Case study report Denmark

Findings from case studies of ProjectZero, Renewable Energy Island Samsø and Innovation Fur

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Publication date:
2017

Citation for published version (APA):
Christensen, T. H., & Friis, F. (2017). *Case study report Denmark: Findings from case studies of ProjectZero, Renewable Energy Island Samsø and Innovation Fur*. SBi Forlag.

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Findings from case studies of ProjectZero, Renewable Energy Island Samsø and Innovation Fur (GreenCom)

Version 1.0

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23 November 2017

ERA-Net Smart Grids Plus | From local trials towards a European Knowledge Community

This project has received funding in the framework of the joint programming initiative ERA-Net Smart Grids Plus, with support from the European Union's Horizon 2020 research and innovation programme.

INTERNAL REFERENCE

- **Deliverable No.:** D2.2
- **Deliverable Name:** Case study report Denmark
- **Lead Partner:** Aalborg University (AAU)
- **Work Package No.:** 2
- **Task No. & Name:**
- **Document (File):** D2.2_Danish Case Study Report_MATCH.docx
- **Issue (Save) Date:** 2017-11-237

DOCUMENT SENSITIVITY

☐	Not Sensitive	Contains only factual or background information; contains no new or additional analysis, recommendations or policy-relevant statements

DOCUMENT STATUS

	Date	Person(s)	Organisation
Author(s)	2017-11-16	Toke Haunstrup Christensen & Freja Friis	AAU
Verification by			
Approval by			

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About ERA-Net Smart Grids Plus

ERA-Net Smart Grids Plus is an initiative of 21 European countries and regions. The vision for Smart Grids in Europe is to create an electric power system that integrates renewable energies and enables flexible consumer and production technologies. This can help to shape an electricity grid with a high security of supply, coupled with low greenhouse gas emissions, at an affordable price. Our aim is to support the development of the technologies, market designs and customer adoptions that are necessary to reach this goal. The initiative is providing a hub for the collaboration of European member-states. It supports the coordination of funding partners, enabling joint funding of RDD projects. Beyond that ERA-Net SG+ builds up a knowledge community, involving key demo projects and experts from all over Europe, to organise the learning between projects and programs from the local level up to the European level.

www.eranet-smartgridsplus.eu

Preface

This report is the outcome of work package 2 *Detailed case studies* of the ERA-Net Smart Grids Plus project *Markets, Actors and Technologies: A comparative study of smart grid solutions* (MATCH), which involves partners from Austria, Norway and Denmark.

The aim of MATCH is to explore how to design and implement comprehensive smart grid solutions that take into account the complexity of factors influencing the effectiveness and success of smart grid initiatives targeted at small consumers. This is studied on basis of detailed national case studies carried out in each of the three participating countries. This report (MATCH deliverable D2.2) presents the main findings from the Danish case studies.

The national case studies establish the empirical foundation for the comparative analysis across cases and countries in work package 3 *Identifying determining factors for integrated and successful smart grid solutions* and for the later work package 5 *Recommendations for designers, planners and policy-makers*. The deliverables from these work packages will be published on the website of MATCH (http://www.match-project.eu/), which also includes further information about the project and its other publications. The latter includes coming scientific papers that are going to explore differences and similarities between cases in further detail in relation to specific research questions.

The empirical work in relation to the national case studies was guided by an analytical framework developed in the MATCH work package 1 *Design of overall analytical framework for case studies*. This deliverable (D1) can be downloaded from the MATCH website. The framework combined different theoretical perspectives in order to establish a shared understanding of how we should approach the cases and what kind of data to collect. This ensured a certain degree of empirical homogeneity between the national case studies.

In order to support the comparative analysis, the national case study reports (D2.1-D2.3) follow the same outline. Thus, in the following, we will first present the national context of the Danish case studies (Chapter 1). This includes a brief introduction to the national profile of Denmark in addition to a presentation of the Danish energy system, policies & regulation, market structure & energy consumption and, finally, the smart grid landscape. Then follows the main part of the report (Chapter 2), which presents the outcome of the Danish case studies. A brief description of the empirical work carried out introduces this chapter, and is followed by three sub-sections presenting the findings from the three national cases: Innovation Fur (GreenCom) on the island of Fur (section 2.1), ProjectZero in Sønderborg (section 2.2) and Renewable Energy Island Samsø (section 2.3). Each of these case presentations is organised in three sub-sections: Background and project characteristics; socio-technical configurations; Discussion of successes and outcomes.

Toke Haunstrup Christensen
Freja Friis

Copenhagen, 17th of November 2017

1 National context factors

1.1 Country profile of Denmark

The kingdom of Denmark (excluding Greenland and the Faroe Islands) has a total area of about 43,000 km². The main part measured by land area is the peninsula Jutland and the rest of the country consists of 406 islands, 78 of which are inhabited, with the largest being Zealand, the Northern part of Jutland and Funen. Denmark also exercises sovereignty over the Faroe Islands and Greenland, but both enjoy autonomous self-government. Compared to the small size of the country, Denmark has an extraordinary extensive coastline of more than 7,300 km, which corresponds to almost 1.5 metres of coast per inhabitant. Denmark's topography is relatively flat with few hills and the highest point being no more than 173 metres above sea level. The flat topography partly explains why Denmark has a long history of farming and the fact that two-thirds of the landscape is agriculture areas (Statistics Denmark, 2016a; IEA, 2011).

