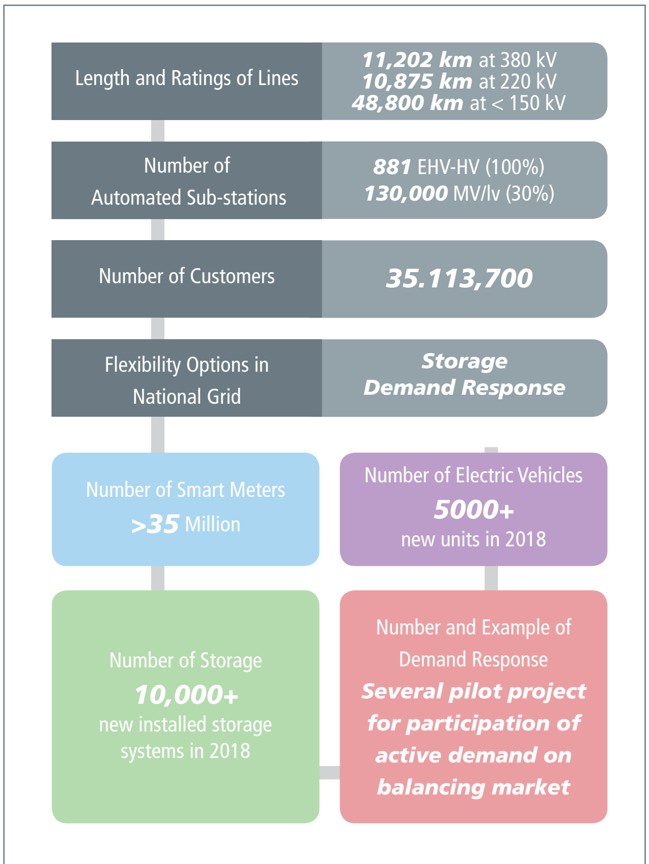



Figure 10-6. Key Smart Grids Facts and Figures by the end of 2018

It is worth saying that both the SEN and the PNIEC mention Mission Innovation as a tool to reach the defined targets for security of supply and the energy transition. With particular reference to smart grids, the following key innovation challenges are identified:

- Observability and control at transmission and distribution level to be achieved in a cost-effective way;
- Integration of all forms of energy storage to increase RES penetration while improving security of supply;
- Integration of the power network with other energy vectors' systems (heating and cooling, natural gas, hydrogen, biogas, water) to increase flexibility and security of the energy system;
- Distributed self-organization vs. central control of the energy system, following a principle of subsidiarity;
- Integration of demand side management and ancillary network services at distribution system level and integration on the transmission operations;
- Legislation/Regulation: New electricity-markets designs.

The implementation of policies linked to the attainment of national objectives involves a number of parties, operating in a manner compliant with European regulations. These parties include, first and foremost, the Italian Competition Authority (AGCOM), the Regulatory Authority for Energy, Networks and the Environment (ARERA), the operators of the national transmission network (namely TERNA SpA), and the 126 companies holding the concessions for electricity distribution, in charge of management, operation, development and planning of their respective network assets.

## 10.3 National Programs in Fields of Smart Grids and Renewable Energy

The most important program supporting R&D activities in the energy sector is the "National Fund for Electric System Research" (RdS). RdS is aimed at the scientific and technological innovation of general interest for the electricity system for an enhancement of competitiveness, security and environmental compatibility, ensuring conditions for a sustainable development.

RdS activity topics span over the entire energy system. The main smart grids and renewable energy R&D topics include: integration of distributed generation, energy storage, active distribution network control, automation and related communication technologies, power electronics, user integration and demand response, DC transmission and distribution, measuring and metering and modelling. RdS activities are financed through a levy on the consumer's electricity bill of an order of magnitude of 0,080 €/kWh and foresee an average annual budget of 70M€ of which about 9,2 M€/year are devoted to smart grids and energy storage. Most of the RdS projects are implemented by public R&D institutions in the context of Program Agreements with MiSE (namely Ricerca sul Sistema Energetico – RSE SpA, the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and the National Research Council (CNR)). Subcontractors include Universities and R&D labs. RdS activities are developed in three-year plans. The newly launched three-year RdS program 2019-2021 (MiSE decree 16 April 2018), aligned with the SET-Plan and the Integrated National Energy and Climate Plan (PNIEC), is developed along the following two main paths:

- Technologies: monitor and develop technologies, solutions and products fundamental for the energy transition;
- Electric System: foster the introduction of technologies, systems and organizational & management models for the energy transition and security.

Beside RdS, the following National Plans and Programs supporting R&D in the smart grids and RES sectors can be mentioned:

- **Regional Operational Plans (POR),** managed by Regional Governments to support smart grids research, fostering the local R&D through the involvement of local industry and research entities. This program uses regional funds also connected to European funds (e.g. European Structural and Investment Funds);
- **National Operational Programs (PON).** By a Ministerial Decree, MISE has allocated in 2018 financial resources for PON - I&C 2014-2020, which include Smart Grids Projects in the distribution network (MV/LV), focused on increasing the hosting capacity of distributed generation based on renewable sources.
- The Ministry of Education and Research (MIUR) has set out the **National Research** Plan for 2015-2020, defining the contents and the governance of applied research. The programs include twelve "specialization areas", among which: Energy, Technologies for life environments, Sustainable mobility, and Smart, Secure and Inclusive Communities.

Moreover, Italy supports National Technological Clusters intended as open and inclusive networks focusing on specific technologies and application areas deemed to be strategic for Italy. Clusters include major national public and private subjects operating in industrial research, training, education and technological transfer. The National Technological Energy Cluster is a no-profit association chaired by ENEA. It currently consists of 72 shareholders, belonging to Business, Public Research and Territorial Representatives sectors. The main goals of the cluster include:

- promote scientific and technological research to foster participation, coordination and launch of national and international initiatives and projects concerning the energy sector, fostering next generation innovative energy technologies and services;
- promote connection and strengthen collaboration and coordination between companies from different sectors and bodies/institutions to foster the development of the national value chain of technological innovation to increase competitiveness of national industry in a global environment;
- strengthen the capacity to develop projects and prototypes, as well as the operational skills of applied and industrial research and facilitate investments in advanced and dedicated technological and scientific-technical infrastructures;
- strengthen the Italian role in addressing the future SET-Plan and contribute to the implementation of the Integrated National Plan for Energy and Climate.

With reference to smart grids topic, the priorities pointed out by the cluster include: innovative planning, operation, monitoring and control systems for electricity transmission and distribution networks to foster integration of distributed generation and renewable energy sources, as well as on hybrid systems (renewable, fossil, storage) of energy production for final uses and for scheduled delivery in the network.

**National smart grid R&D activities in line with IC1 tasks and sub-tasks Program of Work (PoW)**

The National Plans in the Energy and Climate areas consider research, development and innovation activities as essential enablers to reach their goals and the central role played by smart grids.

Among the different national programs supporting R&D in the smart grids sector, the smart grids RD&D activities carried out within RdS are in line with task and sub-task topics of IC1. Such activities are listed as follows.

Task 1 **Storage integration**, Task 2 **Demand response**, Task 3 **Regional electricity highways**, Task 4 **Flexibility options**, Task 5 **New Grid Control Architectures**, and Task 6 **Power electronics**.

In particular, Italy is involved in almost all R&D tasks, as a co-leader role in Tasks 3 "Regional Electricity Highways", Task 5 "New Grid Control Architectures" and Task 6 "Power Electronics" together with India, US and China respectively.

Figure 10-7

| Name of National Activities/ Programmes in Support of Respective Task | Name of POWs Task/Subtask Relevant to the Activities/ Programmes |
|---|---|
| ***National Fund for Electric System Research - RdS*** | |
| Storage systems including electrochemical and power to gas and related interfaces with networks | Task 1 - Sub-task: 1.1 Inventory of storage control approaches |
| Schemes for the rewarding of ancillary services based on storage capacity | Task 1 - Sub-task: 1.5 Inventory of Approaches to integrate Storage into Markets |
| Studies and experimental activities on managing safety aspects of sodium high temperature batteries | Task 1 - Sub-task: 1.6 Storage safety |
| Energy and economic optimization of microgrid operations featuring large shares of RES production, storage and controlled load | Task 1 - Sub-task: 1.1 Inventory of storage control approaches |
| Multi terminal HVDC lines | Task 3 - Sub-task: 3.2 Future challenges for electricity corridors |
| Meteo extreme event forecasting for alert and emergency measures | Task 3 - Sub-task: 3.3 Increased grid resilience by innovative technologies |
| Cost-benefit analysis of grid expansion, including social and environmental benefit | Task 3 - Sub-task: 3.4 Transmission expansion policies: Worldwide trends best practices and proposed possible improvements |
| Schemes for economic compensation of balancing services from the distribution grid to the regional grid | Task 3 - Sub-task: 3.6 Modernization of the existing electricity market |
| The Web of cell concept: testing in real field | Task 4 - Sub-task: 4.4 Localized power balancing |

Figure 10-7

| Name of National Activities/ Programmes in Support of Respective Task | Name of POWs Task/Subtask Relevant to the Activities/ Programmes |
| --- | --- |
| Semantic web tools for integrating spatially coincident heterogeneous data | Task 4 - Sub-task: 4.6 Use of Artificial Intelligence (AI) for Coordination of Flexible Resources |
| Control architecture for balancing heat and power generation in district heating and cooling | Task 5 - Sub-task: 5.4 Control architecture solutions for the electric network convergence and integration with other domains |
| Voltage Sourced Converter (VSC) vs Line Commutated Converted (LCC) control for HVDC | Task 5 - Sub-task: 5.5 Impact of new control architectures on regional grids |
| Benefits of CIM protocol adoption in grid operations | Task 5 - Sub-task: 5.7 Microgrids interoperability |
| Control and protection in mixed AC/DC MV networks | Task 5 - Sub-task: 5.8 Available new technologies for smart grids |
| Cybersecurity in electricity networks: the way forward | Task 5 - Sub-task: 5.9 ICT infrastructures |
| Inverter control and protection schemes coordination | Task 6 - Sub-task: 6.4 Simulation tools and modelling methods for power electronics |
| Solutions for providing synthetic inertia to the grid | Task 6 - Sub-task: 6.5 Technological solutions towards electronic-dominated power system |
| National Technological Energy Cluster | Storage integration, Demand response, Flexibility options, New grid control architectures, and Power electronics |

## 10.4 International Programme Related to Smart Grids and Renewable Energy

Italy is involved with a leading role in several European and international initiatives and platforms in the field of electricity grids and energy systems. Italy is also very active in policy fora such as the **Clean Energy Ministerial** (CEM) and in global initiatives such as **Mission Innovation** (MI). In particular, MI is considered by Italy as a formidable opportunity to accelerate public and private efforts on clean energy research and innovation. It is worth mentioning that Italy has included MI as a priority action in its SEN and PNIEC. Within MI, Italy is involved in all the eight Innovation Challenges, with a strong commitment in IC1 on Smart Grids, where RSE – Ricerca sul Sistema Energetico, on behalf of MISE, co-leads the challenge together with China and India.

Italy has important leading roles also within several high-level bodies of the International Energy Agency (IEA) and in particular chairs the ***Committee on Energy Research and Technology*** (CERT), owns the vice-chairmanship of the ***End Use Working Party*** (EUWP), coordinating 14 Technology Collaboration Programs (TCP). Italy actively participates in several TCPs and in particular holds important coordination roles within the ***International Smart Grids Action Network*** **(ISGAN)** since its inception, contributing to the activities of the various Annexes [4] which aim to improve the understanding of smart grids technologies and systems and to promote adoption of related enabling government policies.

Among the programs and initiatives at European level, Italy is a key player in the ***European Energy Research Alliance*** **(EERA)**. EERA [5] is an alliance founded by leading European Research Organizations with the goal to coordinate research in the energy field across Europe and to accelerate the development of innovative energy technologies by conceiving and implementing Joint Research Programmes (JPs). EERA JPs constitute strategic, permanent collaborations between major research organizations and institutes forming a virtual center of excellence. The present 17 JPs implement the need for better coordination among research organizations from different EU Member States, maximizing synergies and identifying research priorities.

Italy coordinates the JP on Smart Grids that gathers 42 Research Organization from 17 different European countries whose activity cover Technologies and tools for management of future power systems, Storage integration, Flexible power system operation, Prosumer activation and engagement through digitalization and ICT, and Flexible transmission network.

Italy's technological innovation activities are closely coordinated with the European Union Strategic Energy Technology Plan (SET Plan). In this framework, Italy is supporting the implementation of the SET-Plan through the participation in its Steering Group and in the ***European Technology and Innovation Platform on Smart Networks for Energy Transition*** (**ETIP SNET**) [6] actively supporting its Working Groups and the Governing Board. Italy co-led the drafting of the document ***"Vision at 2050 - Integrating Smart Networks for the Energy Transition: Serving Society and Protecting the Environment"*** one of the recent ETIP SNET accomplishments. The vision contributes to the definition of Research & Innovation Roadmaps at national level- involving national operators to achieve the identified innovation objectives and the definition of Country's priority activities.

Italy has also co-leading roles within the Working Group related to the SET Plan Action 4 "Increase the resilience and security of the energy system" aimed at identifying governmental coordinated actions to ensure the achievement of strategic targets for the European energy system, enabled by the deployment of smart grids.

In the framework of projects related to smart grids and renewable energy, Italy participates in many **EU projects** - both as coordinator and as a partner. In particular, concerning the smart grid sector, Italy is involved in projects devoted to active distribution networks, AC and DC high energy corridors, new grid architectures, road-mapping of future research and innovation needs for the energy system and for the integration of DER and energy storage into energy networks.

## 10.5 Case Studies

**PROJECT CASE #1**
**National Fund for Electric System Research (RdS – Ricerca di Sistema)**

### Related Sub-challenge of IC1

Regional grid innovation, distribution grid innovation, micro grid innovation, and/or cross innovation

Tasks 1 - 6

### Type of Project

Theoretical research, technology development, testing and demonstration

### Topic

RdS activity topics span over the entire electric system. The main smart grids R&D topics are: integration of distributed generation, energy storage, active distribution network control, automation and related communication needs and technologies, power electronics, user's network integration and system aspects of demand response, DC distribution.

### Objective

Technical and technological innovation for the electricity system, security and environmental compatibility, ensuring energy system sustainable development.

In particular, the smart grids research program aims to:

- Develop and test models and algorithms for distributed energy resources management and control;
- Study and demonstrate communication technologies for active networks;
- Develop electronic converters and protection schemes;
- Study and demonstrate DC active networks, including failure analysis;
- Analyse power quality requirements of the distribution grid;
- Support energy systems and infrastructure development and deployment;
- Develop storage systems for different power and energy requirements.
- Investigate demand response schemes and develop adequate technological appliances

### Contractors

Public R&D institutions carrying out the RdS activities are: Ricerca sul Sistema Energetico – RSE SpA, the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and the National Research Council (CNR), which are committed in the context of Program

Agreements with the Ministry of Economic Development (MISE). Subcontractors include Universities and R&D labs. The validation of solutions and tools set up during the research activities is carried out through collaborations and agreements with the Italian TSO (TERNA), Italian DSOs and technology providers.

## Period

The RdS activities are carried out according to three-year plans. The year 2018 was a transition year at the end of 2015-2017 period. The new plan for 2019-2021 is currently under public consultation (as of April 2019).

## Ongoing and Achieved Key Findings

Development of algorithms for voltage control, optimal management of flexible resources, load and generation forecasting, including meteorological forecasting algorithms. Output of technological research, such as automation functions or measuring devices have been eventually validated  in actual distribution networks, in the real field. Collaboration with manufacturers and network operators has been instrumental. Development of technologies and new architectures for the management of transmission and distribution grids. For example, assessment of HV network security and resilience by probabilistic methods; Assessing cyber security of ICT operations using a simulation test bed; tools for interoperability and protocol standardisation; new architecture for the integration of MVDC systems in MV distribution grids.

Electrochemical systems for energy storage research activity, are aimed at the development of materials and components, up to their engineering, of advanced electrochemical storage devices for the optimization of technologies already available, but not yet competitive for applications. In the study, high-temperature sodium nickel chloride batteries (Na-NiCl2), lithium batteries (LiB), flow redox batteries (RFB) as well as the development of new storage technologies such as metal-air batteries and methane synthesis through methanation processes (Power to Gas) are considered.

An important research infrastructure used in the frame of the RdS programs is the RSE DER (Distributed Energy Resources) TEST FACILITY. It is a LV microgrid, either operated grid connected or in islanded mode, that interconnects different generators, storage systems and loads to develop studies and experimentations on DERs and smart grids solutions. In particular, this Facility has been extensively used for coupling its AC section with the  LV DC Microgrid section. This has been possible with the development of a prototype of a smart DC breaker.

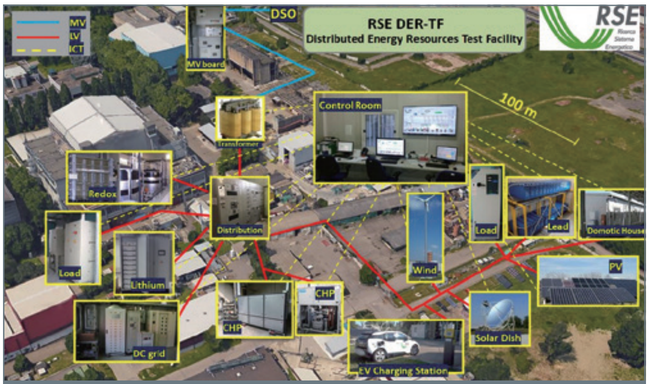


Figure 10-8. RSE Distributed Energy Resources Test Facility

## Added value for IC1 objectives

The smart grids RD&D activities carried out within RdS are fully in line with IC1 objectives and targets, supporting the acceleration of the development, demonstration and deployment of smart grids technologies, services and solutions in the Regional and Distributions Grids as well as microgrids. RdS results are of public domain (www.ricercadisistema.it), thus supporting the knowledge sharing of research undergoing activities, thus helping identifying gaps and opportunities.

## PROJECT CASE #2
## OSMOSE – DEMO 5

## Related Sub-challenge of IC1

Regional grid innovation

Task 3 "Regional Electricity Highways"

## Type of Project

EU project – Research and Innovation Action

## Topic

Multiple services provided by grid devices, large demand-response and RES generation coordinated in a smart management system

## Objective

Develop a smart management system integrating flexibility sources of market players together with flexibility sources of the TSO's infrastructure. The demonstrator, in particular, will address the following use-cases:

- Optimal Coordination for Congestion Management, implementing an advanced Energy Management System capable of handling large amount of data in order to coordinate Power Flow Control devices and Demand Side Response (DSR) resources for congestion management on a portion of the Italian transmission grid.

- Innovative System Services by RES Plants, focusing on the provision of upward and downward Synthetic Inertia and Automatic Voltage Control by large wind/PV power plants. Innovative control algorithms will be implemented and tested with the purpose of assessing, on a real-environment framework, the reliability of this service, its effectiveness in increasing system stability with respect to power unbalances and the availability of RES power plants.
- Increasing availability of systems services from DSR through Aggregation: even though DSR technologies represent a mature, commercially viable and potentially cheaper alternative to system services provided by conventional power plants, the availability of DSR resources on the European Ancillary Market Servicies have not grown yet. This use case will address, through a deeper energy audit of involved customer's productive process, the implementation and testing of Frequency Restoration Reserve and Automatic Voltage Control provided by consumers, with a focus on the role of HV aggregator as key player to increase DSR availability.

### Contractors

TERNA, RSE, Ensiel, IBM IT, ABB IT, Enel Green Power, Enel X, Edison, E2I, Engineering

### Period

48 months (2018-2021)

### Ongoing and Achieved Key Findings

Reduction of RES production curtailment (also through improvement of day-ahead forecasts for HV Lines Thermal Rating and RES production forecasts); assessment of reliability and potential of DSR for effective contribution to congestion management and other system services; assessment of reliability and potential of RES for effective contribution to system stability (inertia and automatic voltage control)

### Added Value for IC1 Objectives

Increase flexibility of electricity resources, markets and operations to ensure effective and full integration of renewables.

## PROJECT CASE #3
## PAN Puglia Active Network

### Related Sub-challenge of IC1

Distribution grid innovation
Task 2 Demand response
Task 4 Flexibility options

### Type of Project

Technology development, demonstration.

### Topic

PAN is a demonstration project of advanced network management solutions, funded under the European Programme NER 300 (New Entrant Reserve).

The selected location covers the entire rural area of the southern Italian Region named Puglia.

The project is based on three main actions:

- Strengthening of the power grid, for its greater efficiency and safety;
- Regional-scale development of an electric vehicle charging infrastructure integrated into the distribution gird, to implement a new model of eco-sustainable mobility with zero emissions;
- Monitoring of energy consumption with the Smart Info+ kit to develop a greater awareness of the use of electricity in homes and small businesses.

In particular, the project will include new functionalities such as self-healing control grid methodologies to reduce the number and the cumulative duration of long and short interruptions, nearly real-time monitoring of generation and grid conditions (including feeders voltage, reactive and active power flows) and predictive maintenance of MV circuit breakers in primary substations. The project involves more than 102 primary substations, 100 remote bus-bars and about 8.000 secondary substations of the e-distribuzione network. The nodes communicate with each other via an always-on broadband network, based on LTE radio access technology. In addition, e-distribuzione will contribute to the deployment of a backbone of charging stations for electric vehicles (58 double point charging stations and 16 Fast Recharge Plus stations, with three charging points) integrated with the distribution grid and located throughout the region along the main roads and in the main touristic areas.

Furthermore, it will be possible to equip 10,000 customers with smart info+ kit providing users with timely information on their energy consumption.

### Objective

The general goal of the project is to improve, at large scale, the performances of the electric distribution network characterized by a high penetration of renewable energy sources, thanks to innovative technologies that allow the advanced active management of the network. The innovative solutions proposed in the project can increase the capability of the grid (Hosting Capacity) to connect renewable energy sources and provide ancillary services maintaining an adequate quality of service.

These objectives will be reached by the realization of an active control system of the power flows produced by distributed generation and by enabling the demand response to promote energy efficiency and thus reducing $CO_2$ emissions

### Contractors

E-Distribuzione is the project lead and sponsor and there are no other project partners

### Period

Ten years (2014-2024) which include five years of construction period (2014-2019) and five years of service period (2019-2024)

### Ongoing and Achieved Key Findings

The PAN project implements a smart grid upon the whole Puglia Region, integrating the energy generated by renewable plants and assuring to customers a constant access to information on their own consumption.

Main outcomes:

- Constant control of the voltage profile on the MV network in order to avoid issues regarding the presence of DG;
- Increase the MV network Hosting Capacity for Distributed Generation enabling the integration of renewable energy sources;
- Increase/maintain the network availability/power quality in presence of high penetration of DER;
- Improve the observability of the MV network;
- Reduction of network losses and consequent reduction of pollutant emissions. Reduction of $CO_2$ emissions;
- Enabling of new added value services.

The project has increased the "customer awareness" fostering the sustainable management of the energy use: residents in Puglia region are benefiting from more reliable electricity supply and real-time information on their energy use.

Primary and secondary stations adopt a new method to reduce the number and duration of power cuts, to enable near real-time monitoring of generation and grid conditions and to predict when maintenance should be performed.

### Added Value for IC1 Objectives

Currently, there are new smart grid projects under development in the regions of southern Italy to foster a greater integration of renewable sources and ensure a better quality of service. Such projects are substantially implementing the same technologies developed and implemented within the PAN project.

The development and demonstration of new smart technologies and grid control systems in the distribution grid will contribute to the achievements of IC1 objectives and targets.

## PROJECT CASE #4
## ComESto (Community Energy Storage)

### Related Sub-challenge of IC1

Distribution grid innovation, cross innovation, microgrid

### Type of Project

PON – Funded by Italian Ministry of Education, Universities and Research

### Topic

Energy community, active prosumers, distributed energy storage, demand response, distributed energy resources, aggregator, energy and ancillary service market.

### Objective

ComESto Project aims to build a distributed aggregation system for a user community and managed in aggregate form, involving Prosumers and Consumers whose plants are managed in real time using DR programs able to co-ordinate with the RES generation systems of the Producers that are part of the aggregation. The aim is to make the end user aware and proactive of managing their own consumptions, maximizing the use of energy from RES and optimizing the production-demand process in order to achieve greater efficiency and thus economic convenience in the final uses of energy. This goal is achieved through integrated and flexible energy systems (nanogrids), as well as through a proper usage of batteries and storage systems. The ComESto project, in line with the priorities of strategic research agendas at national and European level and with the priority technological trajectories of the Energy Specialization Area, revolves around:

- the realization, experimentation and validation of a hybrid system (nanogrid) for single power users not exceeding 5kW (typically civil housing);
- the identification of the types of storage systems (for power and energy services) that best suit nanogrid applications and the experimentation of with innovative solutions at Consumers and / or Prosumers for "behind the meter" use and also at the Producers that together with the first are aggregated in "ComESto";
- the implementation of models and algorithms for aggregated management of storage systems distributed by Consumers, Producers and Prosumers, based on the use of home automation systems and cooperative energy brokerage and the demand aggregation hypothesis;
- the development of technical / economic analysis methodologies necessary for the planning of the electricity grid based on smart grid evolution scenarios aimed at identifying the best of new network interventions;
- the development of the electrical infrastructure as an enabler of new efficient consumer behaviors, encouraging concrete and further involvement of citizens, the diffusion of RES and the sustainable development of urban areas.

### Contractors
e-DISTRIBUZIONE, ENEA, University of Calabria, ENEL Italia S.r.l., Evolvere S.P.A., DISTRETTO TECNOLOGICO HIGH, GREEN ENERGY STORAGE S.r.l., GREENENERGY S.P.A., OCIMA S.r.l., SPINTEL S.r.l., TEN PROJECT S.r.l., TELECOM ITALIA S.p.a., University of SIENA, Marche Polytechnic University.

### Period
2018-2021

### Ongoing and Achieved Key Findings
Identification of the main management models for aggregated systems of producers, producers / consumers and consumers in the presence of distributed storage; optimal design of storage technologies; definition of control logics for the integration of storage systems into the nanogrid; development of a tool for the optimal design of the nanogrid through economic/ energetic criteria; development of predictive models for RES and loads.

### Added value for IC1 objectives
Contribution related to providing solutions for the optimal management of local energy communities also for participation to the various market options in the aggregated form.

## PROJECT CASE #5
## Hybuild (Innovative compact hybrid storage systems for low energy buildings) – Demo 3

### Related Sub-challenge of IC1
Storage Integration

### Type of Project
EU project – Research and Innovation Action

### Topic
Development of hybrid energy storage systems

### Objective
The objective is to exploit compact hybrid energy storage systems to cover space heating and/or cooling, domestic hot water, and electricity demand. The overall impact is to enhance energy savings, leading to reduced greenhouse gas emissions and fossil fuel utilization, thus contributing to the EU energy security.

### Contractors
Comsa Corporación, Universitat de Lleida, CNR–ITAE, Austrian Institute of Technology, Nobatek INEF4, CSEM, EURAC, Fahrenheit, Mikrometal, STRESS scarl, National Technical University of Athens, FRESNEX, ENGINEERING, DAIKIN Greece, OCHSNER, FOSS (University of Cyprus), Municipality of Almatret, AKG, R2M Solution, Municipality of Aglantzia, PINK GmbH

### Period
48 months (2017-2021)

### Ongoing and Achieved Key Findings
At the district level, HYBUILD will harmonize the local management of the residential buildings with the district requirements by implementing a Demand Response (DR) software module enabling the communication between the building manager and entities operating at the district level (e.g. aggregators, energy retailers, etc.).

The developed hybrid systems will be able to efficiently upgrade and store renewable thermal and electrical sources, by means of advanced materials and components, through an integrated, smart and adaptive system control. This smart control will be able to manage all energy fluxes, in order to maximise energy efficiency of the whole system, and to minimize energy demand from the grid or from fossil fuels (e.g. natural gas for heating). The HYBUILD systems combine thermal (sorption, latent and sensible) and electric storage in one system. Solar energy can be stored in a sorption storage and a latent storage (Mediterranean concept) or in a latent storage (Continental concept) and in an electric storage (both concepts).

**Added Value for IC1 Objectives**

Power network storage integration, thermal storage as dispatchable resource, hybrid thermal-electric storage management.

## 10.6 Reference

[1] National Energy Strategy 2017: www.mise.gov.it/images/stories/documenti/Testo-integrale-SEN-2017.pdf

[2] Draft Integrated National Energy and Climate Plan: https://ec.europa.eu/energy/sites/ener/files/documents/italy_draftnecp_en.pdf

[3] National Strategy for Sustainable Development www.minambiente.it/sites/default/files/archivio_immagini/Galletti/Comunicati/snsvs_ottobre2017.pdf

[4] ISGAN website www.iea-isgan.org/

[5] EERA website www.eera-set.eu/

[6] ETIP SNET website www.etip-snet.eu/

# 11. NORWAY

## 11.1 General Framework and Implementation

Norway has a mainland area of 324 000 square kilometers (km$_2$) bordered on the east by Sweden and, within the Arctic Circle, by Finland and The Russian Federation. This includes some 50 000 islands that lie off a long, indented coastline along the North Sea, the Norwegian Sea, and the Barents Sea. The climate is considerably milder than at similar latitudes elsewhere, because of the warm waters of the Gulf Stream. About two - thirds of Norway is mountainous and the mountains divide the country in both north - south and east - west directions. The population of Norway was 5.3 million in January 2019. Energy generation and use by energy source/ carrier is shown in the table below - November 2018 statistics:

The difference between energy generation and national use are imports/exports and losses.

The energy sector in Norway is governed by the Energy Law; the purpose which is to ensure that generation, conversion, transmission, distribution and use of energy are conducted in a socio-economic rational way taking into consideration all private and public interest and parties.

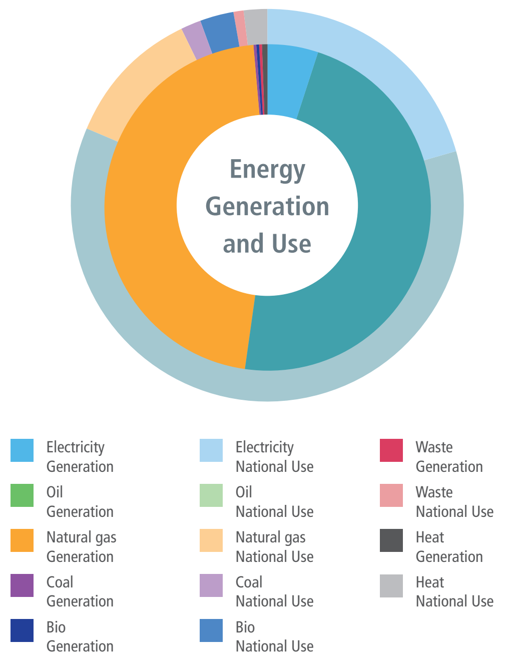



Figure 11-1. Energy Generation and Use in Norway by the End of 2018

In January 2018, a new climate goal act was adopted by the Norwegian Parliament. The objective of the act is to secure a transition to a low carbon/ low emission society by 2050. The target is to reduce GHG emissions by 40% of 1990 levels by 2030 and with 80-95% by 2050. The targets are in line with the Norwegian contributions determined in the Paris Agreement. Meeting the targets will be challenging, because both the country's electricity supply and its energy use in buildings are already essentially carbon free. Consequently, the target has to be met by energy efficiency measures as well as electrification of important energy sectors using renewable energy sources.

Reducing emissions from the transport sector has particular focus in the past and coming years and is an important part of the strategy to meet the national targets. During the last 10 years a policy with many incentives for electric vehicles has been in place. Thus, approx. 30 percent of the total car sales in 2018 was EVs. The total EV-fleet in Norway is now about 200,000 vehicles i.e. 7.2% of all private cars. By 2025, all new cars sold in Norway should be emission free.

Within maritime transport, ships and ferries are being electrified with battery or hybrid solutions.

The aviation authorities (Avinor) and industry partners are working to make Norway a world leader in electric aviation. Avinor has set the goal to make Norway the first country where electric aircraft account for a significant share of the market, and to electrify all Norwegian domestic flights by 2040.

The overall expectations towards 2030 according to a parliament white paper are:

- Reduced growth in energy use compared to the history so far
- More efficient energy use
- Increased use of electricity
- More power intensive electricity use increasing peak powers at all levels in the power system

## 11.2 Status of Renewable Energy and Smart Grids

RES account for close to 100% of Norway's electricity generation. Historically, hydropower supplied close to all the electricity in the country, whereas its current share is around 98%. Wind power generation more than tripled between 2010 and 2017, and now accounts for 2% of the total electricity generation. Another 0.3% is produced from biofuels and waste in CHP plants connected to district heating systems.

Figure 11-2

Trends on renewable electricity generation are shown in Figure 11-3. The Norwegian Water Resources and Energy Directorate, NVE, has estimated a growth in electricity use by 24 TWh towards 2035. The growth is mainly expected in industry, oil & gas sector, data centers and transport.

