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The smart grid research network

Road map for Smart Grid research, development and demonstration up to 2020

Troi, Anders; Jørgensen, Bo Nørregaard; Larsen, Emil Mahler; Blaabjerg, Frede; Mikkelsen, Gert Læssøe; Slente, Hans Peter; Madsen, Henrik; Østergaard, Jacob; Entwistle, Johanne Mose; Nordentoft, Niels Christian

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THE SMART GRID RESEARCH NETWORK

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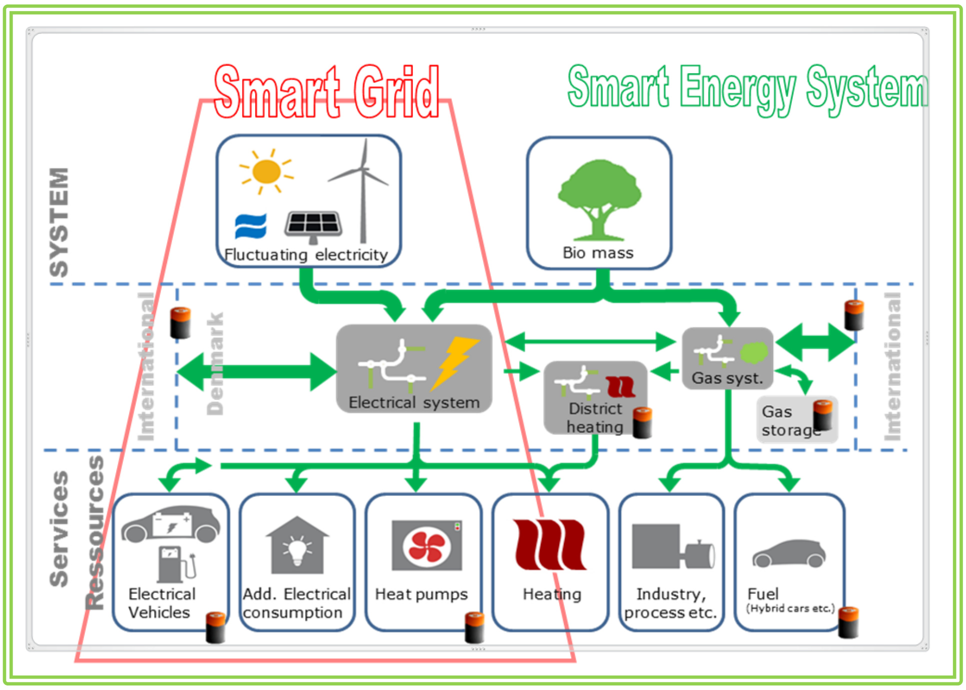

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PREFACE

This road map is a result of part-recommendation no. 25 in *'MAIN REPORT – The Smart Grid Network's recommendations'*, written by the Smart Grid Network for the Danish Ministry of Climate, Energy and Building in October 2011. This part-recommendation states:

"Part-recommendation 25 – A road map for Smart Grid research, development and demonstration

It is recommended that the electricity sector invite the Ministry to participate in the creation of a road map to ensure that solutions are implemented and coordinated with related policy areas. The sector should also establish a fast-acting working group with representatives from universities, distribution companies and the electric industry, in order to produce a mutual, binding schedule for the RDD of the Smart Grid in Denmark.

Time prioritisation of part-recommendation: 2011-2012

Responsibility for implementation of part-recommendation: Universities, along with relevant electric-industry actors, should establish a working group for the completion of a consolidated road map by the end of 2012."

In its work on this report, the Smart Grid Research Network has focused particularly on part-recommendations 26, 27 and 28 in 'MAIN REPORT – The Smart Grid Network's recommendations', which relate to strengthening and marketing the research infrastructure that will position Denmark as the global hub for Smart Grid development; strengthening basic research into the complex relationships in electric systems with large quantities of independent parties; and improved understanding of consumer behaviour and social economics. Naturally the work has spread to related areas along the way. The work has been conducted by the Smart Grid Research Network:

Authors:

Anders Troi, DTU
Bo Nørregaard Jørgensen, SDU
Emil Mahler Larsen, DTU
Frede Blaabjerg, AAU
Gert Læssøe Mikkelsen, Alexandra Institute
Hans Peter Slente, Danish Energy Industries Federation
Henrik Madsen, DTU
Jacob Østergaard, DTU
Johanne Mose Entwistle, Alexandra Institute
Niels Christian Nordentoft, Danish Energy Association
Peter Meibom, Danish Energy Association
Rune Hylsberg Jacobsen, AU
Sune Thorvildsen, Danish Energy Industries Federation
Ulrik Jørgensen, AAU

Co-authors:

Arne Hejde Nielsen, DTU
Carsten Strunge, Energinet.dk
Chresten Træholt, DTU
Henrik Bindner, DTU
Kai Heussen, DTU
Mads Lyngby Petersen, Energinet.dk
Petar Popovski, AAU

Observers:

Eskild Stub Larsen, Danish Ministry of Climate, Energy and Building
Maria Hilligsøe Stubberup, Ministry of Foreign Affairs of Denmark
Jens Brandt Sørensen, Danish Ministry of Climate, Energy and Building
Mette Vingaard, Danish Energy Agency
Jeanette Møller Jørgensen, Energinet.dk
Hanne Thomassen, Danish Energy Agency

Editors:

Susanne Pouline Svendsen, DTU
Moira Eléanore Perrier, DTU

INTRODUCTION

In the March 2012 energy agreement, the parties agreed to draw up a Smart Grid strategy plan in 2012. At the same time, strategic joint initiatives have already been launched in parallel in several areas which make recommendations in various areas for the ongoing work of developing the Smart Grid and exploiting its potential. Examples include the Danish Intelligent Energy Alliance, the DanGrid joint initiative between the Danish Energy Association and Energinet.dk, the Confederation of Danish Industries Smart Grid Network and the Smart Grid Research Network.

With this report, the Smart Grid Research Network aims to identify areas that need to intensify initiatives within research, development and demonstration (RDD). The primary focus has been on activities in the period leading up to 2020. Several of these activities are seen as preconditions for implementations in the period after 2020.

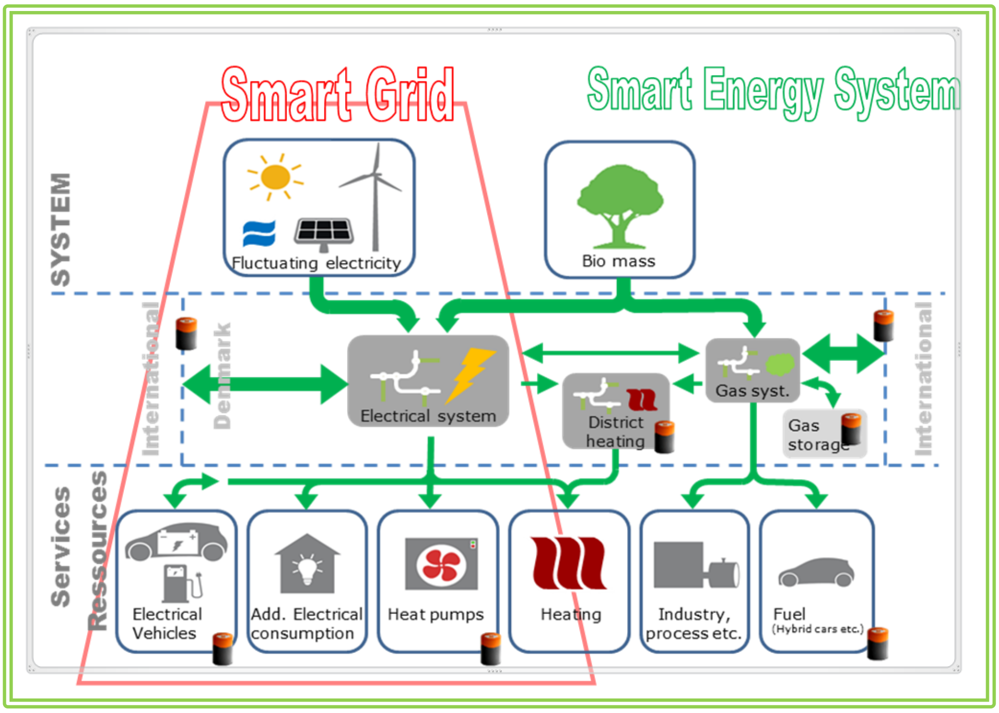
The recommendations focus on areas where Danish research institutions and knowledge centres have significant knowledge and can make a strong contribution, both in Denmark and internationally. There has also been a focus on areas that can attract foreign investment and support a growth agenda. The recommendations do not take into account regulations, taxes etc. It should be noted that these factors can have a decisive influence on the dissemination of individual technologies and solutions.

