Essays on the Smart Grid

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Copenhagen Business School
CBS ITM June 2013
**Foreword**

We believe in the idea that Danish – as well as international – society would benefit from promoting green energy and expanding the concept to reach all enterprises and households. This is not only important in order to meet societal and environmental demands, but would also be conducive to innovation and enable Denmark to gain a competitive advantage in the field. However, we are concerned about the fact that, at present, there is no market for the Smart Grid in Denmark, as Danish energy users as a whole have a stable energy supply, and no incentives for aligning their behavior with Smart Grid patterns and consequently do not perceive the necessity for a change. For any kind of progress to be achieved, enlightenment and education are a necessary prerequisite, but more importantly, what is required at the outset, is a change in the system of incentives and taxation.

In this *preliminary* paper, we aim to explore the problems and possibilities, and endeavor to develop viable solutions that would yield satisfactory results from economic, sustainability and social development perspectives.

The paper serves the purposes of:

- internal clarification on challenges in relation to the Smart Grid issue
- argumentation and lobbying in relation to Danish politicians and authorities
- identification of projects and other combined activities to be undertaken jointly by both the Copenhagen Business School and other higher education institutions and enterprises.

An earlier version of this paper was discussed in a workshop on the Internet of Things on 12 April 2013 at Louisiana, and in this new account will be presented to the participants of a workshop on 4 October 2013 at Copenhagen Business School.

The paper represents different views, and each of the authors is only responsible for his/her own contribution. A collection of professionals have been involved in the elaboration of this paper:

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Introduction to the Smart Grid Issue

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According to a recent report from Danish Energy Association titled “Smart Grid 2.0 in Denmark” [1]

“...it is necessary to devise a new and modern regulation of the grid companies which prioritizes the establishment of balanced and positive investment incentives for rolling out Smart Grid solutions in the distribution system.”

There is a growing interest worldwide to enhance and improve the emission control tools in support of an environmental sustainability agenda. For instance, a Management Information System (MIS) Quarterly special issue on sustainability¹ stresses our responsibility for this problem. The Data Mining and Knowledge Discovery Journal also publish a special issue on sustainability². Thus, we observe that there are multiple facets of the environmental sustainability problem.

Wireless sensor networks are often used to collect the information needed for action, e.g. in Earth Science [8], but also in terms of green economy [2, 9]. To further illustrate the point, we view supporting infrastructure in the form of Zigbee Smart Energy,³ with support for dynamic pricing.

The Smart Grid is expected to collect and control the behavior of consumers and suppliers in order to make the system more effective and sustainable. The consumers or suppliers would be capable of controlling certain appliances in their homes, in order to become resources for the system. For example, the customer or supplier has the option to switch off the freezer for 30 minutes during the night to save energy.

Current Research

Research into environmental sustainability is conducted from an information system perspective, e.g. by [2-4]. In an article in the 12 November 2010 issue of Science, the Visioning Team discusses the significant challenges in earth system science for global sustainability. The authors also call for an unprecedented global initiative to deliver the knowledge society requires to simultaneously reduce global environmental risks while also meeting economic development goals[5]. From an Information Systems perspective, the issue offers contributions to earth science [6] as well as to engineering and control [7]. Examples include information about power consumption, water usage, chemical waste, air pollution, transportation, and logistics.

Watson et al. [2] provide a broad framework for understanding the dynamics of supply and demand in energy flow networks. The main ideas center on flows, sensor networks, and sensitized objects. Wireless sensor nets support objects to communicate in order to achieve a goal, which could be conservation of

¹ http://www.misq.org/ which underpins the importance from top-managers.
² "Data Mining for a sustainable world", edited by Hillol Kargupta, Katharina Morik, and Kanishka Bhaduri
³ http://www.zigbee.org/Standards/ZigBeeSmartEnergy/Overview.aspx
Some applications require to log streams of the sensor data [12]. Applying knowledge discovery methods to streaming data demands new algorithms [11, 10].

**Mini-Smart Grid at Copenhagen Business School**

The mini-Smart-Grid project at Copenhagen Business School (MSC@CBS) seeks to investigate the business opportunities and issues that arise from this new technology. The project revolves around the concepts of Smart Grids, Smart Meters and prosumers. Smart Grids are a new method of managing electricity and power supply. The project has yet to reach its full potential, but it offers a more interactive platform for both the consumer and the main supplier.

At CBS, our work examines the field of automated demand response. Automatic demand response is a method by which buildings and homes temporarily lower their electricity usage — without human intervention — at times when the electricity grid is near full capacity. Automatic demand response has already achieved an average savings of 13% electricity on peak demand in commercial buildings [13]. Building on that premise, a goal for next generation data mining would be to reduce the peak demand even further. For instance, NOBEL - A Neighborhood Oriented Brokerage Electricity and Monitoring System [14] – aims at reducing electricity demand at peak times by 30% through construction of an energy brokerage system, by which individual prosumers are able to hand-over their energy needs directly to both large-scale and small-scale energy producers, and in so doing, making energy usage increasingly more efficient.

Considering a Smart Grid as a type of electrical grid, which attempts to predict and intelligently respond to the behavior and actions of all electric power users connected to it, stresses the role of data analysis. Electrical engineering and computer science collaborate for better distribution of electricity, particularly in peak times [15].

Investigating the interplay of embedded systems, data analysis, and sensor networks for a smart grid and a sustainable world is a complex task which also requires training. For such an education, a discerning and distinctive setup of open source tools is beneficial. At the KDubiq Summer School\(^a\) in 2008, CBS Embedded Software Laboratory utilized an educational platform named Lego Mindstorms that ran the sensor network operating system TinyOS [16] and classified simple two class problems with support vector machines [17]. From 2012, CBS Embedded Software Laboratory has attempted to experiment with a student platform for the investigation of automated response in a Smart Grid as an example of academic education in data analysis and embedded systems.

**Acknowledgement:** The mini-smart-grid@CBS project is supported by the Business in Society on Sustainability Platform at Copenhagen Business School.

References

Smart Grid Challenges
By Peter Møllgaard, Professor of Industrial Organization, CBS

Denmark has the world record in terms of how much wind energy contributes to total domestic demand – and the political ambition is daunting. Currently, 20-30 percent of Danish demand and supply are made up of wind power. In the near future, i.e. 2020, that number should increase to fifty percent according to broad political consensus reached on 22 March 2012. To make this ambition a success it must be the case that power consumption (load) must follow supply to a larger extent than is the case today. This requires that demand be responsive to prices and that society is linked up through a (yet to be developed) smart grid. This note presents some of the challenges this development will pose and indicates possible solutions.