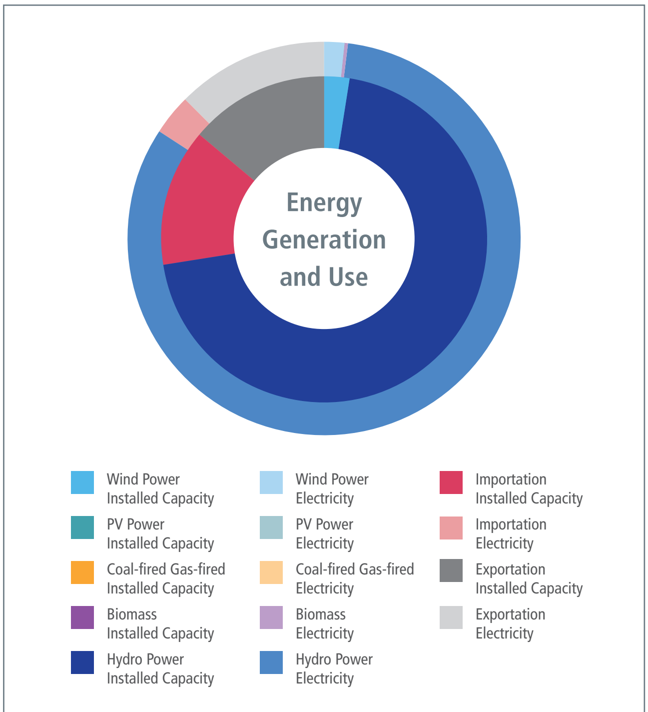



Figure 11-3. Electricity mix by the end of 2017


Figure 11-4. Trends on Renewable Energy Generation

The most important elements of smart grid investments so far have been the roll out of Smart Energy Meters to all electricity customers in Norway and the private investments in EVs. Smart metering was mandated by the energy authorities, NVE and the DSOs in Norway have been the responsible party for the investments. Costs are covered by the grid tariffs. NVE has also mandated Statnett (the Norwegian TSO) to develop a new IT solution for information exchange between actors in the power market, the Elhub. This will facilitate the exchange of smart metering values and customer information needed for settlement and billing of electricity consumers, supplier switching in the retail market. The Elhub was put in operation in February 2019.

**Figure 11-5**

| Name of National Activities/ Programmes in Support of Respected Task | Name of POWs Task/Subtask Relevant to the Activities/ Programmes |
|---|---|
| Length and Ratings of Lines | Transmission<br>11000 km – 420/300 kV<br>Sub transmission<br>19000 km – 132 /66kV<br>MV distribution 100000 km – 22/11 kV<br>LV Distribution<br>>200000km |
| Number of Customers | 2,9 mill. |

| | |
|---|---|
| Flexibility Options in National Grid | Balancing markets for:<br>• Frequency containment reserve<br>• Automatic frequency restoration reserve<br>• Manual frequency restoration reserve |
| Number of Smart Meters | ***2.9*** mill. |
| Prosumers | ***2.200*** |

Number of Electric Vehicles
***200.000***

Number and Capacity of Storage
***>1000***
Hydro Power Reservoirs – Capacity 86,5 TWh

Number and Example of Demand Response
***Approx.. 10 Pilot Projects Have Been Conducted***

Number and Example of Micro Grids
***A Few <10 Modern Micro Grids in Commercial Operation***

Other indicators
***National Smart Meter Hub, Elhub in Commercial Operation (February 2019)***

Figure 11-6

## 11.3 National Programs in Fields of Smart Grids and Renewable Energy

The Research Council of Norway is the R&D-funding agency in Norway. The research council has organized the support for energy research sector in two programs ENERGIX and FME (Centers for Environmentally-Friendly Energy Research). The funding of demonstration projects is covered by two agencies, ENOVA for domestic projects and Innovation Norway for projects that aims mostly at innovation and industrialization:

**The Research Council of Norway, RCN (R&D-funding):**
The ENERGIX program provides funding for research on renewable energy, efficient use of energy, energy systems and energy policy. This encompasses both natural science and engineering as well as social science based research and development. ENERGIX has a wide range of funding instruments, and both industry, research institutes and universities can apply for funding. The program is a key instrument in the implementation of Norway's national

RD&D strategy, Energi21, as well as for achieving other energy policy objectives.https://www.forskningsradet.no/prognett-energix/Home_page/1253980140022

The FME-scheme seeks to develop expertise and promote innovation through long-term research in selected areas of environment-friendly energy. There are today 11 FME centers within renewable energy, energy efficiency, social sciences and $CO_2$ management. The centers are hosted by either research institute or universities. The research activity is carried out in close cooperation between prominent research communities and industry partners.

https://www.forskningsradet.no/prognett-energisenter/Home_page/1222932140849

**ENOVA: Energy and Climate Technology Demonstration**
Enova is a state-owned enterprise owned by the Norwegian Ministry of Petroleum and Energy. Enova's objective is to contribute to reduced greenhouse gas emissions, development of energy and climate technology and a strengthened security of supply. The support to energy and climate technology must result in a reduction of greenhouse gas emissions, promote a long-term shift in energy consumption/generation and improve security of energy supply by utilizing flexibility in energy consumption and generation. Both power/peak power and energy aspects are covered.

It can be costly and risky for individual businesses to start using the newest and most climate-friendly technologies. Enova can make a financial contribution so that projects become economically feasible to implement. Each year, Enova invests more than NOK 2 Billion of public resources in solutions that help build the green Norway for tomorrow.
https://www.enova.no/about-enova/

Innovation Norway: The Environmental technology scheme
The scheme promotes funding of pilot and demonstration facilities in development of new environmental technology in Norway and abroad.

Funded projects are expected to have great potential for commercial development, and it is expected that the environmental effect of the work can be documented. Innovation Norway contributes expertise, networks and funding to reduce risks and facilitate the implementation of such demanding development projects.
http://neec.no/innovation-norway-environmental-technology-enterprises-financing-scheme-miljoteknologiordningen/

**National Smart Grid R&D Activities in Line with POWs Tasks and Sub Tasks**
The Norwegian Smartgrid Centre (NSGC) was established in 2010 on the basis of a recommendation of the Norwegian Ministry of Petroleum and Energy in its national strategy process for defining future Energy R&D in Norway. NSGC is a strategic partnership, organized as a membership organization, where the purpose is to coordinate and promote smart grid R&I initiatives, education, and exchange of information between the members of the NSGC. The NSGC has established Demo Norway for Smart Grids, a national Smart Grid demonstration and laboratory platform to support development, testing and verification Smart Grid technologies, services and use cases

both in real life and laboratory environment. Demo Norway comprises presently nine real demo sites (living labs) with more than 10,000 network customers with Smart meters connected as well as the brand new National Smart Grid Laboratory. Pilot use cases tested have been within demand response, flexibility, smart operation, self-healing, prosumers, zero emission buildings, micro grids, electric transport etc. Demo Norway is coordinated with FME CINEDI – see section 5. The most important R&D activities in line with POWs tasks is shown in the table below.

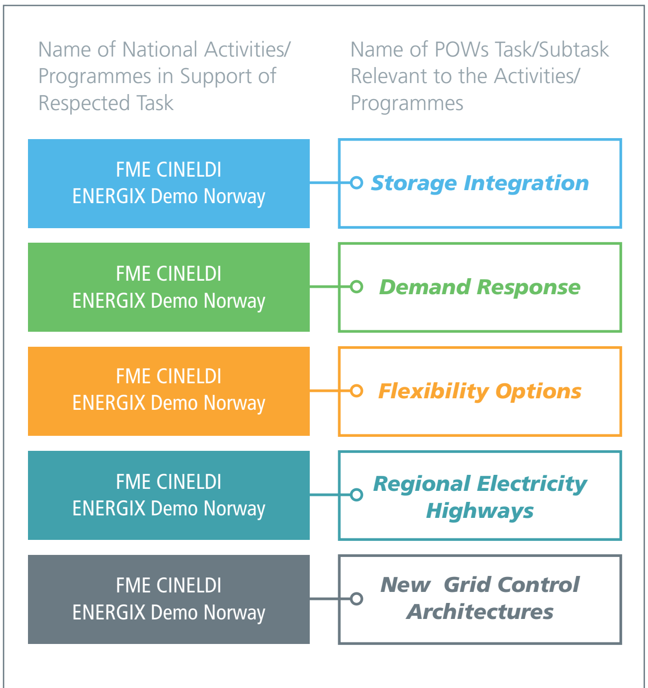


Figure 11-7

## 11.4 International Programme Related to Smart Grids and Renewable Energy

In the field of energy R&D, international cooperation is given high priority in Norway and it is an important supplement to national research efforts, Norway is primarily involved in cooperation under the EU system, the International Energy Agency (IEA) and at Nordic level. In addition to MI the RCN participates in ERA-NET initiatives. Norway is also involved in a number of bilateral funding agreements (the US, Japan Brazil, Canada, India, Japan, China, Russia, Singapore, South-Africa). Foreign research institutions may also be supported in Norwegian R&D-projects.

## 11.5 Case Study

**PROJECT CASE #1**
**FME CINELDI**
**Related sub-challenge of IC1.**

### Related Sub-challenge of IC1

concerning regional grid innovation, distribution grid innovation, micro grid innovation, and cross innovation.

### Type of Project

Theoretical research, technology development and demonstration

### Topic

Smart distribution grids, distribution system asset management and operation, micro grids, TSO-DSO interaction, power system flexibility and demand response.

### Objective

The main objective is to enable a cost-efficient realisation of the future flexible and robust electricity distribution system by developing new concepts, technologies and solutions. By providing new visionary smart grid use cases and testing them in laboratory and real life environments, the knowledge and experience gained will help DSOs, TSO, manufacturers and ICT companies to develop and integrate new technologies and work processes, stimulating innovations. These innovations will in turn contribute to a more sustainable energy system by increasing influx of renewables, electrification of transport and more efficient energy use. The sustainability targets cannot be met unless transformation of the distribution system is addressed.


Figure 11-6

### Contractors
SINTEF Energy Research, The Norwegian University of Science and Technology-NTNU, the Norwegian TSO and main DSOs, International and Norwegian technology and system providers, authorities and member organisations

### Period
2017-2025

### Ongoing and achieved key findings
New methodology for stochastic distribution system planning based on smart meter data

Laboratory testing of new distribution system protection concept allowing meshed distribution system operation increasing grid capacity.

TSO-DSO interaction use-cases, data models for TSO-DSO interaction, TSO-DSO communication requirements

Mapping of the flexibility potential among Norwegian households and more knowledge related to appearance and use of different flexible resources (flexible demand, energy storage and distributed generation).

Mini scenarios and drivers for the future intelligent distribution system innovation

FME CINELDI is a large, long term program with many research tasks inline with the tasks in IC1 POW as indicated in the table in section 3.

## PROJECT CASE #2
## Sparc- SynchroPhasor-based Automatic Real-time Control Related sub-challenge of IC1.

### Related Sub-challenge of IC1
Concerning regional grid innovation

### Type of Project
Theoretical research, technology development and demonstration

### Topic
Smart transmission grids, Wide Area Monitoring, Protection and Control (WAMPAC), PMU technologies, state estimation.

### Objective
The Primary objective is to develop new knowledge, methods and tools for automatic control and protection of transmission systems based on PMU data to improve system stability and robustness to contingencies, and by this contribute to future stable and secure operation of the Nordic power system with an increased share of renewables and HVDC interconnections.

Figure 11-6

### Contractors
SINTEF Energy Research, The Norwegian University of Science and Technology- NTNU, KTH Royal Institute of Technology, Statnett, Svenska kraftnät, Landsnet, Energinet, Fingrid and GE

### Period
2018-2022

### Ongoing and achieved key findings
An aggregated equivalent real time model of the Nordic transmission system is demonstrated in the national smart grid laboratory.

Sparc is of relevance for the IC1 tasks: Regional Electricity Highways and New Grid Control Architectures


# 12. REPUBLIC OF KOREA

## 12.1 General framework and implementation

As a result of global GHG reduction, energy transition trends and the 2016 Paris Climate Change Agreement, a new climate regime has emerged. The energy industry has strengthened its focus on existing supply base through eco-friendly energy production and efficient consumption. As a result, the structure of energy prosumers that expand, consume and produce distributed power sources such as solar energy and ESS has changed. Based on transition of energy and ICT, the new energy industry which actively promotes new energy services related to renewable energy and ICT, is attracting attention as a new growth engine.

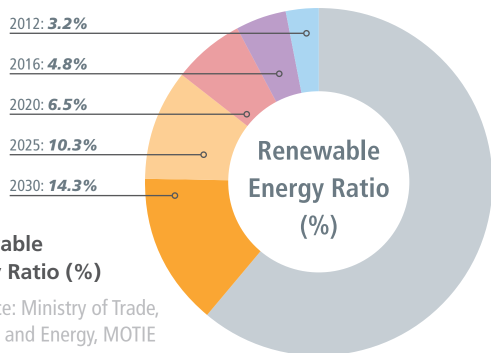
| | |
|---|---|
| Population | ***51,362*** thousands |
| Total area | ***100,364*** km$^2$ |
| ***Energy Mix*** ***302,068*** thousands TOE (Coal 29%, Oil 39.4%, Natural gas 15.6%, Hydro 0.5%, Nuclear 10.4%, Renewables 5.1%) | |
| Electricity consumption | ***543,521 GWh*** |
| Electricity generation | ***553,530 GWh*** |
| Overall network losses | ***3.57%*** |

Reference: Electric Power Statistics Information System, and Korean Statistical Information Service

Figure12-1. Key Figures of Country by 2017

## 12.2 Status of Renewable Energy Source Application

The Korean government announced the "Implementation Plan for Renewable Energy 2030" in December 2017, through the process of collecting opinions from local governments and related organizations. Following the fourth energy basic plan, the proportion of renewable energy is expected to reach 6.5% in 2020, 10.3% in 2025, and 14.3% in 2030. During the 2012 ~ 2030 period, the annual average renewable energy growth rate is 9.7%; higher than the primary energy demand which grew at a CAGR of 0.9% over the same period. And suggested the direction to expand the supply of renewable energy continuously.




**Renewable Energy Ratio (%)**

Reference: Ministry of Trade, Industry, and Energy, MOTIE

Figure12-2.Trend and Targeted Renewable Energy Ratio by 2030

While the proportion of waste has greatly reduced, the supply of renewable energy centered on clean energy is expected to expand by harvesting solar energy and wind power as core energy sources. Compared to 2012, the aim is to cut down wastes (67.8 → 22.7), while increasing solar power (2.7 → 20.8) and wind power (2.2 → 19.1) by 2030. The government plans to use renewable energy as an opportunity to nurture renewable energy industry through R&D initiatives, demonstration projects and export industrialization by presenting a vision to promote participation of clean energy, public participation, and large-scale projects.

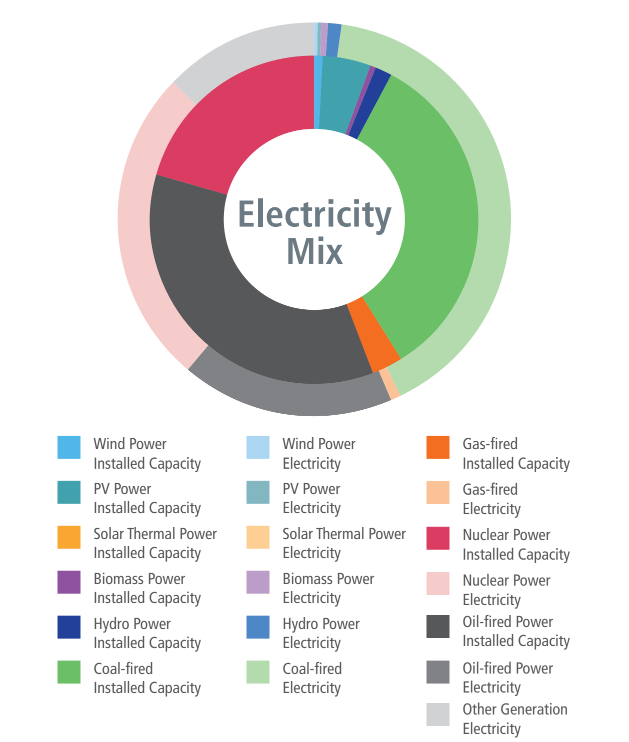



Figure 12-3. Electricity Mix by the End of 2017

Table 12-1. Trend and Targeted New & Renewable Energy Mix Percentile by 2030

| Parameter | | 2012 | 2016 | 2020 | 2025 | 2030 | Annual increase |
|---|---|---|---|---|---|---|---|
| Renewable | Solar Thermal | 0.3 | 0.3 | 1.1 | 2.8 | 3.8 | 26.5 |
| | PV | 2.7 | 7.7 | 13.4 | 17.1 | 20.8 | 23.0 |
| | Wind Power | 2.2 | 2.5 | 5.9 | 12.4 | 19.1 | 23.8 |
| | Biomass | 15.1 | 19.5 | 25.1 | 22.4 | 19.2 | 11.2 |
| | Hydropower | 9.2 | 4.3 | 3.2 | 2.2 | 1.8 | 0.3 |
| | Geothermal | 0.7 | 1.1 | 2.1 | 3.3 | 4.3 | 21.0 |
| | Marine | 1.1 | 0.7 | 0.5 | 0.3 | 0.2 | 0.3 |
| | Waste | 67.8 | 61.7 | 40.2 | 30.2 | 22.7 | 3.3 |
| | Hydrothermal | 0.0 | 0.0 | 2.1 | 2.8 | 3.2 | 46.7 |
| New | Fuel Cell | 0.9 | 1.7 | 3.9 | 3.2 | 2.5 | 15.9 |
| | IGCC | 0.0 | 0.5 | 2.5 | 3.2 | 2.3 | 56.6 |

Reference: New & Renewable energy Action plan 2018

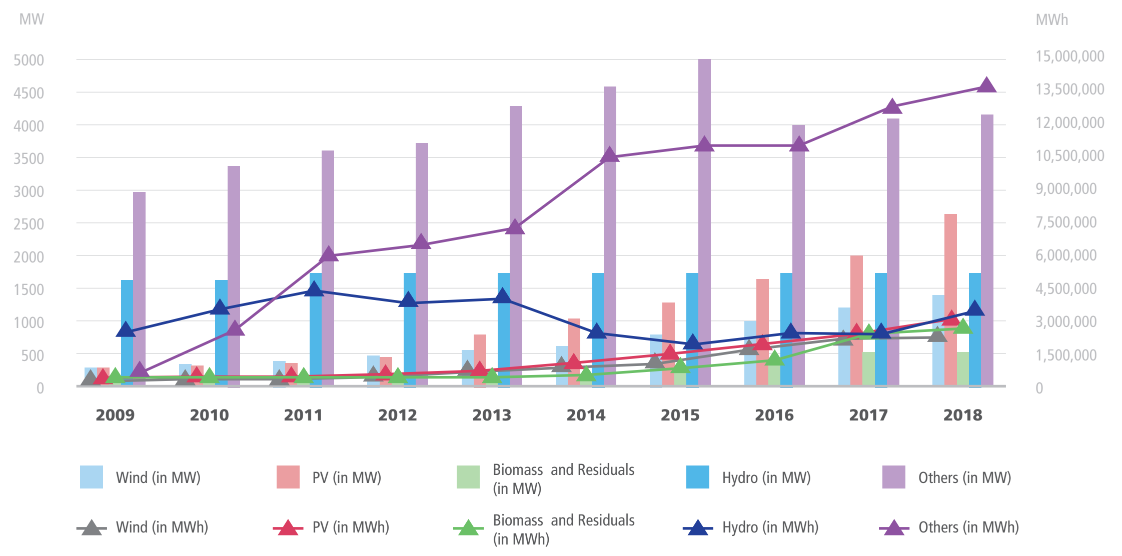



Figure 12-4. Trends on Renewable Energy Generation

## 12.3 Status of Smart Grid

(Grid Structure) At present, in the domestic electric power industry, 6 power generation companies, independent power producers, and community energy systems are producing electric power, and KEPCO (Korea Electric Power Corp.) transports the electric power it purchased from the Korea Power Exchange through the transmission and distribution network, and sells it to general customers. KEPCO owns and operates the national power gird and distribution networks. The transmission network is approximately 31,250 km long, including 835km of 765 kV lines, 8,653 km of 345 kV lines and of 21,530 km of 154 kV and below lines. Transmission lines tend to run from the north-western and south-eastern coastal regions, where much of the generating capacity is located, to major urban and industrial centers in the north-west while high-voltage direct current (HVDC) submarine cables connect the island of Jeju in the south to the mainland. The national power grid is an isolated system with no cross-border transmission lines. The distribution network is approximately 435,549 km long.

(Electricity Market) The domestic smart grid market is expected to grow at a CAGR of 28% from 352 million USD (0.4 trillion KRW) in 2012 to 2.2 billion USD (2.5 trillion KRW) by 2020. Among the five areas of intelligent power grids, consumers, services, transport and new renewals, the smart grid segment accounted for the largest market size, and the smart renewable and intelligent services market was expected to grow at an annual average growth rate of more than 50%. However, the present market creation performance is insufficient, and it is expected that the market will expand rapidly through the government's aggressive new energy industry development policies.

The government has promoted the first smart grid basic plan (2012 ~ 2016) for the establishment of smart grid base cities by the 7 major broad areas, and the consumer electric power market ecosystem (2018 ~ 2022) and plan to invest 4.5 trillion KRW over the next five years. In addition, there are plans to activate new smart grid services, expand smart grid infrastructure and facilities, and create service experience complexes.

**Demonstration stages (Smart city)**

| ***Stage*** | ***Stage 1*** | ***Stage 2*** |
|---|---|---|
| Facility | AMI | PV, ESS |
| Main service | Cost analysis | Apartment ESS<br>Energy grid economics |
| Period | 2019~ | 2019~ |

| ***Stage*** | ***Stage 3*** | ***Stage 4*** |
|---|---|---|
| Facility | PV, ESS, EV | - |
| Main service | V2G based on DRMicrogrid | Sejong smart city service demonstration site |
| Period | 2021~ | End of 2021 |

Reference: 2018, MOTIE

Figure 12-5. Smart Grid Complex Implementation Plan

## 12.4 National Programs in Fields of Smart Grids and Renewable Energy

(Funding Agency) Korea Institute of Energy Technology Evaluation and Planning (KETEP) is a government agency under the authority of the Ministry of Trade, Industry, and Energy (MOTIE) which undertakes a major role in planning, evaluation, and managing national energy R&D projects, founded in accordance with the Energy Act in May 2009.

(National R & D Program: Smart Grid) The Smart Grid Program is a research and development program managed by KETEP that develops technologies to reduce and distribute power demand and develops cross cutting techniques that converge ICT and power grids. There are three sub-programs, namely "Intelligent Transmission and Distribution Technology Development", "Intelligent Consumer Technology Development", and "Electric Device Technology Innovation". The budge for 2018 was about 8.82 million USD (10 billion KRW), and the budget for the first smart grid technology development project in 2019 is about 3.08 million USD (3.5 billion KRW).

(National R & D Program: New & Renewable Energy) The Renewable Energy Technology Development Program is a research and development program managed by KETEP that accelerates the transition to a clean energy-based society and develops technologies to promote greenhouse gas reduction. In addition, new renewable energy is stored in connection with the ESS system, and technologies related to interface such as IoT are developed. There are twelve technologies related to this program: PV, Wind Power, Hydrogen/Fuel Cell, Biomass, Hydropower, Coal Utilization, Waste, Marine, Geothermal Energy, Solar Heat, and Convergence of Renewable Energy Sources. The budget for the first renewable energy technology development project in 2018 was about 49.2 million USD (55.7 billion KRW). The budget for 2019 is about 8.4 million USD (9.5 billion KRW).

(Smart Grid Demonstration Project) There are companies engaged in domestic Smart Grid business such as KT, LG U+, SK Innovation, GS Caltex, Hyundai Heavy Industries, KEPCO, LS Industrial Systems, and Nuri Telecom. The business is going on nationwide.

Establishment of Advanced Metering Infrastructure (AMI). Demonstration projects and micro grid demonstration projects using energy to grid by storing new renewable energy in ESS system is underway. In 2018, Smart Energy City was established in the Magok district of Gangseo Suburb, Seoul. The purpose was to build an integrated energy production and consumption data platform, and also to optimize operation through detailed data analysis. In addition, the company has introduced power peak management, demand response resource discovery registration, and energy prosumer-based shared economic system.

In 2019, a government-funded Smart Grid project that uses the Big Data of Energy Cloud to create an energy network will be carried out.

(International Cooperation Program) A global collaboration program operated by KETEP focusing on the development of innovative energy technologies through international cooperation. The program has two priorities, first is supporting highly innovative technologies and the other is supporting market technology focused on commercialization abroad. In 2018, there were 60 bilateral collaboration projects with 19 countries, including the EU territory, United States, China, Canada, Japan, Vietnam, Singapore, Malaysia, Indonesia, Saudi Arabia, Ghana, etc.; and cooperative activities with IEA and Mission Innovation. In addition, the Korea Smart Grid Project carried out preliminary surveys and feasibility analyzes for smart grid policy, industrial equilibrium surveys and smart grid infrastructure exports to the United States, Africa, Europe and Asia. Such as promoting Smart Green Building project in the United States, demonstrating AMI in Algeria, and establishing independent power generation system in Myanmar. Therefore, we established a cooperation network with overseas governments and related organizations to promote global information, technology exchange and cooperation projects.

## 12.5 Case Studies

PROJECT CASE #1

**Development of and Demonstration of IoT Based Campus Microgrid**

**Related Sub-challenge of IC1**

Micro grid innovation

**Type of Project**

Demonstration

**Topic**

Campus Microgrid, EMS, IoT, MoMC, Big Data

**Objective**

Demonstration for campus microgrid system at Seoul National University

**Contractors**

LS, Gachon University, Kookmin University, Myungji University, Incheon University, Feelingk inc, Seoul National University, LG, Greeninfo inc, KTL, KEPCO, Neopis inc, Naracontrols, Inha University, KETI

**Period**

2015. 06 ~ 2019. 05

**Ongoing and Achieved Key Finding**

**Main objectives of this project are:**

- Decreasing 20% of Peak Load of microgrid in Seoul National University
- Securing Track Record for 4 hours independent grid operation
- Building MG of MGs Center (MoMC) and Microgrid Energy management System(MG-EMS)
- Decreasing 10% energy use by building big-data platform
- Securing interoperability and resilience

**Added Value for IC1 Objectives**

**Accomplishments of this project are:**

- Building campus microgrid system that could secure Renewable Energy Resources in case of massive blackout.
- Reducing $CO_2$ emission; securing track record of campus microgrid system

**PROJECT CASE #2**
**Development of Smart Grid Technology for BIPVT Assisted Heat Pump with Embedded Storage**

**Related Sub-challenge of IC1**

Micro grid innovation

**Type of Project**

Demonstration

**Topic**

BIPVT collector, Air based heat pump, Heating & cooling system, Electrical control, Smart grid

**Objective**

Demonstration of smart grid for BIPVT assisted heat pump

**Contractors**

Kongju National University, Innergie technologies, BonC innovators, CanmetENERGY

**Period**

2018. 11 ~ 2021. 10

**Ongoing and Achieved Key Finding**

**Main objectives of this project are:**

- (Air-type BIPVT collector) Development of light and inexpensive collector
- (Heat pump) Development of BIPVT assisted heat pump for building
- (Smart grid) Development of system control logic for smart grid with BIPVT assisted heat pump system

**Added Value for IC1 Objectives**

**Accomplishments of this project are:**

- Heat pump connected to solar energy system with energy storage for effective energy load matching; and responsible to grid to make it more economical.
- Utility companies can reduce demands for increased energy generation capacity by adopting the new smart control technologies.

## 12.6 Reference

[1] Bayindir et al., Smart grid technologies and applications, Renewable and Sustainable Energy Reviews 66 (2016) 499-516

[2] Jenkins et al., An overview of the smart grid in Great Britain, Engineering 1 (2015) 413-421

[3] Avancini et al., Energy meters evolution in smart grids: A review, Journal of Cleaner Production 217 (2019) 707-715


Figure 13-1. Transmission Lines Projects (380 kV)[13-3]

# 13. SAUDI ARABIA

## 13.1 General Framework and Implementation

The Kingdom of Saudi Arabia is a world leader in the energy sector and a strong advocate of the transition to a clean energy system with a significant emission reduction. By joining Mission Innovation, Saudi Arabia pledged to double its research, development, and demonstration of clean energy technologies by 2021.

Saudi Arabia is considered to be the largest exporter of petroleum liquids in the world. It has the world largest daily production capacity of approximately 12 million barrels. Also, the Kingdom has an estimated 16% of the world's proven oil reserves[13-1] and the fourth largest natural gas reserves in the world. Saudi Arabia is one of the founders and active members of the Organization of the Petroleum Exporting Countries (OPEC).

| | |
|---|---|
| Population (2018)[13-2] | 33,413,660 |
| Total Area (km²) | 2,150,000 |
| GDP per Capita (2018)[13-2] | 21,997 |
| Electricity Consumption (TWh) (2017)[13-3] | 298,439 |
| Electric Power Capacity (GW) (2017)[13-3] | 62,121 |
| Electric Power Capacity (GW) (2017)[13-3] | 88,686 |

Figure 13-2. Key Figures for Saudi Arabia

[13-1] Energy Information Administration, https://www.eia.gov/beta/international/analysis.php?iso=SAU

[13-2] General Authority for Statistics, https://www.stats.gov.sa/en/page/194

[13-3] Saudi Electricity Company Annual Report 2017, https://www.se.com.sa/en-us/Pages/AnnualReports.aspx

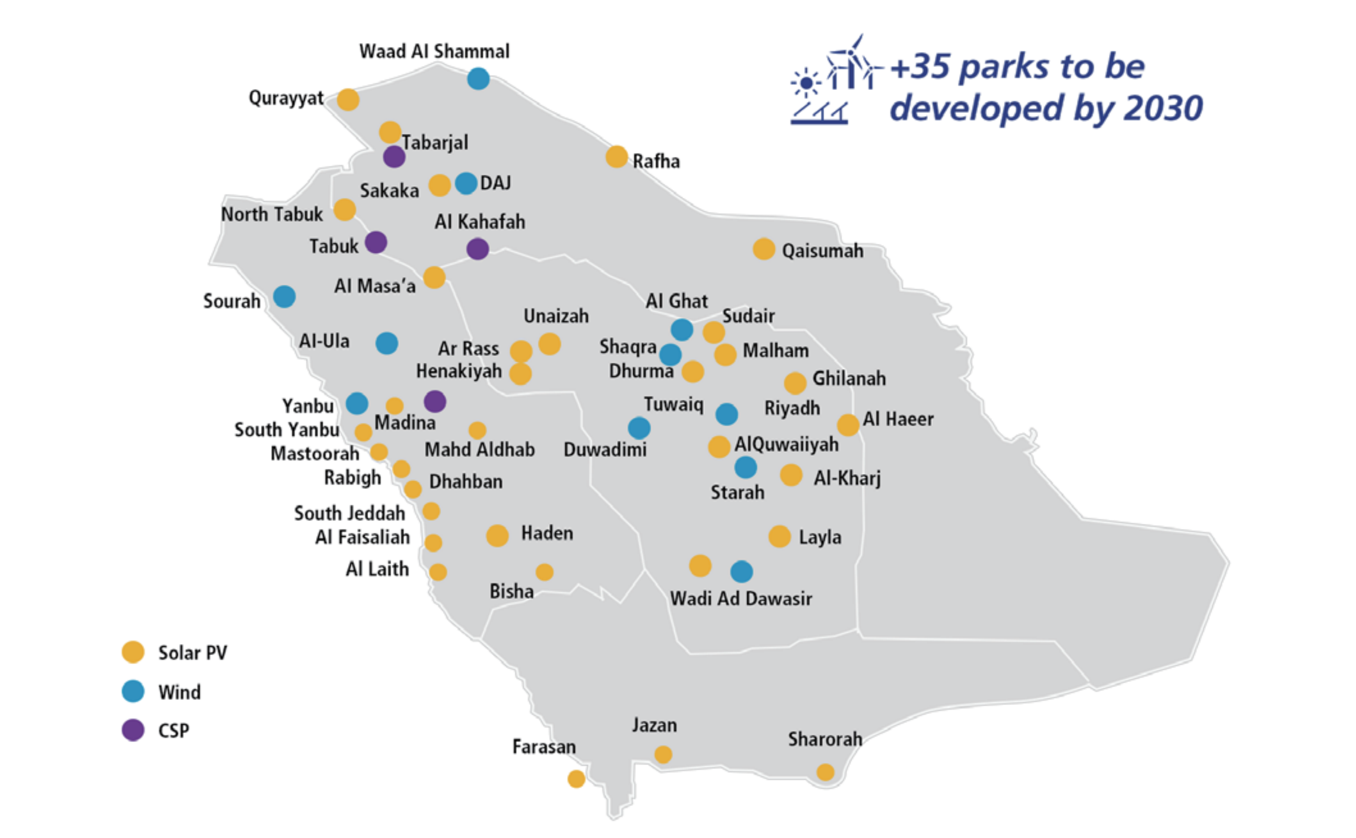



Figure 13-3. Renewable Energy Projects (Courtesy of REPDO)[13-4]

## 13.2 Status of Renewable Energy Applications

Saudi Arabia started the National Renewable Energy Program as a strategic initiative under the Saudi Vision 2030 to maximize the potential of Renewable Energy Sources to electricity generation in the country. The program sets the roadmap and plans for the implementation of RES projects in the Kingdom. The plan sets a target of 27.3 GW of renewable capacity by 2023. On the long-term, the plan is to reach more than 58 GW capacity of RES distributed over 35 locations by 2030. The breakdown of planned renewable energy technologies is shown in Figure 13-4.