Summary

The future energy system, based to a large extent on fluctuating renewable energy sources, requires a new functional structure in order to exploit these energy sources optimally. The future intelligent energy system will be based to a high degree on interaction between various energy sources and transmission systems. The development of flexible services in the electricity market will require that these technologies be developed and demonstrated, including communication and control technologies.

Electricity is expected to become the dominating energy carrier in the long term, and the development of the electricity system into an intelligent system is a short-term prerequisite for the integration of much of the fluctuating renewable energy – with wind power and solar cells as the major contributors.

The first steps in transformation of the energy systems will be focused on the electricity system (Smart Grid). Where appropriate from an economic and societal perspective, this process should also give consideration to future interaction with other energy infrastructures such as gas, district heating and the transport sectors. This is because the Smart Grid is only part of the future ‘smart energy’ system, whereby Denmark is completely independent of fossil fuels.



The committee's initial observations target five sub-areas, each of which face special challenges, but are linked to a high degree by general system considerations. Priorities for the five sub-areas are described briefly below, and then examined in detail in separate chapters.

Chapter 1: The electricity system

The main priority for the electricity system is to ensure that security of supply is maintained at the level necessary for society and that the system is reorganised to be based on renewable energy sources. This requires that knowledge be accumulated in relation to maintaining security and reliability within the electricity system (e.g. in relation to system stability), that the grid be optimally utilised and operated (e.g. in relation to maximum utilisation of its capacity) and that the interaction between resources and the electricity system be optimised, particularly in abnormal operating situations.

Chapter 2: Energy markets

If the priority in relation to the energy market needs to be narrowed, it is recommended that focus be given to new markets (e.g. DSO markets) and the structure and dynamic between new and existing markets on various time scales. To this can be added challenges to introducing renewable energy sources into the market (approaching the target of 100%), the majority of which continue to be supported by special subsidy schemes and tariffs. It is also recommended to conduct research into dynamic taxes and tariffs, and increase the use of probabilistic methods in the operation of the electricity market. Financing greenification and the business models for flexible electricity consumption solutions should also be investigated. In a deregulated system, new market structures will also arise whereby additional operators and service providers offer services to both professional and private consumers. Services which support the function of the system and provide customers with new types of services. Consumer markets and regulations are also an area which should be given priority.

Chapter 3: Components

The main priority in relation to components is the development of intelligent functions in devices. Functions that monitor the grid and load, and provide feedback to the manufacturer about operation of the devices, so they get a clear picture of the devices' 'mission profile'. Devices also need to be able to predict their own internal faults. Development must continually make devices cheaper and more reliable, with the aim of reducing Cost of Energy and promoting an energy efficiency which will lead to a natural market implementation of functional Smart Grid devices.

Chapter 4: Consumers

The Smart Grid is characterised to a certain degree by being dependent on active regulation of electricity consumption taking place in consumer homes. The transition is therefore dependent on the gradual introduction of intelligent products into homes. In order for this development to influence behaviour in relation to energy, it is necessary that consumers accept and understand it. Factors relating to privacy and data security may become relevant in this connection, requiring closer investigation. An understanding of consumers' motivations and barriers for changing behaviour should also guide the development of new technologies and services.

Chapter 5: ICT

Implementing the Smart Grid depends on the right ICT technologies and skills being available. In the area of ICT, it is therefore recommended that research activities be initiated which address software architectures for aggregating Prosumers, and system reliability in relation to data security, IT system security, uptime and fault tolerance. It is also recommended that activities be commenced to investigate the more far-reaching consequences of the current standardisation work being conducted at both the European and international level. There is also a need for a greater focus on robust interaction between control and communication systems.

CHAPTER 1 THE ELECTRICITY SYSTEM

This area covers the entire supply system, consisting of the electricity grid and the devices and users connected to it. Both technical and commercial system aspects play a key role in this area.

This area can be expanded in several ways – in relation to both the transmission and distribution level, central and local energy resources, and solutions in the area of the planning, design and operation of the electricity system. A key issue which is often highlighted is balancing consumption and production in the electricity system, including technical and market-based solutions. However this is only one of several central issues where market solutions can be a key part of the answer. In relation to the electricity system, the following issues also play a similar key role:

- Maintaining security and reliability in the electricity system, for example in relation to system stability.
- Maintaining adequate supply as electricity production capacity moves towards 100% renewable energy, which can demand up to double capacity or more.
- Ensuring optimum utilisation and operation of the grid, for example maximum utilisation of the grid's capacity.
- Optimising interaction between resources in the electricity system, particularly in abnormal operating situations.

There are key links to other areas including electricity markets, consumer behaviour and IT/communication.

Current situation/background

A large number of Smart Grid RDD activities are taking place in Denmark with a specific focus on electricity systems. These activities range from basic research to large-scale demonstration. (See appendix A). The Danish activities are characterised by:

- Close integration and interplay between research and demonstration.
- An emphasis on demonstration, development and application-oriented research – and to a lesser extent on long-term basic research.
- A long tradition of strong cooperation between universities/research institutions, energy companies and the energy industry.

Recognised knowledge deficiencies

Extensive knowledge is required in the area of RDD activities in relation to the electricity system. There is a general need for developing new theories, methods, tools and models in the area of power systems engineering, which incorporate the challenges of the future electricity system and interact with the new opportunities offered by communication technology, computer science and automation technology. These systems must be able to support synergies between various renewable energy sources. There is a need for research which combines power systems engineering with other scientific fields such as control theory, automation technology, computer science, statistics, artificial intelligence, numeric analysis (e.g. sparse matrices methods), systems-of-systems theory (SoSE), etc.

It is recommended that focus be given in future to areas where Denmark can make a difference internationally and exploit the activities to solve key problems in the Danish energy system, and which also hold the potential for strong Danish commercial development through a key international position and a unique Danish knowledge base.

Recognised knowledge deficiencies (not ranked) which Denmark should prioritise, strengthen and disseminate in the short term:

a) Operation support tools and control room solutions, including online stability monitoring and security methods.

b) Optimum utilisation of system components in the network for stability, as traditional synchronous generators are phased out and replaced by inverter-based production, for example from wind turbines and solar cell systems.

c) An active distribution network and interaction with transmission, including systems for the integration of electric vehicles, storage, PV and other DER units.

d) Net planning and dimensioning tools for the Smart Grid network, including impacts of less inertia and short-circuit power in the electricity system.

e) Offshore (HVDC) distribution networks and their system interactions.

Recommendations for research, development and demonstration initiatives

It is recommended that the following activities be initiated:

- Many significant resources (especially major power plants) will disappear from operation of the transmission system and be replaced by local active elements which are not visible to operations. There is therefore a need for new **operation support tools and control room solutions** which enable secure operation of the transmission network. The distribution networks will also become more active and controllable and distribution network operators will need new types of tools for the monitoring (situational awareness) and control of active distribution networks with new flexible resources and proactive utilisation of significant quantities of data – from new sensors (e.g. electricity meters) to tools based on the new real-time algorithms, online optimisation methods and forecasting systems/portals. Methods and systems for **ensuring stability** in the electricity system of the future based on fluctuating renewable energy, primarily from inverter-based devices. There is a need for online tools and methods which can monitor a more dynamic electricity system online in real time, and **continually control and 'intervene' in emergency situations**. PMU technology and wide area monitoring and control systems must be developed.

Methods must be developed to analyse and ensure reliability of the future network, with new resources and flow patterns.