Wind – Risky Power?
Wind energy affects the entire energy system in several ways. As a result of the intermittency of the supply of wind, the volatility of prices and quantity increases; and as a result of the low marginal cost of wind generation, the average price of electricity falls. This means that electricity produced by other technologies becomes less profitable and that investment incentives fall.

As Denmark introduces even more wind energy in the Danish electricity system, business as usual is not an option. It is for example not enough only to increase our international transmission capacity. Instead, we need to invest in smart grids, but this requires us to spend a lot of money on technologies that have yet to be developed and, maybe particularly, to be implemented.

To succeed, we need to focus on open standards and hardware that will allow us to harvest inherent network effects. The more users that focus on a given standard, the more valuable the system will become.

At the same time, it is crucial to understand that technology is only one side of the coin. It is as important to understand the behavior and motivation of firms and of consumers. Consumers should not be taken for granted in this connection. They are not a component that you can program or design – but human being that has to be convinced and motivated to change behavior and to invest in technological solutions.

My research project Risky Power (2007-2011) dealt with the portfolio of generation technologies, capacities and reliability of supply. Risk enters at several levels. Demand for power is stochastic – but so is supply – and hence the risk of a blackout is real. Some generation technologies have a more intermittent nature than others: Energy produced by wind mills is fed into the transmission systems more randomly than power produced by traditional fuels. Thus, the mix of technologies affects the security of supply and the need to invest in reserve capacity. As power markets have been liberalized, decisions to invest in capacity have been decentralized and are now partly or wholly at the discretion of commercial companies. Their incentives to invest in generation capacities depend on market prices. How well markets work, depends on how they are organized and regulated.

As one concrete outcome of the Risky Power project, Sebastian Schwenen defended a PhD thesis on “Security of Supply in Electricity Markets” in 2011 and has published several papers on how the market design may result in a strictly positive probability of a black-out and on how the introduction of smart metering that allows for real-time pricing of final consumers may assuage the problem. In a very clever paper, he showed how capacity markets, i.e. markets that are designed to overcome the lack of investment
in generation capacity, may be a very costly tool to promote supply adequacy if the underlying market is not designed well.

The typical back-up technology has a start-up cost and so will only be started up when price exceeds marginal cost (MC) by a certain amount (a “risk premium”) and will only be shut down once the price falls significantly below MC. This implies that the deployment of back-up generation is affected by increased volatility. Inspired by this problem and also financed by the Risky Power project, Nihat Misir is currently finishing a PhD thesis on “A Real-Options Approach to Determining Power Prices”. In one paper, entitled “Economic Capacity Withholding: Effects of Power Plant Operational Characteristics on Optimal Dispatch Decisions”, he shows that optimal real-options behavior may easily be confounded with market power in that a real options premium may explain up to 25 percent of a monopolist’s mark-up. In his second paper on “Wind Generators and Market Power: Does it matter who owns them?” he shows that ownership to wind mills increases the market power of fossil-fueled generators.

Thus the effects of increasing the share of wind power in total power production are well understood.

**Smarter Energy Systems**

Microeconomics provides a basic insight into the understanding of both local and nationwide power systems. The energy system consists of a lot of components that may be substitutes or complements to each other. If you picture a situation with an offshore wind mill farm and a transformer platform, this point is illustrated easily – perhaps in a rather too obvious way. Electricity from the windmills is transported to the platform and then transformed and sent onshore from the platform. Each of the wind mills is a substitute to each other – delivering roughly the same to the system. And the wind mills and the platform are complements: Without the platform, the windmills are worthless – and vice versa. Together they become very valuable.
At a general level, the energy system is made up of complements and substitutes: carbon fuelled generators, nuclear generators, international transmission, TSOs, DSOs, and so on.

In the future, the intelligent energy grid will contain new and changed components: electric vehicles, heat pumps, fuel cells, and several other things. The societal cost of wind energy will be lower – or the value of the system higher – if we can introduce, improve or make less expensive, complementary technologies that allow storage, for example, or that allow consumption to follow production, rather than the other way around (as is the case today).

The picture also illustrates another thing: there is no blue sky. Often smart grids are launched with a biased view on the benefits - while the associated costs are played down. As a representative of the dismal science – economics – it is suitable for me to point to the fact that the smart grid is not just a sunshine story – there is also a shadow or cost side.

The existing Nordic trade in electricity is smart. It gives Denmark access to an enhanced portfolio of technologies: Nuclear power (Sweden, Finland), hydro power (Norway, Sweden), coal (Germany, Denmark), gas, and wind. Traditionally Norwegian hydropower serves a storage purpose: when Denmark has excess demand for electricity because the wind does not blow, we can import electricity that has been stored in the Norwegian water basins; when Denmark has excess supply of electricity, we can export it to (among others) Norway so the Norwegians can store their electricity “for a rainy day”. Obviously, the value of the storage is significant and so Denmark has to pay more for the electricity we import from Norway than Norway has to pay for the Danish wind power. However, that solution is not applicable in the future. First of all others want to use the Norwegian storage (witness the NorNed connection), secondly our southern and western neighbors (UK, the Netherlands, Northern Germany) also build wind mills, meaning that the need to “get rid of” wind power domestically increases.

To keep more wind power within the borders of Denmark challenges the energy system. It needs to be even smarter. Smart grids are intelligent power systems that can integrate all connected users’ behavior, be they producers, consumers or “pro-sumers”. A “pro-sumer” could for example own solar cells and so produce electricity at day time and consume electricity during night time. In addition to the traditional power system components, a smart grid connects ICT, electric vehicles, hybrid cars, photo voltaics, and more.

A Smart Grid in Denmark costs DKK 10 billion (approximately) according to a report published by Energinet.dk and the Danish Energy Association on 10 September 2010. This analysis focused on that part of the electricity system that would allow for the introduction of more wind mills, more electric vehicles and more heat pumps. The cost of the smart grid relates to re-enforcements of the grid, stability of the system, software, metering equipment and “intelligence at the final consumer.”

This smart grid is estimated to lead to benefits to the order of DKK 8 billion relating to savings on reserves, balancing of the system, electricity production and energy conservation measures, so the net cost is estimated at around DKK 2 billion. However, according to the report, the net cost of traditional expansion of the grid would be DKK 8 billion. In this way, the smart grid beats the traditional solution by DKK 6 billion.
Behavioral Changes

Technological solutions to the smart grid have received a lot of attention while the necessary changes to consumer (and firm) behavior have received less attention. However, today the consumer is king of the electricity market: production follows demand in the sense that the consumer expects the light to switch on when (s)he presses the switch. The smart grid aims to change this to a certain extent. The big question is: How much can demand blow in the wind?