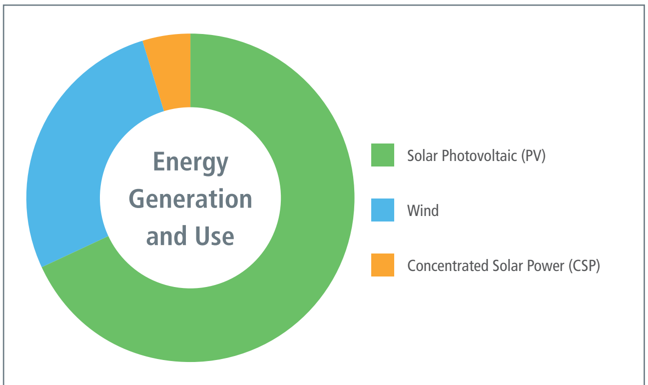



Figure 13-4. The Contribution of Renewable Energy Sources to Electricity Generation

Currently, there are two utility-scale projects under development, the first one is a 300 MW solar farm in the northern region of the Kingdom which is referred to as the Sakaka project. The project is planned to start commercial operation in 2019[13-5]. The second project is a 400 MW wind farm in Dumat Al Jandal[13-6] which will be developed by an alliance between EDF Renewables and Abu Dhabi Future Energy[13-7].

Small scale PV systems are starting to grow mainly in commercial and industrial sectors. PV penetration in the residential sector is relatively low due to heavily subsidized electricity tariff for residential customers.

[13-4] Renewable Energy Project Development Office, https://www.powersaudiarabia.com.sa/web/attach/media/Kingdom-Renewable-Energy-Plan_Ar-En-R04.pdf

[13-5] Renewable Energy Project Development Office, https://www.powersaudiarabia.com.sa/web/all_news.html#ff

[13-6] Ministry of Energy Industry and Mineral Resources, https://ksa-climate.com/making-a-difference/nrep/

[13-7] Masdar, https://masdar.ae/en/news-and-events/news/2019/01/11/11/46/the-edf-renewables-masdar-consortium-awarded-the-dumat-al-jandal-wind-project-in-saudi-arabia

Another area of renewable energy application is solar water desalination. Recently, a 10 MW Solar PV powered desalination plant went operational in Al Khafji, north east of Saudi Arabia, with an estimated desalination capacity of 60,000m³/day utilizing Reverse Osmosis (RO) technology[13-8]. There are a few solar thermal applications but they are still in the technology demonstration phase.

### Main actors in the energy sector

**SEC:** is the Saudi Electricity Company

**REPDO:** is the renewable energy program development office (REPDO) within the Ministry of Energy, Industry and Mineral Resources (MEIM). The office oversees the National Renewable Energy Program (NREP) initiative to ensure its successful implementation and execution.

**ECRA:** is the Electricity & Co-Generation Regulatory Authority which is the regulator of the electricity and water industry in the Kingdom of Saudi Arabia.

**KA-CARE:** is King Abdullah City for Atomic and Renewable Energy which has the responsibility of developing the renewable and nuclear energy industry in the Kingdom and conduct studies with the aim of achieving sustainability of the energy sector in the country.

**KACST:** is King Abdulaziz City for Science and Technology, a governmental entity that carries out scientific research, development, and innovation in various fields. Its mandate is to drive the innovation ecosystem in Saudi Arabia and support industrial development in the country.

## 13.3 Status of Smart Grids

### Electricity Structure

The Saudi electricity system is operated by the Saudi Electricity Company (SEC) along with few small scale Independent Power Producers (IPPs). The electricity system is vertically integrated. As such, SEC oversees the generation, transmission and distribution. The current generation capacity is 88.7 GW where SEC owns 66% of total capacity installed, the remaining 34% is distributed among several independent power producing entities[13-9]. The transmission network interconnects the entire Kingdom with approximately 78,723 km long double circuit transmission lines with voltage levels varying from 110-380 kV. The distribution sector is currently solely managed by SEC across the county except for the two industrial cities in Al-Jubail and Yanbu. The distribution networks consist of approximately 301,669 km long of overhead double circuit lines and 314,510 km of underground double circuit cables[13-9].

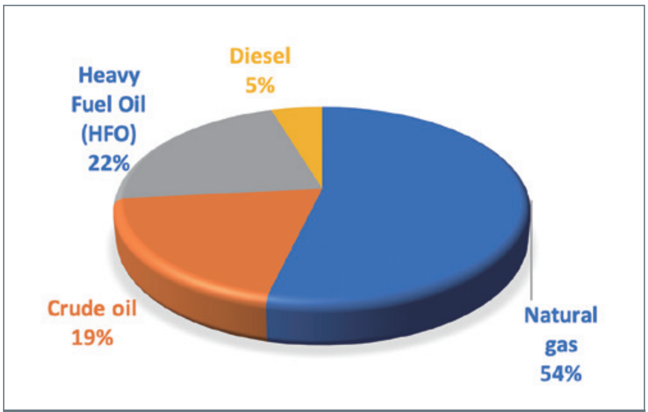



Figure 13-4. Type of Fuel Used for Electricity Generation[13-9]

### Load Characteristics

Given the high temperature climate of the Kingdom, 70% of electrical demand is attributed to air condition units[13-9]. The peak demand in the country is during the afternoon period which coincides with the high intensity of solar energy. The residential sector consumes approximately half of the electric energy produced followed by the industrial sector as shown in Figure 13-5.

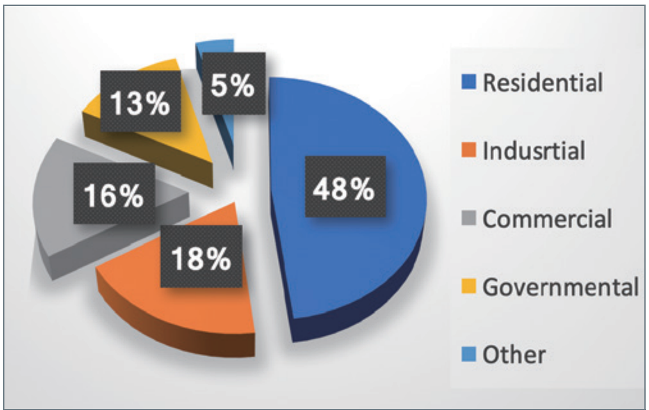



Figure 13-5. Electrical Energy Consumption by Sector[13-9]

Water desalination is a major energy consumer in Saudi Arabia. The Kingdom is the largest producer of desalinated water in the world[13-9] with an estimated average yearly production of 1.62 billion m³ of desalinated water. The water desalination industry is primarily operated by the Saline Water Conversion Corporation (SWCC) along with a much smaller scale desalination entity.

[12-8] Advanced Water Technology, http://www.awatertech.com/projects

[12-9] Electricity & Co-Generation Regulatory Authority Annual report, https://www.ecra.gov.sa/ar-sa/MediaCenter/doclib2/Pages/SubCategoryList.aspx?categoryID=4 [Arabic only]

**Smart Grid**

The implementation of smart grid technology is still at its early state in the Kingdom. However, the rapid increase in peak demand of approximately 6% per year is a major driver to accelerate the adoption and transition to a more efficient smart grid.

ECRA of Saudi Arabia has a smart grid strategy which studied the cost/benefit aspects of Smart Grid technologies. The study also reviewed the major challenges of the electricity sector in the country which it can be summarized in three key challenges. The first challenge is the rapid increase in demand and subsequently the need for additional power capacity to supply the demand. The second challenge is the relatively high energy losses in the electrical network. The third challenge is related to the quality of supply especially at the distribution level, where the average number and time of power disturbance can be reduced. The study pointed out the potential direct and indirect benefits for implementation smart meters, and how Smart Grids technologies can improve quality of service due to lowering network losses and maintain continuity of service by reducing the duration of outages.

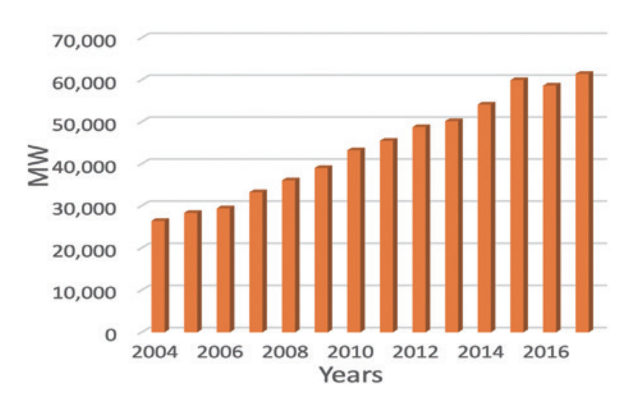



Figure 13-6. Evolution of Peak Demand

In addition, the Saudi Electricity Company (SEC) is adopting a smart grid strategy. The implementation of the strategy started with introducing an information, communication and technology (ICT) platform providing business intelligence for processing and managing information of both business and operation data. Also, SEC is working on several projects to implement several Smart Grids technologies such as: Wide Area Network, Advanced Metering Infrastructure, and Flexible AC Transmission System (FACTS).

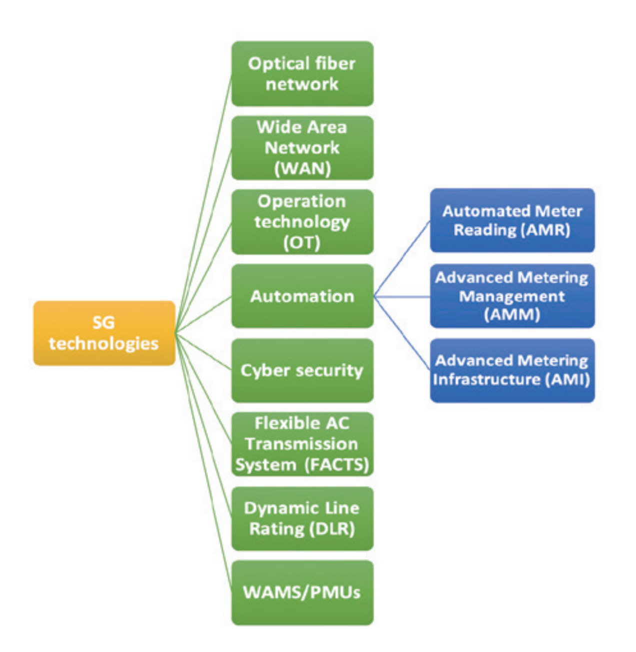



Figure 13-7. Smart Grid Enabler Technologies as Adopted by National Grid (Transmission Network Operator)

## 13.4 National Programs in Fields of Smart Grids and Renewable Energy

One of the major activities in the area of Smart Grids research, demonstration and innovation (RDI) is the joint research and development center between SEC and KACST that was established in 2015 with the focus on the distribution sector. The main areas that the center is working on include electrical power quality, protection systems, renewable energy integration, and substation automation and control.

In addition, the government has taken steps for ensuring energy efficiency with the establishment of the Saudi Energy Efficiency Center (SEEC). The center is responsible for enhancing the utilization of energy in three main sectors; industry, transportation and buildings which consumes 90% of produced energy.

For small scale renewable integration, in 2017 the Electricity & Co-Generation Regulatory Authority (ECRA) has approved and issued the regulations for residential PV installation. The regulations set out the requirement and procedures for end users to install and approved their PV installations.

**Case Study**

The Integrated System Monitoring and Decision Support System for Distribution Networks (ISMDSS) is a development project for monitoring and decision support solutions. The project is a joint collaboration between KACST and SEC and aims to develop a solution for providing real time synchronized measurements for the distribution network. A decision support system is developed utilizing the collected data and several software applications to provide control center and planning engineers with the capability of more insightful decision making.

**Executive Summary**

The Kingdom of Saudi Arabia is a world key player in the energy sector. Due to its fast economic development, it is experiencing a rapid increase in electrical power demand. To cope with the ever-increasing demand, a roadmap for smart grids and the integration of Renewale Energy Sources (RES) has been developed. By the year 2030 it is expected that nearly 58.7 GW of available electricity generation capacity will be provided by RES while the rest will be supplied from the conventional fossil-fuel energy sources and nuclear power plants. The implementation has already started with two renewable projects in the Kingdom comprising a 300 MW solar PV as well as a 400 MW wind farm. The Kingdom of Saudi Arabia is currently undergoing a major electricity structure transition to an open energy market-based model which would reform the rules and regulations of the electricity industry.

# 14. SWEDEN

## 14.1 General Framework and Implementation

With a population of approximately 10 million people, Sweden is a sparsely populated country, characterized by its long coastline, extensive forests and numerous lakes. It has a surface area of 447 435 km$^2$, roughly comparable to that of Spain, Thailand or California.

Sweden's economy is energy intensive and the energy system is characterized by a high degree of electrification. The total amount of electricity used, including distribution losses, amounted to 142 TWh during 2017[14-1]. Most of the electricity is used in the residential and service sector, followed by the industry sector.

Swedish electricity production is based largely on hydropower and nuclear power. In 2017 the total electricity supply is made up of 160 TWh, of which 64,5 TWh hydropower, 63 TWh Nuclear power, 17,5 TWh Wind power and 15 TWh from thermal power (mainly biomass-based).

[14-1] Energy in Sweden Facts and Figures 2019, Swedish Energy Agency 2019

### Energy Policy Goals and Long-term Vision

The Swedish energy policy targets for 2020 as passed by the Swedish parliament are:

- The proportion of renewable energy in the transport sector must be at least 10 per cent by 2020.
- Sweden's greenhouse gas emissions to be 40 per cent lower than in 1990.
- 20 per cent more efficient energy consumption than in 2008.

Additionally, by 2030, Sweden should have a vehicle stock that is independent of fossil fuels and, according to a broad parliamentary 5 party agreement in 2016 (The Swedish Energy Policy agreement of 10th of June 2016), the following long term goals and vision were enacted:

- No later than 2045, Sweden shall have no net emissions of greenhouse gases to the atmosphere, and will thereafter achieve negative emissions.
- The goal in 2040 is 100% renewable electricity production.

The national authority for energy policy issues is the Swedish Energy Agency (SEA). SEA is subordinate to the Ministry of the Environment and Energy, and regulated by the Government through the instruction and annual appropriations directives. SEA works for a sustainable energy system, combining ecological sustainability, competitiveness and security of supply. The Agency finances research for new and renewable energy technologies, smart grids, and the vehicles and transport fuels of the future. The Agency also supports commercialization and growth of energy related cleantech.

## 14.2 Status of Renewable Energy and Smart Grids

As of 2018 Sweden has an almost fossil-free electricity production and the share of renewable electricity production has grown extensively during the 2000s, with wind power accounting for the largest portion of the increase. This development can be explained by a variety of factors, where the key policies include:

- Energy tax on electricity and fuels enacted decades ago
- Carbon dioxide taxation on fossil fuels since 1991
- Green certificate system for renewable energy since 2003
- The energy research programmes having supported extensive research and innovation that have applications in society. The energy research grant constitutes an important means of influence and control for transforming the energy system.

### The Electricity Certificate System Supports Renewable Electricity Production

The rapid growth of wind power over the last decade was mainly driven by the Green certificate system. The electricity certificate system is a market-based system that aims to increase the share of renewable electricity production. For every MWh of electricity produced by an approved renewable energy facility, the producer receives an electricity certificate. Electricity suppliers and certain electricity users in turn are required to purchase a certain proportion of electricity certificates in relation to their electricity sales or electricity use, a so-called quota obligation. The quotas are calculated based on the expected expansion of renewable electricity, the expected electricity sales and the electricity consumption with quota obligations.

Looking towards 2030-2050, the major innovation challenges with regards to renewable energy include and relate to the following three trends:

- the transition to replace roughly 40-50% of the electricity supply which today is based on nuclear power with variable renewable electricity sources
- a continuous accelerated trend where a few large scale central power generators are supplemented with and gradually replaced by many distributed medium and small-scale generators
- an anticipated increase in electricity demand when new electricity consumers from the transport sector emerge

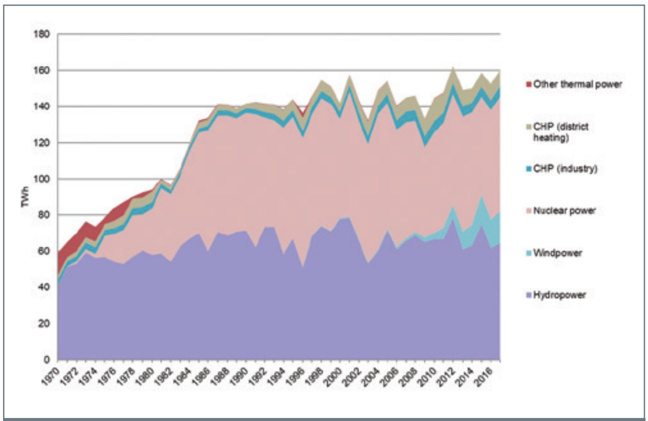



Figure 14-1. The Net Electricity Production by Source and Total Electricity Use in Sweden 1970–2015, TWh[14-2]

### Grids Structure and Electricity Market

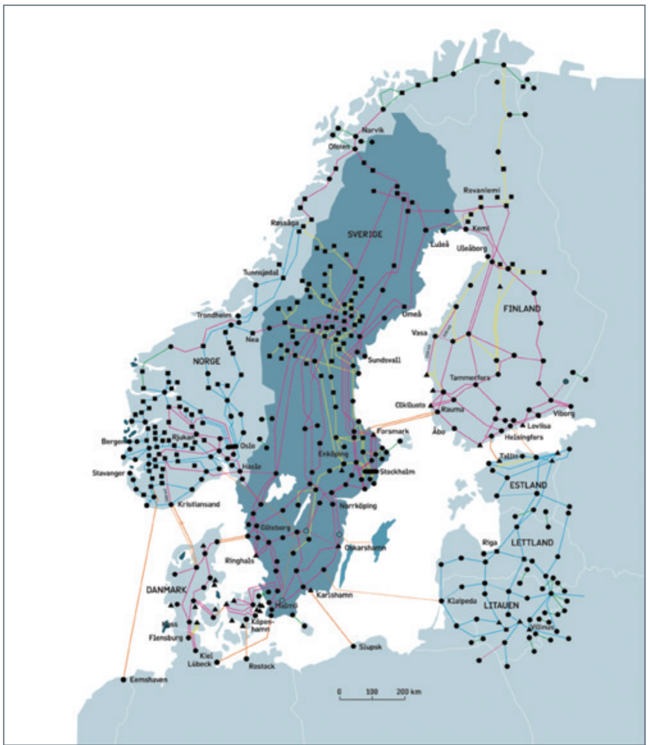



Figure 14-2. The Integrated Nordic Power System

The Swedish electricity system is part of the integrated Nordic electricity system and market. The electricity market is deregulated for supply and production of electricity, whereas the network companies operate the distribution network under a monopoly market setup. The picture above shows the high degree of interconnectivity (more than 20 percent) between the Nordic countries. Electric power is traded on the Nordic Power Exchange spot-market called Nord Pool. In recent years, our Baltic neighbor countries have joined and as of 2014 there is a price coupling between 15 countries – mostly in northern Europe, but also France and the Iberian Peninsula.

The main grid is owned and maintained by the TSO Svenska Kraftnät (the National Grid Authority), and the distribution networks are owned privately or by municipalities. The Energy Markets Inspectorate oversees the non-government distribution systems for electricity and natural gas. The Swedish Energy Market Inspectorate regulates the revenues for each network company, under a four-year revenue cap. The regulation is technology neutral and does not give any specific incentives for new technology. However, complementary incentives for effective utilization of the electricity network and security of supply (few disruptions in delivery) are included in the regulation.

The Swedish electricity system is divided into four electricity areas, and the electricity price can differ from one electricity area to the next depending on the restrictions between these areas. The aim of the partitioning into electricity areas is to make it clear where in Sweden there is a need to reinforce and expand the national grid. It also provides a clear indication of where in the country there is a need to increase electricity production to better match the level of consumption in that specific area.

The electricity is traded on the electricity exchange Nord Pool Spot, implemented by Sweden and Norway in 1996. In addition to Statnett and Svenska kraftnät, the transmission system operators in Finland, Denmark, Estonia and Lithuania are also owners of Nord Pool. Nord Pool's participants include power producers, electricity suppliers, major end-users, portfolio managers, capital managers and brokers. In 2015, the companies on Nord Pool Spot traded 489 TWh of electricity, 374 TWh of which in the Nordic and Baltic countries[14-3]. Electricity can also be traded off the exchange bilaterally between seller and buyer or within electricity companies.

[14-2] Swedish Energy Agency and Statistics Sweden. Notes: Wind power was included in hydropower up to and including 1996.

[14-3] Nord Pool Spot, Annual report 2015, Power without borders.

### Sweden’s Smart Meter Roll Out

Sweden’s deployment of Advanced Meter Infrastructure began in 2003 when the Swedish parliament decided that by 2009 all electricity customers should have monthly billing based on actual consumption from monthly meter readings for residential and small business customers, and hourly readings for larger customers with a fuse above 63 A. This requirement resulted in a full-scale installation of AMR/AMI systems for nearly all Swedish consumers (5.2 million). The total cost of the roll out of AMR/AMI systems was estimated at 1.5 billion euro and was completed in 2009.

Since the deployment, many DSO’s have found that their roll-out led to both expected financial benefits and to non-financial benefits in service quality, customer satisfaction and improved safety on the network.

### The Swedish Smart Grid Forum Supports the Implementation of the National Smart Grid Road Map

The Swedish Smart Grid Forum is a national forum appointed by the Swedish Ministry of the Environment and Energy. The purpose and mandate of the Forum is to contribute to knowledge development and to strengthen the capability and capacity for smart grid solutions for the future, in Sweden and globally.

The goals of the Swedish Smart Grid Forum are:

- An electricity market with active customers, as well as the robust and effective integration of 100 percent renewable electricity.
- Sweden is a hub for smart grids, with internationally recognized expertise and a natural test bed for smart grids.
- Growing the number and variety of exporting smart grid companies, services and products in Sweden.

The mission of the Swedish Smart Grid Forum is to develop a dialogue about the benefits of smart grid. The forum will provide a platform for stakeholders that want to contribute and be part of the development of the future grid.

The Swedish Smart Grid Forum has further developed a strategy for increased flexibility in the energy system by use of smart grid technology. The strategy includes four key areas that are central to enabling desirable business models as well as increased supply and demand for services and products in the area. These areas are:

1. Prerequisites for new business models for flexible services
2. Developed market for system services

3. IT security and protection of personal integrity
4. Dissemination of information and knowledge

The Swedish Smart Grid Forum has also developed a strategy for internationalization. The strategy identifies international co-operation as key issue but also the benefits of platforms that gather relevant stakeholders nationally and internationally.

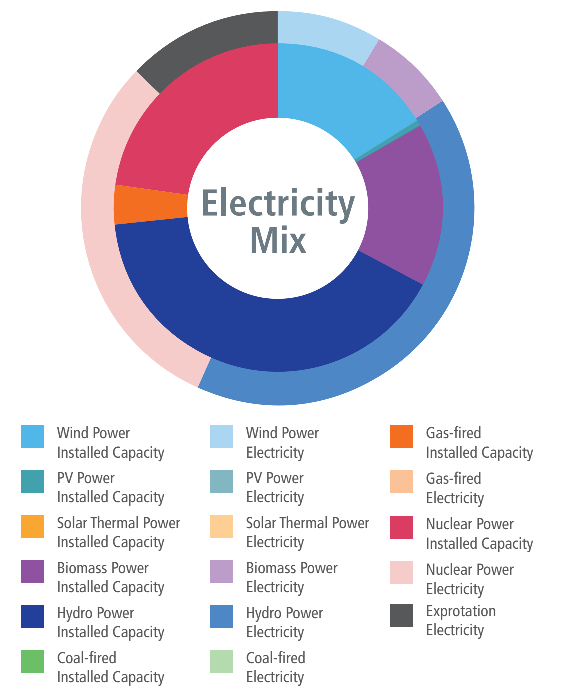



Figure 14-3. Electricity Mix by the End of 2016

| | |
|---|---|
| Number of Smart Meters | **5.2** Million (100 % of electricity customers) |
| Number of Electric Vehicles | **28,000** [14-4] |
| 545 000 km Lines of Which: | **329 500** km underground and **215 500** km overhead lines |
| Transmission Lines are: | **15 000** km at 400 kV and 220 kV<br>**170** Network Companies<br>(various size, some publicly and privately owned) |

*Note: The table could be filled by the national-level data, or separately by the state/region/province-level data if available.

Figure 14-4. Key smart grids facts and figures by the end of 2018

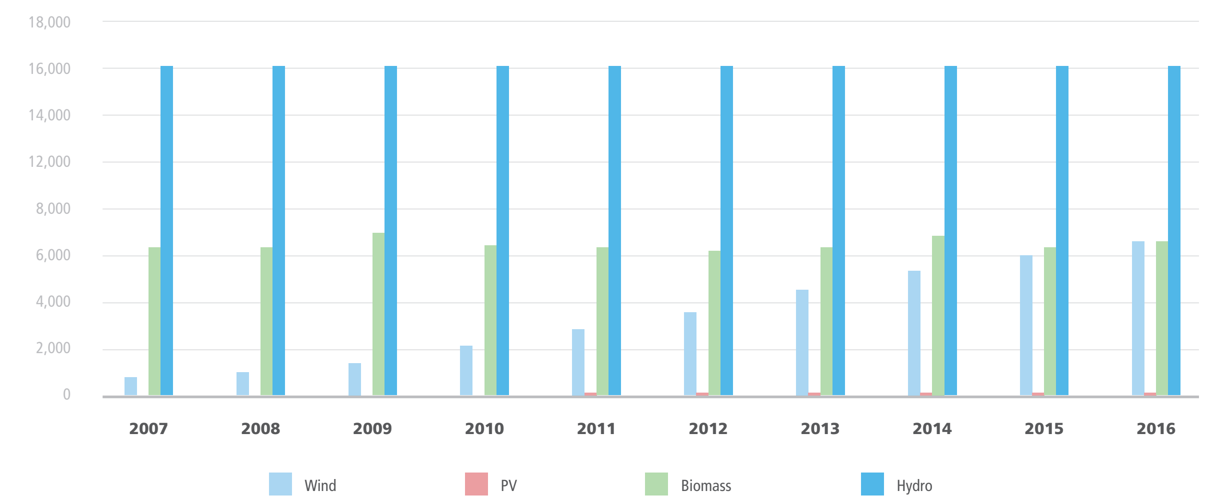



Figure 14-5. Trends on Renewable Energy Generation

[14-4] http://elbilsstatistik.se/startsida/se-statistik/

[14-5] SamspEL - http://www.energimyndigheten.se/forskning-och-innovation/forskning/fornybar-el/elnat-och-elmarknad/program/samspel/

[14-6] SweGRIDS - https://www.kth.se/en/ees/omskolan/organisation/centra/swegrids

[14-7] ERA-Net SES - https://www.eranet-smartenergysystems.eu/

## 14.3 National Programs in Fields of Smart Grids and Renewable Energy

Sweden has a national energy research policy and a national road map for smart grids (developed by the Swedish Smart Grid Forum). There is also an overarching governmental energy policy, for which the energy RD&I works as a key trial and implementation tool. Sweden has a common overall strategy for the whole energy system and within this strategy there are sub-strategies for different areas. The overall RD&I strategy is based on five overarching energy research and innovation challenges as described in the picture below.

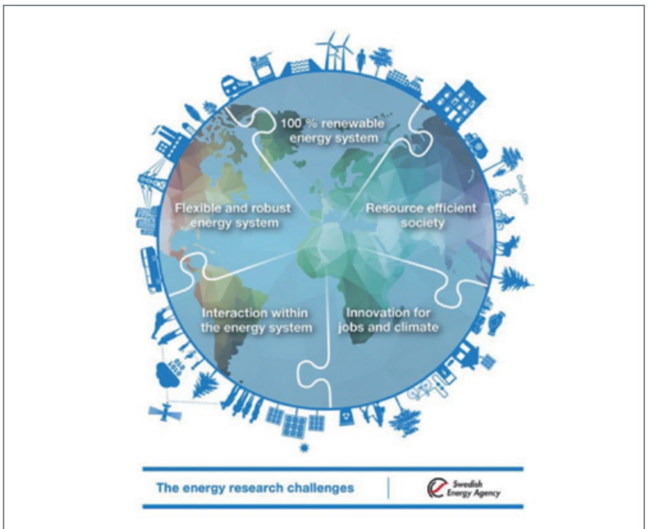



Figure 14-6. Research and Innovation Challenges

The main publicly supported framework for research, innovation and demonstration in the smart grids spectrum is the Swedish Energy´s programme **'INTERACT'** (SamspEL[14-5]). The programme has a vision for 2050 and projects funded through the programme are selected on the basis that they can yield results contributing to certain societal effects by 2030. Over the last five years, SEA has provided approximately 50MEUR of funding for smart grids. Funding for individual projects range between 0,05MEUR to ~2.5MEUR. Roughly 50% is supporting applied research and 40% goes towards innovation and demonstration projects. About 10% of the funding is directed to basic research.

**SweGRIDS**[14-6] is an important centre for smart grids and energy storage which besides the national programme SamspEL constitutes a significant share of the RD&I collaboration activities on smart grids between industry and universities. The centre is located at KTH and Uppsala University and receives substantial funding from the Swedish Energy Agency.

SEA also provides support for business development and market introduction, mainly based on loans. Communication about project results to the electricity sector and the broader public is further used to aid market introduction.

## 14.4 International Programme Related to Smart Grids and Renewable Energy

Sweden is actively participating in the European SET-plan collaboration on smart grids, mainly through the multilateral member-state initiative ERA-Net Smart Energy Systems[14-7] (SES). ERA-Net SES is joint programming platform with participation of 30 funding partners in 23 European countries and regions, collaborating on a common vision for Smart Energy Systems in Europe. The core goal of this initiative is to build up a sustainable cooperation structure between national and regional programs in Europe, as well as to enable coordination with other relevant initiatives on a European and global Level. ERA-Net SES intends to provide substantial contribution to the European Strategic Energy Technology Plan (SET-Plan). The initiative arranges yearly joint RD&I calls for transnational collaboration projects and where specifically Smart Grids is one of two main focus areas. Furthermore, to foster transnational learning and maximize impact, ERA-Net SES developed the Knowledge Community as one of its central instruments. This network consists of the funded projects, other bodies within ERA-Net SES as well as external stakeholders.

Through IEA and the Clean Energy Ministerial Sweden is also actively participating in the International Smart Grid Action Network, ISGAN. ISGAN creates a mechanism for multilateral government-to-government collaboration to advance the development and deployment of smarter electric grid technologies, practices, and systems. ISGAN is managed by its Executive Committee and Sweden has currently the position as chair in the initiative.

## 14.5 Case Studies

### PROJECT CASE #1
### Data Center Micro-grid Interaction

**Related Sub-challenge of IC1**

Micro grid innovation

**Type of Project**

Demonstration

**Topic**

Micro-grid
Data center
Photovoltage cells
Battery storage
Thermal storage

**Objective**

The overall objective of the project is, through demonstration, to show that data centers in combination with renewable electricity production and energy storage can be an important part of the future electrical system. The intention is to demonstrate that the installation can be used for peak shaving and load balancing as well as island operation during periods when conditions permits.

**Contractors**

**As partner of the Energy agency project:**

RISE SICS North
ABB AB
E.ON Värme Sverige AB
Vattenfall AB
Acon AB
Ericsson AB

**As contractor of the demonstrator facility:**

BOX Modul – EDGE datacenter
SWEGON – cooling systemABB – microgrid controller
BORÖ – thermal storage
NorthStar – battery storage
CEJN – quick connections
Bensby Rostfria – stainless hoses
IVAB – expansions cones
ENOC and F-RACK – data center equipment
Johanssons rör – piping installation
EITECH – electrical installation

**Period**

2017-01-01 – 2019-06-30

**Ongoing and Achieved Key Findings**

Research facility for AI based forecast operation optimization. Machine Learning testbed based on live measure data.

**Added Value of IC1 Objective**

In the future energy system works as load balancers for a more stable electrical gird, by that increasing the grid utilization. In that way grid investment can be delayed when CAPEX is converted to OPEX.