- There is significant socio-economic potential in developing an **active distribution network**, including systems for better capacity utilisation of the distribution network, congestion management, dynamic configuration, etc. This area involves the development of original solutions in relation to state estimation, dynamic network configuration, dynamic relay setting, etc. New technologies and solutions for interaction between the transmission network and active distribution network should, in particular, be explored. Denmark is already making good progress in this area, with several large demonstration projects. This area also involves the development of micro grid technology, software agent technology and service-oriented architectures. Developments in relation to the DC low voltage grid should be monitored, and resources should be available to pursue this area if it is found to be relevant. Denmark is internationally recognised for its research and implementation of systems for the optimum **system integration of electric vehicles and stationary energy storage technologies**. The electric vehicles area – which is fairly complex due to complex user patterns and dynamic locations, and where Denmark is an ideal pilot country – has particular potential for the development of unique solutions.

- The existing electricity system has been developed and designed based on a number of **tools and methods for planning and dimensioning**, for example in relation to network planning and ensuring adequate ancillary services for a stable network. These tools have been developed based on decades of experience and do not take into account Smart Grid technologies, which radically change the opportunities for planning and optimisation. There is therefore a need for new tools which incorporate the new fluctuating resources, the new market-based solutions and communication infrastructures with given characteristics (reliability etc.). As there is a decrease in the number of major power plants and other synchronous generator based plants in operation, the **inertia and short-circuit contribution** from these will disappear. Where operation support tools and control room solutions contribute to a more optimal utilisation of the electricity system's available resources, there may be a need in future to redesign connected components and equipment. There is therefore a need for knowledge about the impact of and solutions for maintaining the electricity system's voltage and frequency stability with less inertia and short-circuit power in the system. A number of impacts are expected from PV, heat pumps and electric vehicles in the LV/MV grids, which will require new analyses and solutions in relation to fault management, voltage quality (PQ), short-circuit power and voltage profiles etc.

- Denmark is expected to play a key role in development of the new (offshore) **HVDC supply network,** designed to alternate between new market solutions and a local active distribution network, and be connected intelligently and efficiently to the HVAC system, for example via multi-terminals. There is therefore both a need and potential for developing a number of new original solutions which can become market leaders.

Time recommendations to the road map

It is recommended that the current activities in the area of the active distribution network which have already been initiated, be carried on and improved as specified in the GAB analysis. Activities related to energy storage in the electricity system should be given particular priority in the years ahead. New areas of activities relating to operation support tools, tools and methods for planning and dimensioning, and the HVDC grid, should be initiated in 2014 and thereafter.

Synergies/possible export and employment effects

In order to realise the commercial potential, it is important that the right framework conditions are in place, as these will largely determine whether jobs, growth and exports follow. The following points are also essential:

- Ongoing close cooperation between universities/research institutions and the industry, to ensure knowledge transfer and close dialogue in relation to the development of the technological solutions.

- The aim is for Denmark to drive international development and avoid only developing local Danish solutions which do not have international potential and anchorage and which are therefore not sustainable in the longer term. To ensure this, it is important that Denmark focuses on international cooperation and becomes, as a minimum, a European test laboratory. The major internationally visible demonstration projects such as Bornholm (EcoGrid EU), Kalundborg (Smart City Kalundborg), Holsted (the cell project) and the PowerLabDK platform, which are receiving major international attention, must be exploited in this regard. Existing communication activities etc. must be refined to support such a development to an even greater extent.

- In order for research results to be used in companies and translate into new, competitive products and technologies, it is absolutely essential that they are original and of the highest quality. Originality is best achieved by giving researchers at the leading edge the opportunity to pursue the trajectories where they can see we lack knowledge. This demands greater focus and priority for basic research, not targeting a very specific product and technology. It will be essential to give basic research greater priority in this manner if a new Danish industry is to flourish in this area, which is sustainable – also in the long term and can continue to drive growth, exports and knowledge-intensive jobs. The alternative is that the countries where the original development takes place will take over the commercial potential.

CHAPTER 2 ENERGY MARKETS

During the last decade, the energy markets and retail sales of electricity have been deregulated in Europe. Smart Grids – in this context, intelligent electricity grids – are the next step towards an economically viable 100% RE-based electricity system, where the majority of electricity production and consumption possibly come from smaller units and customers, with various degrees of subsidies and incentives. A solution needs to be found for how the market places should operate, and how a number of subsidised technologies can compete in the market place with free price discovery.

The realisation of the Smart Grid requires prompt improvements to the design of the electricity market and the development of new market processes and business models. Without basic knowledge and the realisation of modern energy markets – possibly with flexible prices, taxes and tariffs – it is difficult to imagine a reliable, economic and green electricity grid. In this context, the need to distinguish between various markets for electricity is heightened based on how the markets are structured, and who is being encouraged to participate in new higher risk markets. It is not only price per unit of service which is relevant here, but also the many other factors related to the transaction between buyer and seller which can be included in an agreement.

A key Smart Grid priority is the creation of new local **electricity distribution markets**. They can only be established on a solid foundation with the continued development of the wholesale markets. It will therefore continue to be important to ensure a market development that can contribute to realising the flexible resources and thereby create a framework for the socio-economically efficient exchange of energy. By creating the opportunity for greater flexibility on the electricity production and consumption side, it will be possible to integrate greater quantities of renewable energy, the electricity consumption of electric vehicles, and local production from solar cells.

Current situation

Our spot and intraday systems will be developed from primarily being based on the Scandinavian market system and around the Scandinavian electricity exchange, to having increasing market links with the South. The same will be true for development of the market for reserves and regulating power for balancing the electricity system. The slow **reserves and regulating power services** have been designed based on the ability of central and local power plants to gear up or down. All market platforms have been developed to support electricity systems based on nuclear power and thermal plants burning fossil fuels. As Denmark moves towards 50% and 100% RE, with a primary focus on wind power and other fluctuating production, the marketplaces will be challenged.

Several projects have already researched the opportunities for establishing flexible consumption, which would help with the balancing of the electricity system. To date, flexible consumption has been based on consumers receiving a price signal on a shorter time interval (e.g. 5 minutes) than electricity is purchased for on the wholesale market (e.g. 1 hour), to achieve a better distribution of consumption and utilise the grid and production capacity. There has been a focus on communication and control issues, while a change in the market in terms of varying prices and changes to the production time scale have been overshadowed.

Flexible consumption can be traded in the spot market, in the market for regulating power, and even as primary and frequency reserves (e.g. some of the CHP plants' electric boilers). The challenge is to collect the many small consumption units into an adequate bid in these markets. This is the responsibility of the **aggregators** and balance responsible companies. Smart Grid Denmark 2.0, a new initiative which mobilises and exploits flexible electricity consumption and production from small customers, has been developed by Energinet.dk and the Danish Energy Association. This initiative aims to establish an effective market for trading standardised flexibility products. The trade in flexibility is initially expected to take place bilaterally, and via a simple marketplace during an interim period. It is important that the platform is integrated with the existing marketplaces, so the flexible services have the best opportunity for creating value.

While the development in the wholesale market is characterised by international market solutions, the situation on the retail market is more sluggish, with the use of regulation and a lack of trade across borders. The market was opened up in 2003 so all electricity consumers could freely choose an electricity supplier, but in 2011, the Danish Competition and Consumer Authority highlighted continued weak competition and a lack of dynamism. Several elements need to help change the picture and support Smart Grid development. These are:

a) The DataHub, which will collect electricity customers' meter data and support a change in vendor.

b) The wholesale model, aimed at improving competition on the electricity market, whereby electricity suppliers become the main players on the market in relation to consumers. They must deliver a combined product – 'supplied electricity' – to consumers, consisting of electricity, grid and system services.

c) MR-NER's (Nordic Council of Ministers for Business, Energy & Regional Policy) vision of a harmonised Scandinavian retail market in 2015 with a wholesale model as an integrated element of the future market design.

The overlap between the Nordic vision and the Danish market design based on DataHub and the wholesale model provide a foundation for Denmark to be able to contribute to an acceleration of development of the retail market at the Scandinavian level.