Experience tells us not to take it for granted that consumers will change behavior in the electricity markets. When Denmark liberalized the retail market for electricity, it took a long time to get a fraction of consumers to react. A report from the Danish Competition Authority (Konkurrenceredegørelse 2008) showed that only two percent of households had changed electricity supplier since the retail market was fully liberalized four years earlier. A few more (five percent) had changed product without changing supplier so around eight percent had undertaken an active choice in the retail market for electricity. While not impressive, this squares with international empirical experience although the UK and Norway have had better results in terms of mobilizing customers.

A survey investigation undertaken among 1,000 households in the fall of 2007 by GfK sheds some light on why electricity consumers do not switch suppliers. 70 percent answered that only significant savings would make them change supplier while 10 % mention the possibility of getting a greener alternative. Only five percent mention the possibility of a better service at the competitors.

Thus it is difficult to mobilize households in the retail market for electricity and this poses a significant challenge for the smart grid: How to achieve increased consumer response or awareness, more competition and better sustainability at the same time?

A possible answer lies in a combination of smart meters, dynamic tariffs, an improved price comparison site and the newly established Data Hub containing all basic data on all retailing customers in Denmark.

Smart meters may in and of themselves increase the price awareness of consumers; see Danish Competition Authority (2009). However, to make consumers active it is a problem that only a small fraction of the price consumers pay for power is subject to competition. Tariffs, taxes, PSO contributions and VAT amount to almost 80 percent of the final price – and those are by and large independent of the whole sale price of power.

Price signals will be amplified if it is not only 20 percent of the price that fluctuates with the wind. An obvious proposal is therefore to make tariffs and taxes dynamic so as to reward consumers for postponing consumption when the power system needs it, e.g. when the wind does not blow, until such time where a larger load is beneficial for the power system and the climate.

In April 2009, the Danish Minister of Climate and Energy asked the Danish Transmission Systems Operator (TSO: Energinet.dk) to establish a system to facilitate the exchange of individual customer load profiles and other data to facilitate switching of suppliers. The resulting DataHub went live in March 2013. If the DataHub is combined with one or more price comparison sites that consumers could use to carry out this switching (and not just to get an impression of potential savings), this would facilitate switching and mobilize consumers to a larger extent thereby to some degree solving the challenge that consumer inertia represents to the smart grid. Technically, this should be possible if the “consumer switching site” could get
access to the individual customers’ records at the DataHub. Since it is the intention that customers should be able to access their own data, such a solution should be possible. This consumer switching site could be organized through the existing price comparison site, www.elpristavlen.dk, but could also be a new service (or “app”) supplied by a private firm. For further on this idea, see my study Active Consumers and Economic Performance, released 21 June 2011, (Danish with English abstract: http://taenk.dk/sites/taenk.dk/files/aktive_forbrugere_og_oekonomisk_performance_15062011.pdf).

Harnessing Consumer Flexibility
TotalFlex is a research project sponsored by ForskEL - Energinet.dk’s programme for supporting research and development within eco-friendly electricity production technologies. The project will run from 2012-2015 and will build on results of a number of earlier research projects within among others smart grids and home automation. The project is carried out as a joint project between Neogrid Technologies, Aalborg University, Copenhagen Business School, Nyfors, NEAS, Conscius and Zense Technology.

The aim of TotalFlex is to establish a flexible electricity grid that includes the entire food chain from production to end user - and which can give everyone involved financial and environmental benefits. The vision is to develop a cost-effective, market-based system that utilizes total flexibility in energy demand and production, taking balance and grid constraints into account.

CBS takes the lead in a work package labeled “Design and development of a market place”, the purpose of which is to design, develop and test electronic market places to trade flex-offers, i.e. a pro-sumer’s offer to be flexible as to when to place load. The correct design of the market places will allow the flex-offer (and its derivatives) to be priced correctly and this is crucial for the correct use of the scarce resources. In other words, the market places will allow the market to determine the correct reward for shifting away from peak load or for acting flexibly.

Such a widespread use of flex-offers requires a series of new markets. Most importantly, there will be a need for numerous market places where the right to use distribution grid capacity is traded. To facilitate an optimal usage of the radial network in an uncertain world, it will be necessary to have tariffs set in real time at thousands of radial grids. The pricing and market clearing will have to be automated and the markets must be linked since the balancing agents, commercial traders and the network operators may need to involve several local grids. Other types of new market will have to be established as well, e.g. markets for flex offers where individual households as well as aggregators and grid owners can interact. One of the tasks in the project is to determine which markets are necessary to match supply and demand for both energy and grid services.

The design, development and testing of such markets raises a series of interrelated issues.

One is to define the goods to be traded and how flex-offers can be bundled to create goods that are best suited for market exchange. Another issue is to analyses how such commodities should ideally be priced. A third set of issues is to investigate how such pricing and allocations can be approximated in actual markets. The final set of issues will be to test and demonstrate some actual market designs.

One barrier to the development of markets for flex-offers could be transactions costs relating to individual households’ trading in the market. Based on the past experience of mobilizing customers in the retail
markets for electricity, it is obvious that one cannot expect customers to be constantly alert. For this reason, home automation will be necessary in order to control the loads and to create the flex offers. It is also for this reason that we expect an electronic market to be the right solution. Only few human players would want to play this market in real time.

This conclusion is supported by a study of the price sensitivity of electricity demand in households (EA Energianalyse et al., 2009, “Prisfølsomt elforbrug i husholdninger”). In an experiment among 593 households that all used electric heating for which reason their load was significantly higher than that of the average Danish household, 355 households were randomly selected to become a control group while the treatment group of 238 households were subdivided into three different treatments. 46 households were endowed with DEVI automation that would allow the household to react to price changes according to their preferences; 172 households would get an e-mail or a text message with prices for the next 24 hours indicating whether these were relatively high or low; and 20 households were endowed with an Electronic Housekeeper that would give an overview of the electricity price when the customer asked for it. Significant effects were found only for the DEVI automation treatment group that would lower their load at high prices and increase it at low prices. This data set is currently thoroughly investigated using micro econometrics in a working paper by PhD student Luis Boscán on “An Empirical Assessment of demand response by retail consumers of electricity in Denmark” (2013, working title).

**Future Electricity Markets**

The ‘5s’ project on Future Electricity Markets is supported by the Danish Council for Strategic Research and is a common undertaking between CBS, the Department of Mathematical Sciences at the University of Copenhagen, and DTU Informatics, DTU Management Engineering and DTU Electro. The project aims to identify changes to electricity markets made necessary by the integration of substantial amounts of renewable energy into the power system. The project period is 2013-2017.

CBS is especially responsible for a work package on how to enable demand-side management in power markets, i.e. the focus is on releasing the potential for demand flexibility. This requires that the transaction costs of different solutions be investigated to determine the optimal incentive structure and market designs for flexibility across markets.