### PROJECT CASE #2
### Hot Water Carnot Battery

**Related Sub-challenge of IC1**

Cross innovation

**Type of Project**

Demonstration

**Topic**

Electricity storage, waste heat utilization, geothermal

**Objective**

1. Utilize industrial waste heat
2. Develop a > 100 MWh battery not requiring scarce metals
3. Meet target LCOE or LCOS of around 100 €/MWh el
4. Prove that hot water is an economic and suitable medium for electricity storage

**Contractors**

Climeon – project lead, technology
RISE – balancing power regulations, heat pumps
KTH – heat pumps, lab services

**Period**

Demo project 2016-2018

**Ongoing and Achieved Key Findings**

1. Electricity can be stored in hot water. The electricity content in combination with Climeon power plants corresponds to a pumped hydro plant with a level difference of 600 m.
2. Industrial waste heat of ca 60 °C can be utilized to produce 90 °C hot water at a COP of 4-5, thus giving a battery turnaround efficiency of 40-50% and reduced footprint of industrial operations.
3. A Climeon battery in combination with geothermal production of hot water, at typical COP values of 30-40, allows the highest electricity recovery of all known batteries, 300-400%, meeting LCOS targets of ca. 100 €/MWh. (This battery is not a Carnot battery, strictly speaking.)

### Added Value of IC1 Objective

The solution is suitable for distributed power networks, it is perfect for cooperation between renewable energy providers such as solar and wind on one hand, and geothermal or waste heat producers on the other hand. Both small scale (1-20 MWh el) and large scale (above 100 MWh el).

## PROJECT CASE #3
## Increased Self Consumption of Photovoltaic Power for Electric Vehicle Charging in Virtual Networks

### Related Sub-challenge of IC1

Regional and cross innovation

### Type of Project

Demonstration and commercialization

### Topic

Electric vehicle charging, Solar electricity production, Smart electric car charging, Traceability, Power control

### Objective

To establish a network for producers of solar electricity and charging stations for electric cars in order to increase the use of renewable energy and reduce the load on the electricity grid.

### Contractors

Municipality of Uppsala, project owner
Solelia Greentech, project manager, technology
Uppsala University, Research
Tromsö University, Research
Tromsö municipality
Uppsala parking company
Aktea

### Period

2016-04-01 – 2019-01-31

### Ongoing and Achieved Key Findings

The project has shown that the charging power can be controlled overall for charging stations that use standardized protocols for communication regardless of make or operator. This can create a real space for new renewable electricity production for electric car charging and, in addition, relieve the electricity grid both regionally and nationally. Electric car charging control can also create increased self-consumption of locally produced solar electricity.

### Added Value of IC1 Objective

Improving the efficiency and clarity of the interaction between electricity production and consumption constitutes the basis for the proposed business model. The services for "Smart Solar Charging" developed in the project can partly avoid investment in new production and distribution of electric energy for new charging stations. This in turn means that more charging stations can be installed without increasing the capacity for supplying electricity.

## PROJECT CASE #4
## High voltage direct current breaker at low cost - HIBREAK

### Related Sub-challenge of IC1

Regional grid innovation

### Type of Project

Technology development and demonstration

### Topic

HVDC, circuit breaker, grid protection, power transmission

### Objective

To develop a full-scale breaker module that could be included as one of a number of identical parts in a real DC breaker applicable in an HVDC network. The module should be tested under realistic conditions at a testing institute for electrical power equipment. Based on the results, the strategy for commercialization of the system is updated and verified.

### Contractors

SCiBreak AB, Svenska Kraftnät, KU Leuven

### Period

2017-2018

### Ongoing and Achieved Key Findings

SCiBreak's technology VARC for protection of HVDC links and grids can be made at radically reduced cost compared to competing technologies. The project has shown that it can be scaled up to high voltage (40 kV) and current (10 kA).

### Added Value of IC1 Objective

SCiBreak's technology allows for radical cost reductions in HVDC systems. The project results prove that it can be scaled up to the necessary voltage and current ratings.

PROJECT CASE #5
## Adaptive Control of Energy Storage (ACES)

### Related Sub-challenge of IC1
Distribution grid innovation and micro grid innovation

### Type of Project
Technology development, demonstration and commercialization

### Topic
Energy storage, adaptive control, AI, Optimization, energy quality

### Objective
Improved profitability of energy storage through adaptive control and new business models

### Contractors
Metrum Sweden – Managing partner
RISE, Insplorion, Fraunhofer IFF – WP2 Hardware development, Reijlers Embriq – WP3 Adaptive Control System Glava Energy Center, Vänerenerg, ABB - WP4 Demonstrators,
MINcom, WP5 Market & Billing
Power2U – Others

### Period
01.09.2018 – 01-03.2021

### Ongoing and Achieved Key Findings
Market Study – Mapping of relevant energy services for Swedish and German regulatory environments. A Reference group is initiated with potential customer throughout the electricity value chain to select the most promising services for the demonstrators.

Demonstrators - test platform will be physical tests in different environments in terms of load patterns and local generation, in conjunction with software simulation. New sensor technology for battery health monitoring will be implemented in a pilot battery system and will be tested in lab environment.

### Added Value of IC1 Objective
Added value is expected in the technology, market and adoption layers. Developments within AI optimization and improved battery health monitoring could increase the profitability and utilization of battery storage. The integration of a bilateral billing system (WP5) eases commercialization of new energy services, e.g. for end-users and DSOs.

## 14.6 Reference


[1]J. Marcos, O. Storkel, L. Marroyo, et al. Storage requirements for PV power ramp-rate control[J]. Solar Energy 99 (2014): 28–35.

[2]B. M. Mazumdar, M. Saquib, A. K. Das. An empirical model for ramp analysis of utility-scale solar PV power[J]. Solar Energy 107 (2014): 44–49.

[3]D. Connolly, H. Lund, B.V. Mathiesen, et.al. The technical and economic implications of integrating fluctuating renewable energy using energy storage[J]. Renewable Energy 43 (2012) :47-60.

[4]M. Jannati, S.H.Hosseinian, B.Vahidi, et al.A survey on energy storage resources configurations in order to propose an optimum configuration for smoothing fluctuations of future large wind power plants[J]. Renewable and Sustainable Energy Reviews 29(2014): 158–172.

# 15. THE UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

## 15.1 General Framework and Implementation

The United Kingdom of Great Britain and Northern Ireland is deeply committed to combatting climate change and has ratified the Paris Agreement. The UK parliament approved a 57% reduction target for greenhouse gas emissions from 1990 levels by the end of fifth carbon budget (2028-2032), with a target of 80% reduction on 1990 levels by 2050[15-1] set in the Climate Change Act 2008[15-2]. Developing smart grid technology and investing in clean energy innovation is key to achieving this and securing the UK's future prosperity and energy security, as stated in the Government's Clean Growth Strategy, published in October 2017. [15-3]

The UK has already reduced greenhouse gas emissions by around 42% since 1990.[15-4] The UK government and national governments of Scotland, Wales and Northern Ireland have set a shared policy commitment to continuing this progress, prioritising clean growth and modernising their energy systems. This work is led by the UK Department for Business, Energy and Industrial Strategy (BEIS). Over £2.5 billion is being invested by the UK Government to support low carbon innovation from 2015 to 2021.[15-5] The Government and Ofgem, the gas and electricity industry regulator, are taking action alongside industry to modernise the energy grid and integrate renewable energy sources, improving efficiency through smart technologies and applications such as smart meters, storage and demand response, as outlined in the Smart Systems and Flexibility Plan (July 2017).[15-6]

As global markets are transformed by the shift to clean growth, the UK aims to become one of the best places in the world to develop and sell clean energy technologies.[15-7] The UK's work with its partners in Mission Innovation will be an integral part of this.

[15-1] The Clean Growth Strategy, HM Government, October 2017, p. 21; https://www.gov.uk/government/publications/clean-growth-strategy

[15-2] http://www.legislation.gov.uk/ukpga/2008/27/contents

[15-3] The Clean Growth Strategy, HM Government, October 2017

[15-4] 2017 UK greenhouse gas emissions: final figures- statistical release, BEIS, February 2019

[15-5] The Clean Growth Strategy, p.11

[15-6] Upgrading our Energy System - Smart Systems and Flexibility Plan, July 2017

[15-7] Industrial Strategy, p. 43

### The UK Electricity Grid

In April 2005[15-8] Scotland, England and Wales' systems (Great Britain) were combined into a single market with a single System Operator- National Grid ESO.[15-9] Since 2001 the grid in Northern Ireland connects to Great Britain through the Moyle Interconnector[15-10] and the System Operator (SO) in Northern Ireland is System Operator – Northern Ireland (SONI).[15-11]The Single Electricity Market (SEM) was set up in 2007 to combine the electricity markets of Northern Ireland and the Republic of Ireland.[15-12]

Three Transmission Owners (TOs) develop, operate and maintain a high voltage system within distinct onshore transmission areas in Great Britain. These are National Grid Electricity Transmission plc for England and Wales, Scottish Power Transmission Limited for southern Scotland and Scottish Hydro Electric Transmission plc for northern Scotland and the Scottish islands groups.[15-13]In Northern Ireland, Northern Ireland Electricity Networks Ltd owns and operates the electricity transmission and distribution networks.[15-14] Offshore wind farm connections are owned by Offshore Transmission Owners (OFTO). [15-15]

There are 14 licensed Distribution Network Operators (DNOs) in the UK and each is responsible for a regional distribution services area, with several smaller networks owned and operated by Independent Network Operators (IDNOs) operating within these areas.[15-16] The DNOs and TOs are regulated by Ofgem[15-17] and in Northern Ireland they are regulated by the Utility Regulator Northern Ireland (UREGNI).[15-18]

Five UK interconnectors allow trade with Europe: England-France (2 GW capacity), England-Netherlands (1 GW), Northern Ireland-Ireland (0.6 GW), Wales-Ireland (0.5 GW) and England-Belgium (1GW; commissioned in early 2019). These accounted for 4.2 % of electricity supplied in 2017.[15-19] There are upcoming projects to establish new connections to France, Norway, Denmark and the Republic of Ireland by the mid-2020s.[15-20]

### Upcoming Challenges: Heating and Transport

The increasing uptake of Electric Vehicles and the decarbonisation of heat pose new challenges for the electricity system which smart technologies will be key to meeting.

The UK has an extensive gas grid which fuels heating in the majority of buildings in the UK.[15-21] In its Future Energy Scenarios 2018, National Grid Electricity System Operator (ESO), predicts that to meet the 2050 carbon targets heating needs to move away from natural gas to low carbon sources, such as electric heat pumps, low carbon gases and district heating schemes supplied by low carbon sources.[15-22] The UK has a varied mix of renewable technologies that can play a part in decarbonising heat: wind, solar photovoltaics, hydro and some marine technologies - all used in electricity generation. Biomass is used in electricity and heat generation. Solar, heat pumps and deep geothermal are used directly in heat generation.[15-23]

The Government's Road to Zero strategy sets out ambitious plans to support large-scale Electric Vehicle (EV) uptake to 2040.[15-24] EVs create new opportunities for Demand Side Response (DSR) and can act as storage where they are able to export to the grid. This rollout will require smart technologies.[15-25]

[15-8] Digest of UK Energy Statistics (DUKES), BEIS, 2017, p.129

[15-9] https://www.ofgem.gov.uk/sites/default/files/docs/2005/02/9549-2605.pdf , pp.5-6, retrieved: 28/03/2018

[15-10] https://www.elexon.co.uk/about/background-to-the-industry/interconnectors/ , retrieved: 20/03/2018

[15-11] http://www.soni.ltd.uk, retrieved: 23/03/2018

[15-12] http://ireland2050.ie/past/electricity/, retrieved: 20/03/2018

[15-13] https://www.ofgem.gov.uk/electricity/transmission-networks/gb-electricity-transmission-network, retrieved: 20/01/2019

[15-14] https://www.nienetworks.co.uk/about-us, retrieved: 27/02/2019

[15-15] Offshore Transmission Market update, PriceWaterhouseCooper and Ofgem, October 2018

[15-16] https://www.ofgem.gov.uk/electricity/distribution-networks/gb-electricity-distribution-network, retrieved: 23/03/3018

[15-17] https://www.ofgem.gov.uk/electricity/distribution-networks/gb-electricity-distribution-network, retrieved: 23/03/3018

[15-18] http://www.soni.ltd.uk/AboutUs/, retrieved: 23/03/2018

[15-19] DUKES 2018, p.113

[15-20] https://www.ofgem.gov.uk/electricity/transmission-networks/electricity-interconnectors, retrieved: 26/03/2018

[15-21] https://www.oftec.org.uk/consumers/heating-off-the-mains-gas-network, Retrieved: 20/03/2018

[15-22] Future Energy Scenarios 2018, National Grid, p. 25

[15-23] DUKES 2018 Chapter 6: Renewable sources of energy, p.155

[15-24] https://www.gov.uk/government/publications/reducing-emissions-from-road-transport-road-to-zero-strategy, retrieved: 27/02/2019

[15-25] Smart Systems and Flexibility Plan Update, 2018, p.9

## 15.2 Status of Renewable Energy and Smart Grids

### The Current Status of UK Renewable Energy

In 2017, 10.2 % of total energy consumption came from renewable sources, up from 9.2 % in 2016[15-26] and the UK currently has the largest installed offshore wind capacity in the world.[15-27]

An increasing proportion of the UK's electricity supply is from renewable sources, primarily wind, solar and bioenergy, accounting for 27.9 % of total generation (99.3 TWh) in 2017[15-28].

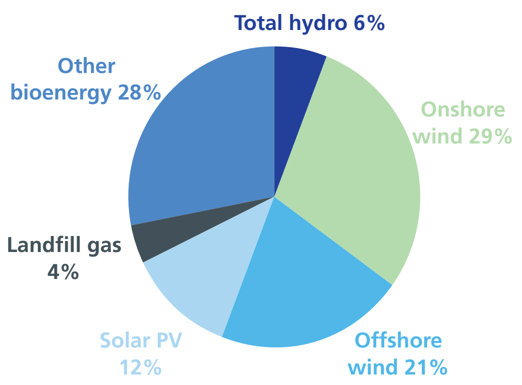



Figure 15-1. Electricity Generation by Renewable Fuel Source 2017.[15-29]

The UK is on track to exceed the ambition of delivering 30% of electricity from renewables in 2020-21.[15-30]According to the regulator Ofgem, the average unit of electricity generated in 2016 was 64% cleaner than in 1990 (emitting 242 grams of carbon dioxide per kWh compared with 680 grams). [15-31]

### The Future of Renewable Energy in the UK

The low carbon share of UK electricity generation (renewables and nuclear generation as a proportion of all power producers) is projected to rise from 22% in 2010 to 58% in 2020. [15-32]

The UK aims to phase out the use of unabated coal to produce electricity by 2025 [15-33] and the Government has committed to phasing out the installation of high carbon forms of fossil fuel heating in new and existing businesses off the gas grid during the 2020s, starting with new build. [15-34]

Ofgem's Feed-in Tariffs (FIT) scheme (2010-2019) has been the Government's subsidy scheme for the uptake of renewable and low-carbon electricity generation technologies. [15-35]

The Government's main mechanism to support the continued uptake of low-carbon electricity generation is the Contracts for Difference (CfD) scheme delivered through.

CfDs incentivise investment in renewable energy by providing developers of projects with high upfront costs and long lifetimes with direct protection from volatile wholesale prices, also protecting consumers from paying increased support costs when electricity prices are high. [15-36]

### Changing Roles

As detailed in the Smart Systems and Flexibility Plan (2017)[15-37], the roles of actors in the energy system are evolving.

National Grid ESO, has published the 'System Needs and Product Strategy', to improve its information sharing, to make it easier for industry to see and meet future system needs.[15-38] Through close consultation and engagement with industry, for example through its Power Responsive campaign,[15-39] National Grid has been working to remove barriers and stimulate participation of new types of suppliers and smart technologies, providing greater access to smart solutions and distributed resources including DSR and storage.[15-40]

At distribution level, Distribution Network Operators (DNOs) in local electricity networks are transitioning to a Distribution System Operator (DSO) role, which involves more active management of networks, including procurement of market solutions to network issues and greater coordination between

[15-26] DUKES 2018, p.155
[15-27] The Industrial Strategy, HM Gov, 2017, p. 15
[15-28] DUKES 2018, p.155
[15-29] DUKES 2018 Chapter 6: Renewable sources of energy, p.159
[15-30] DUKES 2018, p.171
[15-31] State of the market report- OFGEM, 2017, p. 80
[15-32] Updated energy and emissions projections 2017, BEIS, January 2018, p. 34
[15-33] Industrial Strategy, p. 15
[15-34] IClean Growth p. 67
[15-35] Ihttps://www.ofgem.gov.uk/environmental-programmes/fit/about-fit-scheme, retrieved: 27/02/2019
[15-36] https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference, retrieved: 27/02/2019
[15-37] https://www.gov.uk/government/publications/upgrading-our-energy-system-smart-systems-and-flexibility-plan, retrieved: 27/02/2019
[15-38] System Needs and Product Strategy, National Grid, p. 1
[15-39] http://powerresponsive.com/, retrieved: 27/02/2019
[15-40] Smart Systems and Flexibility Plan, p. 7

the transmission and distribution boundary.[15-41] DNOs have started to open up the delivery of network requirements to market-based smart solutions (storage and DSR, for example), to reduce network cost and deliver savings for consumers.[15-42]

Feasibility studies funded by BEIS have explored how local flexibility markets could allow innovative technologies and business models to be used to value and trade flexibility in the electricity system at distribution level.[15-43] These studies investigated several different approaches to engaging distributed flexibility, including smart Time of Use tariffs, domestic aggregators and online flexibility market platforms. BEIS's current FleX competition will build on these prior studies' proposals for market platforms, in the form of a "Flexibility Exchange". A Flexibility Exchange is a marketplace which allows flexibility providers to access both local and national markets.

The role of consumers is also evolving. For instance, close to 1 million homes[15-44] (of a total 27 million[15-45]) now have solar panels on their roofs. Increases in battery usage and these types of small-scale renewable energy generation are enabling consumers to feed excess power back into the local grid and uptake of smart technologies are enabling greater flexibility for consumers. Aggregators also have a growing role in co-ordinating the balancing of the increasingly complex electrical demand and supply in their local areas.

## 15.3 National Programs in Fields of Smart Grids and Renewable Energy

To support the development of a smart, sustainable energy sector from 2010-2015, the UK's Department of Energy and Climate Change[15-46] (which became BEIS in 2016) invested £175m in 278 projects to support innovation in: offshore wind, carbon capture and storage (CCS), energy storage, marine energy, bioenergy, nuclear fission, advanced heat storage, and support for disruptive businesses and technologies through the flagship Energy Entrepreneurs Fund.

Between 2015 to 2021 the UK Government expects to invest more than £2.5 billion in research, development and demonstration of low carbon energy, transport, agriculture and waste. This includes the following: [15-47]

- Up to £505m from BEIS's Energy Innovation Programme, which aims to accelerate the commercialisation of innovative clean energy technologies and processes.[15-48] £70m of this is for smart systems innovation and has already funded multiple innovation programmes, including:[15-49]
    - Feasibility studies on first-of-a-kind large scale energy storage, and approaches to valuing and trading flexibility at a local level.
    - Feasibility studies on domestic and commercial demand side response.
    - A competition focused on energy storage cost reduction, including technologies such as flow batteries, power-to-gas systems and novel battery chemistries.
    - Jointly with OLEV (the Office for Low Emission Vehicles), a £30m innovation competition supporting the development and demonstration of a range of innovative vehicle-to-grid (V2G) technologies and business models, through more than 20 projects, making the UK one of the first markets to explore V2G at scale.
- In January 2019 BEIS also launched:
    - The Storage at Scale competition, up to £20m funding for innovative, replicable solutions which could provide a market competitive alternative to conventional commercial large-scale energy storage technologies.
    - The FleX competition which will support the development and demonstration of innovative solutions to value and trade flexibility.
- Up to £1.2 billion of funding will also come from UK Research and Innovation (UKRI).[15-50] Between them the Government and UKRI expect to invest around £265m in smart systems research, development, and demonstrations.

[15-41] Electricity Network Innovation Strategy, p. 11
[15-42] Smart Systems and Flexibility Plan, p. 18
[15-43] https://www.gov.uk/guidance/funding-for-innovative-smart-energy-systems, retrieved: 27/02/2019
[15-44] Upgrading Our Energy System, Smart Systems and Flexibility Plan, p. 5
[15-45] https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/adhocs/005374totalnumberofhouseholdsbyregionandcountryoftheuk1996to2015, retrieved: 23/03/2018
[15-46] https://www.gov.uk/guidance/innovation-funding-for-low-carbon-technologies-opportunities-for-bidders
[15-47] The Clean Growth Strategy, p. 50
[15-48] The Clean Growth Strategy, Footnote, p. 50
[15-49] https://www.gov.uk/guidance/funding-for-innovative-smart-energy-systems, retrieved: 27/02/2019
[15-50] The Clean Growth Strategy, p.50

- Up to £246m for the Faraday Battery Challenge, on electric batteries. To date the Faraday Battery Challenge has supported the creation of the £78m Faraday Institution to speed up research into battery technologies, through which £42m has already been invested in four 'fast-start' projects[15-51] on extending battery life, battery system modelling, recycling and reuse and next generation solid state batteries.

- Up to £620m of funding from a range of Departments, including BEIS, DfT, DfID and Defra and additional Industrial Strategy Challenge Fund support. This includes the £102m Prospering from the Energy Revolution Challenge.[15-52] This programme will research, develop and demonstrate integrated smart local energy solutions across power, heat and transport to provide cleaner and cheaper energy for consumers, while building more prosperous and resilient communities.

- The devolved Governments for Scotland, Wales and Northern Ireland also fund and support low carbon innovation.[15-53]

Ofgem is also running its Innovation Link initiative where those with new services or ideas can seek advice on how they can navigate existing market and regulatory rules. In addition, Ofgem is making up to £720m of regulated expenditure available to gas and electricity network companies in Great Britain, to support smarter, more flexible, efficient, and resilient networks. £70m annually is specifically for electricity networks as part of their annual Network Innovation Allowance (NIA) competitions.[15-54] There are opportunities for international partnerships in these competitions.[15-55]

### Smart Systems Policy

The policy direction to guide this innovation and the wider smart transition is set out in the Smart Systems and Flexibility Plan (July 2017), in which the Government and Ofgem highlighted three key areas of focus where they will work alongside industry to deliver a smarter, more flexible energy system: removing barriers to smart technologies, including storage; enabling smart homes and businesses; and making markets work for flexibility. [15-56]In October 2018 Government and Ofgem published a progress update to the plan, announcing that half of the original actions had now been implemented and identifying nine new actions they are undertaking.

### Smart Metering Implementation Programme

The UK Government has also committed to offering every household and small business in Great Britain a smart meter by the end of 2020.[15-57] As of September 2018 (last available statistical update) there are around 12.8 million smart and advanced meters operating across homes and businesses in Great Britain, by both large and small energy suppliers - a 6 % increase from the previous quarter.[15-58]

Smart meters are set to provide the cornerstone of the smart energy system of the future for domestic and smaller non-domestic consumers. For example, data from smart meters can help support consumers to use energy when it is cheaper and enables half-hourly electricity settlement,[15-59] which is expected to provide commercial incentives on energy suppliers to develop and offer time of use tariffs and similar innovative products. Cost-effective elective half-hourly settlement has been in place since June 2017[15-60] and by the end of 2019 Ofgem intends to take a decision on the approach for implementing half-hourly settlement on a market-wide basis.[15-61]

[15-51] https://faraday.ac.uk/fast-start-projects/, retrieved: 27/02/2019
[15-52] https://www.gov.uk/government/news/prospering-from-the-energy-revolution-full-programme-details, retrieved: 27/02/2019
[15-53] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/651916/BEIS_The_Clean_Growth_online_12.10.17.pdf (Table 3, page 52)
[15-54] For further details: https://www.ofgem.gov.uk/network-regulation-riio-model/network-innovation/electricity-network-innovation-competition
[15-55] https://www.ofgem.gov.uk/network-regulation-riio-model/network-innovation/electricity-network-innovation-competition, retrieved: 27/02/2019
[15-56] mart Systems and Flexibility Plan, p. 4
[15-57] https://www.gov.uk/government/news/smart-meters-the-smart-choice, retrieved: 27/02/2019
[15-58] Smart Meters, Quarterly Report to end September 2018, Great Britain, BEIS, 29 November 2018, p.3 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/759735/2018_Q3_Smart_Meters_Report_FINAL.pdf,
[15-59] https://www.ofgem.gov.uk/electricity/retail-market/market-review-and-reform/smarter-markets-programme/electricity-settlement retrieved: 27/02/2019
[15-60] https://www.ofgem.gov.uk/publications-and-updates/half-hourly-settlement-update-november-2017, retrieved: 04/04/2018
[15-61] Electricity Settlement Reform Significant Code Review Launch Statement, Ofgem, 24th July 2017, p. 4, retrieved: 03/04/2018

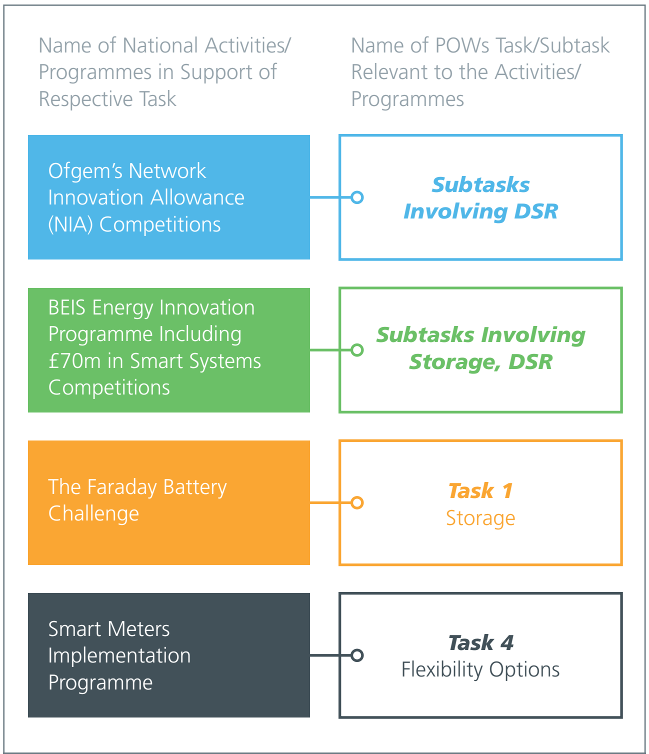



Figure 15-2

## 15.4 International Programme Related to Smart Grids and Renewable Energy

The UK is committed to the objectives of Mission Innovation and is playing an active role in its work through roles as vice-chair of the Steering Committee and Head of the MI secretariat. The UK is actively involved in all the Innovation Challenges and co-leads the Heating and Cooling Challenge.

The UK is also currently running two bilateral international competitions in smart energy with Mission Innovation partners from 2018 to 2021. The UK and South Korean Governments have committed up to £6m, to deliver a bilateral competition on smart energy innovation. Projects supported by this competition include a pilot energy flexibility trading platform, gamification of EV charging/ V2G charging/ discharging and a liquid air production and storage system.[15-62] In addition, the UK and Canada are running the Power Forward Challenge, offering over £11m to develop the best smart energy systems, including grids and storage, for the needs of the 21st Century[15-63].

[15-62] http://www.gov.uk/guidance/funding-for-innovative-smart-energy-systems#funding-for-uksouth-korea-bilateral-collaboration-on-smart-energy-innovation, retrieved: 27/02/2019

[15-63] https://impact.canada.ca/en/challenges/power-forward, retrieved: 16/01/2019

The UK also actively participates and influences the direction of clean energy innovation more generally through other multilateral fora such as:

- the UK's input and participation in the EU's Strategic Energy Technology Plan,
- the EU's Horizon 2020 Energy R&D funding programme,
- the UK's membership of IRENA (International Renewable Energy Agency) and the International Energy Agency's Energy Technology Network, including its individual Technology Collaboration Programmes (TCPs). The UK is currently a participant in smart grids-related TCPs including the International Smart Grid Action Network (ISGAN); Energy Technology Systems Analysis (ETSAP); and Energy Storage (ECES).

## 15.5 Case Studies

**PROJECT CASE #1**
**Keele University Smart Energy NetworkDemonstrator**

### Related Sub-challenge of IC1

Multiple Sub-Challenges: Cross-cutting Innovation

### Type of Project

Demonstration

### Topic

Living laboratory | Multi-Energy Vector | Research, Development & Innovation | Smart Energy

### Objective

Keele University is working with businesses, as well as graduates and academics, to create Europe's first 'at scale' Smart Energy Network Demonstrator (SEND) – a living laboratory where new energy-efficient technologies, consumer behavior and business models can be researched, developed and tested in a real-world environment.

The Demonstrator will build on Keele University's privately-owned and managed infrastructure, comprising:

- 600 acre site, making it the UK's largest university campus; 341 buildings, ranging from academic, student residential, staff flats & houses, and Science & Innovation Park business accommodation; 204,000m² built environment; 80,000m² development-ready land ; 12,000+ staff and students on site per day
- Campus energy demand of 39.2GWh pa (Gas) and

23.8GWh pa (Electricity)
- 10km+ of underground gas network (6 MP/ LP meter points); 18km+ of electrical network (cable) with 22 sub-stations (11kV/400V); 28km+ of fibre-optic cabling; 16km+ of surface and foul water drainage; 16km+ of mains water network; 6km district heating (3 networks)

The SEND programme is part-funded through the European Regional Development Fund (ERDF) as part of the England 2014 to 2020 European Structural and Investment Funds (ESIF) Growth Programme. The programme is also receiving funds from the Department for Business, Energy and Industrial Strategy.

### Contractors
Siemens, Stopford Energy & Environment, Burns & McDonnell

### Period
2017- 2021

### Ongoing and Achieved Key Findings
- Deliver a living laboratory covering 5000 residents and 12,000 working population across domestic, commercial and industrial energy demands by mid-2019.
- Integrate at least 5MW renewable generation by 2020.
- Integrate the energy generation, supply and demand across power, gas, heat, transport and data communications to support energy supply and R&D.
- Horwood Energy Centre (SEND Control Room) is due to open in Q3 2019.

### Added Value of IC1 Objective
- A reduction in CO2e of 4096 Tonnes per annum by 2021 (circa 30% of current CO2e levels)
- Supporting 243 SME businesses to access and engage in the Smart Energy marketplace. Support the establishment of nine new Smart Energy businesses.
- 16 three-year Research, Development and Innovation projects with SMEs to develop new products and services alongside 25 3-month projects to feed into SEND.
- Facilitating the introduction of seven “new to firm” Smart Energy Products or Services.

## PROJECT CASE #2
## Electric Nation

### Related Sub-challenge of IC1
Multiple Sub-Challenges: Cross-cutting Innovation

### Type of Project
Technology demonstration

### Topic
Electric vehicles, distribution networks, demand management, smart charging

### Objective
- Expand current understanding of the impact on electricity distribution networks of charging a diverse range of electric vehicles at home. A previous project ‘My Electric Avenue’ was able to build up a bank of knowledge, however its trial was confined to one type of EV with the same battery size and charging rate. This project seeks to discover how the impact will be altered by different types of vehicles with different sizes of battery that charge at different rates, across up to 700 trial participant EV drivers, each installed with a home smart charger.
- Build a better understanding of how vehicle usage affects charging behaviour given diversity of charging rate and battery size.
- Evaluate the reliability and acceptability to owners of EVs of smart charging systems and the influence these have on charging behaviour.

### Contractors
Project Lead/Funder: Western Power Distribution (funded through the Network Innovation Allowance scheme set by Ofgem).

Collaboration Partners: EA Technology, DriveElectric, Lucy Electric GridKey, TRL

### Period
2016-2019

### Ongoing and Achieved Key Findings
The project is ongoing at the time of writing but has already published findings on the charging behavior of participants based on their electric vehicle type/battery size.

Image Source: January 2018 Customer Research and Trial Update Report. Other reports have included details of participant’s willingness to sign-up for apps to interact with the smart charging system and use of these apps. Future reports will include the level of response observed when participants could earn a financial reward based on the time of day when they charged their vehicle.

Outputs will continue to be published throughout the project and further information is available from the project website: http://www.electricnation.org.uk/

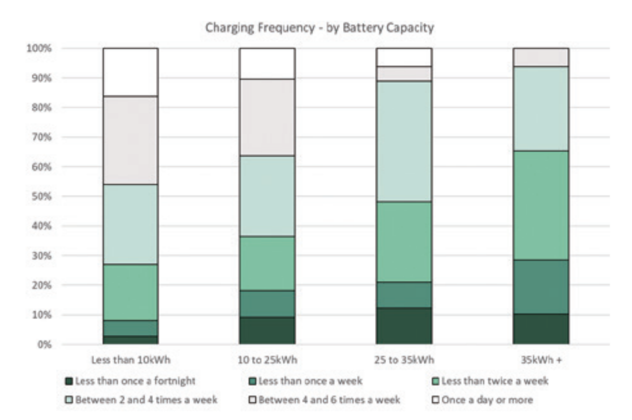



Figure 15-3

### Added Value of IC1 Objective

Demonstrating charging behavior for all types of plug-in vehicles, including those which will become more prevalent in the future (7kW charging, larger batteries).

Researching the customer acceptability of smart charging (demand side management) solutions to mitigate the impact of EVs on distribution networks.

Developing a Network Assessment Tool to predict where uptake of EVs will occur, the impact this will have and methods by which this can be mitigated.