Recognised knowledge deficiencies

We do not know whether the existing electricity markets will be able to adapt to and handle the next two decades with dominating volumes of fluctuating production without operational failures and price peaks, leading to higher prices. New forms of design for electricity markets and procedures for establishing **market equilibrium** therefore need to be investigated. For the same reason, different time resolution on the day-ahead, intraday and reserve markets should be researched, and the structural interaction between these markets and any distribution system operator markets should be evaluated. Attention should be given to the market place on which wind power, with its associated uncertainty, can best be traded. Real-time markets and the marketisation of system services should be investigated. More specifically, in the area of flexible consumption, price signals, bid/ask markets and other contracts need to be contrasted. If consumers are to receive signals that vary over time, the connection between the signals and production – both technical and in terms of payment – must be re-evaluated. While the effect of greater time resolution is investigated, there is also a need to investigate the relationship between short term variation and long-term supply stability. This is currently reflected in contracts covering capacity for backup, storage and buffer solutions, which can be made available in response to fluctuations in production from wind power etc.

It will also be necessary to investigate the dynamics between various markets (electricity, heating, CO_2 trading, etc.), countries (e.g. with flow-based market links) and energy sources (e.g. hydrogen, biomass, gas, etc.) over different time scales.

Involving additional energy technologies will also place new demands on market structure. These technologies are based on active involvement of users, at the household level (investing in heat pumps, electric vehicles or other types of electricity producing equipment) and in terms of cooperation between players at the town level or between companies and housing associations. The market is not simply used to exchange products, paid for at a given local and time defined price, but also security of supply and quality, as will be clearly expressed in the service systems made available. New markets at the distribution system operator level can potentially support this and help delay expansion of the distribution network.

The transformation of consumers into producers needs to be investigated. If there are limits to how small distributor production and flexible consumption among **prosumers** can be without the financial advantages being lost, these need to be determined. The way prosumers influence the market strength of existing major producers must also be evaluated. Business models for flexible electricity consumption should also be validated. This includes contract conditions between aggregators and consumers with flexible electricity consumption.

It will also be useful to investigate how electricity is taxed, as taxes account for a major proportion of electricity bills. Flexible taxes and tariffs can potentially encourage customers to change their consumption as production increases from RE plant. Researchers can identify the best ideas, which are fair and give the Government the same income.

To ensure financing for the green transformation, models should be developed which can attract new investors such as pension companies.

There will most likely need to be greater use of **probabilistic methods** in the operation of the electricity market. Research must identify new indices for security of supply and new models for network calculations which can contribute to more cost-oriented and reliable calculation of the need for various types of reserves.

Recommendations for research, development and demonstration initiatives

The wholesale market will generally be developed with a European, market-based perspective in mind. This will ensure that Danish producers get access to larger markets in the longer term, and are thus able to compete with foreign producers. Larger markets will also increase competition for the delivery of products to end customers, grid companies and Energinet.dk, leading to positive socio-economic effects. Effort should continue to be made to develop the electricity markets nationally and internationally, with the aim of allowing additional players to make their flexibility services available.

Future research projects into flexible consumption should have more focus on changing and optimising the market, as current projects are focusing primarily on technical challenges. This includes new time scales for trading and a real – not just virtual – restructuring of the markets.

It is important to structure the markets so they support the new technological solutions, adapted to a composite energy system with many distributed producers. Various solutions also need to be researched which aim to create greater stability. One model is to work with various contract models that work with the sale of regulating power, backup capacity, etc. This will mean incorporating factors other than the primary optimisation based on prices. Another approach is to attempt to extend the market models with futures trading. These design changes are therefore strongly related to the structure of the markets. Derivative solutions should be identified in relation to long-term contracts and other forms of agreement. Incentives for innovation need to be considered just as much as price optimisation.

With respect to one of the new markets, the DSO market, it would be useful to get one or more grid companies to develop and test a demonstration of a local market platform for local flexibility services, as described in the 'Smart Grid Denmark 2.0' report, with support from research institutions.

On the purely theoretical side, research projects focusing on probabilistic methods in the electricity market are recommended. Once the theory is better understood, it may be possible to demonstrate it in production control for the reserve market, and then other markets.

With respect to where cooperation partners should be drawn from, transmission operators and universities from European countries could benefit from cooperating in new demonstration projects, including with countries such as Great Britain, which Denmark will be trading with if the North Sea Offshore Grid is constructed. Within Scandinavia, it is essential to get Nord Pool Spot involved in future demonstration projects and development of the market design and market equilibrium procedures, as they control many of the markets. Within Denmark, there generally needs to be a major effort from the private sector in terms of participation in new demonstration projects.

Time recommendations to the road map

Two of the largest Smart Grid projects in Denmark focusing on electricity markets, Ecogrid EU and iPower, will be completed in 2015 and 2016, respectively. To keep development advancing in Denmark, new projects must already be planned now, so they can commence in early 2015. If more electric vehicles and 50% RE are to become a reality in Denmark in the early 2020s, then we must agree on our Smart Grid solutions as soon as possible.

Synergies/possible export and employment effects

The electricity market is primarily being developed for the sake of society. Lower electricity prices and customer comfort and environmental considerations are often the priorities, so it is difficult to predict direct export and employment effects. If Denmark becomes the first country to offer flexible prices for all residents, for example, one might expect synergies where technological innovation and services developed in Denmark can be exported.

More specifically, one can expect software for managing energy consumption to be developed, such as apps for mobile telephones, which can be exported to other countries.

CHAPTER 3 COMPONENTS

Components are electrical devices which make it possible to control power/energy quickly and efficiently on the electricity production side, transmission and distribution side and consumption side, making them important elements in the design of the Smart Grid. These might be components for power transformers for wind turbines, solar cells, fuel cells, etc., active filters, compensators, remote-control of medium voltage transformers on the electricity grid and for devices which control electric motors (pumps, fans, compressors), household devices, lighting and heating. Components are becoming increasingly efficient and intelligent, so that they can control and monitor the system precisely, as well as more communicative and hence controllable in relation to the surrounding world, via wireless or cable communication. Many devices have so much built-in intelligence that they will soon be able to monitor the electricity grid or the item being controlled, and thereby increase operational reliability. Finally, components can be equipped with functions that work actively with the grid to maintain frequency and voltage, and can offer functions such as active filtering of harmonic operations when islanding, adding value to the product.

Current situation/background

Denmark has been a strong leader in the area of energy efficiency for many years via the development of efficient electric devices which can save significant amounts of energy. Two technologies are vitally important. One is ICT – including software – which enables control and interaction with the outside world, and the other is power electronics, which can efficiently translate electrical energy from one form to another. Technology is also used to control solar cells and wind turbines, so that they can produce controllable energy on the grid. The combination provides intelligent, controllable and efficient energy systems which can be used to manage the grid. There is also a major focus on opportunities for improving grid performance by adding active components such as compensators, active filters and more controllable transformers. Companies such as Danfoss, Grundfos, Vestas, Siemens, KK-Electronics and ABB are well-known for this technology, but a number of other companies also produce based on the technology.

The components are subject to many requirements, especially where they will be participating in grid management longer term. Characteristics such as availability, reliability, protection, and ability to handle grid faults, are essential. The devices also face development challenges such as requirements that they take up less space and become cheaper and more efficient.

Within the areas of ICT and power electronics, many activities are taking place which can support the development of these products and their intelligent use in the grid. In ICT, communication, electronics, wireless technology, control technology, embedded systems and reliable software are seeing a high degree of close interaction between research institutions and companies.

In power electronics, there is close interaction between industry and research institutions, operationalised, for example, via the Centre for Electrical Energy Systems (CEES) and other bilateral initiatives. The latest key initiatives contributing to development of the technology are the Centre of Reliable Power Electronics (CORPE) and the Intelligent and Efficient Power Electronics (IEPE) advanced technology platform. The Region of Southern Denmark has also established a Cluster for Lean Energy, assembling a number of companies to initiate projects and set up joint infrastructure.

Wind turbines and other RE technologies and electricity consumption need to be further developed so that they can provide to a greater extent. Ancillary services from these technologies need to replace services currently provided by the major power plants. The way the services are defined and interact within the system must also be developed so that the special characteristics of the new resources are optimally exploited. Several technologies have been found to have very attractive business cases. Due in part to its wind turbine industry, Denmark is ideally positioned to supply global solutions and profit from investment in this area.

Recognised knowledge deficiencies

The development of inexpensive, reliable and controllable devices is vitally important in order to be able to control renewable electrical energy production and dynamically control consumption. The following deficiencies/challenges have therefore been identified:

The devices need to be continually getting cheaper with the aim of achieving rapid market penetration and contributing to reducing 'Cost of Energy' for the electricity producing units. New subcomponents are also appearing on the market which can significantly change the layout and design of these devices, making new design methods necessary.