Presently only very large customers participate in balancing markets and harvest benefits from acting flexibly. If households and SMEs are to provide flexibility, it should not only be automatized as described above: it will also be necessary to aggregate the flexibility before it is traded in one of the markets.

The various power markets are linked. Future power markets may include capacity markets, futures markets, forward markets, spot markets, balancing markets, retail markets and possibly derivatives markets for demand flexibility. In addition, one could envision markets for grid congestion at various levels of the grid and thus node or area specific tariffs. This would allow for price signals to reflect the scarcity of flexibility and of “band width” of the grid and thus provide incentives to shift load and to invest in generation flexibility or grid enforcements. The work package analyses various market structures and determines their relative performance in terms of price structures, reliability of supply and incentives to invest in capacity, in grids and in automation/ICT.
All these changes to the power system and electricity markets require regulatory changes. It is important that regulation does not become a straitjacket that prevents the markets from developing and the behaviour from changing.
Why There Is No Market for the Smart Grid Today
By Kim Østrup, adjunct professor, CBS

Denmark as a Test Bed
Denmark has been a test bed for the Smart Grid. "Edison" tested smart charging of electrical cars, and "EcoGrid" currently examines the management of electrical devices e.g. heat pumps in homes and factories against the 5 minute NordPool market. “I- power” addresses virtual power plants. The Danish electricity provider DONG has successfully completed a so-called e-flex project. These demonstration projects have achieved success and stakeholders have frequently inquired about future demonstration projects. However, the answer does not lie in committing to another pilot project, but instead focusing on actual market-based projects and a market for the Smart Grid. For, without a market and the involvement of real-life users, there would be neither investments nor marketable innovations.

As illustrated by Figure 1 below, in earlier times, due to coal-fired power stations, it was a relatively easy undertaking to manage production based on knowledge about day-time temperatures, as electricity was generated and produced for a smaller area. Today, bio-fuel, windmills, wave energy, and solar power are but a few of the means of generating electricity available to mankind. The old mainframe could be managed efficiently and without difficulty, but when decentralization occurred, management issues were bound to arise. Wind power and solar energy stations are managed on the basis of weather forecasts that can be broken down to hours. To build an IT-system for managing production is a considerably challenging task (this would require a virtual power plant). What information is required to do this, and how can such information be effortlessly and smoothly integrated with the old system? Hence, the supply-side appears fairly complicated as it has peaks from wind and solar.

When we look at the issue of demand, the question arises: How is it possible to manage without using the energy, when there is actually an insufficient supply of energy? How should people deal with peaks? If peaks can be cut off, it would result in enormous savings of coal, and this would be termed as demand-response. An example can be cited from the local government, where there is a pump that cleans water and supplies fresh water to homes. If that pump stopped functioning for 15 minutes, nobody would really pay attention.

Demand-response refers to the use of communication and switching devices which can release deferrable loads quickly, or absorb additional energy to correct supply/demand imbalances. Can a consumer be encouraged to stop utilizing the heat pump or the refrigerator for even half an hour? Peaks exist both on the demand-side as well as the supply side, and it is in the best interests of the consumers to be able to deal effectively and efficiently with these peaks and to balance electricity. When electricity is produced, it has to be consumed at the same time. Is it therefore practicable and feasible to construct an IT-system, which would be capable of managing both the demand and supply sides at the same time? My concept and vision to achieve this is to manage the system by means of pricing the demand-response generation. If the energy price is high, reduce the consumption, and if the energy price is low, prosumers should use all their devices.
The NordPool

NordPool Spot runs the leading power market in Europe, the NordPool market, representing big users and big producers, but consumers are not included.

The Nordic countries are connected in a grid and a market for electricity has been established. However, this paper does not address the implications of the grid design and future methods of transporting electricity over long distances, since these are, at this juncture, immature technologies.

The Nordic market for electricity - NordPool (http://www.nordpoolspot.com) - utilizes futures and spot markets and is very volatile. The spot market prices can vary from more than 10 DKK per kWatt/hour to less than -5 DKK. The target group for this consists mainly of major players in the energy market as well as TSO PSO and the industry directly. Therefore, symmetrical and balanced information on both demand and supply is essential, which, albeit, cannot be expected for consumers. A fact additionally worth mentioning is that consumer prices are regulated by the Danish Energy Regulation Authority.

**A Pricing Model for Private Households**

When we consider the matter of private households, it would appear as if the basic idea of a demand response system proves to be more applicable and feasible, as indicated by the fact that consumer under certain conditions would be able to shift demand from peak to off peak hours. Scaling this notion to a larger consumer base would consequently imply larger savings in power plant capacities which were originally designed to satisfy peak hour demand. In order to satisfy electricity consumption during peak hours, utilities primarily use fossil fuel. Hence, a significant reduction of the peak levels of electricity would, in turn, drastically reduce the CO₂ footprint and capacity cost. A simple peak load pricing model would be the
ideal strategy to successfully accomplish this reduction in peak loads, but with prices being fixed over a period of time the system apparently lacks the necessary economic incentives to innovate for new solutions and to reduce peak demand.

The above mentioned demonstration projects have proven it is technically feasible to automatically control electrical devices such as washing machines, heath pumps, electrical heaters, water heaters or electric cars through the use of software. A user-friendly means of arriving at this goal would be to handle the device according to convenience factors specifying comfort intervals for temperature, light and time to power on audiovisual equipment. Another pertinent example would be local government street lights as well as pumps for fresh water and for cleaning water, which could automatically be turned down to a predefined operational level.

Applying the factor dependent device control to the demand response system leads to the cognition and understanding that the control of electrical devices could certainly be based upon price signals. However, the control would have to be constructed in such a way, as to ensure that every electrical device would not start or stop simultaneously, which would result in a collapse.

On the supply side, an increased proportion of electricity production based on wind and solar energy poses the issue of uncontrolled peaks in production. As storage of energy is expensive electricity should in effect be consumed when it is produced. Ideally, the incentive system should create a demand, which matches the fluctuations in production. Without the adaptation of demand to the fluctuations in production, the grid would automatically require large investments in technical capacity to handle new peaks. To cite an example, weather forecasts have become very precise and it is possible to predict wind and solar production on an hourly basis depending on the lead time. This in turn would signify that it would be practicable to forecast expected production from wind and solar plants which could subsequently be used as a basis for predicting market prices and optimizing the controllable production.

A factor which complicates the issue is the government guarantee for a fixed transfer price from wind energy, which in the case of sea wind turbine parks, is a multiple of the market price.