## PROJECT CASE #3
## Moixa's ERIC project (Energy Resources for Integrated Communities)

### Related Sub-challenge of IC1

Multiple Sub-Challenges: Cross-Cutting Innovation

### Type of Project

Demonstration

### Topic

Residential Energy Storage, Aggregation, Virtual Power Plant, Solar Self-Consumption, Peak Reduction

### Objective

To demonstrate how distributed storage in a community can be managed to reduce average peak grid load by 65% and increase self-consumption of local PV energy across the community by twofold.

To design, develop and test in a real community the installation of the software platform that will deliver a range of services to communities and the national grid.

Key goals for the project, aimed at demonstrating value:

1. Reducing average peak household grid load to 500W (1.5kW current DNO planning assumption). This would provide a demonstration of using community energy storage to reduce the need for grid reinforcement, valuable to DNOs and building developers.
2. Increasing self-consumption of local distributed generation across the community to 100%. Through managed storage based on a community energy tariff this would provide cost savings to the households and reduce the unbalancing effect of export onto the grid from distributed generation, thus saving reinforcement cost and allowing communities to deploy more distributed generation capability.
3. Demonstrating the ability for the community to act as an active network participant, providing balancing services, such as STOR (Short Term Operating Reserve), and load shifting response. If the system as a whole can react to grid level signals within 2 seconds (goal) then it could also participate in, & profit from, the Fast Frequency Response National Grid program (FFR).

### Contractors

Moixa Technology, Bioregional, Oxford City Council, GreenSquare, JoJu Solar, Oxford Brookes University, Re-energise, British Gas and SSEN.

The project was funded by Innovate UK, BIS, Moixa, British Gas and Scottish and Southern Energy Power Distribution.

### Period

January 2015 - April 2017

### Ongoing and Achieved Key Findings

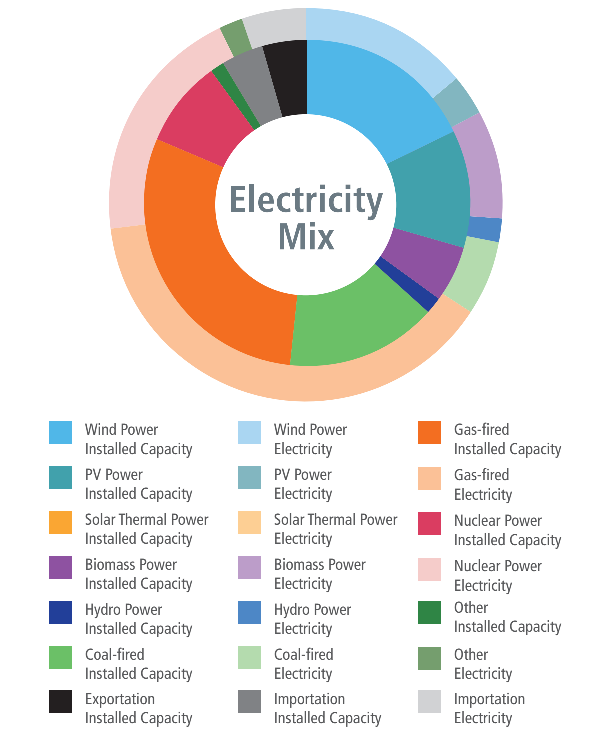
Deployed 180KWh of smart energy storage across 82 homes, a school and community centre in East Oxford. This generated considerable data over two and a half years, showing how aggregate storage can act as a community asset, leveraging local solar and enabling peer to peer energy sharing. All key goals were achieved.

ERIC also showed how GridShare delivers value across multiple stakeholders:

- For Oxford City Council tenants, it has helped increase solar self-consumption and aid fuel poverty by lowering household bills and engaging residents.
- Helped develop new local energy-tariff models for British Gas, leveraging GridShare Utility dispatch and community energy flow services, to reduce wholesale and settlement costs.
- The project has subsequently helped Moixa to expand, deploy GridShare to manage over 50 MWh of residential energy storage, and raise over £16m in funding.

### Added Value of IC1 Objective

Demonstrated how aggregate storage can help the local network provider, Scottish and Southern Electricity Networks, manage power quality and defer capital upgrades.




Data are taken from DUKES 2018, available here: https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes

Figure 15-4. Electricity Mix by the End of 2018

[15-64] Some projections are available at National Grid ESO website and the latest publication is: https://www.nationalgrideso.com/insights/future-energy-scenarios-fes, retrieved: 27/02/2019

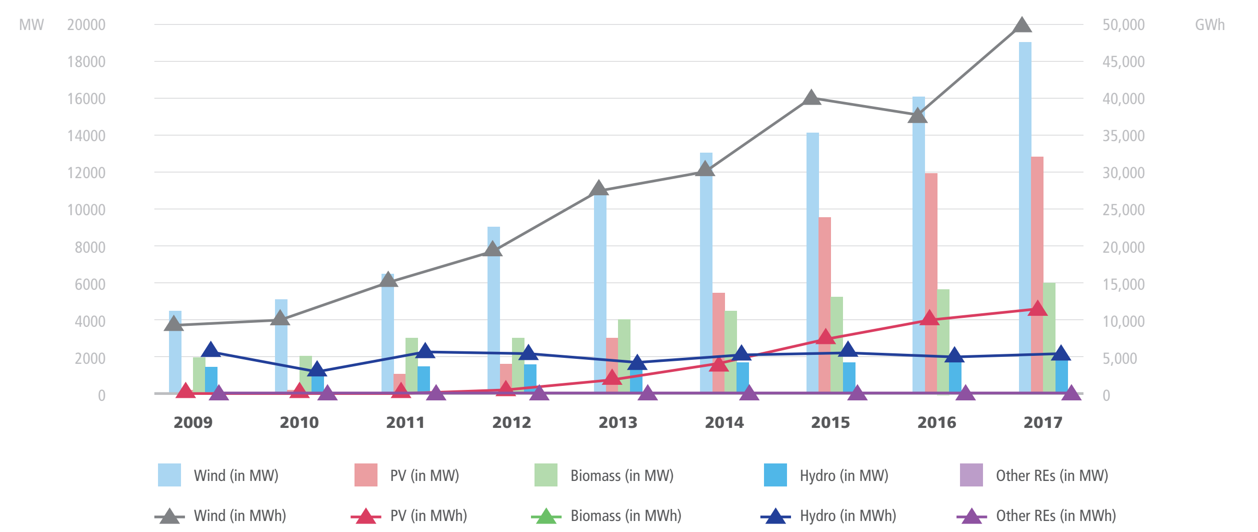



Figure 15-4. Trends on Renewable Energy Generation (Up to 2017)[15-64]

### Length and Ratings of Lines

In Great Britain: National Grid Electricity Transmission plc owns the high voltage electricity transmission network in England and Wales and National Grid Electricity System Operator operates it across Great Britain. This transmission system is made up of approximately 7,200 km (4,470 miles) of overhead line, 1,400 km (870 miles) of underground cable and around 330 substations. [15-65]

Ireland: There are around 6,800 km of high-voltage power lines, cables and substations across Northern Ireland and the Republic of Ireland. This grid links generators of electricity to the distribution network and supplies large demand customers. The network infrastructure is owned by the Electricity Supply Board (ESB) in their subsidiary Northern Ireland Electricity Networks Limited. [15-66]

### Number of Customers

UK population: estimated 66 million in 2017. [15-68]

### Number of Automated Sub-stations

All major transmission substations operate with high voltages and are remotely monitored and controlled. At lower voltages DNOs are also increasingly automating their network as the DSO transition progresses. In the UK there are approximately the following types of substations: [15-67]

| | |
|---|---|
| Grid Supply Point 400kV to 132kV: | ***380*** |
| Bulk Supply Point 132kV to 33kV: | ***1,000*** |
| Primary 33kV to 11kV: | ***4,800*** |
| Distribution 11kV to 400/230V: | ***230,000*** |

In addition there were 349,000 pole-mounted 11 kV/400 V transformers.

### Flexibility Options in National Grid (Great Britain Only)

National Grid Electricity System Operator has a portfolio of flexibility solutions, information on which can be found on the System Operators website in publications including their System Needs and Product Strategy, System Operability Framework and presented in their Future Energy Scenarios. [15-69]

### Number of Smart Meters (Great Britain)

At end September 2018 there were around 12.8 million smart and advanced meters operating across homes and businesses in Great Britain. [15-70]

The Department for the Economy in Northern Ireland has no plans at present to install smart meters in Northern Ireland.

### Number of Customers

At end September 2018 there were 185,470 ultra-low emission vehicles registered in the UK.[15-71]

### Number and Capacity of Storage (Great Britain only)

National Grid's future scenarios 2018 suggest there was around 3GW of storage on the system in GB in 2017, the vast majority of which is pumped hydro. National Grid also outlines between 12-29GW of electricity storage could be deployed by 2050.[15-72]

### Number and Example of Demand Response (Great Britain Only)

National Grid's Future Energy Scenarios 2018 suggests there was around 2GW of I&C demand side response capacity in 2017, which includes behind the meter generation and storage and outlines that there could be between 4-8GW of I&C DSR capacity by 2050. [15-73]

### Number and Example of Micro Grids

Some UK project examples include: Centre for Alternative Technology Microgrid, Wales, Isles of Scilly, Isle of Eigg and Knoydart.

Figure 15-5

[15-64] Some projections are available at National Grid ESO website and the latest publication is: https://www.nationalgrideso.com/insights/future-energy-scenarios-fes, retrieved: 27/02/2019

[15-65] https://www.nationalgrid.com/sites/default/files/documents/Substation%20construction%20and%20refurbishment.pdf, retrieved: 27/02/2019

[15-66] Community Fund and Proximity Payments – EirGrid, 2016

[15-67] ENA Adaptation to Climate Change First Round Report under the ARP, Electricity Transmission and Distribution Network Companies, April 2011, http://www.emfs.info/sources/substations/, retrieved: 27/02/2019

[15-68] Office of National Statistics, https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/articles/overviewoftheukpopulation/november2018, retrieved: 27/02/2019

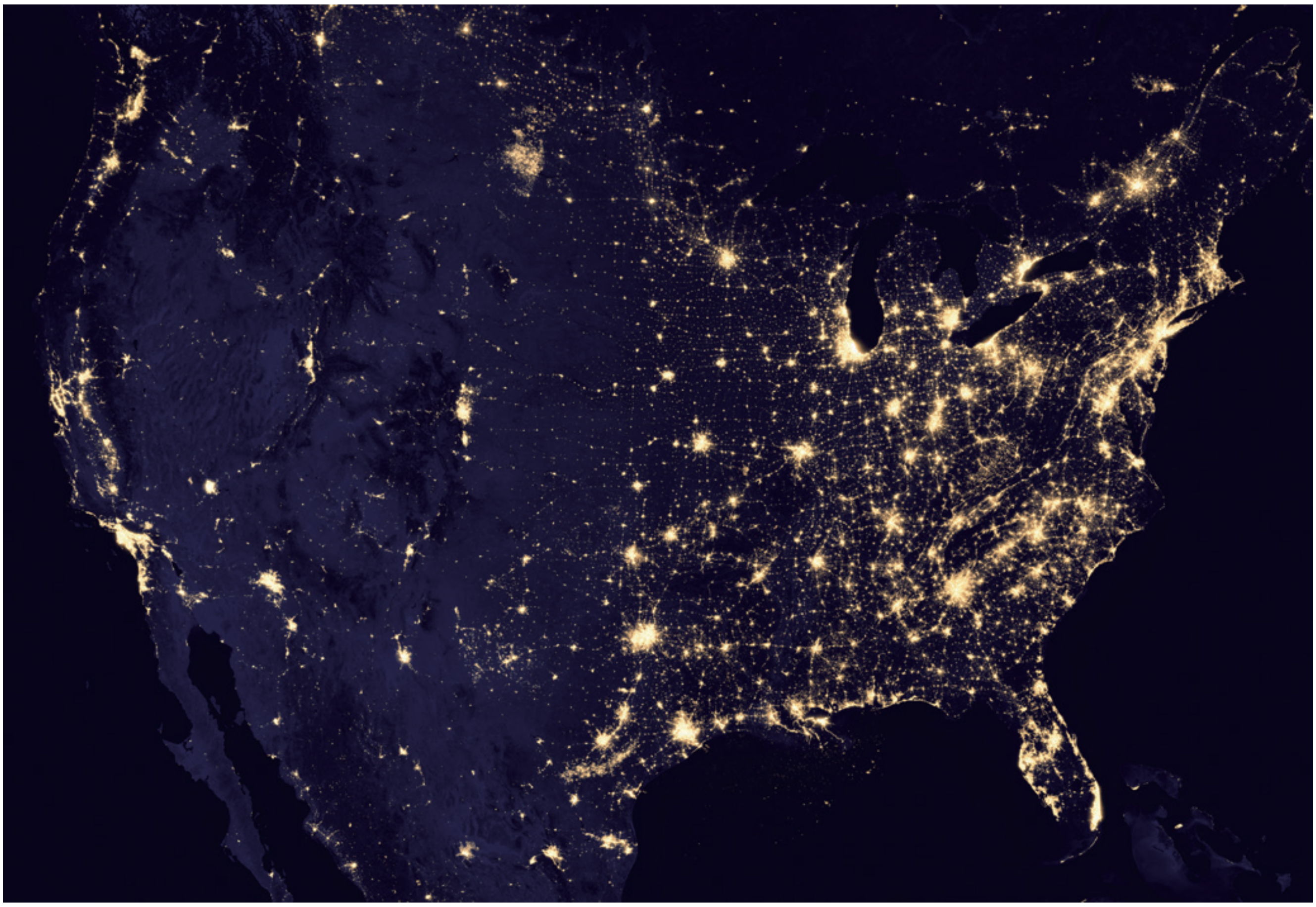
[15-69] National Grid: https://www.nationalgrideso.com/balancing-services, retrieved: 27/02/2019

[15-70] https://www.gov.uk/government/publications/smart-metering-implementation-programme-progress-report-2018, Retrieved: 27/02/2019

[15-71] Source: https://www.gov.uk/government/statistics/vehicle-licensing-statistics-july-to-september-2018, Table VEH0130, retrieved 27/02/2019

[15-72] http://fes.nationalgrid.com/fes-document/, retrieved: 27/02/2019

[15-73] Ibid



# 16. THE UNITED STATES OF AMERICA

## 16.1 General Framework and Implementation

The United States is one of the world's largest energy producers as well as one of the world's largest energy consumers. As such, it has maintained an "all the above" national energy policy that is based on the general principle of utilizing its nuclear, fossil and renewable energy resources in the most economic manner that supports its overall energy security and economic development goals. The United States is the world's third most populous country and the second largest electricity consumer. Key figures for the United States are shown below in Figure 16-1. Average electricity prices from the three major demand sectors are given to illustrate the cost of delivering reliable electricity in a deregulated, unsubsidized electricity market [1]

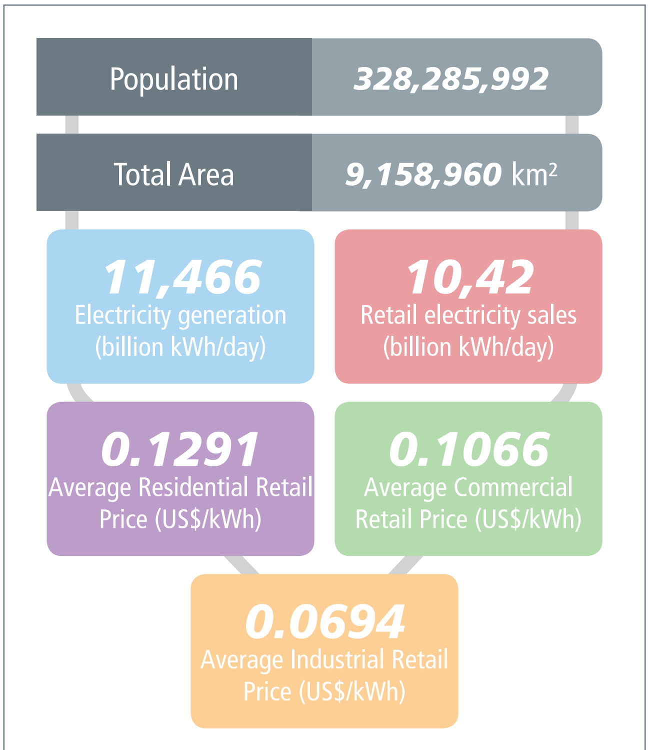



Figure 16-1. Key Figures of US by End of 2018

Figure 16-2 shows how the energy resources utilized to generate electric power have changed in the recent past and are expected to change in the future through 2050 in response to changes in resource prices and energy conversion technology development and implementation. It is seen that as the U.S. moves towards 2050, electricity generation will be dominated by natural gas followed by renewables with both coal and nuclear having projected level generation.

The base case U.S. scenario shown in Figure 16-2 reflects a modest electricity demand growth, the retirement of older, less-efficient fossil fuel units, and a continued expected decline in the capital cost of renewables as well as continued low natural gas process [2].

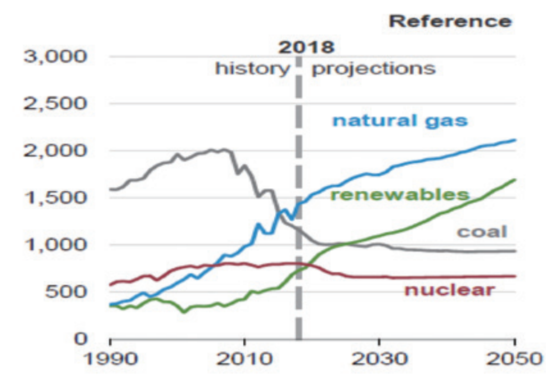



Figure 16-2. U.S. Electricity Generation from Selected Fuels [2] (Billion Kilowatt Hours)

## 16.2 Status of Renewable Energy and Smart Grids

The recent trends in renewable energy electricity generation over the past ten years are shown in Figure 16-3 below. Here it is shown that by far the greatest growth has been seen in solar PV, while wind power has shown the largest growth by total generation each year. This reflects the fact that the U.S. has both abundant solar and wind resources.

While the U.S. Department of Energy's office of Energy Efficiency and Renewable Energy has supported energy research and development that has led to the continued cost reductions and performance increases in renewable energy technologies, the U.S. states have set aggressive targets on renewable energy implementation. A major focus of the targets are through the adoption of state wide renewable energy portfolio standards (RPS). The status of state RPS is tracked and continually updated by the North Carolina Clean Energy Technology Center through the Database of State Incentives for Renewables & Efficiency (DSIRE) [4]. A summary of existing RPS policies as of October 2018 is presented in Figure 16-4. Here it is seen that 29 states, plus Washington DC and 3 U.S. territories have implemented RPS which ranges from 10%-100%. It is noteworthy that two of the most populous states, New York, and California have aggressive goals, with both states having a 50% RPS for the year 2030. This large range illustrates how the support of aggressive renewable energy targets are both a matter of renewable energy resources availability and political support from the overall population impacted.

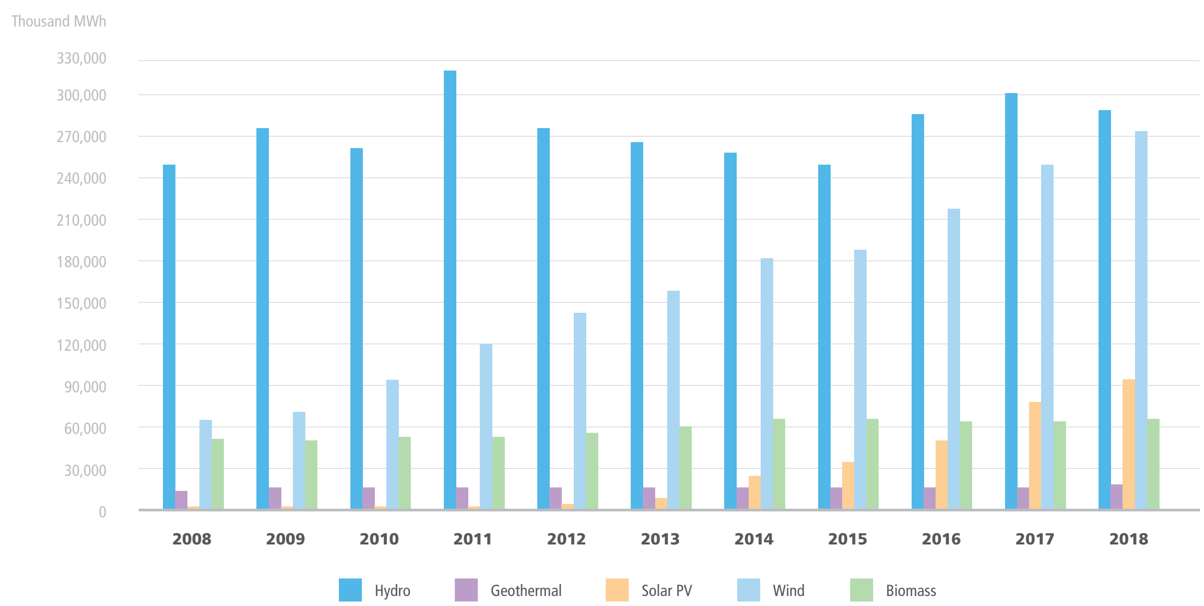



Figure 16-3. Trends in Renewable Energy (Thousand MWh) [3]

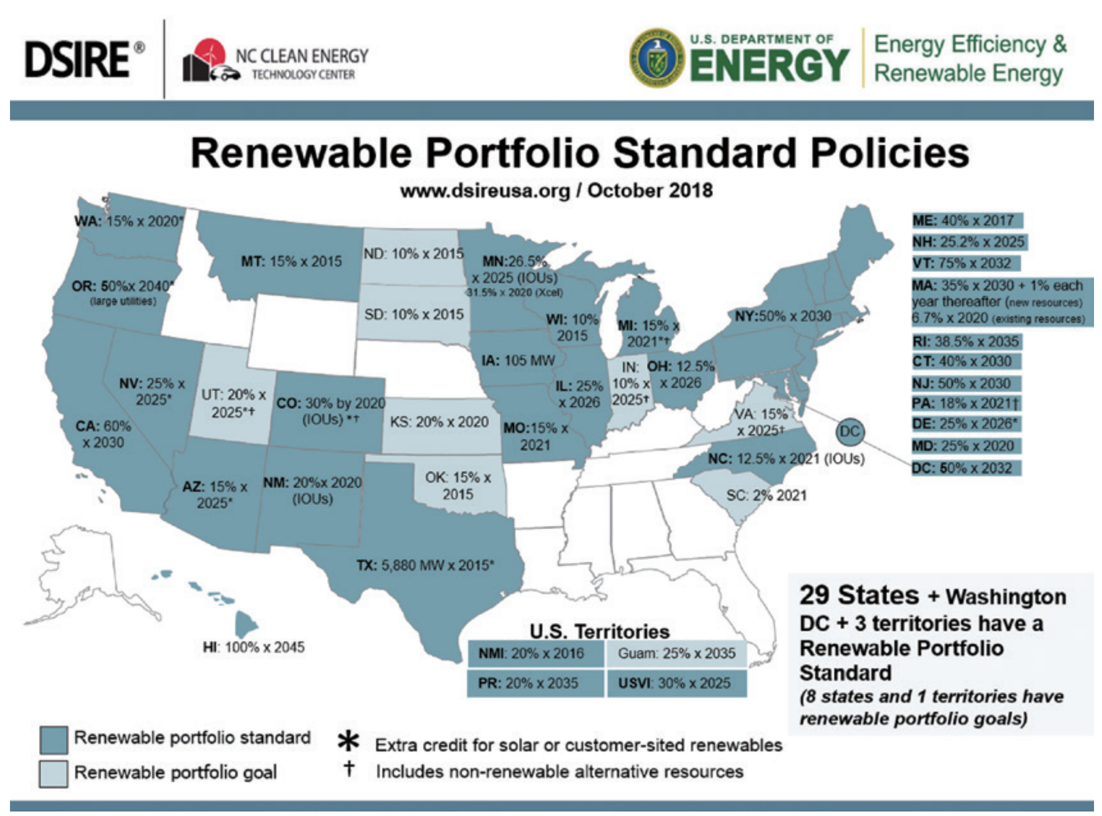
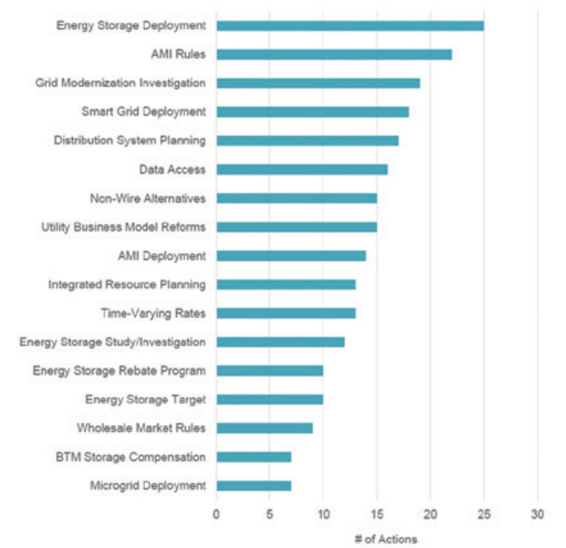



Figure 16-4. U.S. States with Renewable Energy Portfolio Standards [4]

The U.S. electric power system is the centerpiece of the U.S. economy. Virtually every aspect of American commerce and industry depends on the continuous availability of affordable electric power. The U.S. Department of Energy's Office of Electricity (OE) provides national leadership to help ensure that the U.S. energy delivery system is secure, resilient and reliable. OE is pursuing technologies to improve grid reliability, resiliency, efficiency, flexibility, functionality, and security while making investments and sponsoring demonstrations aimed at bringing new and innovative technologies to maturity and helping them transition to market. Key characteristics of the U.S. grid are shown below in Figure 16-5.

| | |
|---|---|
| Number of generators | ***19,000*** |
| Number of transmission sub-stations | ***55,000*** |
| Number of customers | ***145,000,000*** |
| High-voltage transmission lines (miles) | ***642,000*** |
| Distribution lines (miles) | ***6,300,000*** |
| Deployed phasor measurement units (PMUs) | ***2500*** |
| Number of smart meters | ***78,901,590*** |
| Number of electric vehicles (EV & PHEV) | ***1,116,483*** |
| Number and capacity of storage (#/MW) | ***103*** units/ ***7,489*** MW |

Figure 16-5. Key U.S. Smart Grids Facts and Figures by the End of 2018




Note: Chart refers to total actions, not total states for each action.

Figure 16-6. Top U.S. Grid Modernization Actions of 2018 (3ed Quarter) [6]

OE reports on the status of smart grid investment in the U.S. through the publication of a biannual report known as the Smart Grid System Report [5]. This report was last published in 2018 and is intended to provide the status of smart grid deployment nationwide, resulting benefits, and the challenges yet remaining as the U.S. moves forward with the electric grid modernization. Here it was reported that the U.S, annual smart grid investments rose 41% between 2014 and 2016 from US$3.4 billion to US$4.8 billion and they are expected to rise to US$13.8 billion in 2024.

As an example of the range of smart grid activities being undertaken, in the third quarter of 2018, 39 states plus the District of Columbia took a total of 276 policy and deployment actions related to grid modernization, integrated resource planning, the application of distributed energy resources (DERs) as non-wires alternatives, utility business models, rate reforms, and the application of advances metering infrastructure, energy storage systems, and microgrids [6]. The top policy and deployment actions are given below in Figure 16-4. From this, it is seen that energy storage led the actions, followed by AMI (Advanced Metering Infrastructure) rules, smart grid investigations, and smart grid deployment.  Note that the 17 smart grid metrics shown in Figure 16-7 and tracked on a quarterly basis in the 50 States of Grid Modernization report shows the broad range of benefits that are being seen across the country from smart grid implementation.

## 16.3 National Programs in Fields of Smart Grids and Renewable Energy

Access to electricity is so critical to a robust economy and national security that the U.S. National Academy of Engineering named “electrification” the greatest engineering achievement of the 20th century. However, the grid we have today must be modernized to include the attributes necessary to meet the demands of the 21st century and beyond. To respond to the challenge, the U.S. Department of Energy (DOE) established the Grid Modernization Initiative (GMI) in June 2014 to develop a holistic vision for grid modernization across the Department.  GMI represents a comprehensive partnership between DOE, the national laboratories, industry and others to accelerate the development of technologies, modeling analysis, tools, and frameworks to help enable grid modernization adoption. The GMI’s Multi-Year Program Plan provides a roadmap of the DOE strategies [7]. The GMI’s six technical areas are shown in Figure 16-7.

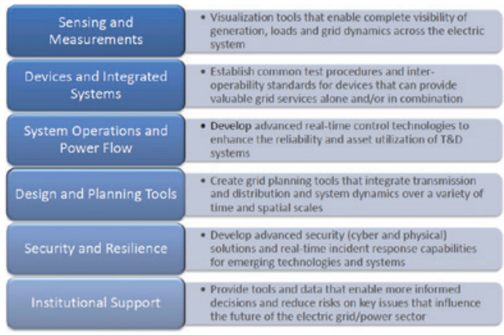



Figure 16-7. Top U.S. Grid Modernization Actions of 2018 (3ed Quarter) [6]

DOE undertakes an annual peer review of its projects from the above six technical areas in order to offer the unique opportunity for public private engagement in the research, development, and deployment areas. The peer review is open to the public, with the most recent review on September 4-7, 2018, in Arlington, Virginia [8]. At this review over 90 projects from GMI’s portfolio were presented to the public. In support of the further implementation of the GMI, on January 24, DOE announced US$40 million in new FY19 funding which support research across the six GMI technical areas.

The Grid Modernization Laboratory Consortium (GMLC) was established as a strategic partnership between DOE and the national laboratories to bring together leading experts, technologies, and resources to collaborate on the goal of modernizing the nation’s grid. The benefits of the GMLC include more efficient use of resources; shared networks; improving learning and preservation of knowledge; enhanced lab coordination and collaboration; and regional perspective and relationships with local stakeholders and industry. One of the main components of the GMI portfolio is the Grid Modernization Lab Call, which is a comprehensive effort of eighty-eight projects that span over the course of three years managed by the national laboratories.  Initial results of the eighty-eight projects became available in 2018 and together these integrated efforts will deliver new concepts, tools, platforms, and technologies to better measure, analyze, predict, and control the grid of the future [9].

The U.S. Department of Energy’s Office of Energy Efficiency and Renewable Energy (EERE) is leading the development of U.S. renewable energy resources. The EERE investment in renewable energy technologies is directed by its 2016-2020 Strategic Plan and Implementation Framework [10]. EERE designs its portfolio to make a significant impact in transforming the national energy landscape and maximizing taxpayer returns. Ultimately, EERE’s goal for its investments is to make clean energy technologies and services more available and reliable while lowering their direct and indirect costs, both to energy users and society as a whole. The EERE investment approach is designed to address specific gaps in the technology development pathway, or areas where the private sector or other non-government stakeholders are unable to make the required investments to the scale or in the timeframe required for clean energy technologies to be commercialized. The economic impact of this strategy is that to date, third-party evaluations have determined that an EERE taxpayer investment of US$12 billion has already yielded an estimated net economic benefit to the U.S. of more than US$230 billion, with an overall annual return on investment of more than 20% [11].

An example of major new initiatives was the October 2018 selection of 53 innovative research projects supported by US$53 million that have a goal of lowering solar electricity costs and support a growing solar workshop [12]. The projects will advance research and development in PV and concentrating solar-thermal power. The projects are spread across 21 states plus the District of Columbia.

Another major program announced in October 2018 was a US$46 million program to advance holistic solutions that provide grid operators the situational awareness and mitigation strategies against cyber and physical threats [13]. A goal of these projects will be to develop and validate control strategies, real-time system monitoring, robust communications and other technologies to make solar power at the bulk power and distribution levels more resilient. It is through support of such programs that the U.S. can increase the levels of PV penetration at the national level.

## 16.4 International Programme Related to Smart Grids and Renewable Energy

The U.S. Department of Energy's Office of International Affairs (IA) is the official lead for U.S. major bilateral and multilateral energy agreements. Through a variety of cross-cutting program initiatives, the Office of International Affairs responds to the most pressing global energy challenges, ranging from energy security and market volatility to long-term efforts to reduce carbon pollution and the impacts of climate change. IA has the responsibility for coordinating the efforts of diverse elements in the Department of Energy to ensure a unified voice in U.S. international energy policy.

Select examples of smart grid and renewable energy related are given below. DOE OE is helping to lead the activities of the Asia Pacific Cooperation Forum (APEC) Energy Resiliency Task Force (ERTF). The APEC Energy Resiliency Task Force (ERTF) was established upon the instructions of the Energy Ministers during the 12th Asia-Pacific Economic Cooperation (APEC) Energy Ministers' Meeting (EMM12) held in Cebu, Philippines on 13 October 2015 [14]. The ERTF operates under the APEC Energy Working Group (EWG) and holds two meeting a year held on the side of the EWG meetings. The ERTF is co-chaired by the U.S. and the Philippines. Its objective is to implement the Energy Ministers' instructions to promote energy resiliency in the APEC region anchored on the four strategic priority sub-themes identified in the Cebu Declaration, the outcome document of the EMM 12, to wit: 1) Climate-proofing energy infrastructures; 2) Providing an avenue for cutting-edge energy efficient technologies; 3) Advocating community-based clean energy use in energy poverty-stricken areas; and, 4) Improving energy-related trade and investment in APEC.