Demands on the control and communication elements of the devices are continually increasing, and it is a challenge to ensure they have software which has been tested and is sufficiently reliable.

A grid based far more on power electronics will be built, which can contribute in relation to harmonic load/noise, given this has not adequately been standardised. A filter is also typically placed between devices and the grid, providing dynamic interaction between the units. Far more of the electricity grid is being placed underground, leading to increasing risk of resonance problems on the grid, which can be stochastic and require management to avoid destroying components or even the grid.

The functionality of electrical devices is constantly becoming more advanced. Examples of intelligent functions include being able to predict loads and problems on the grid, and adding more management options to the grid. The latter includes participating in voltage and frequency regulation on the grid, actively filtering harmonic flows, and handling 'Fails Ride Through' and islanding, if permitted and desired. The latter functions have not been developed into their final form and not been adequately tested to ensure reliable operation in all cases on the grid. Components can also serve as sensors on the grid and thereby supply information for centralised management. This can include information about the state of the grid, and providing warnings if critical situations arise. Finally, a higher degree of transformer automation and regulation on the grid could also contribute to improved performance.

Recommendations for research, development and demonstration initiatives

A number of initiatives should be commenced to promote the development of controllable devices on the grid:

- Design tools for optimising electrical components, including their expected performance using new subcomponents, which can challenge the classic way of designing devices. It is currently expected that components will be able to work with a frequency ten times higher than today.
- Development of new control methods for electrical components which fulfil the future grid requirements and efficient load management. This includes the possibility of utilising system services from other energy sources, including the transport and heating sectors.
- Testing of the new functionalities on the grid, with the aim of being able to provide the given functionalities, on both a small and a large scale. Interplay between solar cells, heat pumps and electric vehicles is also of interest in this regard.
- Establishment of better test tools for software in the components, to ensure high software reliability and hence device reliability.
- Analysis of electrical and harmonic phenomena in relation to the widespread use of electrical components with power electronics, including tools for identifying critical configurations and operational factors on the grid.
- Development of intelligent functions in the components that monitor the grid and load, and provide feedback to the manufacturer about operation of the devices, so they get a clearer picture of the components' 'mission profile'. The components will also be made capable of predicting their own internal faults.
- Active participation in standardisation work – in relation to both consumers and the grid – to ensure that component manufacturers and the electricity sector have the best conditions for developing and producing services and components.

Time recommendations to the road map

It is recommended that the new functionalities soon be tested on a small scale and a slightly larger scale in order to clarify the potential of the devices. There is also a pressing need to clarify conditions in relation to harmonic problems on the grid, as these may result in changes to grid and device requirements in the longer term.

Synergies/possible export and employment effects

Companies producing electrical devices have experienced constant growth for many years. This trend is expected to continue as power electronics and ICT will be incorporated into an increasing number of products. For example, the market for power electronics in vehicles has seen two-digit growth rates, and stronger positioning will give companies greater opportunities.

CHAPTER 4 CONSUMERS

Danish consumers are currently used to virtually 100% security of supply. One of the challenges facing the transition to the Smart Grid is that consumers at the present time see no need for a Smart Grid. From this difficult starting point, consumers need to become an asset rather than being seen as a problem or a load in the future Smart Grid. In order to do this we need to better understand what can motivate consumers to change their present behaviour and become involved in installing equipment and solutions which can support this change and at the same time develop technological solutions which create opportunities to shift consumption time wise.

The following section will distinguish between households and small consumers (including prosumers, who also contribute to production) and larger companies and institutions operating under different regulations and on markets which take into account the scale of their energy consumption.

Current situation/background

The group of consumers consists of individual households, companies and institutions, which may or may not work together. Large companies and institutions are expected to more easily be motivated by economic incentives due to the size of the possible savings achieved. Conversely, major economic savings are not expected to be possible for private consumers, which is partly why non-economic incentives are also required.

From earlier research and development programmes we know that private electricity consumption and private electricity consumers are complex. The motivation that drives consumers to use electricity in the way they do can therefore rarely be reduced to economic or environmental factors (although this is assumed to depend on the type of consumer). These are just some of a number of motivations and values which impact on why we consume electricity in the way we do, and which can motivate us to change behaviour. Others include comfort, time, technology, play and fellowship, doing the right thing, social identity, security in the home and design and aesthetics. Finally, there is a major lack of technological solutions which comfortably and automatically shift time of consumption, temporally, or based on a desire to engage electricity consumers. Energy related technologies are lacking which support this engagement to a higher degree. An understanding of users' motivations and barriers is precisely what should drive development of the efficient solutions and market of the future.

Recognised knowledge deficiencies

The magnitude of the hidden balancing reserve represented by the flexibility of energy consumption in industry has been investigated earlier ('Price elastic electricity consumption among large electricity consumers' (*Priselastisk elforbrug hos de større elforbrugere*), Dansk Energi Analyse A/S & Norenergi ApS, for Energinet.dk, August 2005), but there is a lack of advanced process control systems which can exploit this energy flexibility without compromising production time or quality. An example of a project which addresses this issue is 'Smart Grid Ready Energy Cost Effective Artificial Light Management for Greenhouses'

(*Smart Grid Ready Energiomkostningseffektiv Kunstlysstyring til Væksthusgartnerier*) under the EUDP/GUDP programmes.

Earlier demonstration projects have primarily been measurement and monitoring projects which have contributed to the development of new methods and technical knowledge about consumption. However, these projects lack knowledge about what motivates consumers to change their behaviour. There have been some demonstration projects involving private consumers and their homes. Projects such as eFlex, MCHA and Bolig for Livet have accumulated knowledge about private consumers' motivations and barriers in relation to changing consumption behaviour at home. However, these studies are limited in their scope and conclusions.

We have identified the following knowledge needs which exist in relation to the Smart Grid and consumers:

Do various maturation phases exist for the prosumer transition to Smart Grid?

a) What are the needs and preferences of prosumers which can lead to new forms of involvement and engagement in the Smart Grid of the future?

b) How can we translate existing knowledge about consumer practices, motivations and values into relevant products, services and markets which create involvement and value for users, while also supporting the transition to a Smart Grid society?

c) Anthropological studies and the development of new platforms where consumer optimisation of energy consumption in relation to flexibility, energy savings and the desire to consider the environment can be accommodated, for example through automation.

d) How can the market for large energy consumers be developed so they are motivated to and supported in implementing energy savings and participating in the flexible adaptation of the distribution of their consumption etc.

e) New intelligent solutions to comfortably and automatically shift consumption temporally.

f) What effect do various Smart Grid initiatives have on consumer and prosumer behaviour and involvement? Effect is understood here as the consumer's experience of satisfaction with the initiatives correlated with the real effect in terms of reduced CO_2 emissions at the individual, company or national levels.

Recommendations for research, development and demonstration initiatives

<u>Research</u>

Design research into new processes and methods for translating consumer insights into the effective design of products, services and markets.

Design research into effective mechanisms for changing behaviour through design, e.g. ‘nudging’ as a method.

Research into new methods for assessing the outcome of Smart Grid initiatives which combine qualitative/quantitative data with (static and mobile) sensor and meter data.

Anthropological, sociological and behavioural psychology research into users’ (both individuals and companies etc.) motivations and barriers in relation to changing energy consumption behaviour.

Research into methods for using frequent meter readings (e.g. smart meters) to identify and advise on possible energy efficiency improvements (such as the detection of undesired standby consumption, options for re-insulation and better regulation of the energy supply).

Research into principles and methods for the prediction and management (relocation) of consumption, for example through variable prices.

Development

How can we translate existing knowledge about usage practices and consumer motivations and values into relevant products, services and markets which create value and involvement for users, while also supporting the transformation to a Smart Grid society?

Development of solutions which automatically and comfortably – or based on greater involvement and ownership – shift time of consumption, so that it harmonises with the instantaneous production of renewable energy. For example, solutions which allow low-energy buildings and buildings with ground heat and solar heating to provide far more flexibility than is available using existing solutions.

Demonstration

We recommend that Future Living Labs be developed where projects can accumulate knowledge about how consumers and prosumers will act under changed (future) conditions. The framework should be realistic, such that the knowledge acquired is based on actual practice and not on imagined scenarios. In addition to realistic Living Labs, knowledge can be acquired using ‘provotypes’, which can provoke new needs or barriers among consumers.