Besides the prices discussion, the changing behavior of consumers, who also wish to produce and become so-called prosumers, has to be emphasized. Buildings, for private use as well as for other purposes, are equipped with technology for producing and storing energy. The notion of zero energy houses has now been introduced. Micro wind turbines, solar cells and water based solar connectors can be assembled and built into the building constructions. This would indeed add to the construction costs of new buildings, thus implying that Smart Grid incentives should consider financing the constructions of zero-energy buildings.

The pricing models for the consumer should ideally consider the unwanted effects of both the demand and supply peaks and aim to optimally utilize the off peak situation. The market should also be able to drive the transformation to Smart Grid and effectively and efficiently use pricing signals to manage the demand response. But the actual reality is that there is no real price differentiation and the flat levies make the Smart Grid irrelevant for consumers.

5 For instance the company Grundfos is working on a system called GateSense, which is expected to serve as a platform for Internet of Things in Denmark. Among other things, it would be be able to control heat pumps.
For example, let us consider this price structure:

![Price Structure Diagram]

Basically the raw price for electricity is 40 øre, whereas the typical price a Dane pays at home is 2.20 DKK. This 2.20 DKK is divided into 1 DKK which is a flat tax, and the rest is distribution, other flat levies and VAT. This would imply that procuring electricity at half price, or for a mere 0.20 DKK during night-times, would hardly work as an incentive to make consumers modify and change their behavior, let alone to invest in new devices and solutions for demand response. There is no apparent business model for the entrepreneur and no benefit to the consumer. The system in fact directly hinders any progress by rendering the Smart Grid irrelevant, destroying the competition and irrevocably reversing the push toward green energy.

The simplest solution recommended, would be to have the tax and distribution charges as a percentage of the electricity price. The tax could be designed in a way so as to be revenue neutral. The distribution charge could also be viewed as sensitive to peaks, by levying a higher charge in peak hours, rather than in off peak hours. (Distribution charges could also be analyzed further as wind and solar energy could theoretically generate a lower price in peak hours). If consumer prices could vary from say 0.50 DKK to 5 DKK, consumers would perhaps invest in demand respond.

Alternative incentive structures could be based on technology neutrality and address taxing the input factors such as coal, gas, wood according to their respective CO2 emission rates.

The conclusion arrived at is that the real issues is to design a predictable and stable pricing model, which would offer an incentive to consumers to appropriately modify and change their behavior and invest in technology. The pricing model should also work as an incentive to develop technology and systems over and above the Smart Grid as well as introduce real competition, as witnessed from the success of electric cars, which are based on the technical option of intelligent charging against the pricing model. In the current model, competition does not drive the Smart Grid market and thus, accounts for the fact that Denmark probably levies the highest tax on green energy in the world.

A market approach to introduction of Smart Grid would be to stimulate competition.
The first step would be to introduce taxes and distribution charge as a percentage as of the electricity price for consumers.

In the telecommunication industry, competition is driven by new service. There are also rules for establishing a reselling business. This type of market is developing for energy in some countries, e.g. in the USA, and would be able to drive smart grid applications. Thus, the second step would be to provide resellers with equal access to information e.g. the market prices, production information and status information on the grid.

Further progressive innovation of the Smart Grid would necessitate a third step, namely, the introduction of open standards for hardware, software and information, similar to the internet. This was the fundamental constituent and core essence of the internet innovation explosion, which was based on open standards. Thus, in laymen’s terminology, a washing machine should be able to talk to the wind mill.

How does innovation occur?
A pertinent question at this stage would be, do people actually respond to incentives? When solar cells came into the market, private producers were able to sell electricity back at the same price at which they had purchased it, rendering this a valid and fair transaction. As the number of solar cell installations has risen practically ten times within a year, new jobs have been created. Consumers have become increasingly aware about the environment and their electricity usage and consumption and responded positively to the incentive of using soft-powered electricity, for example solar energy for the swimming pool and for heating.

Today, consumers perceive no incentive to change suppliers even when the price is cut dramatically. But with the tax as a percentage, it would be an interesting and worthwhile proposition, to look at prices and thereby, promote the Smart Grid through service competition. As mentioned earlier, this would be similar to the telecommunications sector, where intense competition in services in the 90’ies was responsible for
the rapid progress and accelerated development of that sector. There is no reseller market for the electricity sector in Denmark. This scenario is in contrast to the USA, where if a consumer turns off the cooling system for an hour a week, he would be able to procure electricity at a 20% cheaper rate from a reseller.


The question remains to be answered, whether it is feasible to manage peaks and thus, reduce the CO₂ footprint while at the same time, stimulating innovation as well as acquiring comparable revenue from taxes? The answer lies in combining technical research with Information Technology and economics. This is indeed an area for Copenhagen Business School to explore, while considering the challenge that today, the taxes for wind energy are equivalent to taxes for coal energy, and this is a potentially damaging scenario.

The conclusion reached is that taxes should be proportional, i.e. taxes and distribution charges should be a percentage of the electricity price for consumers. The Ministry of Tax does not support such a solution, as it would imply uncertainty about the revenue, but in reality the Ministry’s position is blocking the introduction of the Smart Grid.

The key question is whether the high energy tax in Denmark should be viewed as a way to generate tax revenue or a way to change the behavior of the energy consumers. It would hardly be consistent to pursue both aims at the same time.

Enumerated below are two project ideas that – if realized – would definitely succeed in promoting a positive development:
## INCENTIVE MODELS: Designing pricing models for consumers that optimize investments in electricity production, reduce CO2 footprint and create innovation

### Issues
- To what extent does competition work, and can competition drive the changes?
- What sort of government regulation is necessary to implement change?
- As high tax on green energy is counter-productive, how can this problem be managed?
- There are no apparent incentives for Smart Grid implementation and demand-response
- What kind of pricing models would be acceptable to consumers?
- Does the profit incentive factor of utilities services create a conflict with society's desire for CO2 reduction?
- Is there technology neutrality in taxes and subsidies?
- How should the IT-system be designed?