DOE has led the development of the International Smart Grid Action Network (ISGAN) [15]. In July 2010, the International Smart Grid Action Network (ISGAN) was launched in Washington, D.C., at the first Clean Energy Ministerial (CEM) meeting, a forum for energy and environment ministers and stakeholders from 23 countries and the European Union. Then, in April 2011, ISGAN was formally established as the International Energy Agency (IEA) Implementing Agreement for a Co-operative Programme on Smart Grids, operating under the IEA Framework for International Energy Technology Co-operation. ISGAN participants report periodically on progress and projects to the CEM (Clean Energy Ministerial), in addition to satisfying all IEA Implementing Agreement reporting requirements. An example of ISGAN activities is the annual ISGAN Award of Excellence which is sponsored in partnership with the Global Smart Grid Federation. The award, which was began in 2014, recognizes excellence innovation, integration, and transformation of smart grid systems. The award theme for 2019 is "local Integrated Energy Systems (Smart Microgrids). The 2019 award will be presented at the tenth Clean Energy Ministerial in May 2019 in Canada.

DOE EERE has led the Solar Decathlon since 2002 [16]. The Solar Decathlon is a collegiate competition comprising of 10 contestants that challenges student teams to design and build highly efficient and innovative buildings power by renewable energy. The winner will be those teams that best blend design architectural and engineering excellence with innovation, market potential, building efficiency, and smart energy production. Since its inception in the U.S., the Solar Decathlon has expanded to Europe, China, Latin America, Africa, and the Middle East to involve an additional 160 teams and nearly 19,000 participants. The Solar Decathlon has established a worldwide reputation as a successful educational program and workforce development opportunity for thousands of students. It has also educated the public about the benefits, affordability, and availability of clean energy solutions by generating widespread media coverage and harnessing digital tool to reach millions of people.

## 16.5 Case Studies

**PROJECT CASE #1**
**Interoperability [17]**

### Related Sub-challenge of IC1
Reginal grid innovation

### Type of Project
Technology development

### Topic
Interoperability, gird architecture, cyber-security

### Contractors
Pacific Northwest National Laboratory, Lawrence Berkeley National Laboratory, Argonne National Laboratory, National Renewable Energy Laboratory, Smart Grid Interoperability Panel (SGIP), National Institute of Standards and Technology (NIST), GridWise Architecture Council (GWAC), EPRI, Standards Developing Organizations (SDOs), Utilities, Vendors

### Period
2016-2018

### Objective
Energy infrastructure should be flexible enough to accommodate change in response to new, expected, or unexpected internal or external system drivers. This collaboration effort with industry articulates general interoperability requirements along with methodologies and tools for simplifying the integration and cyber-secure interaction among the various devices and systems that constitute the electric power grid. This includes related end-use systems such as buildings, electric vehicles, and distributed energy resources.

The mission of this project is to establish a strategic vision of interoperability for grid modernization with implementation illustrations. The objectives are:

- Establish a strategic vision for interoperability
- Measure the state of interoperability in technical domains
- Identify gaps and roadmaps
- Ensure industry engagement.

**PROJECT CASE #2**
**Distribution System Decision Support Tools [18]**

### Related Sub-challenge of IC1
Distribution grid innovation

### Type of Project
Technology development/demonstration

### Topic
Distribution system planning, distributed energy resources

### Contractors
National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, American Public Power Association, National Rural Electric Cooperative Association, Interstate Renewable Energy Council, Pedernales Electric Cooperative, National Grid, Arizona Public Service Company, Black and Veach, Natl. Assoc. of Regulatory Utility Co

### Period
2016-2018

### Objective
In this project, a multi-lab team is identifying a comprehensive menu of strategies that facilitate and support enhanced utility distribution system planning. This includes guidance on how to consider and incorporate non-wires alternatives, distributed energy resources, and advanced grid components and systems. The team is educating and providing technical assistance for state regulatory agencies, such as public utilities commissions, as well as rural electric cooperatives, municipal utilities, and investor-owned utilities. The team is also identifying significant gaps in existing and emerging EDP approaches, as well as identifying and applying tools and methods that address these issues.

**PROJECT CASE #3**
**Alaska Microgrid Partnership [19]**

### Related Sub-challenge of IC1
Microgrid innovation

### Type of Project
Technology development/demonstration

### Topic
Microgrids, energy storage, lifecycle cost, design and planning tools

### Contractors
Lawrence Berkeley National Laboratory, National Renewable

Energy National Laboratory, Pacific Northwest National Laboratory, University of Alaska, Fairbanks; Alaska Center for Energy & Power; Renewable Energy Alaska Project; Intelligent Energy Systems; Institute for Social & Economic Research

**Period**

2016-2018

**Objective**

Alaska—perhaps more than any other region in the country—faces unprecedented challenges in modernizing its rural energy infrastructure. Across the state there are approximately 200 isolated microgrid systems that are not connected to larger grids, with most of these systems relying almost exclusively on imported fuel (primarily diesel) to meet electrical, space/water heating and transportation requirements. These communities, whose populations range from 50 to 6,000 people, are comprised primarily of native Alaskans, have some of the highest energy costs in the nation (up to ~10 times the national average), arguably the lowest power reliability, and are the least resilient, with impacts due to failure or supply disruptions often lasting days to months.

Because of their remoteness, microgrids are expensive to build and maintain, and the fuel imported into the communities is a high priced commodity. It is a goal of many Alaskans to integrate renewable energy, efficiency and storage into these microgrids—with the expectation that the new technologies will reduce a community's reliance on diesel fuel while improving reliability and resiliency. Currently about 40 communities have deployed some kind of renewable system; however, there are still significant challenges to overcome. Integrating intermittent resources into existing diesel systems, combined with fluctuating demand, can cause strain on the microgrid system if controls and hardware are not upgraded as well. Often, energy storage or demand management systems can be deployed to smooth the sometimes abrupt changes in generation or demand, but this is frequently accompanied with higher initial costs and leads to more complicated O&M requirements. The purpose of the Alaska Microgrid Partnership is to address these significant challenges and advance the development of the next generation of hybrid power systems for isolated communities.

The over-arching goal of the Alaska Microgrid Partnership is to reduce diesel fuel consumption by 50% in Alaska's remote microgrids without increasing system lifecycle costs, while improving overall system reliability, security, and resilience. Data sources and information will be developed and shared with other stakeholders across Alaska and the Arctic.

## PROJECT CASE #4
## Development of Integrated Transmission, Distribution, and Communications Models [20]

**Related Sub-challenge of IC1**

Cross innovation

**Type of Project**

Technology development

**Topic**

High penetration variable renewables, distributed generation, distributions models, transmission models, design and planning tools

**Contractors**

Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Sandia National Laboratory

**Period**

2016-2018

**Objective**

Significant amounts of variable, and increasingly distributed generation, as well as other distributed resources, are expected to enter the U.S. electrical infrastructure. The traditionally abundant reserves in the system have eroded due to increased penetration of variable resources, impairing system reliability. To operate the power system with a leaner reserve margin, distributed generation resources must play a role in maintaining—or improving—system resiliency and reliability. This requires new control and protection systems, along with supporting communication networks. This is a revolution in how the power system is planned and operated: the power system is relying more heavily on hierarchical and distributed control systems with greater dependency on a variety of communication media. However, we lack modeling and simulation capabilities for the industry to understand such transmission distribution and communication (TDC) interdependency but have confidence in deploying systems that will meet, or improve upon, current reliability, efficiency, and cost-effective benchmarks.

Our flexible and scalable open-source co-simulation framework will fill this gap. We are integrating simulators designed for separate TDC domains to simulate regional and interconnection-scale power system behaviors at unprecedented levels of detail and speed. The target is to scale up to linking a 50,000-node transmission system with millions of distribution nodes, coupled with 100,000 communication points. This simulation should enable planning studies in a turnaround time of minutes to hours, instead of days with today's simulation technologies, a speedup of 50 to 100 times – a feat not previously done before.

This comprehensive TDC simulation tool is fundamental for investment decision-making by industry. It's also important to help quantify the impact of the ever-increasing high penetration variable generation on power grid reliability and resiliency.

**PROJECT CASE #5**
**Increasing Distribution Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (Decentralized FLISR) [21]**

**Related Sub-challenge of IC1**
Cross innovation

**Type of Project**
Technology development

**Topic**
devices and integrated system testing, distributed energy resources, microgrids

**Contractors**
Pacific Northwest National Laboratory, Oak Ridge National Laboratory, National Renewable Energy Laboratory, Anderson Civic Center, Muscatatuck Urban Training Center, Avista Utilities, Duke Energy, GE Grid Solutions, University of North Carolina Charlotte, University of Tennessee, Smart Electric Power Alliance

**Period**
2016-2018

**Objective**
Distribution systems could achieve increased resiliency through flexible operating strategies. This project will accelerate the deployment of resilient and secure distribution concepts, culminating in a field demonstration in South Carolina. It will do this through the flexible operation of traditional assets, distributed energy resources (DERs), and micogrids using OpenFMB, a reference architecture for security and interoperability. This change of treating DERs and microgrids as boundary conditions will enable more system flexibility with adaptive settings. The capabilities developed will be applicable to all of Duke's service territory: South Carolina, North Carolina, Florida, Ohio, Indiana, and Kentucky.

## 16.6 Reference


[1] U.S. Energy Information Administration, Short-Term Energy Outlook, Washington, DC, https://www.eia.gov/outlooks/steo/report/electricity.php

[2] U.S Energy Information Administration, Annual Energy Outlook 2019, Washington, DC, https://www.eia.gov/outlooks/aeo/

[3] U.S. Energy Information Administration, Electricity Monthly, Washington, DC https://www.eia.gov/electricity/monthly/

[4} Database of State Incentives for Renewables & Efficiency, NC Clean Energy Technology Center. http://www.dsireusa.org/

[5] 2018 Smart Grid System Report, United States Department of Energy, Washington, DC. https://www.energy.gov/oe/downloads/2018-smart-grid-system-report

[6] 50 States of Grid Modernization, Q3 2018, North Carolina Clean Energy Technology Center. https://nccleantech.ncsu.edu/2018/11/01/the-50-states-of-grid-modernization-39-states-dc-took-action-on-grid-modernization-in-q3-2018/

[7] U.S. DOE Grid Modernization Multi-Year Plan, U.S. Department of Energy, Washington, DC https://energy.gov/downloads/grid-modernization-multi-year-program-plan-mypp

[8] GMI Peer Review, Washington, DC, https://www.energy.gov/grid-modernization-initiative-0/2018-grid-modernization-initiative-peer-review

[9] GRID Modernization Laboratory Consortium, https://gridmod.labworks.org/

[10] DOE EERE 2016-2020 Strategic Plan and Implementation Framework, https://www.energy.gov/eere/downloads/eere-strategic-plan

[11] About the Office of Energy Efficiency and Renewable Energy, https://www.energy.gov/eere/about-office-energy-efficiency-and-renewable-energy

[12] Department of Energy Announces $53 Million in New Projects to Advance Solar Technologies, Washington DC. https://www.energy.gov/articles/department-energy-announces-53-million-new-projects-advance-solar-technologies

[13] Department of Energy Announces $46 Million to Improve Resiliency of Solar Generation, Washington, DC. https://www.energy.gov/eere/articles/department-energy-announces-46-million-improve-resiliency-solar-generation

[14] APEC Energy Resiliency Task Force, https://www.esci-ksp.org/wp/ertf/

[15] International Smart Grid Action Network (ISGAN), https://www.iea-isgan.org/

[16] DOE EERE Solar Decathlon, https://www.solardecathlon.gov/about.html

[17] U.S. Department of Energy, GMLC https://gridmod.labworks.org/projects/1.2.2

[18] U.S. Department of Energy, GMLC https://gridmod.labworks.org/projects/1.4.25

[19] U.S. Department of Energy, GMLC https://gridmod.labworks.org/projects/1.3.21

[20] U.S. Department of Energy, GMLC https://gridmod.labworks.org/projects/1.4.15

[21] U.S. Department of Energy, GMLC https://gridmod.labworks.org/projects/1.5.03

# 17. European Union

## 17.1 General framework

The European Union has since long supported the objective of dramatically reducing greenhouse gases emissions to ensure that the global temperature increase of the planet stays below 2°C. To achieve this goal, EU has engaged in a process leading to emissions reduction by 80-95% in 2050 with intermediate steps, **targeting reduction of emissions by at least 40% by 2030,** increasing the share of **renewable energy to 32%**, and achieving an **energy efficiency target of 32.5%** (when compared with the projected use of energy in 2030). According to the EC[17-1], the road to a net-zero greenhouse gas economy could be based on a joint action along different strategic building blocks: i.e **energy efficiency** in the building environment, **deployment of renewables** to fully decarbonise the energy supply (by 2050, electrify more that 53% of the final energy demand, generating more than 80% of electricity from renewable energy sources), adoption of **clean, safe and connected mobility**, evolution toward a **circular economy** with particular reference to industry (recovery and recycling of raw materials), development of an adequate **smart network infrastructure and inter-connections** (smart electricity networks, data/information grids, hydrogen pipelines, sector integration, etc.), bio-economy and carbon sinks (sustainable biomass for heat production biofuels and biogas, precision farming and agriculture, advanced agroforestry techniques, afforestation and restoration of degraded forests), **carbon capture and storage and use (CCUS).**

The Energy Union was launched in 2015, aiming at accelerating the modernisation of the Europe's entire economy, making it low- carbon and efficient in energy and resources, while leveraging social wealth and fairness. It sets broader goals covering five mutually reinforcingdimensions: **energy security,** internal **energy market, energy efficiency, decarbonisation** (including renewable energy development), **research, development and competitiveness.** For the research pillar, the Strategic Energy Technologies (SET) Plan has been a key deliverable and crucial component linking EU, Member States, industry and academia. The SET Plan coordinates low-carbon research and innovation activities in the EU Member States and other participating countries (Iceland, Norway, Switzerland and Turkey) and helps structuring European and national research programmes triggering investments on common priorities in low-carbon technologies.

[17-1] COM(2018) 773 final Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank : "A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy"

The SET Plan has adapted its structure and processes to effectively accelerate the transformation of the EU's energy system in line with this new focus, putting forward:

- A more targeted focus: ten actions structured around the research and innovation priorities of the Energy Union have been developed;
- An integrated approach to look at the energy system as a whole;
- A new management structure to increase transparency, accountability and monitoring of progress, as well as a result-oriented approach;
- A strengthened partnership between the Commission, the SET Plan countries and the stakeholders, including research organisations and industry.

The SET Plan has identified 10 actions for clean energy technologies research and innovation, based on an assessment of the energy system needs, on their importance for the energy system transformation and their potential to create growth and jobs in the EU. The ten actions of the SET Plan are the following:

1. Develop performant renewable technologies integrated in the energy system
2. Reduce the cost of key renewable technologies
3. Create new technologies and services for consumers
4. Increase the resilience and security of the energy system
5. Develop energy efficient materials and technologies for buildings
6. Improve energy efficiency for industry
7. Become competitive in the global battery sector (e-mobility)
8. Strengthen market take-up of renewable fuels
9. Drive ambition in carbon capture and storage/use deployment
10. Increase safety in the use of nuclear energy

The main operational instruments of the SET Plan are the following:

- **The SET Plan Steering Group:** The Steering Group (SG) formalises the interaction among the European Commission, the EU Members States and other countries associated with the SET Plan efforts (namely Norway, Iceland, Switzerland and Turkey) and parties to it. It constitutes its main governance structure. This Steering Group creates a flexible framework for countries and the EC for strategic planning and implementation and aims to maximise the cost-effective contribution of technology to the targets of the Energy Union.
- **European Technology and Innovation Platforms (ETIPs):** They are recognised as key industry-led communities to develop and implement the SET Plan R&I priorities, with the aim to foster innovation in low-carbon energy technologies and bring such new technologies to the market. They provide consensus-based strategic advice on the SET Plan covering technical and non-technical aspects (e.g. industrial strategy, market opportunities, exploitation of research results, innovation barriers, need for specific research activities, strategy for international cooperation, education, environmental and social impacts) and addressing links with other sectors in view of an increased system integration. They support the SET Plan in the development and monitoring mechanisms of the SET Plan R&I priorities. Among the 9 existing technology platforms, the ETIP SNET (Smart Networks for an Energy Transition) gathers stakeholders in the energy networks sector under the coordination of industrial operators (network operators and technology providers). This initiative monitors the achievement of technological, legislative and regulatory goals that enable the deployment of intelligent network solutions. ETIP SNET recently published its VISION2050, the Monitoring Report and Research Roadmap;
- **European Energy Research Alliance (EERA):** it is an alliance of European public research centres and universities. EERA gathers around 250 research centres and universities across 30 countries, coordinated into 17 Joint programmes. Among them, the EERA JP Smart grids is focused on electric networks with the aim of aligning national research programs with common objectives, in order to limit duplication and promote synergies. This initiative involves 42 partners from 17 countries and develops research activities on control architectures, integration of storage, renewable energy, user involvement and modernization of transmission networks.
- **Implementation Working Groups (IWGs):** they were established to tackle the SET Plan's research and innovation actions, optimizing national R&I funding programmes to jointly implement activities of common interest. In particular the IWG4 complements the ETIP SNET, leveraging the priorities of the governments of the 15 participating countries, identifies and agrees on concrete objectives for the implementation of energy grid intelligence solutions. Joint public research projects are planned, promoting the establishment of regulatory frameworks which facilitate innovation and adoption by the users.
- **Public Private Partnerships (PPPs):** they were created to enable a long-term, strategic approach to research and innovation, reducing uncertainties by allowing for

long-term commitments, pooling resources into a critical mass. These initiatives enable innovative technologies to get faster to the markets, enabling the scale of research and innovation effort needed to address critical societal challenges and major EU policy objectives.

## 17.2 National Programs in Fields of Smart Grids and Renewable Energy

The main European programme supporting research and innovation in the field of Smart Grids and Energy Systems is the Horizon 2020 Programme (H2020). This is the biggest EU Research and Innovation programme to date with nearly €80 billion funding available over 7 years (2014 to 2020) in a set number of thematic areas. Its successor, the new Horizon Europe Programme, will run from 2021 to 2027.

Under Horizon 2020, nearly €6 billion have been allocated to Research and innovation in the area of Energy, with approximately €700 million allocated to projects in the field of Smart grids, Storage and Energy system during the period 2014-2020 (WP2014-2015: € 239 million[17-2], WP2016-2017: € 166 million[17-3], WP2018-2019: € 174 million[17-4]).

The priorities funded under these calls focus on the following areas:

### - Distribution:

- Distribution grid and retail market
- Demonstration of smart grids, storage and system integration technologies with increasing share of renewables: distribution system
- Flexibility and retail market options for the distribution grid

### - Transmission:

- nnovation and technologies for the deployment of meshed off-shore grids
- Transmission grid and wholesale market
- Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables
- Solutions for increased regional cross-border cooperation in the transmission grid

### - Storage:

- Local / small-scale storage
- Large scale energy storage
- Next generation technologies for energy storage

### - RES Heating & Cooling: Developing the next generation technologies of renewable electricity and heating/ cooling

### - Cross-cutting:

- Research on advanced tools and technological development
- TSO – DSO – Consumer: Large-scale demonstrations of innovative grid services through demand-response, storage and small-scale (RES) generation
- Pan-European Forum for R&I on Smart Grids, Flexibility and Local Energy Networks
- Customers engagement in demand-response

### - Geographical and energy islands:

- Integrated local energy systems (Energy islands)
- Decarbonising energy systems of geographical Islands
- European Islands Facility - Unlocking financing for energy transitions and supporting islands to develop investment concepts

Complementary to H2020, there are other European programmes providing funds to research and innovation relevant to Smart Grids and Energy Systems:

- ERA- Net Smart Energy System (SES): it is a transnational research, development and innovation (RDI) programme funded by several European member states, regions and the European Commission. ERA-NET SES is the result of the merging of two ERA-NETs: ERA-Net Smart Grids Plus (SG+) and ERA-Net Regional and local energy systems and networks (RegSys). In total, since 2015, ERA-Net SG+ provided over € 53 million funding to 34 transnational projects. The 2018 REGSYS call is expected to provide additional € 33 million funding.
- Other EU programmes: European Structural and

[17-2] Allocated budget, based on BRIDGE report: https://www.h2020-bridge.eu/wp-content/uploads/2018/02/Brochure-of-BRIDGE-projects-V16.pdf

[17-3] idem

[17-4] Based on information days presentations. 2017 info day: https://ec.europa.eu/inea/sites/inea/files/02_info-days-remy-mod20mvs.pdf €73 million for 2018 call ; 2018 info day: https://ec.europa.eu/inea/sites/inea/files/03._es1_es2_es6_michela_final_-_10h.pdf €101 million for 2019. Budget 2020 is estimated (figures not yet available).

Investment Fund (ESIF) It provides funding at National and or Regional level. One of the focus area of ESIF is research and innovation. The LIFE programme provides funding for deployment and test solutions with a positive impact on Environment and Climate. The European Fund for Strategic Investments (EFSI) helps overcome the current investment gap in the EU. EFSI is one of the three pillars of the Investment Plan for Europe that aims to revive investment in strategic projects around the continent to ensure that money reaches the real economy. The Connecting Europe Facility (CEF) Energy programme aims to upgrade the EU's energy infrastructure to match future demand for energy, to ensure security of supply or to support large-scale deployment of energy from renewable sources. A total budget of € 5.35 billion is available for the 2014-2020 period, € 4.5 billion of which in the form of grants.

## 17.3 Case Studies

**PROJECT CASE #1**
**WISEGRID – Wide Scale Demonstration of Integrated Solutions and Business Models for European SmartGRID** [17-5]

### Related Sub-challenge of IC1-2

Task 2 – Demand response

### Type of Project

Demonstration, EU H2020

### Topic

Technologies for Consumers (Demand response, Smart appliance and smart metering), Grid technologies (Network management, monitoring and control tools), Distributed storage technologies (batteries, Electric Vehicle, thermal Energy storage), Generation technologies (Wind turbine and PV), Market (Electricity market and ancillary services)

### Objective

- To integrate and demonstrate innovative and advanced Demand-Response mechanisms that will facilitate the active participation, protection and empowerment of the European consumers and prosumers in the energy grid and market, through flexible RES generation, self-consumption and storage, or through intermediaries (aggregators, etc.)
- To address:
  - The smartening of the distribution grid to gain advanced monitoring and awareness of variable generation and consumption loads, and the integration of VPPs and microgrids as active balancing assets
  - The integration of renewable energy storage systems in the network, such as batteries or heat accumulator
  - The integration of tools to plan the deployment of electric mobility services, as well as the management of loading and unloading of these vehicles -including the possible use of their batteries as storage systems or VPPs

### Coordinator

Etra Investigacion y Desarrollo SA (Spain)

### Period

2016-2020

### Ongoing and Achieved Key Findings

- Wisegrid Cockpit: cockpit for DSOs or microgrids operators to control, manage and monitor their own grid;
- WiseCORP: corporate application to effectively manage the energy assets of a building allowing Demand Response participation;
- WiseCOOP: Application achieving energy deals while relieving beneficiaries from administrative procedures and cumbersome research;
- WiseGRID Electric Vehicle Platform (EVP): for vehicle-sharing companies and e-vehicles fleet;
- WG FastV2G: EV charging station that will make possible to use EV as dynamic distributed storage devices.


Figure 17-1

[17-5] http://www.wisegrid.eu
[17-6] http://interflex-h2020.com/

PROJECT CASE #2

**InterFlex - Interactions Between Automated Energy Systems and Flexibilities Brought by Energy Market Players** [17-6]

### Related Sub-challenge of IC1-4

Task 4 – Flexibility options

### Type of Project

Demonstration, EU H2020

### Topic

Technologies for consumers (demand response and smart metering), Grid technologies (Micro-grid), distributed storage technologies (batteries, Electric vehicle and thermal Energy storage), Market (Ancillary services)

### Objective

- To demonstrate a set of technologies and solutions in a real-scale environment in the context of an increasing share of renewable energy sources (e.g. 50% by 2030)

- To use high-level maturity technologies (TRL 5-8)

- To develop demonstration projects in five EU Member States (Czech Republic, France, Germany, The Netherlands and Sweden) and validate new business models integrating:
  - Distributed energy resources (wind, solar)
  - Flexibilities on a local scale (storage; optimized utilization of different energy carriers such as electricity, gas or heat, smart EV charging)

### Coordinator

ENEDIS (France)

### Period

2017-2019

### Ongoing and Achieved Key Findings

- Enhanced DSO and aggregators platforms (and related interfaces): To provide innovative energy services for all the players in the energy market, to use simultaneously flexibilities from multiple sources, to trade them locally on a "Local flexibility market", and to control them remotely (for instance through the German demo "Smart Grid Hub");
- Multi-services business models for battery storage, including use of EVSE: To test residential and larger, shared battery systems to relieve network congestion, and increase the renewable hosting capacity of the grid;
- Recommendations for grid code evolutions allowing for an increase in DER hosting capacity: To increase DER hosting capacity thanks to using volt-var control V/Q or to using the Q(U) and P(U) characteristics of smart inverters;
- New business models for optimization of DSO operation by exploiting the interaction with district heating, district cooling, micro-CHP or other multi-energy devices: To exploit untapped potentials for flexibility provision: flexible use of hybrid heating systems that can run on both electricity and gas and exploitation of thermal inertia and the interaction between thermal and electricity grids;
- Recommendations and market organisation on running a planned and automated islanded mode: Recommendations for the grid codes on the observability and management of microgrids.


Figure 17-2

PROJECT CASE #3

**EMPOWER - Local Electricity Retail Markets for Prosumer Smart Grid Power Services** [17-7]

### Related Sub-challenge of IC1

Task 2 – Demand response

Task 5 – New grid control architectures

### Type of Project

Technology development, EU H2020

### Topic

Technologies for consumers (demand response, smart appliance and smart metering), Grid technologies (Network management, monitoring and control tools, Micro-grid), distributed storage technologies (batteries, Electric vehicle), generation technologies (Wind turbine and PV), Market (Electricity market and Ancillary services)

[17-7] http://www.empowerh2020.eu/

### Objective

- To define a community for local trading of energy, flexibility and energy related services;
- To create a trading system for continuous exchange of energy, flexibility and service contracts and any combinations of these;
- To design a cloud-based ICT platform for operating local markets;
- To implement and test the ICT platform in three pilot sites for several distribution grid management and services (i.e., decision-making, load forecasting, consumer profiling, load aggregation, demand-response programs, energy consumption and supply balancing, cost reduction);
- To offer communication services, like web access and mobile apps to participants to support their engagement to the ICT platform.

### Coordinator

SCHNEIDER ELECTRIC NORGE AS (Norway)

### Period

2015-2017

### Ongoing and Achieved Key Findings

- EMPOWER platform: Provides an ICT platform for local electricity trading between neighbours;
- Customized version of the EMPOWER platform: Customized version of the EMPOWER platform for German public utility market & Nordic retailer market;
- EMPOWER multi-agent system (MAS): Managing and optimizing multiple loads and feeds in a microgrid or congested local market;
- IoT for smart grids: Creating and supporting a local energy community for different energy management purposes;
- Forecasting system: System for forecasting loads, feeds and congestion problems.

[17-8] http://www.goflex-project.eu/

[17-9] http://www.re-serve.eu

[17-10] http://www.realvalueproject.com/

## PROJECT CASE #4
## GOFLEX - Generalized Operational FLEXibility for Integrating Renewables in the Distribution Grid [17-8]

### Related Sub-challenge of IC1

Task 4 – Flexibility options

Task 1 – Storage integration

### Type of Project

Technology development, Demonstration, EU H2020

### Topic

Technologies for consumers (demand response), Grid technologies (Network management, monitoring and control tools), distributed storage technologies (batteries, Electric vehicle, thermal energy storage), Market (Ancillary services)

### Objective

- To focus on active use of distributed sources of flexibility to provide services for grid operators, balance electricity demand and supply, and optimize energy consumption and production at the local level;
- To support data-driven decisions for stakeholders thanks to a backbone data-services platform offering localised estimation and short-term predictions;
- To test solutions at three European demonstration sites in Germany, Switzerland and Cyprus involving over 400 prosumers from industry, buildings and transport.

### Coordinator

IBM IRELAND LIMITED (Ireland)

### Period

2016-2019

### Ongoing and Achieved Key Findings

The project builds upon existing technology (TRL5-7) from several areas:

Figure 17-3


Figure 17-4

- Energy flexibility management system: An integrated system, applicable to small, medium and large prosumers, for the automatic management of energy flexibility
- Demand-response schemas and infrastructures
- Energy storage systems
- Electrification of transport
- Distribution grid monitoring and management
- Energy data management infrastructures

An expected outcome of the project is an increase to technology readiness level of seven or eight.

**PROJECT CASE #5**
**RESERVE - Renewables in a Stable Electric Grid** [17-9]

### Related Sub-challenge of IC1
Task 5 – New grid control architectures

### Type of Project
Technology development, EU H2020

### Topic
Grid technologies (Network management, monitoring and control tools), Market (Ancillary services)

### Objective
- To enable up to 100% penetration of renewables by developing innovative approaches to system level automation based on innovative ancillary service provision with a close to market level of maturity, supported with validation of the concepts and policies using a pan-European real time simulation Infrastructure, anchoring the approach with the main sectors in Europe and beyond

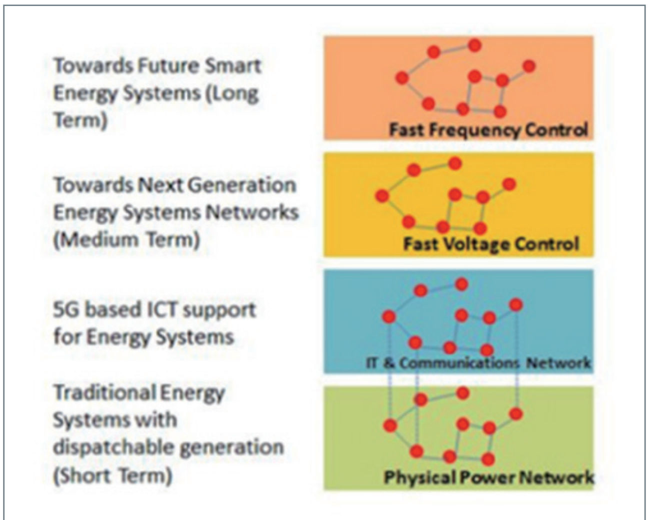



Figure 17-5

- To develop two innovative research approaches, Linear Swing Dynamics (LSD) and Virtual Output Impedance (VOI), enabling the stabilisation of voltage and frequency in energy systems with little inherent inertia; supported by inter-disciplinary research on ethical business models for energy systems based on 100% use of RES

### Coordinator
ERICSSON GMBH (Germany)

### Period
2016-2018

### Ongoing and Achieved Key Findings
- New techniques for frequency management with up to 100% RES: Continued stable operation of the power grid even when the proportion of RES generation reaches very high levels and the use of fossil fuels is reduced;
- New techniques for voltage control with up to 100% RES: Stable power supplies even as the proportion of power generation based on RES increases towards 100%;
- Villas node co-simulation Software: Enabling co-simulation of very complex power network scenarios.

**PROJECT CASE #6**
**REAL VALUE – Realising Value from Electricity Markets with Local Smart Electric Thermal Storage Technology** [17-10]

### Related Sub-challenge of IC1
Task 2 – Demand response

### Type of Project
Demonstration, EU H2020

### Topic
Technologies for consumers (demand response, smart appliance and smart metering), distributed storage technologies (Thermal Energy Storage), Market (Electricity market and Ancillary services)

### Objective
- To accelerate innovation and develop the business models necessary for use of small-scale energy storage in residential homes and other types of buildings such as schools and small commercial properties;
- To use a combination of physical demonstrations in Ireland, Germany and Latvia along with innovative modelling techniques, in order to demonstrate how local small-scale energy storage, optimised across the whole EU energy system, with advanced ICT, could bring benefits to all market participants.

### Coordinator

GLEN DIMPLEX IRELAND (Ireland)

### Period

2015-2018

### Ongoing and Achieved Key Findings

- DSM Smart Tariff: To customise the benefit from variable electricity pricing;
- Power system modelling and market modelling: Modelling of systems which are relevant for thermal storage - possibility on electricity networks;
- VPP optimisation algorithm: Simplified process for managing numbers of complex devices to provide value for system operators;
- Consumer engagement guidance: Guidances for interaction with large number of consumers across different demographics;
- Understanding of grid and network constraints: Practical learnings on wide spread use of flexible devices for DSM purposes on distribution networks.