Demonstration projects and the associated follow-up research can identify which needs consumers and prosumers have under these changed conditions. How are consumer practices influenced and how well do consumers accept factors such as indoor climate and lighting? The projects also provide knowledge about what motivates new consumption behaviour. This knowledge is essential for the development of existing or new improved solutions.

The projects must include a high degree of demonstration of technological and IT solutions to shift time of consumption.

We recommend Living Lab demonstration projects at the level of the household, district, apartment complex, and workplace (office and production), and in relation to transport.

Examples of existing Living Labs for demonstration projects: Grundfos College in Aarhus, www.grundfoskollegiet.dk, Energy Flex House, Danish Technological Institute, www.teknologisk.dk and Active House, www.vkr-holding.com.

An essential part of the demonstration projects should naturally also be technical and qualitative effect evaluation of the potential of initiatives in relation to the Smart Grid.

<u>Smart Grid interfaces</u>

It is further recommended that the role of Smart Grids in relation to other energy systems be considered at the level of Smart Cities, as we assume that the majority of the future flexibility will lie at the level of Smart Cities. Read more about this in chapter 6.

Time recommendations to the road map

Initiatives and projects have been partially initiated and must be maintained and strengthened. New initiatives in the area should be commenced as quickly as possible, as many of the smart solutions of the future must be based on knowledge of consumers.

Synergies/possible export and employment effects

The accumulation of knowledge about which Smart Grid solutions have an impact on users and how specific technical solutions can contribute to comfortably shifting consumption temporally will provide a foundation for the export of Smart Grid products and solutions.

CHAPTER 5 INFORMATION AND COMMUNICATION TECHNOLOGY (ICT)

ICT plays an essential role in the integration of distributed energy resources (DERs) such as distributed CHP plants, wind turbines, solar cells and prosumers – i.e. consumers who can regulate their energy consumption dynamically – as ICT provides communication between the individual units in the grid and ensures that these act correctly to maintain system stability. In earlier development and demonstration projects, the use of ICT has primarily been application oriented with no special focus on developing the ICT technologies and skills essential for the development of advanced Smart Grid solutions. There is therefore a need at the moment for focused efforts in relation to ICT to ensure that the necessary ICT skills are available for development of the future Smart Grid components and system solutions.

Current situation/background

During the transformation to Smart Grid, the complexity of the entire electricity system will be increased through the diverse nature of interconnected components and subsystems. This will require that the foundational Smart Grid architecture is robust towards function deviations and threats to IT security, so that system faults and resulting grid failures are prevented[1]. With the introduction of the Smart Grid, the grid – as critical social infrastructure – will be opened and changed in terms of communication in a way which will permit new types of terrorist attack, unless IT security is managed correctly. Given that ICT is a foundational Smart Grid technology, ICT failure will have serious consequences for the overall grid in terms of system operation and security, market share and data security.

The introduction of the Smart Grid will provide access to large quantities of operating data. Data which provides a basis, among other things, for charges by grid companies and electricity suppliers to consumers and Energinet.dk’s balance calculations with the various players, and information about relocation and changes to supplier. In addition to its importance to traditional electricity grid players, this data also provides opportunities for new service providers (for example through access via the Data Hub[2]). The availability of such data is important for the analysis of user behaviour and later influencing such behaviour through various incentives. However, the Data Hub cannot be used for system monitoring services and operation of the balance market, as it only contains historical data. A similar service will therefore be needed which can supply real-time data.

There is a focus at the European level on standardising Smart Grid communication protocols[3]. Relevant standardisation bodies have therefore initiated the necessary standardisation work in relation to Smart Grid communication protocols for distribution of price signals, advertising flexibility capacity and conditions for its utilisation, bid negotiations for utilisation of flexibility capacity, monitoring and control of offered flexibility capacity, and authentication and authorisation of units connected to the smart grid. While it can be expected that the current standardisation work will accommodate the basic need to counter threats to IT security, it can also be expected that more advanced Smart Grid solutions will lead to new requirements, demanding additional ICT research efforts.

Recognised knowledge deficiencies

With respect to the standardisation work in relation to communication protocols, there are two general recommendations[4] which primarily determine the overall design of open communication systems: (a) formulation of flexible standards (b) re-use of existing mature standards, where possible. The connection of units will be dominated by wireless standards and Power Line Communication (PLC) standards. However, the use of the existing standards cannot guarantee that the high demands Smart Grid applications are subject to will be met in terms of uptime, IT security and reliability. There is a significant technological knowledge hole in relation to using existing wireless and PLC standards to build resilient connections and networks which will be scalable in step with the number of connected smart grid units. While there is a focus on 'self-healing' technologies to guarantee uptime, IT security and reliability[5 +6] at the European and US level, similar initiatives are lacking at the national level[7]. There is generally a greater need to focus on IT security in relation to the electricity system. While there are many years of experience with robustness in relation to faults in the existing electricity system – faults are quickly identified and isolated and insufficient power contribution is quickly covered by other resources – there is a lack of experience with the significance of IT security in relation to maintaining robustness in the electricity system.

Currently accepted Smart Grid ICT standards provide communication functionality and information models at the component level, but protocols are lacking at higher levels which directly support service-oriented aggregation of Smart Grid units. Similarly, the current platform lacks concepts which facilitate the competitive delivery of Smart Grid services.

Another knowledge deficiency relates to a systematic approach to requirements specification for critical and distributed ICT systems: Smart Grid transformation of the grid will introduce complex critical social infrastructure, whereby communication failure can cause system failure. Resilient System concepts and analysis and design approaches which address the combination of electricity system and ICT systems, are lacking. Initiatives are underway at the national level which is studying resilient control systems in connection with distributed systems, for example in the area of process control. However, no initiatives are known which are based on resilient solutions for the Smart Grid.

Recommendations for research, development and demonstration initiatives

It is recommended that the following activities be initiated:

- **Large-scale demonstration trials**, in the short term, integrating distributed energy resources and prosumers **to test how various Smart Grid IT standards work in practice**, when these are incorporated into the same Smart Grid IT system. There should be a particular focus on dysfunctional effects arising as a result of their combination and the combination of system operation and control. There should also be a focus on algorithms and architectures which minimise dependencies on communication and increase autonomy in the system, in order to survive communication disruptions and breakdowns.

- **Research and development in the area of analysis methods and software tools** and open communication/information standards to **identify optimum combinations of**

distributed energy resources and prosumers during aggregation under various market conditions and taking into account the season, dependent variations in consumption and production. As a criterion for methods, tools and standards, a focus on open architectures and platform solutions to support innovation potential is recommended.

- Research to determine the required level of uptime, IT security and reliability for communication connections, and innovation in the area of network technologies and protocols which can fulfil these requirements. The reliability requirement should be seen in the context of **software technologies for establishing 'Resilient Systems'**. In this context it is important to differentiate the various aspects of Smart Grids (transmission, distribution, home energy management systems (HEMS)), which can lead to the most cost-effective communication solution. Control technologies which have minimum communication requirements should also be identified and prioritised here in relation to emergency situations.

- Accumulate knowledge about methods and structures for **maintaining electricity system robustness in relation to IT security** as IT security becomes an increasing threat to the security of the electricity system. Closer investigation of IT security issues for Smart Grids in a Danish context is therefore required. This includes examination of how **international standardisation currently underway applies to Smart Grid solutions adapted to the Danish context**, and the extent to which new

- A **greater research and development focus** on software technologies in the area of Resilient Systems through activities which ensure Danish research on par with International research, with the aim of developing **self-healing Smart Grid systems**. Platform concepts should also be established to be systematically incorporated into Smart Grid applications and system components to the extent this is technically possible.

- Investigations regarding **establishment of a portal for data** which can provide a foundation for reliable prognosticating of smart grid assets, to guide an efficient balance market.

Time recommendations to the road map

It is recommended that activities in relation to system robustness be undertaken during the 2015-2017 period, that activities in relation to analysis of the consequences of standardisation work currently underway be undertaken during the 2014-2016 period, and that activities in relation to research and development of models for aggregating prosumers be conducted during the 2014-2016 period.