### Topics

#### The Danish Utility structure
- Concentration and local supplier
- Competition
- Consolidation

#### The NordPool Market
- Function, competition, basis for pricing

### The vertical markets
- The transmission and distribution market
- Market structure
- Players
- Pricing structure
- Import / export
- The Danish wholesale market
- Is there a reseller market?
- The Danish retail market
- The Danish business market
- The Danish consumer market

### Tax and subsidy structure
- Price regulation

### Production structure
- Structure
- Players
- Technologies
- CO2 footprint
- Price structure and subsidies, e.g. price guarantees for wind mills.
- Tax based on CO2 footprint

#### Policy recommendation:
- Models for end user pricing and design of tax / subsidies

## INCUBATOR FOR SMALL GRID AND RELATED PRODUCTS
Creating an environment for business ideas and technical innovation based on Smart Grid for students and entrepreneurs.
Helping create start up

### Concept
- To combine the technical skills from Power Lab DTU with the business skills of ITM.
- Bring CBS and DTU students together e.g. in common projects
- Give technical and business support to entrepreneurs
- Teaching an advanced course in smart grid and related systems and services for Technical and Business students

### Structure
- The activities could be located at Power Lab
- Researchers should be allocated from DTU and CBS

### Projects
- Establish a one semester course
- Thesis for DTU and CBS students
- Identifying common research project e.g.
  - Pricing models for demand-response
  - Optimal control of electrical devices based on price signals
  - Decentralized balance of demand and production of electricity

### Partners
- DTU/ Power lab and CBS/ ITM
Det eksisterende distributionssystem i U.S. er på mange områder meget gammelt, og kommende investeringsforslag til modernisering bør derfor fokusere langsigtet samtidig med man opretholder et pålideligt system. En omstrukturering af infrastrukturen vil kunne sikre et smartere Grid, der kan fremme engros- og detal konkurrencen for levering af strøm samt fremskynde udskiftningen af en aldrende transmission- og distributionsinfrastruktur. Undersøgelser vedr. vedvarende energi viser, at et Smart Grid kan blive nødvendigt, hvis sol, vind, geotermisk og andre vedvarende energiteknologier skal give et betydeligt bidrag til det nationale el-behv. Der er behov for Smart Grid investeringer til forbedring af fjernovervågning og automatisk styring eller fjernstyring af faciliteter på højspændingstransmissionsnet og distributionsnet, ligesom der skal installeres Smart Meters og tilhørende kommunikationsmuligheder på kundernes præmisser, så kunderne kan modtage real-time prisoplysninger og / eller drage forde af mulighederne for at indgå kontrakt med deres leverandør om at fjernstyre forbrugerens apparater i forhold til engrospriser og netværksbelastning. Flere og flere stater i USA er begyndt at iværksætte projekter indenfor Smart Grid, nogle mere end andre, og omkostningerne er typisk finansieret gennem regularerede priser for fysisk distribution. Omkring 140 projekter er blevet finansieret med omkring $5,5 milliarder (tal fra 2009).

Elmarkedets karakteristika
Elforbruget varierer meget afhængig af tidspunktet på dagen og tiden på året, størst er forbruget i de varmeste og koldeste perioder i dagtimerne. Da elektricitet med den nuværende teknologi ikke kan lagres i elmarkedet og være tilgængeligt for at afbalancere udbud og efterspørgsel i spidsbelastningsperioder, opstår der høje marginale omkostninger i produktionen. Elektricitet er den ultimative ”just-in-time” fremstillingsproces, hvor udbud skal være produceret til at imødekomme efterspørgslen på et aktuelt tidspunkt. I takt med, at efterspørgslen stiger, afsender kraftværkerne først ”base load” derefter ”intermediate” og til sidst ”peaking” kapacitet – med højere og højere marginal operating omkostninger. I dag varierer størstedelen af forbrugerens priser ikke dynamisk efter den tid, de forbruger, og dermed afspejler priserne ikke den marginale omkostning i el-produktionen. Dette skyldes, at eksisterende målere kun optager aggregeret forbrug fx ved måned- eller kvartalsafslæsning. I nogle stater er der dog mulighed for at vælge time-of-use meters, som opkræver forskellige takster baseret på forud fastsatte priser i forudbestemte peaks og off-peaks – der bygger på historiske data.

Forbedring af højspændingstransmissionsnettet
Højspændings transmissionsnettet er centralt for driften af et moderne system; de gør det muligt at imødekomme lokalt spredt efterspørgsel med lokalt spredt produktion på en effektiv og pålidelig måde. I USA er der konstateret betydelig overbelastning på bestemte tidspunkter af året, af tre primære grunde: (1) Transaktionsomkostningerne ved at flytte strøm, fx nord til syd, er høje og kræver transaktioner med flere regionale transmissionselskaber, uafhængige systemoperatører og andre balance-ansvarlige med forskellige forretningsmodeller, forskellige afregningsregler og priser for transmissionstjenester.
(2) systemoperatører lægger vægt på pålidelighed, hvilket gør at de opretholder en margin for at være forberedt på uventede begivenheder og

(3) de fleste operatører har utilstrækkelig overvågning, kommunikation og kontroludstyr på deres højspændings netværk, de kan ikke ”se” hvilken tilstand de tilgrænsende net er i. Rapport fra EPRI (Electric Power Research Institute) vurderer, at amerikanske kraftsystemer opnår 99,9 % pålidelighed i højspændingstransmissionsnet, og at over 90 % af de udfald der opleves af privatpersoner skyldes fejl på distributionssystemet, og ikke transmissionsystemet. Men hvis uheldet er ude, kan et brud påvirke 50 millioner forbrugere og vare op til et par dage, så omkostningerne bliver derfor høje.

Smart Grid investeringer i højspændingstransmissionen vil sandsynligt give endnu højere afkast i takt med, at højspændingstilsluttede vind- og solenergi vokser. Højspændingsnet baseret på vind og solenergi installationer leverer elektricitet sporadisk, hvilket betyder de er drevet af vejret snarere end af udbud og efterspørgsel og engrospriserne. Et typisk problem her er, at produktionen ikke kan kontrolleres eller afsættes ud fra økonomiske kriterier ligesom traditionelle el-produktionsteknologier. At skabe konstant balance mellem udbud og efterspørgsel kræver, at operatørene har mulighed for at reagere meget hurtigt på hurtige ændringer i energistrømmen på forskellige steder i netværket. Rapporten fra EPRI anslår, at investeringsomkostningerne ligger på omkring $ 56-64 milliarder, samt disse investeringerne i en bedre overvågning af højspændingstransmissionsnet repræsenterer den mest omkostningseffektive kategori af Smart Grid investeringer.

Automatisering af lokale distributionsnet

Smart Grid teknologier, der anvendes på de lokale distributionssystemer, omfatter øget fjernovervågning og dataopkøb af feeder loads, spænding og forstyrrelser, automatiske afbrydere, forbedret kommunikation med ”intelligente” distributions understationer, transformere, og beskyttelsesudstyr og støtte til kommunikationsinfrastruktur og databehandlingssystemer. Smart Grid investeringer i lokale distributionsnet giver mulighed for at reducere drifts- og vedligeholdelsesudgifter, for at forbedre pålideligheden og reaktioner på udfald, forbedre strøm kvalitet, at integrere distribuerede vedvarende energikilder, især solcelleanlæg installeret hos kunder, der producerer strøm intermitterende samt at implementere Smart Meters, der kan måle kundernes realtid forbrug og gøre mulighed for dynamisk prissætning, der afspørger engrospriserne.