Figure 17-6

## PROJECT CASE #7
## TILOS – Technology Innovation for the Local Scale, Optimum Integration of Battery Energy Storage [17-11]

### Related Sub-challenge of IC1

Task 1 – Storage integration

Task 5 – New grid control architecture

### Type of Project

Demonstration, EU H2020

### Topic

Technologies for consumers (demand response, smart metering), grid technologies (Micro-grid), distributed storage technologies (Batteries, Thermal Energy Storage), Generation technologies (Wind turbine, PV), Market (Electricity market and Ancillary services)

### Objective

- To develop and operate a prototype battery storage system, based on NaNiCl2 batteries that will be provided with a smart grid control system. The battery system will support both grid-forming (stand-alone microgrid) and grid-following (microgrid coupled with the main grid) operation and will also prove its interoperability with the rest of the microgrid components, including centralized RES, demand side management (DSM), and distributed, residential heat storage in the form of domestic hot water;
- To examine new case studies with the development of an advanced microgrid simulating tool, i.e. the Extended Microgrid Simulator, able to simulate different storage technologies and microgrid configurations (stand-alone, grid-connected and power market-dependent systems);
- To address social issues (public engagement) and develops novel business models and policy instruments.

### Coordinator

PIRAEUS UNIVERSITY OF APPLIED SCIENCES (Former Technological Educational Institute of Piraeus) (Greece)

### Period

2015-2019

### Ongoing and Achieved Key Findings

- Integrated NaNiCl2 Battery & Grid-forming Battery Inverter: MW-scale multi-functional BESS supporting island operation
- Prototype Smart Meter & DSM Panel: Smart Meter & DSM Panel for the monitoring and remote control of residential and other type of loads
- Forecasting Platform: Robust forecasting platform able to interface EMS

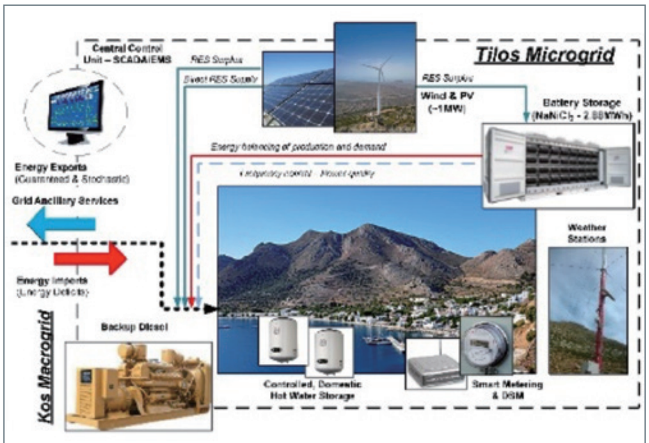



Figure 17-7

## PROJECT CASE #8
### FLEXITRANSTORE - An Integrated Platform for Increased FLEXIbility in smart TRANSmission grids with STORage Entities and large penetration of Renewable Energy Sources [17-12]

**Related Sub-challenge of IC1**

Task 4 – Flexibility options
Task 2 – Demand response
Task 1 – Storage integration

**Type of Project**

Technology development, Demonstration, EU H2020

**Topic**

Technologies for consumers (demand response), grid technologies (Network management, monitoring and control tools), Large-scale storage technologies (Battery), Generation technologies (Wind turbine, PV), Market (Electricity market and Ancillary services)

**Objective**

- To assist the evolution towards a pan-European transmission network with high flexibility and interconnection levels;
- To ensure that the management of the technologies developed with the Flexible Energy Grid demonstrates flexible resource applications that mitigate the effects of RES variability on the network.

**Coordinator**

European Dynamics Belgium S.A. (Belgium)

**Period**

2017-2021

**Ongoing and Achieved Key Findings**

- RES storage integration: Mitigate Renewable Energy Source volatility towards a "near-dispatchable" nature
- FACTS devices for congestion relief: Relieve congestion and exploit remaining grid capacity
- Market platform: Demonstration of an elaborated market platform that remunerates flexibility services through the wholesale market
- Flexible and stable conventional generation: Solutions tailored for Gas Turbine plants to improve stability from low frequency oscillations and provide several services: frequency response capacity, black-start
- Demand side flexibility at the TSO-DSO border: Controllers and battery storage situated at the TSO-DSO border

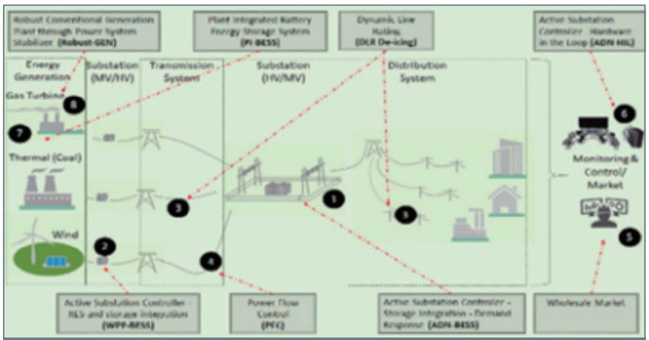


Figure 17-8

## PROJECT CASE #9
### FUTUREFLOW – Designing eTrading Solutions for Electricity Balancing and Redispatching in Europe [17-13]

**Related Sub-challenge of IC1**

Task 2 – Demand response
Task 5 – New grid control architecture

**Type of Project**

Demonstration, EU H2020

**Topic**

Technologies for consumers (demand response), grid technologies (Network management, monitoring and control tools), Market (Electricity market and Ancillary services)

**Objective**

- To design and pilot test, at a plausible scale, comprehensive techno-economic models for open and non-discriminatory access of advanced consumers (DR) and distributed generators (DG) to the Regional Platform for ancillary/balancing and redispatching services;
- To design and implement cross-border balancing and redispatching mechanisms, including the Common Activation Function (CAF) tailored to congested borders, based on a harmonized set of requirements for DR and DG to be able to compete in these markets.

**Coordinator**

ELES (Slovenia)

**Period**

2016-2019

[17-11] http://www.tiloshorizon.eu/
[17-12] www.flexitranstore.eu
[17-13] http://www.futureflow.eu/

## Ongoing and Achieved Key Findings

- Definition of power consumers and DER owners that can become secondary reserve (aFFR) market providers: To convince all market players and regulators about the soundness of the technical and market design approach about aFFR market providers;
- Techno-economic model to optimize coupling of secondary reserve (aFRR) markets: Increase balancing market liquidity, reducing costs of RES integration and security of supply, with accommodation of massive intermittent generation;
- Cyber secure Flexibility Aggregation Platform and Regional Balancing and redispatching cross-border platform: To reduce the gap in electricity end-uses prices for industry vis-à-vis the EU major trading partners;
- Deployment roadmap for most promising use cases for cross-border exchange of aFRR with DR and DER: To describe how integrated balancing markets work and what can be anticipated with its expansion from 4 countries to EU wide.

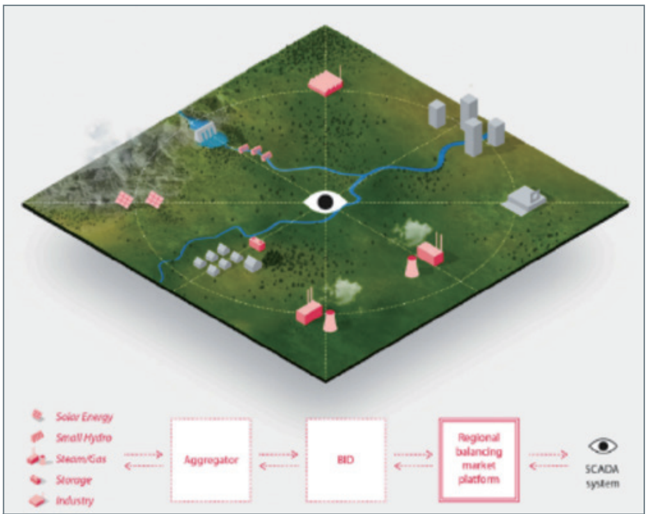



Figure 17-9

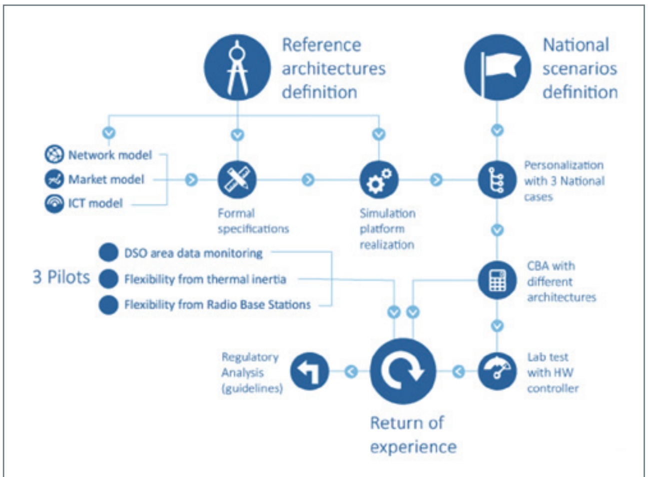



Figure 17-10

PROJECT CASE #10

**Smartnet – Smart TSO-DSO interaction schemes, market architectures and ICT Solutions for the integration of ancillary services from demand side management and distributed generation** [17-14]

### Related Sub-challenge of IC1

Task 5 – New grid control architectures

### Type of Project

Instruments development, EU H2020

### Topic

Market (Electricity market and Ancillary services)

### Objective

To provide optimised instruments and modalities to improve the coordination between the grid operators at national and local level (respectively the TSOs and DSOs) and the exchange of information for monitoring and for the acquisition of ancillary services (reserve and balancing, voltage control, congestion management) from subjects located in the distribution segment (flexible load and distributed generation)

### Coordinator

RICERCA SUL SISTEMA ENERGETICO - RSE SPA (Italy)

### Period

2016-2018

### Ongoing and Achieved Key Findings

- SmartNet TSO-DSO ancillary services market simulator: Comprehensive model including transmission, distribution, DER for detailed technical economic assessments;
- SmartNet testing facility for DSO system monitoring and control: Real time monitoring and control of distribution grid located DER from the national TSO;
- SmartNet testing facility for AS provision from thermostatically controlled loads: To use a scattered amount of thermostatically controlled loads as flexibility resources;
- SmartNet testing facility for AS provision from localized storage facilities: To use a scattered amount of localized storage systems-controlled loads as flexibility resources;
- An analysis procedure to discover ICT requirements in energy systems: Possibility to maintain links between data flow diagrams and ICT requirements in SGAM tools; and to use parametrized scripts to alter ICT requirements and to assess their impacts on the system design.

[17-14] http://smartnet-project.eu/

# APPENDIX I
## IC1 R&D Tasks and Subtasks in the Smart Grids Field

| | |
|---|---|
| ***Task 1 – STORAGE INTEGRATION*** | |
| 1.1 | Inventory of storage control approaches |
| 1.2 | Comparison tools for integrating storage into operations |
| 1.3 | Inventory of approaches to integrate storage into system planning |
| 1.4 | Comparison tools for integrating storage into planning |
| 1.5 | Inventory of Approaches to Integrating Storage into Markets |
| 1.6 | Storage safety |
| ***Task 2 – DEMAND RESPONSE*** | |
| 2.1 | Status review of demand response |
| 2.2 | Demand response potential in different systems and processes |
| 2.3 | Use of demand response in distribution network operation and planning |
| 2.4 | Microgrid as a provider of demand response and Flexibility |
| ***Task 3 - REGIONAL ELECTRICITY HIGHWAYS*** | |
| 3.1 | Electricity corridors: State-of-the-art worldwide |
| 3.2 | Future challenges for electricity corridors |
| 3.3 | Increased grid resilience by innovative technologies |
| 3.4 | Transmission expansion policies: Worldwide trends best practices and proposed possible improvements |
| 3.5 | Monitoring and management of future transmission corridors |
| 3.6 | Modernization of the existing electricity market |
| 3.7 | Survey on technology innovation needs |

# APPENDIX I
## IC1 R&D Tasks and Subtasks in the Smart Grids Field

| | |
|---|---|
| ***Task 4 - FLEXIBILITY OPTIONS*** | |
| 4.1 | Identifying the key Flexible generations |
| 4.2 | Optimal planning and scheduling of RES power plants |
| 4.3 | Innovative approaches for energy storage selection and control |
| 4.4 | Localised power balancing |
| 4.5 | Advancement of existing demand response strategies |
| 4.6 | Use of Artificial Intelligence (AI) for Coordination of Flexible Resources |
| ***Task 5- NEW GRID CONTROL ARCHITECTURES*** | |
| 5.1 | Collection of available new grid control architectures |
| 5.2 | Basis for control architectures comparison |
| 5.3 | Enhanced new control architectures |
| 5.4 | Control architecture solutions for the electric network convergence and integration with other domains |
| 5.5 | Impact of new control architectures on regional grids |
| 5.6 | Impact of new control architectures on distribution grids |
| 5.7 | Microgrids interoperability |
| 5.8 | Available new technologies for smart grids |
| 5.9 | ICT infrastructures |
| ***Task 6 - POWER ELECTRONICS*** | |
| 6.1 | Power application of Wide-Band-Gap devices |
| 6.2 | Development of power converter at MV level and HV level |
| 6.3 | High-density and high-efficiency converter for distributed renewable energy and storage |
| 6.4 | Simulation tools and modelling methods for power electronics |
| 6.5 | Technological solutions towards electronic-dominated power system |

# APPENDIX II

## IC1 Deep-dive Workshops after IC1 Official Launch in Beijing

### THE SECOND IC1 DEEP-DIVE SMART GRIDS INNOVATION WORKSHOP

*16-18 November 2017, New Delhi*

The 2nd **MI IC1 deep dive international workshop** held during 16th – 18th November 2017 was co-organized by India, Italy and China and hosted at IIT Delhi, India. The three-day workshop encompassed closed-door technical brainstorming sessions on ongoing IC1 activities for two days, a public event to disseminate contributions of MI IC1 on smart grids and an expo to showcase national and bilateral research developments on smart grids on the third day. More than 80 internationally acclaimed experts in the field of energy, policymakers from the government and leaders from 13 countries convened together for leveraging the emerging technologies to realize reliable & smart power system and bridge critical gaps in smart grids globally.


The co-leads of MI IC1: Dr. Sanjay Bajpai (IN), Dr. Luciano Martini (IT) and Dr. Yibo Wang (CN) welcomed the enthusiastic participants from MI IC1, IEA and ISGAN representatives, smart grids stakeholders such as policy makers, senior advisors, technical experts, industry representatives and investors. The distinguished guests at the ceremony included Prof. Ashutosh Sharma, Secretary (DST), Dr. Renu Swarup, Senior Adviser (DBT), Dr. Arun Kumar Verma, Joint Secretary, Ministry of Power, Dr. Anju Bhalla, Joint Secretary, DST among many others. The inaugural statements cited the importance of public-private partnerships through knowledge sharing, collaborative programmes, and investments together to accelerate the availability of advanced technologies that will define a clean & affordable global energy mix. Following the

formal introduction of participants alongside the review of on-going IC1 activities and the adoption of agenda for three days, the brainstorming closed door technical session on 16th Nov, 2017 with MI IC1 representatives provided valuable insights into the status of smart grids and concluded over a round table discussing and identifying the sub-challenges in smart grids in their respective countries.

Next day the closed door technical session commenced with the launch of R&D Tasks, Key Performance Indicators (KPI) to monitor IC1, Funding Opportunity Announcement (FOA) of **5 Million USD** by India, Business and Investor Engagement (BIE), IC1 service platform and MI IC1 prize.

The public event on 18th Nov, 2017 dispersed the contributions and potential opportunities of MI and IC1 in general and 2nd MI IC1 deep dive workshop in particular. Prominent deliverables among them was the release of **Country Report–2017** on MI


smart grids activities, strategies and vision of 14 IC1 countries along with the launch of ambitious **UI-ASSIST: India-US collaborative programme** and **India-UK joint programme** on virtual clean energy center wherein two centers in India, UK India clean Energy Research Institute (UKICERI) and India-UK Centre for Education and Research in Clean Energy Centre (IUCERCE) were embarked strengthening the common deliberations of MI countries. The workshop concluded with unanimous adoption of **New Delhi Declaration** by MI members and henceforth released confirming that the nexus of MI member countries will intensely continue to work together on agreed R&D priorities to enable high integration of clean sources to the power grid. Moreover, a collaboration agreement was signed between RSE, Italy and IIT Roorkee, India represented by Dr. Luciano Martini from Italy and Dr. N. P. Padhy from India. The workshop concluded successfully with the exhibition tour showcasing various research activities performed by the national institutions and entities.

# APPENDIX II
## IC1 Deep-dive Workshops after IC1 Official Launch in Beijing

### THE THIRD IC1 DEEP-DIVE WORKSHOP ONE STEP CLOSER TO A SUSTAINABLE FUTURE
*20-22 May 2018, Copenhagen - Malmö*

MI IC1 smart grids held the 3rd deep-dive workshop on 20-21 May 2018 in Malmö and a public event on 22 May 2018 in Copenhagen, as side events of the CEM9 and MI-3.

The first two days, gathered technical experts, policy makers, funding agencies and international organizations from all over the world, giving the opportunity to the representatives from eleven IC1 countries and from key international organizations/initiatives as IRENA, IEA-ISGAN, and ETIP SNET to discuss the ongoing activities and next steps.

An important outcome of this 2-day workshop was the approval of the Oresund Joint Statement and Recommendations that testifies the IC1 member's strong commitment. The Recommendations were handed over to the Ministerial representatives during the public event on 22 May in Nordhavn, Copenhagen.

Close to 90 people participated in the public workshop hosted by the Danish Partnership for Smart Energy Networks and Swedish Smart Grid Forum. The purpose of the workshop was to gather decision makers, experts and others with interest in intelligent energy systems to discuss the latest advancements around the world, innovation priorities and identify international collaboration possibilities, business opportunities as well as innovation potentials. We were so fortunate to have several Ministerial representatives participate in the welcome session in the morning which allowed us to hand over a Joint Statement and Recommendations based on the outcome from the first two days in Malmö to government officials from Denmark, Sweden, India and Italy.

**Joint Statement**
In the Joint Statement it was stressed that the IC1 working group continue its commitment to strongly support the ongoing fruitful joint collaboration within innovation Challenge #1. The aim is to promote the development and deployment of future grids powered by high penetration of renewable energy and to continue to strive towards the development of innovative clean energy technologies and solutions for their seamless integration into smart grids.

Following the official hand-over the technical program continued. The presentations included mostly smart grid issues but also district heating, digitalization and inspiration from other projects around the world were highlighted.

# APPENDIX II

## IC1 Deep-dive Workshops after IC1 Official Launch in Beijing

### THE FORTH IC1 DEEP-DIVE SMART GRIDS INNOVATION WORKSHOP

*21-23 November 2018, Rome*

The 4th IC1 deep-dive workshop gathered IC1 representatives from 17 countries, the European Union, smart grids experts, Industry leaders, representatives from Governments & International Organizations.

In a very insightful closed-door meeting held on 21 Nov., IC1 members openly exchanged ideas on key results to date and strategic development of IC1 activities. As main outcomes of the meeting the R&D Task Program of Work 2019-2020 was approved, key activities towards the Country Report 2019 were defined, the IC1 website was launched and effective collaboration opportunities with IC2 and IC7 identified.

The **1st MI-IC1 Industry Workshop** was a full day event organized by IC1 on 22 Nov. that was held at ENEL Auditorium.
At the workshop, with more than 80 participants, MI IC1 objectives and activity were shared with industry and IC1 actions towards Business and Investor Engagement (BIE) were presented and discussed. Sixteen industry success stories about smart grids innovation and public-private cooperation were shared by industry representatives from all over the world and IC1 Countries representatives.

Two successful round-tables involving both IC1 members and industry representatives were organized, fine tuning the interaction and identifying responsibilities and expectations of grid stakeholders to accelerate the adoption of smart grids innovative technical solutions.

In line with the spirit of Mission Innovation and IC1 approach with industry, the Smart Grids Innovation Accelerator (SGIA) Platform was launched. The SGIA will serve as a suitable tool to enable sharing technical results and best practices, catalyzing the public and private sectors joint efforts towards IC1 goals to accelerate the development & deployment of innovative smart grids technologies worldwide.

Finally, the 4th IC1 "Public event" was held on 23 Nov. at GSE premises, gathering more than 90 participants. The strong commitment from the three IC1 co-leading countries was expressed by Hon. Andrea Cioffi, Undersecretary of State from the Italian Ministry of Economic Development, H.E. Reenat Sandhu, Ambassador from the Embassy of India in Italy and Prof. Sun Chengyong, Counselor for Science and Technology

from the Embassy of China in Italy that also received the Rome Declaration. A document that confirms the IC1 members strong commitment in supporting the ongoing fruitful collaboration highlighting the strategic importance of public-private partnerships, the launching of the SGIA platform and the establishment of fruitful collaborations with the International Smart Grid Action Network (ISGAN).

This event included a successful Round Table, involving the main Italian actors of the smart grids value chain, industry top-level management shared their view and strategy towards smart grids innovation, development and deployment. Moreover, smart grids priorities and innovative solutions were presented by key industry representatives from several IC1 countries. A specific session of the event was dedicated to the interaction and collaboration with international initiatives and organizations, where a letter of intent (LoI) between IC1 and ISGAN was officially signed to foster effective collaboration on strategic topics of mutual interest in the field of smart grids.

The 4th IC1 workshop represented an important milestone along the path of international collaboration on Smart Grids Research, Development, Demonstration and Deployment towards the achievement of the overall MI goals.

# APPENDIX III

## Electricity Mix by the End of 2018

Table 1. Electricity Mix by the End of 2018

| | Australia | | Austria | | Canada | | China | |
|---|---|---|---|---|---|---|---|---|
| | Installed Capacity (GW) | Electricity (GWh) | Installed Capacity (GW) | Electricity (GWh) | Installed Capacity (GW) | Electricity (GWh) | Installed Capacity (GW) | Electricity (TWh) |
| Wind Power | 6.309 | 16,267 | 3 | 6,600 | 12.239 | 31,829 | 184.26 | 366 |
| PV Power | 11.233 | 12,081 | 1 | 800 | 2.913 | 3,350 | 174.63 | 177.5 |
| Solar Thermal Power | 0 | 0 | 0 | 0 | 648 $MW_{th}$ | n.a. | 0.24 | n.a. |
| Biomass Power | 1.522 | 3,539 | 0.3 | 3,200 | 2.475 | 11,284 | 17.81 | 90.6 |
| Hydro Power | 7.544 | 17,452 | 6 | 28,900 | 80.859 | 383,374 | 352.26 | 1,232.90 |
| Coal-fired Power | 24.567 | 156,563 | 0.084 | 13,200 | 9.275 | 58,041 | 1,010 | 4,452 |
| Gas-fired Power | 15.505 | 50,245 | 0.598 | 4,700 | 17.362 | 59,764 | 83.3 | 223.6 |
| Oil-fired Power | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| Nuclear Power | 0 | 0 | 5 | 11,100 | 14.033 | 95,418 | 44.66 | 294.4 |
| Other Generation | 0.408 | 5,259 | 0 | 0 | 6.85 | 6,757 | n.a. | n.a. |
| Importation | 0 | 0 | n.a. | 29,342 | n.a. | 9,900 | n.a. | n.a. |
| Exportation | 0 | 0 | n.a. | 22.817 | n.a. | 62,200 | n.a. | n.a. |

| | Finland | | France | | Germany | | India | |
|---|---|---|---|---|---|---|---|---|
| | Installed Capacity (GW) | Electricity (GWh) | Installed Capacity (GW) | Electricity (GWh) | Installed Capacity (GW) | Electricity (GWh) | Installed Capacity (GW) | Electricity (GWh) |
| Wind Power | 2 | 4,795 | 15.108 | 27,800 | 59.24 | 11,400 | 35.14 | 52,666 |
| PV Power | 0.066 | 44 | 8.527 | 10,200 | 45.93 | 600 | 25.21 | 25,871 |
| Solar Thermal Power | 0.06 | n.a. | 0 | 0 | n.a. | n.a | n.a | n.a |
| Biomass Power | n.a. | 2,602 | 2.026 | 9,700 | 7.72 | 2,950 | 9.21 | 15,252 |
| Hydro Power | 3.1 | 14,610 | 25.51 | 68,300 | 5.5 | 1,190 | 49.92 | 126,134 |
| Coal-fired Power | n.a. | 5,531 | 2.997 | 5,800 | 45.38 | 13,820 | 197.45 | 10,082,90 |
| Gas-fired Power | n.a. | 3,220 | 12.151 | 31,400 | 29.63 | 4,430 | 24.94 | 47,000 |
| Oil-fired Power | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| Nuclear Power | n.a. | 21,574 | 63.13 | 393,200 | 9.52 | 5,300 | 6.78 | 38,500 |
| Other Generation | 2.75 | 12,139 | (other fossil fuels) 3.440 | 2,200 | n.a. | n.a. | 0.637 | n.a. |
| Importation | n.a. | 22,204 | n.a. | 26,000 | n.a. | 2,843 | 1.5 | n.a. |
| Exportation | n.a. | 1,778 | n.a. | 86,000 | n.a. | 7,425 | 11.15 (approx.) | n.a. |

# APPENDIX III
## Electricity Mix by the End of 2018

Table 1 - Electricity mix by the end of 2018

| | Italy | | Norway | | Korea | | Sweden | |
|---|---|---|---|---|---|---|---|---|
| | Installed Capacity (GW) | Electricity (GWh) | Installed Capacity (MW) | Electricity (GWh) | Installed Capacity (GW) | Electricity (GWh) | Installed Capacity (MW) | Electricity (MWh) |
| Wind Power | 10.31 | 17,318 | 1.188 | 2,900 | 1.214 | 2,161.585 | 6.5 | 16 |
| PV Power | 20.12 | 22,887 | 54 | 43 | 5.062 | 2,461.897 | 0.18 | 0 |
| Solar Thermal Power | n.a | n.a | n.a | n.a | n.a | n.a. | n.a. | 0 |
| Biomass Power | 4.2 | 17,818 | n.a | 0.5 | 0.53 | 2,347.089 | 6.5 | 13 (2015) |
| Hydro Power | 21.93 | 49,275 | 31,837 | 143,112 | 1.785 | 6,633.585 | 16.2 | 75 |
| Coal-fired Power | 61.6 | 182,487 | n.a | n.a | 36.698 | 231,886.59 | 0 | 0 |
| Gas-fired Power | | | n.a | n.a | 3.417 | 6,000.037 | 1.6 | 0 |
| Oil-fired Power | n.a. | n.a. | n.a. | n.a. | 38.735 | 100,132.338 | n.a. | n.a. |
| Nuclear Power | n.a. | n.a. | n.a. | n.a. | 22.529 | 148,426.725 | 9 | 56 |
| Other Generation | (Geothermal and Bioenergy)4.36 | 5,708 | n.a. | n.a. | n.a. | 73,201.246 | n.a. | n.a. |
| Importation | n.a. | 47,179 | 6,200 | 6,112 | n.a. | n.a. | n.a. | 0 |
| Exportation | n.a. | 3,270 | 6,200 | 21,276 | n.a. | n.a. | n.a. | 23 |

| | UK | |
|---|---|---|
| | Installed Capacity (GW) | Electricity (GWh) |
| Wind Power | 19.84 | 50,004 |
| PV Power | 12.78 | 11,525 |
| Solar Thermal Power | 0 | 0 |
| Biomass Power | 6.05 | 31,869 |
| Hydro Power | 1.87 | 5,928 |
| Coal-fired Power | 16.33 | 22,530 |
| Gas-fired Power | 32.89 | 136,746 |
| Oil-fired Power | n.a. | n.a. |
| Nuclear Power | 9 | 70,336 |
| Other Generation | 1.70 | 6,838 |
| Importation | 5 | 18,167 |
| Exportation | 5 | -3,407 |

# APPENDIX IV

## Trends on Renewable Energy Generation

| Australia | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Period | Wind | | PV | | Biomass | | Hydro | |
| Capacity | MW | GWh | MW | GWh | MW | GWh | MW | GWh |
| 2018E | 5794 | 14989 | 8601 | 9930 | 1521 | 3534 | 7543 | 15839 |
| 2017 | 4856 | 12597 | 6329 | 8072 | 1396 | 3501 | 7543 | 16285 |
| 2016 | 4333 | 12200 | 5352 | 6838 | 1390 | 3790 | 7542 | 15318 |
| 2015 | 4210 | 11467 | 4419 | 5531 | 1373 | 3592 | 7540 | 13445 |
| 2014 | 4097 | 10252 | 3636 | 4416 | 1370 | 3499 | 7539 | 18421 |
| 2013 | 3257 | 7960 | 2841 | 3826 | 1368 | 3144 | 7522 | 18270 |
| 2012 | 2592 | 6970 | 1912 | 2559 | 1365 | 3044 | 7522 | 14083 |
| 2011 | 2449 | 6085 | 1075 | 1530 | 1354 | 2102 | 7522 | 16807 |
| 2010 | 1877 | 5052 | 257 | 425 | 1348 | 2777 | 7514 | 13249 |
| 2009 | 1538 | 3824 | 61 | 156 | 1344 | 2795 | 7334 | 11869 |

Notes:
Data is reported by Financial Year (FY2018 spans July2017 - June 2018)
Data for 2018 is currently estimated

| Austria | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Period | Wind | | PV | | Solar Thermal | | Biomass | | Hydro | |
| Capacity | MW | MWh | MW | MWh | MW | MWh | MW | MWh | MW | MWh |
| 2030E [1-2]* | 7000 | 17400000 | 12000 | 11900000 | 0 | 0 | 724 | 5200000 | 18000 | 46000000 |
| 2018 | 3045 | n.a. | n.a. | n.a. | 0 | 0 | n.a. | n.a. | n.a. | n.a. |
| 2017 | 2887 | n.a. | 1268 | n.a. | 0 | 0 | 310 | n.a. | 14115 | 42088000 |
| 2016 | 2730 | n.a. | 1096 | n.a. | 0 | 0 | 310 | n.a. | 14118 | 42916000 |
| 2015 | 2489 | n.a. | 937 | n.a. | 0 | 0 | 321 | n.a. | 13650 | 40465000 |
| 2014 | 2110 | n.a. | 785 | n.a. | 0 | 0 | 318 | n.a. | 13581 | 44730000 |
| 2013 | 1681 | n.a. | 625 | n.a. | 0 | 0 | 321 | n.a. | 13420 | 45671000 |
| 2012 | 1337 | n.a. | 362 | n.a. | 0 | 0 | 320 | n.a. | 13362 | 47618000 |
| 2011 | 1106 | n.a. | 187 | n.a. | 0 | 0 | 325 | n.a. | 13209 | 37745000 |
| 2010 | 1016 | n.a. | 95 | n.a. | 0 | 0 | n.a. | n.a. | 12919 | 41575000 |
| 2009 | 1001 | n.a. | 52 | n.a. | 0 | 0 | n.a. | n.a. | 12649 | 43650000 |

https://www.eeg.tuwien.ac.at/eeg.tuwien.ac.at_pages/research/downloads/PR_464_final_report_Stromzukunft_Oesterreich_2030_(TU_Wien_-_EEG_Mai_2017-final).pdf (table14)[1]https://www.eeg.tuwien.ac.at/eeg.tuwien.ac.at_pages/research/downloads/PR_464_final_report_Stromzukunft_Oesterreich_2030_(TU_Wien_-_EEG_Mai_2017-final).pdf (table14)

# APPENDIX IV

## Trends on Renewable Energy Generation

| Canada | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Period | Wind** | | PV | | Biomass** | | Hydro** | |
| Capacity | MW | GWh | MW | GWh | MW | GWh | MW | GWh |
| 2017 | 12,239 | 31,829 | 2,913 | 3,350 | | | | |
| 2016 | 11,973 | 30,462 | 2,723 | 3,135 | 2,475 | 11,284 | 80,859 | 383,374 |
| 2015 | 11,214 | 25,163 | 2,579 | 2,506 | 2,507 | 9,553 | 79,623 | 378,598 |
| 2014 | 9,694 | 22,315 | 2,904 | 2,190 | 2,043 | 9,107 | 78,359 | 378,786 |
| 2013 | 7,803 | 17,784 | 1,210 | 1,392 | 1,580 | 9,173 | 75,720 | 387,981 |
| 2012 | 6,204 | 10,087 | 766 | 881 | 1,655 | 8,522 | 75,573 | 372,076 |
| 2011 | 5,265 | | 559 | 642 | | | | |
| 2010 | 4,008 | | 291 | 335 | | | | |
| 2009 | 3,319 | | 95 | 109 | | | | |

**Sources:**
* Unpublished internal NRCan analysis using Statistics Canada data.
** https://www.neb-one.gc.ca/nrg/sttstc/lctrct/stt/lctrctysmmr/lctrctysmmr-eng.html
**Wind:** https://canwea.ca/wind-energy/installed-capacity/
**PV Power:** http://www.iea-pvps.org/?id=93
**Solar Thermal:** https://www.iea-shc.org/solar-heat-worldwide (glazed and unglazed water collectors)

| China | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Period | Wind | | PV | | Solar Thermal | | Biomass | | Hydro | |
| Capacity | GW | TWh | GW | TWh | GW | GWh | GW | TWh | GW | TWh |
| 2050E* | 1000 | 2000 | 1000 | 1400 | 180 | 720 | 59 | 368 | 720 | 2100 |
| 2030E* | 400 | 800 | 400 | 420 | 30 | 90 | 53 | 314 | 580 | 1720 |
| 2020E* | 200 | 400 | 200 | 280 | 5 | 10 | 28.9 | 152 | 380 | 1250 |
| 2018 | 184.26 | 366 | 174.63 | 177.5 | 0.24 | n.a. | 17.81 | 90.6 | 352.26 | 1232.9 |
| 2017 | 163.67 | 305 | 130.25 | 118.23 | 0.02 | n.a. | 14.884 | 79.43 | 341.19 | 1194.5 |
| 2016 | 148.64 | 241 | 77.42 | 66.2 | n.a. | n.a. | 12.14 | 64.7 | 332.11 | 1180.7 |
| 2015 | 129.34 | 185.6 | 43.18 | 39.2 | n.a. | n.a. | 10.3 | 52 | 319.54 | 1112.7 |
| 2014 | 97.31 | 159.8 | 28.05 | 25 | n.a. | n.a. | 9.48 | n.a. | 304.86 | 1060.1 |
| 2013 | 77.16 | 134.9 | 17.45 | 9 | n.a. | n.a. | 7.79 | 35.602 | 280 | 896.3 |
| 2012 | 62.66 | 100.8 | 6.5 | 3.5 | n.a. | n.a. | 5.819 | 21.14 | 249 | 864.1 |
| 2011 | 47.83 | 73.2 | 2.93 | 0.91 | n.a. | n.a. | 4.36 | 19.1 | 230.51 | 662.45 |
| 2010 | 31.31 | 50.1 | 0.86 | n.a. | n.a. | n.a. | n.a. | n.a. | 213.4 | 686.3 |
| 2009 | 17.67 | 27.6 | 0.28 | n.a. | n.a. | n.a. | n.a. | n.a. | 196 | 571.7 |

*Note: Targets of national RE plan of Wind, PV, Solar thermal and Biomass(2020E*,2030E*,2050E*) is the basic scenario from 'China Wind, Solar and Bioenergy Roeadmap 2050' http://www.cnrec.org.cn/cbw/zh/2014-12-25-456.html. Targets of national RE plan of Hydro generation is from 'Hydropower Development 13th Five-Year Plan' by National Energy Administration. The source of historical data-by-year is the public data released by National Energy Administration and China Electricity Council.