Synergies/possible export and employment effects

The widespread use of distributed energy resources in Denmark makes it possible to test many different ICT concepts in practice, which is in advantage in relation to acquiring knowledge and the associated exports in the form of intelligent software solutions.

CHAPTER 6 COHERENT ENERGY SYSTEM OF THE FUTURE

In the years ahead there will be increasing focus on a coherent energy system and not simply a balanced electricity grid with a higher proportion of renewable energy. This is due to the need for overall optimum utilisation of energy and to reduce the use of fossil fuels in other parts of the energy system, and the opportunities that exist for buffer capacity and energy storage in other parts of the energy system – which are a major challenge in the electricity system.

Development of the overall energy system will result in more units and plants being connected on both the consumption and production side. This will create new opportunities for interconnection at the same time as it becomes necessary in specific areas to establish these infrastructure connections. This will mean connections between the electricity grid, which is the primary focus of the Smart Grid, and other energy infrastructure such as the heating network, gas network, etc.

One of the challenges in this respect is that such connections often take place in the production and consumption area, while the infrastructure is often parallel. For example, connections often occur in the area of production in relation to the co-generation of electricity and heat, which opens the way for a managing the temperature in district heating supply as a way of regulating production of electricity, whereas in the area of consumption it is about the ability to store energy in electric vehicles and heat pump systems with a reservoir capacity. This focus also entails greater interest in intermediary institutions and structures such as towns, local areas, and groups of companies and housing institutions which will play a major role in facilitating this integration of the various elements of the total energy system.

Current situation/background

The current situation is characterised by various energy systems at different phases of development, with the electricity system leading the way and other parts of the infrastructure in the process of or commencing a similar development. However, Denmark already has a widespread combination of electricity and heat production in a number of different types of small and large plants, providing good opportunities for coordination. The currently separate systems already challenge the need to create coherent planning of the energy system, even though this must necessarily take into account the fact that extensive and separate infrastructure has been established, which does not simply exist as technical systems with their own criteria for utilisation, but also as economic and institutional conditions for change.

In parallel with development in the area of the Smart Grid there has been incremental development in energy utilisation in the construction sector. This is occurring as several municipalities experiment with and test more local solutions to the heating supply, for example by promoting heat pumps or distributed heating solutions in combination with low-energy or active buildings. This development in the construction sector, particularly in relation to heating systems, is not taking place in interaction with the national Smart Grid plans, but is due to other, local, considerations related to sustainable urban development.

These local initiatives are challenging current perceptions about optimisation of the electricity system and its robustness, with these signs of change in the heating and electricity supply at several points locally. Coordinating these parallel development processes represents a challenge.

Recognised knowledge deficiencies

If we are to achieve total energy system efficiency and the active involvement of groups of network users (in the form of local consumers who invest in composite energy units, and local areas with homes and cooperating commercial companies, and infrastructures which involve towns and infrastructure companies in the area of transport), there is a need for research focusing on active user roles and new institutions which span the existing divisions of supply systems and networks and do not implicitly view the involved users (players) as relatively isolated and passive consumers primarily interested in security of supply and prices.

In this context it is necessary to develop an understanding of the link between Smart Grids and Smart Cities, which are currently developing in parallel but largely autonomously, based on different perspectives and approaches. Smart Cities have a broader perspective than the development of energy infrastructure, are less focused on market and service development and discuss urban development to a greater degree. A combined vision could be formulated as Smart Energy Systems.

In the medium term, investigation is also needed into new forms of cooperation between the various energy providers and infrastructure owners, and analysing the effects of payment and tariff conditions, which can either promote or inhibit a higher degree of integration and optimisation of utilisation of the combined energy system.

While optimisation based purely on a Smart Grids focus could optimise electricity supply utilisation by balancing fluctuating consumption across days and longer periods and optimising electricity grid capacity, involving the total energy system would open the door to a higher degree of storage and buffer capacity and allow a number of energy savings to be made more relevant and attractive both in the area of production and among consumers or cooperating consumer groups which can provide this type of service to the total system. The heating system typically has greater buffer capacity than the electricity system, giving the connected solutions potential also in relation to optimisation of the smart grid electricity system.

Recommendations for research, development and demonstration initiatives

Three new research focus areas are therefore needed in the coming period up until 2020.

1. The first views the energy system as a whole rather than as isolated elements in terms of the electricity system, gas system, district heating system, etc. Ways it might be necessary to restructure the institutions that work with regulating the various elements of the energy system need to be investigated. The aim is to investigate the regulation and framework for various elements of the energy system, their cooperation and mechanisms for market creation and price discovery. Given the

different stakeholders in the various elements of the energy system, new forms of regulation may be required based on investigation of whether existing structures and control mechanisms may give rise to suboptimal conditions or other undesirable consequences for the total energy system.

2. The second should focus on the new roles various players who have previously been viewed as either isolated consumers or commercial entities can adopt in connection with organising local energy systems, etc. There could be a focus here on the role intermediary players such as towns and new trading companies can play. The ways consumers, companies and other players can function as owners of both production and consumption units in a total energy system should also be examined.

3. The third involves maintaining Denmark's strong position in the area of total and integrated solutions, where it is politically important that experiments and investigations are carried out where researchers and industry can mature the coherent energy systems and demonstrate to the surrounding world that they are sustainable.

In extension of this research work there will be a need in the medium term to establish large-scale tests, demonstrations and experiments which bring connections between the various elements of the energy system into play. There is reason here to examine the various elements of a total energy system which should be brought into play.

1. One area comprises local solutions linked to connections between various energy forms and opportunities for storage and creating substitutions, which can support overall efficiency and utilisation, and savings in total energy consumption.

2. Another area comprises special challenges linked to getting energy consumption for transport and the need for transport better connected to other forms of energy utilisation, so the transport sector's energy consumption can be optimised and more closely integrated with the rest of the energy system.

3. The third area to be examined is the integrated control and regulation of the total energy system with the aim of achieving overall reduction goals, both in relation to energy consumption and climate and environmental impacts, to be achieved through control aimed at efficient energy utilisation overall and through energy savings.

There is also a major need for further research, development and demonstration of technologies for energy conversion and storage. Consideration of these matters is related to this work and should be further analysed in subsequent investigations.

Time recommendations to the road map

The focus in this area will primarily be at the level of experiments, demonstrations and investigations, as well as future-oriented research which paves the way for a broader vision in relation to Smart Energy Systems and Smart Cities, where 'smart' not only refers to control and IT systems but also includes new roles for users and operators in these extended systems.

At the practical, instrumental level, involving experiments with demonstrations to create cohesion at the local level between energy systems, for example in relation to links between heating and electricity production and new systems that can serve as energy storage with specific connection opportunities, there is a need to initiate programme activities aimed at developing the foundation for an integrated energy system for implementation, with the first phase starting already in 2017-18. This work will also generate renewed interest in the way energy markets are structured and the price incentives incorporated into the integrated systems.

On the research side, a foundation must be built for the necessary changes to the institutional structure and perception of the players involved, and for regulating and creating markets for integrated energy services, both between providers and in relation to consumers and new players who take on both roles. In this research, the perspective of new roles for consumers, constellations of consumers, prosumers and intermediary organisations should be carried on based on the total energy system. The time frame for implementation is basically the same as above, but will also point forwards to development activities and demonstrations for the period beyond 2020.

Synergies/possible export and employment effects

For decades, Denmark has had a large export market linked to integrated energy systems which produce both heat and electricity (co-generation). With the development of Smart Energy Systems, this area will gain a control and regulation dimension which will open up new opportunities for technology and system exports. A major proportion of Danish production is not only linked to the production of renewable energy but also to the integrated production of heating and the control and regulation of heating systems and energy utilisation. There is thus already an established, solid base which can be built on in terms of export potential and employment.

CHAPTER 7 RESEARCH DEVELOPMENT SUPPORT PROGRAMMES

Current situation/background

In general, Danish energy research programmes cover the entire innovation chain from strategic research, to development and demonstration, while market maturation and similar activities must be sought in programmes which are not dedicated to the energy sector.

While the entire innovation chain is covered, a certain overlap exists between programmes this overlap ensure that RDD activities do not fall between two programmes.