I 2030 skønner National Research Council at omkring 4,5 % af den nationale bilpark vil være elektriske plug-ins. Dette har stor betydning for distributionsnettet, da kortere opladningstider ved højere spændinger kan give betydelige belastninger, selv med en beskeden udbredelse af elbilerne. Her opstår en mulighed for at ændre prissætningen, da disse elbiler med fordel vil kunne oplades om natten, vil der i disse perioder

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kunne opstå peaks, men da prissætningen fungere efter time-in-use, vil forbrugsprisen ikke afspejle de marginale produktionsomkostninger.

**Smart Meters og incitamenter for dynamisk prissætning**

Smart Meters kan måle real-time elforbrug. De kan også have to-vejs kommunikation, der muliggør real-time detailpriser bundet til variationer i engrosprisene og kan føre til fjernstyring af kundernes efterspørgsel ved at lade detailleverandøren eller kunden justere apparats udnyttelse i kundens hjem eller forretningslokation. For eksempel kan en kunde programmeres at reducere elforbruget i visse tidsperioder. Prispolicy vil nu afhænge af de marginale produktionsomkostninger.

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From Smart Grid to Smart Deployment
By Kim Behnke, Head of R&D at Energinet.dk

Smart Grid, Smart Energy even Smart Living are used as contemporary buzzwords in the effort to describe the many aspects of changing the way we generate and use electricity. Smart Grid or Smart Grids have a total of 213,000 hits on Google, but are they just visions and colorful power point presentations? Does the Smart Grid have a business model? Does it have a roadmap for real full-scale deployment?

Smart Grid – an integrated part of a renewable vision
Denmark is obligated by a strong climate and energy policy to undertake a historic shift of paradigm in the methods by which it generates electricity and heat in the coming years. Going from 30% wind power already accomplished in 2012 and a total of 42% RE (renewable energy), it could be argued that Denmark has taken substantial steps down the road towards sustainability. But the Danish Parliament has taken a decision on a very ambitious scheme, namely, that by 2020, in barely 7 more years, the annual electricity consumption would consist of 50% wind power and 70% RE. This leads to the first obstacle, because electricity is not balanced on an annual basis, but 50 times per second! 50% wind power a year would imply that there would be up to 200-300% coverage of electricity consumption in 700–1,000 hours, – and 0% generation during several days in a year. 2020 is not end of story. Even more ambitiously, the Danish parliament aspires that by 2035, the entire generation of electricity and heat in Denmark would be based on 100% RE.

At this juncture, an abridged historical flashback would shed further light on this decision: by the end of the second oil crisis in 1979, Denmark had reached a clever resolution. The cooling water from power plants was distributed through pipelines as district heat. Today 60% of Danish households are heated by district heat, not merely from the major power plants, but also from approximately 750 local CHP units (combined heat and power).

Phasing out the coal-fired power plants ahead of time would signify that by 2030, the electricity system would work on wind power and a few biomass-fuelled thermal power plants. This in turn would denote that numerous district heat costumers would also require new RE-based energy.

The answer to the Danish challenge would be to move forward, at full speed, with new interconnectors to neighboring countries, deploying all the novel aspects of the Smart Grid, such as intelligence in the power system. In several power systems in other countries, there is a compelling platform for Smart Grid evolution, due to grid congestion, lack of generation capacity or old grids falling behind with existing maintenance plans. However, in Denmark, the Smart Grid vision exists as an integrated part of the revolutionary renewable energy plan.

The report of 2010
The Smart Grid with an aggregation of RES (renewable energy sources) and other DER (distributed energy resources) for optimal grid services, is every grid operator’s dream of a sustainable, flexible power system. But is it also a feasible solution from an economical or rather socio-economical perspective?
In 2010, the Danish Energy Association and Energinet.dk determined that they would present a full-size comprehensively developed business case for Smart Grid deployment in Denmark by 2025. The result of this decision proved to be promising. By 2025, the Smart Grid approach is expected to generate a positive socioeconomic revenue of more than DKK 6 billion [1] (EUR 0.8 billion).

The primary contribution of this positive business case was to avoid investments in “Dumb” Grid and start investing in the Smart Grid.

An imaginary example of the difference between the Dumb Grid and Smart Grid is illustrated by a suburban area with 48 villas and a 0.4 kV cable supply of electricity. When the inhabitants of the villas purchased electric vehicles (EVs), the grid was only equipped to charge three EVs simultaneously as the residents prepared dinner. EV number four would cause the fuse to blow! Investments were made in the Dumb Grid to enlarge the transformer and install an extra cable. Investments in the Smart Grid would be ‘the little grey box’ with communication and access to aggregator and price signals. The Smart Grid solution would allow 65 EVs to get charged from 4 pm to 7.00 am or for a period of 15 hours, without any discomfort or aggravation for the inhabitants.

The true challenge is that much of the investments required for a Smart Grid platform would come from the regulated business of the DSOs (distribution system operators) and a major portion of the cash back benefits from Smart Grid activities would be achieved by the service providers, the electricity vendors and the consumers.

To cite an example, the DSOs would be required to ensure investments in Smart Meters, which are a prerequisite for the Smart Grid. The electricity vendor and aggregator require the measurements from hourly readings, in order to provide a more beneficial settlement to the consumers, when they postpone consumption to a relatively less expensive hour. This asymmetric value chain calls for an innovative approach and several updates to the regulation and tax systems. The eventual employment of the Smart Grid is therefore not merely a question of technical and market approaches, but also of a change of policies.

The Minister of Climate, Energy and Building Martin Lidegaard, arrived at a decision to form a Smart Grid Network of experts by the end of 2010. These experts were directed to examine and enumerate all the barriers to a full-scale Smart Grid deployment in Denmark before 2025. The result was 35 recommendations showing a possible and feasible roadmap to the Smart Grid [2]. The first report on the Smart Grid in Denmark report has subsequently served as foundation for a Smart Grid family tree. All the reports are available at www.energinet.dk. This paper attempts to take a closer look at two of the reports.
The power market and Smart Grid

Denmark is a part of the Nordic Power market with the NordPool Power exchange in Oslo. Most of the daily electricity generation and consumption is sold day-ahead at NordPool Spot, and is termed Elspot [3]. In addition, there is an intraday market called Elbas, which is also hosted by NordPool Spot. Imbalances in the power system are traded in the regulation power market or balancing market on a common Nordic platform, NOIS. All imbalances are remunerated by the balance responsible commercial parties.