# APPENDIX IV

## Trends on Renewable Energy Generation

| Denmark | | | | | |
|---|---|---|---|---|---|
| Period | Wind | PV | Solar Thermal | Biomass | Hydro |
| Capacity | TJ | TJ | TJ | TJ | TJ |
| 2017 | 53,208 | 2,705 | 5,035 | 91,868.45 | 64 |
| 2016 | 46,014.23 | 2,678 | 4,642 | 89,733,26 | 69 |
| 2015 | 50,879.13 | 2,175 | 3,713 | 9,0077.82 | 65 |
| 2014 | 47,083 | 2,144 | 3,444 | 76,861 | 54 |
| 2013 | 40,044 | 1,863 | 2,890 | 79,814 | 48 |
| 2012 | 36,972 | 374 | 1,254 | 79,662 | 63 |
| 2011 | 35,187 | 54 | 789 | 84,243 | 61 |
| 2010 | 28,114 | 22 | 657 | 92,268.16 | 74 |
| 2009 | 24,194 | 14 | 591 | 82,841 | 68 |

Source: https://ens.dk/sites/ens.dk/files/Statistik/tabeller2017_-_tables2017.xlsx

| Finland | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Period | Wind | | PV | | Solar Thermal | | Peat | Hydro | | Biomass and Residuals |
| Capacity | MW | GWh | MW | GWh | MW | GWh | GWh | GWh | GWh | GWh |
| 2030E* | 8,000 | 30,000 | | 700 | | | | | 15,000 | 147,000 |
| 2020E* | 2,500 | | | | | | | | | |
| 2018 | 2,000 | 5,857 | | | | | | | | |
| 2017 | 2,000 | 4,795 | 66 | 44 | | | 2,602 | 3,100 | 14,610 | 11,246 |
| 2016 | | 3,068 | | 19 | 47 | | 2,731 | | 15,634 | 10,852 |
| 2015 | 1,005 | 2,327 | | 10 | | | 2,895 | | 16,584 | 10,753 |
| 2014 | | 1,107 | 11 | 8 | | 16 | 3,194 | | 13,240 | 11,122 |
| 2013 | | 774 | | 6 | 37 | | 2,970 | | 12,672 | 11,346 |
| 2012 | 288 | 494 | | 6 | | | 3,438 | | 16,667 | 10,546 |
| 2011 | | 481 | | 5 | | | 5,058 | | 12,278 | 10,588 |
| 2010 | | 294 | | 5 | | | 5,858 | | 12,743 | 10,400 |
| 2009 | | 277 | | 4 | 19 | | 4,124 | | 12,573 | 8,274 |

# APPENDIX IV
## Trends on Renewable Energy Generation

| France | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Period | Wind | | PV | | Solar Thermal | | Biomass | | Hydro | |
| Capacity | MW | MWh | MW | MWh | MW | MWh | MW | MWh | MW | MWh |
| 2050E | The REs enable to reach the carbon neutrality by 2050 | | | | | | | | | |
| 2030E | Overall the REs should reach 40% of the electricity production in 2030 | | | | | | | | | |
| 2028E | | 96,000,000 to 100,000,000 | | 43,000,000 to 53,000 | | | | 9,000,000 to 10,000,000 | | 62,000,000 |
| 2023E | | 62,000,000 to 64,000,000 | | 24,000,000 to 25,000,000 | | 9,000,000 | | 62,000,000 | | |
| 2018 | 15,108 | 27,800,000 | 8,527 | 10,200,000 | | | 2,026 | 9,700,000 | 25,510 | 68,300,000 |
| 2017 | 13,549.6 | 24,000,000 | 7,654 | 9,200,000 | 0 | 0 | 1,953 | 9,100,000 | 25,521 | 53,600,000 |
| 2016 | 11,761.4 | 20,900,000 | 6,773 | 8,400,000 | 0 | 0 | 1,918 | 8,700,000 | 25,470 | 64,000,000 |
| 2015 | 10,324.5 | 21,100 ,000 | 6,196 | 7,400,000 | 0 | 0 | 1,703 | 8,000,000 | 25,430 | 59,100,000 |
| 2014 | 9,271.4 | 17,100,000 | 5,296 | 5,900,000 | 0 | 0 | 1,598 | 7,500,000 | 25,415 | 68,100,000 |
| 2013 | 8,157 | 15,900,000 | 4 ,366 | 4,700,000 | 0 | 0 | 1,496 | 7,100,000 | 25,434 | 75,500,000 |
| 2012 | 7,536 | 14,900,000 | 3,727 | 4,100,000 | 0 | 0 | 1,346 | 5,800,000 | 25,407 | 63,800,000 |
| 2011 | 6,714 | 12,104,344 | 3,004 | 2,333,366 | 0 | 0 | 1,110 | 5,396,110 | 25,857 | 51,237,721 |
| 2010 | 5,762 | 9,944,990 | 1,044 | 620,000 | 0 | 0 | 928 | 4,441,000 | 25,641 | 68,002,014 |
| 2009 | 4,573 | 7 ,911,570 | 277 | 173,971 | 0 | 0 | 818 | 4,130,000 | 25,424 | 62,414,397 |

Sources: Multi-annual Energy Programming (PPE) for targets, "bilan électrique RTE 2018" (2012 to 2018), Ministry statistics (MTES / SDES) (2009 to 2011)
Note: Figures stated prior to 2011 contain data for continental France only.

| Germany | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | Wind | | PV | | Solar Thermal | | Biomass | | Hydro | | Other REs | |
| Capacity | MW | GWh | MW | GWh | MW | MWh | MW | GWh | MW | GWh | GW | GWh |
| 2050E* | n.a | n.a. | n.a | n.a. | n.a. | n.a. | n.a | n.a. | n.a | n.a. | | |
| 2030E* | 73,500[a)] | n.a. | 66,300[a)] | n.a. | n.a. | n.a. | 6,200[a] | n.a. | 5,600[a)] | n.a. | 1.3 | |
| 2020E* | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | | |
| 2018 | 59,240 | n.a | 45,550 | n.a | n.a. | n.a. | 7,720 | n.a. | 5,500 | n.a. | | |
| 2017 | 55,876 | 106,614 | 42,394 | 39,895 | n.a. | n.a. | 7,987 | 45,486 | 5,608 | 19,800 | | |
| 2016 | 49,586 | 79,924 | 40,716 | 38,098 | n.a. | n.a. | 7,669 | 44,996 | 5,601 | 20,546 | | |
| 2015 | 44,580 | 80,624 | 39,224 | 38,726 | n.a. | n.a. | 7,467 | 44,573 | 5,589 | 18,977 | | |
| 2014 | 38,614 | 58,497 | 37,900 | 36,056 | n.a. | n.a. | 7,260 | 42,232 | 5,580 | 19,587 | | |
| 2013 | 33,477 | 52,737 | 36,710 | 31,010 | n.a. | n.a. | 7,036 | 40,113 | 5,590 | 22,998 | | |
| 2012 | 30,979 | 51,680 | 34,077 | 26,380 | n.a. | n.a. | 6,753 | 38,266 | 5,607 | 22,091 | | |
| 2011 | 28,712 | 49,857 | 25,916 | 19,599 | n.a. | n.a. | 6,424 | 32,136 | 5,625 | 17,671 | | |
| 2010 | 26,903 | 38,547 | 18,006 | 11,729 | n.a. | n.a. | 5,463 | 29,179 | 5,407 | 20,953 | | |
| 2009 | 25,732 | 39,420 | 10,566 | 6,583 | n.a. | n.a. | 4,871 | 26,334 | 5,340 | 19,031 | | |

Figures for 2030 are estimates of [7], for 2018 are from [2] and the remaining from [8]
[2]Fraunhofer Institute for Solar Energy Systems ISE. Energy Charts. [online] Available at: https://www.energy-charts.de/ [Accessed 13 Feb. 2019]. (2019)
[7]Bundesnetzagentur. Genehmigung des Szenariorahmens 2019-2030, Szenario B 2030. (2018)
[8]Federal Ministry of Economics and Technology (BMWi). Energy Data: Complete Edition. https://www.bmwi.de/Redaktion/EN/Artikel/Energy/energy-data.html. (2018)

# APPENDIX IV

## Trends on Renewable Energy Generation

| India | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | Wind | | PV | | Solar Thermal | | Biomass | | Hydro | | Other REs | |
| Capacity | MW | GWh | MW | GWh | MW | GWh | MW | GWh | MW | GWh | MW | GWh |
| 2050E* | 222,000 | 560,000 | 150,000 | 385,000 | 46,000 | 181,000 | 11,000 | 1280,000 | 75,000 | 263,000 | n.a. | n.a. |
| 2030E* | - | 188,000 | - | 243,000 | n.a. | n.a. | - | 63,000 | - | 24,000 | - | - |
| 2020E* | 60,000 | 112000 | 100,000 | 162000 | n.a. | n.a. | 10,000 | 37000 | 5,000 | 15000 | - | - |
| 2018 | 35138.15 | 52,666 | 25212.26 | 25,871 | n.a. | n.a. | 9075.50 | 15,252 | 4517.45 | 5,056 | 138.30 | 358 |
| 2017 | 32700.64 | 46,011 | 14771.69 | 12,086 | n.a. | n.a. | 8181.70 | 14,159 | 4389.55 | 7,673 | 114.08 | 213 |
| 2016 | 28700.44 | 28,604 | 9012.66 | 7,450 | n.a. | n.a. | 7907.34 | 16,681 | 4333.85 | 8,355 | 49.40 | 269 |
| 2015 | 25088.19 | 28,214 | 4878.87 | 4,600 | n.a. | n.a. | 4677.55 | 14,944 | 4176.90 | 8,060 | 48.34 | 414 |
| 2014 | 22465.03 | 33768.2 | 3062.68 | 3,350 | n.a. | n.a. | 4165.55 | - | 3990.90 | - | 56.58 | - |
| 2013 | 21136.2 | - | 2631.90 | - | n.a. | n.a. | 3094.60 | - | 3816.91 | - | - | - |
| 2012 | 18550.5 | 4508.70 | 1245.05 | 83.483 | n.a. | n.a. | 3135.33 | 348.99 | 3550.5 | 330.083 | 83.24 | 19.266 |
| 2011 | 16179.00 | 1110.00 | 32.39 | - | n.a. | n.a. | 2600.13 | - | 2,913.00 | - | 44.75 | - |
| 2010 | 10647.45 | 695.80 | 6.00 | - | n.a. | n.a. | 2167.73 | - | 2604.92 | - | - | - |
| 2009 | 9344.13 | - | 2.12 | - | n.a. | n.a. | 1650.43 | -- | 2160.48 | - | - | - |

*Note: Approximated values are considered based on the Indian Energy Security Scenarios 2047 using default pathway: http://indiaenergy.gov.in/iess/default.php,
https://mnre.gov.in/file-manager/annual-report/2014-2015/EN/Chapter%201/chapter_1.htm,
https://npp.gov.in/installedCapacityReports,
http://erpc.gov.in/wp-content/uploads/2018/06/carbon-emissions-from-power-sector-7062018.pdf, http://www.cea.nic.in/reports/annual/generationreview/gen_target-2018.p

| Italy | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | Wind | | PV | | Solar Thermal | | Biomass | | Hydro | | Geothermal and Bioenergy | |
| Capacity | GW | GWh | GW | GWh | GW | GWh | GW | GWh | GW | GWh | GW | GWh |
| 2030E* | 17.85 | 40,500 | 59 | 69,000 | 0.9 | 3,000 | 3.2 | 15,000 | | | | |
| 2020E* | 11.61 | | 32 | | 0.21 | | 3.91 | | | | | |
| 2018 | 10.31 | | 28.74 | | 0.07 | | | | 21.93 | | 4.36 | |
| 2017 | 9.78 | 17,700 | 19.68 | 24,400 | | | | 19,378 | 22.84 | 36,200 | 4.3 | 6,201 |
| 2016 | 9.42 | 17,689 | 19.3 | 22,104 | | | 4.12 | 19,509 | 21.75 | 42,432 | 4.26 | 6,289 |
| 2015 | 9.2 | 14,844 | 18.89 | 22,942 | | | | 19,396 | 21.65 | 45,537 | 4.17 | 6,185 |
| 2014 | 8.67 | 15,178 | 18.59 | 22,306 | | | | 18,732 | 21.49 | 58,545 | 4.13 | 5,916 |
| 2013 | 8.5 | 14,897 | 18.19 | 21,589 | | | | 17,090 | 21.89 | 52,773 | 4.06 | 5,659 |
| 2012 | 8.06 | 13,407 | 16.78 | 18,862 | | | | 12,487 | 21.75 | 41,875 | 3.9 | 5,592 |
| 2011 | 6.93 | 9,856 | 12.77 | 10,796 | | | | 10,832 | 21.57 | 45,823 | | 5,654 |
| 2010 | 5.81 | 9,126 | 3.47 | 1,906 | | | | 9,440 | 21.35 | 51,117 | | 5,376 |
| 2009 | 4.9 | 6,543 | 1.42 | 677 | | | | 7,557 | 21.19 | 49,138 | | 5,342 |

Source: Elaboration from TERNA data

# APPENDIX IV
## Trends on Renewable Energy Generation

| Norway | | | | | | |
|---|---|---|---|---|---|---|
| Period | Wind | | PV | | Hydro | |
| Capacity | MW | TWh | MW | TWh | MW | TWh |
| 2035E* | | 18 | 1,250 | 1 | | 147 |
| 2017 | 1,188 | 2.9 | 54 | 0.04 | 31,837 | 143 |
| 2016 | 873 | 2.1 | 33 | 0.03 | 31,600 | 149 |
| 2015 | 867 | 2.5 | 18 | 0,01 | 31,372 | 138 |
| 2014 | 859 | 2.2 | 16 | 0.01 | 31,240 | 136 |
| 2013 | 818 | 1.9 | 14 | 0.01 | 31,033 | 129 |
| 2012 | 705 | 1.5 | 13 | 0.01 | 30,509 | 142 |
| 2011 | 512 | 1.3 | 11 | 0.01 | 29,969 | 121 |
| 2010 | 425 | 0.9 | 11 | 0.01 | 29,693 | 117 |

| Korea | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | Wind | | PV | | Solar Thermal | | Biomass | | Hydro | | Other REs | |
| Capacity | MW | MWh | MW | MWh | MW | MWh | MW | MWh | MW | MWh | MW | MWh |
| 2018 | 1,423 | 2,456,371 | 2,626 | 3,061,006 | n.a. | n.a. | 530 | 2,786,670 | 1,789 | 3,329,545 | 4,222 | 13,972,694 |
| 2017 | 1,234 | 2,161,585 | 2,044 | 2,461,897 | n.a. | n.a. | 530 | 2,347,089 | 1,785 | 2,772,598 | 4,104 | 12,861,419 |
| 2016 | 1,048 | 1,673,879 | 1,613 | 1,806,952 | n.a. | n.a. | 355 | 1,441,664 | 1,782 | 2,756,905 | 4,036 | 11,673,764 |
| 2015 | 847 | 1,332,252 | 1,340 | 1,533,222 | n.a. | n.a. | 269 | 1,038,754 | 1,762 | 2,106,966 | 5,030 | 11,615,544 |
| 2014 | 641 | 1,136,286 | 1,050 | 1,124,867 | n.a. | n.a. | 155 | 567,956 | 1,759 | 2,705,957 | 4,613 | 10,956,644 |
| 2013 | 578 | 1,143,549 | 727 | 747,317 | n.a. | n.a. | 139 | 450,033 | 1,746 | 4,216,147 | 4,396 | 7,435,457 |
| 2012 | 487 | 908,447 | 466 | 508,044 | n.a. | n.a. | 95 | 427,878 | 1,738 | 3,953,570 | 3,729 | 6,590,870 |
| 2011 | 422 | 857,645 | 358 | 461,364 | n.a. | n.a. | 89 | 440,803 | 1,712 | 4,483,786 | 3,689 | 5,993,480 |
| 2010 | 378 | 811,788 | 348 | 443,033 | n.a. | n.a. | 89 | 425,550 | 1,621 | 3,626,321 | 3,410 | 2,870,473 |
| 2009 | 347 | 678,104 | 344 | 389,836 | n.a. | n.a. | 93 | 432,036 | 1,615 | 2,763,043 | 2,948 | 929,804 |

Reference:Electric Power Statistics Information System

# APPENDIX IV

## Trends on Renewable Energy Generation

| Sweden | | | | | |
|---|---|---|---|---|---|
| Period | Wind | PV | Solar Thermal | Biomass | Hydro |
| Capacity | MW | MW | MW | MW | MW |
| 2016 | 6,520 | 175 | n.a. | 6,500 | 16,181 |
| 2015 | 6,029 | 104 | n.a. | 6,314 | 16,184 |
| 2014 | 5,420 | 79 | n.a. | 6,804 | 16,155 |
| 2013 | 4,470 | 43 | n.a. | 6,504 | 16,150 |
| 2012 | 3,745 | 24 | n.a. | 6,444 | 16,203 |
| 2011 | 2,899 | 16 | n.a. | 6,414 | 16,197 |
| 2010 | 2,163 | n.a. | n.a. | 6,578 | 16,200 |
| 2009 | 1,560 | n.a. | n.a. | 7,001 | 16,203 |
| 2008 | 1,021 | n.a. | n.a. | 6,420 | 16,199 |
| 2007 | 780 | n.a. | n.a. | 6,405 | 16,209 |

| UK | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Period | Wind | | PV | | Biomass | | Hydro | | Other REs | |
| Capacity | MW | MWh | MW | MWh | MW | MWh | MW | MWh | MW | MWh |
| 2017 | 19,835 | 50,004 | 12,776 | 11,525 | 6,047 | 31,869 | 1,875 | 5,928 | 18 | 4 |
| 2016 | 16,174 | 37,263 | 11,912 | 10,411 | 5,755 | 30,064 | 1,835 | 5,390 | 13 | 0 |
| 2015 | 14,306 | 40,275 | 9,601 | 7,533 | 5,273 | 29,257 | 1,777 | 6,297 | 9 | 2 |
| 2014 | 13,074 | 31,959 | 5,528 | 4,054 | 4,579 | 22,619 | 1,729 | 5,888 | 9 | 2 |
| 2013 | 11,282 | 28,397 | 2,937 | 2,010 | 4,025 | 18,100 | 1,709 | 4,701 | 8 | 5 |
| 2012 | 9,030 | 19,847 | 1,753 | 1,354 | 3,163 | 14,734 | 1,693 | 5,310 | 9 | 4 |
| 2011 | 6,596 | 15,963 | 1,000 | 244 | 3,103 | 13,313 | 1,678 | 5,692 | 4 | 1 |
| 2010 | 5,421 | 10,286 | 95 | 40 | 2,089 | 12,261 | 1,646 | 3,591 | 4 | 2 |
| 2009 | 4,420 | 9,283 | 27 | 20 | 1,916 | 10,674 | 1,634 | 5,231 | 2 | 1 |

Source - DUKES 6.4: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/729373/DUKES_6.4.xls

# APPENDIX IV
## Trends on Renewable Energy Generation

| USA | | | | | |
|---|---|---|---|---|---|
| Period | Hydro | Geothermal | Solar PV* | Wind | Biomass* |
| Capacity | MW | MW | MW | MW | MW |
| 2018** | 290,353 | 16,809 | 92,455 | 274,677 | 63,298 |
| 2017 | 300,333 | 15,927 | 77,007 | 254,303 | 62,761 |
| 2016 | 287,812 | 15,826 | 51,483 | 226,872 | 62,572 |
| 2015 | 249,080 | 15,918 | 35,805 | 190,719 | 63.632 |
| 2014 | 259,367 | 15,877 | 26,482 | 181,655 | 63,990 |
| 2013 | 268,565 | 15,775 | 8.121 | 167,840 | 60,858 |
| 2012 | 276,240 | 15.562 | 3,451 | 140,822 | 57,622 |
| 2011 | 319,255 | 15.316 | 1,012 | 120,177 | 56,671 |
| 2010 | 260,203 | 15,219 | 423 | 94,652 | 56,089 |
| 2009 | 273,445 | 15,009 | 157 | 73,886 | 54,493 |
| 2008 | 254,831 | 14,840 | 76 | 66,363 | 55,034 |

In Thousand MWh
*For 2014-2016 PV includes utility and small scale PV, Biomass includes wood, landfill gas, biogenic municipal solid waste, and other waste biomass
** 2018 data is a rolling average from November 2017-November 2018

# APPENDIX V

## Key Smart Grids Facts and Figures by the End of 2018

### Australia

| | Data and Figures |
|---|---|
| Length and Rratings of Lines | Approx. 232,000 km transmission lines > 115 kV<br>Approx. 572,000 distribution lines < 69 kV<br>(the North American Bulk Electric System (BES) includes approx. 430,000 km of high voltage transmission lines in Canada, United States and Mexico, including 34 active transmission lines between Canada and the United States and 33 interprovincial lines within Canada)[i] |
| Number of Customers | Approx. 100% of total population |
| Number of Smart Meters | > 81% of all meters in Canada are smart |
| number of Electric Vehicles | approx. 72,800 BEVs and PHEV on the road<br>> 5,800 Level 2 charging outlets<br>> 850 Level 3 charging outlets |
| Number and Example of Micro- grids | E.g. Lac-Mégantic micro-grid |

[i] https://www.nrcan.gc.ca/energy/electricity-infrastructure/18792

### Finland

| | Facts and Figures |
|---|---|
| length and ratings of lines | 415,000 km |
| number of automated sub-stations | 1000 |
| number of customers | 3,563 million |
| flexibility options in national grid | Reserve markets |
| number of smart meters | 3,5 million |
| number of electric vehicles + hybrids | 2,400 + 13,100 |

### China

| | Facts and Figures |
|---|---|
| length and ratings of lines | ≥220kV, 733393km |
| capacity and ratings of transformers | ≥220kV, 4022550MVA |
| number of customers | 6844.9TWh |
| flexibility options in national grid | Hydro pump<br>Storage |
| number of smart meters | 471Billion |
| number of electric vehicles | 2.61 Billion |
| number and capacity of storage | 29.7GW |
| number and example of demand response | 28,000 demand response for peak load sheaving |
| number and example of micro grids | 34 |

### France

| | Facts and Figures |
|---|---|
| length and ratings of lines | 106,000 km (transmission), 1,359,000 km(distribution) |
| number of automated sub-stations | 2,200 (transmission), 150,000 (low voltage transformers with sensors) |
| number of customers | 36000000 |
| number of smart meters | 17,000,000 (35,000,000 by 2021) |
| number of electric vehicles | 163000 |

# APPENDIX V

## Key Smart Grids Facts and Figures by the End of 2018

| Germany | |
|---|---|
| | Facts and Figures |
| Length and Rratings of Lines | 1,845,385 km<br>(up to 380 kV AC, 500 kV DC links planned)<br>220 – 380 kV: ~36,000 km<br>60 – 220 kV: ~96,000 km<br>6 – 60 kV: ~520,000 km<br>230 / 400 V: ~1,120,000 km |
| Number of Customers | Approx. 100% of total population |
| Number of Smart Meters | > 81% of all meters in Canada are smart |
| number of customers | 50468192 |
| number of smart meters | < 100,000 (~ 5 Mio. binding) |
| number of electric vehicles | 53,861 (2018) |
| number and capacity of storage | Pumped storage: 27, 4.6 GW<br>Battery storage: ~14,000, 78 MW |
| number and example of demand response | Mainly industrial customers, e.g. chemical, stele, paper, automotive |

| Italy | |
|---|---|
| | Facts and Figures |
| length and ratings of HV lines | 11,202 km at 380 kV<br>10,875 km at 220 kV<br>48,800 km at < 150 kV |
| number of automated sub-stations | 881 EHV-HV (100%)<br>130,000 MV/lv (30%) |
| number of custumers | 35,113,700 |
| flexibility options in national grid | Storage |
| number of smart meters | >35 Million |
| number of electric vehicles | +5000 new units in 2018 |
| number and capacity of storage | +10,000 new installed storage systems in 2018 |
| number and example of demand response | Pilot project for participation of active demand on balancing market |
| number and example of micro grids | > 5<br>Savona campus (smart polygeneration microgrid) |

| India | |
|---|---|
| | Facts and Figures |
| Length and Rratings of Lines | 407291 CKM;<br>878403 MVA;<br>(for 220 KVA and above Trans. Network) |
| number of customers | 254.817 million households (Electricity coverage of 99.7% as on 9 Jan 2019) |
| number of smart meters | |
| number of electric vehicles | 266886 |
| | (As on date 10-03-2019) |

| Norway | |
|---|---|
| | Facts and Figures |
| length and ratings of lines | Transmission<br>11000 km – 420/300 kV<br>Sub transmission<br>19000 km – 132 /66kV<br>MV distribution 100000 km – 22/11 kV<br>LV Distribution<br>>200000km |
| number of customers | 2,9 mill. |
| flexibility options in national grid | Balancing markets for:<br>• Frequency containment reserve<br>• Automatic frequency restoration reserve<br>• Manual frequency restoration reserve |
| number of smart meters | 2,9 mill. |
| Prosumers | 2200 |
| number of electric vehicles | 240,000 |
| number and capacity of storage | >1000 hydro power reservoirs – capacity 86,5 TWh |
| number and example of demand response | Approx.. 10 pilot projects have been conducted |
| number and example of micro grids | A few <10 modern micro grids in commercial operation. |
| Other indicators… | National smart meter hub, Elhub in commercial operation (February 2019) |

# APPENDIX V

## Key Smart Grids Facts and Figures by the End of 2018

| Sweden | |
|---|---|
| | Facts and Figures |
| number of smart meters | 5.2 million (100 % of electricity customers) |
| number of electric vehicles | 28 000 [1] |
| 545 000 km lines of which: | • 329 500 km underground and<br>• 215 500 km overhead lines |
| Transmission lines are: | 15 000 km at 400 kV and 220 kV<br>170 Network Companies (various size, some publicly and privately owned) |

[1] http://elbilsstatistik.se/startsida/se-statistik/

| USA | |
|---|---|
| | Facts and Figures |
| Number of generators | 19000 |
| Number of transmission sub-stations | 55000 |
| Number of customers | 145000000 |
| High-voltage transmission lines (miles) | 642000 |
| Distribution lines (miles) | 6300000 |
| Deployed phasor measurement units (PMUs) | 2500 |
| Number of smart meters | 78901590 |
| Number of electric vehicles (EV & PHEV) | 1116483 |
| number and capacity of storage (#/MW) | 103 units/ 7,489 MW |

| UK | |
|---|---|
| | Facts and Figures |
| length and ratings of lines | In Great Britain: National Grid Electricity Transmission plc owns the high voltage electricity transmission network in England and Wales and National Grid Electricity System Operator operates it across Great Britain. This transmission system is made up of approximately 7,200 km (4,470 miles) of overhead line, 1,400 km (870 miles) of underground cable and around 330 substations.[1]<br><br>Ireland: There are around 6,800 km of high-voltage power lines, cables and substations across Northern Ireland and the Republic of Ireland. This grid links generators of electricity to the distribution network and supplies large demand customers. The network infrastructure is owned by the Electricity Supply Board (ESB) in their subsidiary Northern Ireland Electricity Networks Limited.[2] |
| number of automated sub-stations | All major transmission substations operate with high voltages and are remotely monitored and controlled. At lower voltages DNOs are also increasingly automating their network as the DSO transition progresses. In the UK there are approximately the following types of substations:[3]<br><br>Grid Supply Point 400kV to 132kV: 380<br>Bulk Supply Point 132kV to 33kV: 1,000<br>Primary 33kV to 11kV: 4,800<br>Distribution 11kV to 400/230V: 230,000<br>In addition there were 349,000 pole-mounted 11 kV/400 V transformers. |
| number of customers | UK population: estimated 66 million in 2017.[4] |
| flexibility options in national grid (Great Britain only) | National Grid Electricity System Operator has a portfolio of flexibility solutions, information on which can be found on the System Operators website in publications including their System Needs and Product Strategy, System Operability Framework and presented in their Future Energy Scenarios.[5] |
| number of smart meters (Great Britain) | At end September 2018 there were around 12.8 million smart and advanced meters operating across homes and businesses in Great Britain.[6]<br><br>The Department for the Economy in Northern Ireland has no plans at present to install smart meters in Northern Ireland. |
| number of electric vehicles | At end September 2018 there were 185,470 ultra-low emission vehicles registered in the UK.[7] |
| number and capacity of storage (Great Britain only) | National Grid's future scenarios 2018 suggest there was around 3GW of storage on the system in GB in 2017, the vast majority of which is pumped hydro. National Grid also outlines between 12-29GW of electricity storage could be deployed by 2050.[8] |

# APPENDIX V
## Key Smart Grids Facts and Figures by the End of 2018

| | |
|---|---|
| number and example of demand response (Great Britain only) | National Grid's Future Energy Scenarios 2018 suggests there was around 2GW of I&C demand side response capacity in 2017, which includes behind the meter generation and storage and outlines that there could be between 4-8GW of I&C DSR capacity by 2050.[9] |

[1] https://www.nationalgrid.com/sites/default/files/documents/Substation%20construction%20and%20refurbishment.pdf, retrieved: 27/02/2019

[2]Community Fund and Proximity Payments – EirGrid, 2016

[3] ENA Adaptation to Climate Change First Round Report under the ARP, Electricity Transmission and Distribution Network Companies, April 2011, http://www.emfs.info/sources/substations/, retrieved: 27/02/2019

[4]Office of National Statistics, https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/articles/overviewoftheukpopulation/november2018, retrieved: 27/02/2019

[5] National Grid: https://www.nationalgrideso.com/balancing-services, retrieved: 27/02/2019

[6] https://www.gov.uk/government/publications/smart-metering-implementation-programme-progress-report-2018, Retrieved: 27/02/2019

[7] Source: https://www.gov.uk/government/statistics/vehicle-licensing-statistics-july-to-september-2018, Table VEH0130, retrieved 27/02/2019

[8] http://fes.nationalgrid.com/fes-document/, retrieved: 27/02/2019

[9] Ibid

# FINAL REMARKS

The Country Report 2017 (CR2017) including the contribution by fourteen IC1 members was presented and distributed to all the delegates attending the 2nd Smart Grids Innovation Workshop, a public event organized by Mission Innovation IC1 on 18 November in New Delhi, India.

This Smart Grids Innovation Challenge Country Report 2019 (CR2019) represents an updated version of the previous report since it includes data up to year 2018 and contributions by four additional IC1 members. The Country Report 2019 has been finalized with the purpose to be announced and officially released during the Mission Innovation Ministerial plenary meeting on 28 May 2019 at the Vancouver Convention Center as part of the CEM10/MI-4 event hosted by Canada. Moreover, the CR2019 is intended to be publicly announced during the 1st CEM ISGAN – MI IC1 joint Workshop, organized by Mission Innovation IC1 and ISGAN on 29 May at the Vancouver Convention Center as a 1-day official side-event of the CEM10/MI-4.

This report contains information about strategy, vision, ongoing smart grids activity and case studies from sixteen IC1 countries and the European Union: Australia, Austria, Canada, China, Denmark, Finland, France, Germany, India, Italy, Norway, Republic of Korea, Saudi Arabia, Sweden, United Kingdom, United States of America, and European Union.

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