There is also a major focus on Smart Grids internationally, and there are several initiatives under FP7 which cover the need in the European context. Going forward, this will be replaced by Horizon2020, which is expected to carry on this line.

Recognised needs

Since 2010, over DKK 1 billion has been allocated to support Danish energy research. This funding supports the area broadly and not only Smart Grids. If Smart Grids are to contribute to a green growth agenda, they will require a significant ongoing RDD effort, which needs to be supported by the funding programmes.

This road map provides a general picture of the RDD needs in the short term in the area of Smart Grids. Further effort is required to identify specific initiatives and projects up until 2020, and to sketch out an RDD direction towards, say, 2050.

The general trend is that the more frequent the demonstration projects, the greater the need for funding. Several technology areas and particularly components have now come so far that they simply have to be demonstrated.

Large joint international RDD projects which receive grants under FP7, etc., often find that their budgets are trimmed. This can result in a financing shortfall which the Danish partners have difficulty meeting themselves. It is therefore recommended that the Danish programmes be open to topping up the financing of European projects.

Recommendations for RDD initiatives

Danish energy research programmes must give high priority to Smart Grids going forward and ensure an unbroken innovation chain and that RDD activities are quickly moved along the innovation chain. This can be achieved, for example, through the joint financing and coordination of large RDD projects between the programmes. Danish programmes must be open to RDD projects which also relate to the development of model tools, anthropological projects for prosumer behaviour, and similar non-technical needs.

Based on current and completed RDD projects, the research network must analyse which new projects are necessary to achieve the political goal of a Danish Smart Grid in 2020. This analysis must also identify the most important Smart Grid focus areas up until 2050.

There needs to be a smooth process for achieving co-financing between European and Danish sources of funding. For example, it must be possible to apply for co-financing, independent of the deadlines of the national programmes.

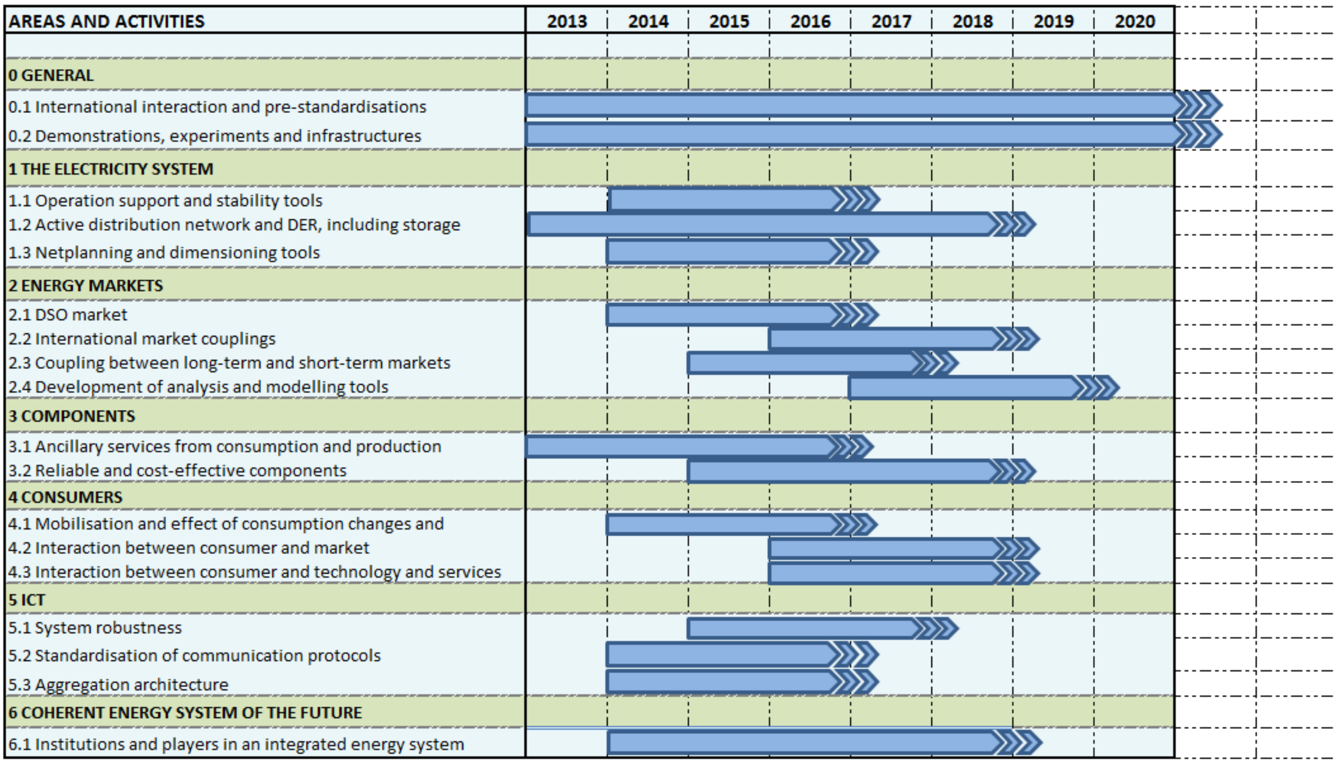
Synergies/possible export and employment effects

Internationally, Denmark is well advanced in the implementation of Smart Grid solutions. To exploit this leading position it is important to show that we are using the technologies ourselves. This underlines the need for demonstration sites which can demonstrate the use of individual technologies as well as the entire system approach, where Denmark's major strength lies.

CHAPTER 8 ROAD MAP FOR SMART GRID RESEARCH AND DEVELOPMENT

The network has prioritised the timing of the identified activities with a focus on expected needs related to the national implementation of the Smart Grid and particularly the Danish Government's Energy Plan.

The figure below is an activity calendar based on discussions and meetings where members of the Smart Grid Research Network have agreed on relative activities for each area. The figure focuses primarily on activities during the 2013-2020 period.



The figure above should not be interpreted as a complete picture of the situation, but rather as a brief overview of activities in various areas. The research network recommends that further analyses be carried out to provide a more long-term perspective.

APPENDICES

Appendix A
RDD activities currently underway in Denmark

The largest and most important individual activities include:

- iPower, which draws together a large proportion of the Danish players in the area of Smart Grids and has several electricity system technologies under development, especially in relation to Smart Grid architectures, aggregation, active distribution networks and DSO market solutions.

- EcoGrid EU, which represents Europe’s largest Smart Grid demonstration project supported by the EU. Technologies in the area of the electricity market, active distribution networks and consumer behaviour are being developed and tested.

- Other Bornholm activities, encompassing a set of projects which are developing and demonstrating various solutions in the area of Smart Grids, including system integration for electric vehicles, solar cells and heat pumps, micro grid solutions, system services for smart energy consumption, intelligent control of wind turbines, etc.

- Smart City Kalundborg, where a large-scale open platform is being implemented which enables various suppliers to offer solutions in free competition.

- The Cell Controller Project, where advanced control concepts for the future active distribution network are demonstrated.

- PowerLabDK, a world leading experimental platform for development of the Smart Grid of the future. The platform includes facilities in four locations (Lyngby, Roskilde, Ballerup and Bornholm) and offers unique international opportunities for the development of future technologies.

APPENDIX B
MEMORANDUM: **Where can Danish Smart Grid projects receive government funding from?**

NOTES

[1] Technology Roadmap Smart Grids, OECD/IEA, 2011, URL: www.iea.org. Accessed on October 2012.

[2] Datahub, Energinet.dk, URL: energinet.dk/DA/El/Datahub/Sider/Datahub.aspx. Accessed on October 2012.

[3] Final report of the CEN/CENELEC/ETSI Joint Working Group on Standards for Smart Grids. May 2011.

[4] Final report of the CEN/CENELEC/ETSI Joint Working Group on Standards for Smart Grids. May 2011.

[5] The European Electricity Grid Initiative (EEGI): a joint TSO-DSO contribution to the European Industrial Initiative (EII) on Electricity Networks. Public version. September 2009.

[6] Anticipates and Responds to System Disturbances (Self-Heals). National Energy Technology Laboratory. U.S. Department of Energy. September 2010.

[7] 'Analysis of the Danish electricity industry's Smart Grid RDD initiatives' (*Kortlægning af den danske elbranches Smart Grid FUD-indsats*). Energinet.dk and the Danish Energy Association. January 2011.