In the present Nordic market, the TSO (transmission system operator) is responsible for the physical balance in the power system during the hours of operation. The TSO is a single buyer of the services and facilitates the power market by making it physically possible to transport power from sellers to buyers. The TSO is responsible for keeping the power system in balance, as well as for the overall physical management and control of the national power system, and ensuring that the frequency is maintained at 50 Hz. The TSO also provides ‘ancillary services’ facilities over and above the maintenance and balance of energy flow and power. Non-visible technical services like frequency, inertia, reactive power, voltage control and short circuit power are mandatory for operating an Alternating Current (AC) power system.

The Nordic market ensures most of the services today. The price is relative smaller and volumes relatively larger in the day-ahead market, Elspot. In balancing the power market, the quantity needed is much smaller, but the price is substantial larger.
The market was originally designed for power plants. But it has been established that the load or consumption is equally relevant for balancing the power system. Hence, the Smart Grid truly possesses the potentials for proving beneficial to consumers, since it is relatively easy to operate and often has no additional marginal costs. More generation from a power plant or less consumption, induce an equal contribution towards balancing the power system, but a power plant generally, has higher marginal costs for generating the next kWh.

*Smart Grid technologies allowing for remote control or demand response according to price signals should not only look at the day-ahead prices, but benefit from the fact that an aggregated DER has a much higher market value if it is active in the Balancing Market.*

Numerous demonstration projects concluded that the annual benefit of optimal electricity consumption based upon the day-ahead market prices would provide a typical Danish household (4,000 kWh/year) with a benefit of approximately EUR 100 per year. But if the same family decided to invest in a heat pump for domestic amenity, the benefit would be an additional EUR 200 per year. Additionally, if the family were to utilize further intelligent Smart Grid options, and purchase an electric vehicle (EV), this would offer them considerably higher monetary savings.

The aim of the EcoGrid EU project [4] on the island of Bornholm is to improve the balancing mechanisms, through the introduction of a five minutes real-time price response, with the goal of providing additional regulation power from smaller customers, with both reducible demand and excessive load in periods. Approximately 2,000 homes have been equipped with a Landis &Gyr (L&G) Smart Meter, with a five-minute resolution and necessary residential gateway for fast demand response. The objective is to demonstrate the value of integrating demand response as an important part of the balancing of the power system within the hour of operation. This is expected to help the TSO to balance fluctuating DER, thus allowing for better utilization of renewable energy (RE) from wind power, avoiding local grid congestion to the benefit of the DSO and sharing the economic benefits, by offering the consumers an annual bonus for flexible behavior.
The vision for a 5 min broadcasted price signal in the EcoGrid EU project

Then question then arises that, what is the ‘right price’ for avoiding local grid congestions, achieving better voltage control and assuring the flexibility of DER market participation?

The Dan Grid model completes the circle

The Smart Grid Network prepared a list of thirty-five recommendations for the Danish Energy Association and Energinet.dk, in order to aid them to elucidate the following cornerstones of the Smart Grid: Describe a national concept for the Smart Grid; decide on an information model for the necessary Information and Communications Technology (ICT) using open international standards; chart a roadmap for Smart Grid deployment, with shared roles for DSOs the TSO and other key stakeholders.

The recommendations resulted in the publication of the DanGrid report or ‘Smart Grid in Denmark 2.0’ in October 2012 [5]. The unique attribute of this report lay in its suggestion for the introduction of a local market for flexibility.

The local market for flexibility would be fully deployed in phases. Phase 1 would consist of bilateral agreements between the DSO and the local DER, with a negotiated price for flexibility. Phase 2 would comprise publication and transparency of the local prices for flexible DER using tenders. Phase 3 would be a ‘real’ market platform, where all bids from the aggregator would be visible, and DSO operators would
have the option to choose the most beneficial offer for services required to avoid congestion or the necessity for voltage control.

The principal significance of this report would be the communication that the balance responsible parties and the aggregators must ensure complete coordination with the existing market for services in the different market platforms. This would in turn, allow for further utilization of the DER, when the TSO would get access to these additional means of balancing the power system.

*The important and primary message would thus be that the Smart Grid business case is only attractive to all stakeholders in the value chain, if everyone is able to “get a slice of the action”. The Smart Grid allows for all the DER to be aggregated; offers local flexibility services for the DSO; further utilization of resources through a responsible balance for bids in the existing market and balancing benefits for the TSO. Smart Grid consumers should be active in all the power market platforms for optimal revenue for all the parties involved in the process.*

**Smart Grid Strategy – the Parliamentary Frame**

As illustrated by the Smart Grid family tree from Denmark, numerous aspects of the evolution of the Smart Grid evolution have been examined, described and allocated to relevant stakeholders. The final endorsement for the Smart Grid was advanced by the Minister of Climate, Energy and Building in March 2013, with the publication of a National Smart Grid strategy [6].

![Smart Grid Strategy Diagram](image)

*Master plan from the Danish smart grid strategy*

The commitment from the Danish Parliament was of vital importance and had great significance, as demonstrated by the government’s inclination and willingness to remove barriers on the road to Smart Grid deployment. The Smart Grid strategy aims to bring Danish consumers a substantial step closer towards managing their own energy consumption. The strategy combines digital smart meters with hourly resolution and remote reading (already deployed by 55% of consumers), with variable tariffs instead of a flat rate. This would enable consumers to use power when it is least expensive. Furthermore, the tax on electricity used for heat pumps or EV has been reduced. By 2014, a wholesale model is expected along with an hourly settlement. Moreover, in March 2013, a national Data Hub was established, offering consumers additional access to personal data and an effortless replacement of electricity vendors.
Denmark has ably demonstrated that it has all the necessary tools for Smart Grid deployment in the coming years. Encouraging consumers to use energy more efficiently is a key aspect of the Strategy. All DSOs as well as other key stakeholders are obligated by the roadmap charted out by the DanGrid model. However, there are a few hurdles to be crossed before final successful implementation:

- Firstly, there is a critical and urgent necessity for new service providers to begin offering consumers new shared services, by utilizing the different platforms of the power market.
- Secondly, there is a requirement to ensure an open dialogue with consumers, in order to guarantee their participation in the new and innovative solutions recommended by the Strategy. Are the consumers willing to be flexible on a cold winter day or do they prefer to be in control and charge of the entire situation themselves? On the other hand, do they favour control of the operation and performance being exercised by the aggregator?

The revolution witnessed in the telecommunication sector, and the eager acceptance of new services provided to the consumers, proves that there is reason for optimism in the energy sector too. The introduction of smart phones is a show case of how to proceed from Smart Grid to Smart Deployment – it is a well-documented fact that all people today desire ‘Smart Living’, and it is in our hands, to turn this vision into a reality.

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