The position between a continent and an ocean means that the Danish weather often changes. The average temperature ranges from -1 °C in February to 17 °C in July. Further, because of Denmark's northern location, there are large seasonal variations in daylight with short days during the winter (7 hours of daylight) and long summer days (17 ½ hours).[1]

By January 2016, the population was 5.7 million people. The country has witnessed decreasing birth rates and a general ageing of the population, but due to immigration the Danish population has still increased slightly. Overall, Denmark has about 2.7 million households, which results in an average household size of 2.2 persons (Statistics Denmark, 2017). Reflecting the global trend of urbanization, the populations of the largest cities (including Copenhagen, Aarhus, Odense and Aalborg) are increasing, while the population size in the peripheral regions decreases. Hence, municipalities covering the peripheral areas are in particular struggling with a variety of strategies to retain and attract citizens to their region (Local Government Denmark, 2014).

Over half of the population (58%) live in owner-occupied dwellings with an average area per person that has increased continuously during the years, which is partly explained by more people living alone, partly by a general increase in the size of new-built owner-occupied dwellings. In particular, 70% of people aged 50-70 years live currently in owner-occupied dwellings, while there is a greater share of 20-33-year-olds and persons aged around 80 years living in rented dwellings (Statistics Denmark, 2016a).

Based on a liberal capitalist economy, the Danish welfare state regime follows the Scandinavian social democratic welfare model, with principles of universalism and social rights extended to both the working and the middle classes. With one of the world's highest personal income tax rates, this entails the pursuit of high equality and high-quality service provision for all (Esping-Andersen, 1990). For example, almost all citizens in Denmark receive social services at shorter or longer periods in their lives, e.g. children families are offered day-care institutions (with a limited user charge) and child benefits, and a major part of the elderly receive pensions, nursing care, nursing homes (with a limited user charge), help in their homes etc. (Statistics Denmark, 2016a)

Ageing of the population in combination with low birth rates and difficulty in keeping labour market participation high have resulted in the emergence of a policy discourse, which emphasises the future pressure on public budgets being a major challenge to the Danish welfare state. Accordingly, the policy response has recently been to limit access to early retirement and to implement cuts in social security and unemployment benefits (Larsen et al., 2017). Recently, the number of retired persons has passed 1 million (Statistics Denmark, 2016a).

[1] www.dmi.dk

Although the five regions are responsible for the provision of hospitals, the State and local government level (98 municipalities in total) take care of almost every other matter such as housing policy, urban and regional planning, environmental issues etc. Most of the social welfare (e.g. home help of elderly, unemployment benefit and programmes, schools etc.) is provided at the municipality level. The four largest municipalities are also covering the four largest Danish cities: Copenhagen (602,500 inhabitants by 2017), Aarhus (335,700 inhabitants), Aalborg (212,000 inhabitants) and Odense (200,600 inhabitants). The remaining 94 municipalities have an average size of 46,800 inhabitants; hereof, 79 have more than 23,000 inhabitants and only 15 less (the smallest five being islands like Samsø). (Statistics Denmark, 2017)

Since Denmark in 1972 joined the European Community (EU in 1993), the national policy within financial affairs, foreign policies, justice, social dimensions and energy and climate etc. has been influenced by the current EU-regulation on many areas.

The national growth in GDP in 2016 counted for 1.6%, and the average GDP per inhabitant is about 41,000 EUR[2]. The disposable income differs according to the municipality of residence as e.g. the metropolitan areas and large cities account for the greatest incomes. In 2014, the unemployment rate was 6.4% of the total workforce, which is among the lowest in Europe[3]. Based on a Eurostat survey, Denmark accounts for the highest consumer prices in the EU. Regarding this, in particular consumption and money spent on dwelling (including rent and heating) have increased, while expenses on food and beverages have decreased (Statistics Denmark, 2016a).

1.2 The Danish energy system

The Danish power transmission network is divided into two separate grids; the Western transmission grid (Jutland and Funen) is connected to the European continental grid, while the Eastern grid (Zealand and islands south of Zealand) is connected to the Nordic grid via connections to Sweden. Since 2010, the Eastern and Western areas have been connected via a 600 MW DC connection across the Great Belt (between Funen and Zealand). The East grid includes four AC interconnections with a total transmission capacity of 1,900 MW to Sweden and a 600 MW DC connection to Germany. The West AC transmission connection to Germany is determined by congestion in the surrounding grids and has a normal capacity of 1,500 MW in the southbound direction and 950 MW in the northbound direction. Further, West Denmark is connected with DC connections of 740 MW to Sweden and 1,040 MW to Norway. (Sorknæs et al., 2013)

Denmark is part of the Nordic power trading market Nord Pool, which is a platform for day-ahead and intraday trading. The day-ahead Nord Pool spot market operates in the Nordic countries, the Baltic countries and the UK.[4] Because the Danish grid is separated into two different areas, and as a result of bottlenecks in the electrical grid in the Nord Pool Spot area, the Danish electricity market is divided into two price areas; West Denmark and East Denmark.

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[2] www.geotema.dk

[3] https://data.oecd.org/unemp/unemployment-rate.htm

[4] http://www.nordpoolspot.com/TAS/Day-ahead-market-Elspot/

Figure 1: Overview of the Danish Electricity Transmission Network

Reproduced from: www.energinet.dk

According to the World Economic Forum, Denmark has one of the highest energy securities and reliable electricity systems in Europe.[5]

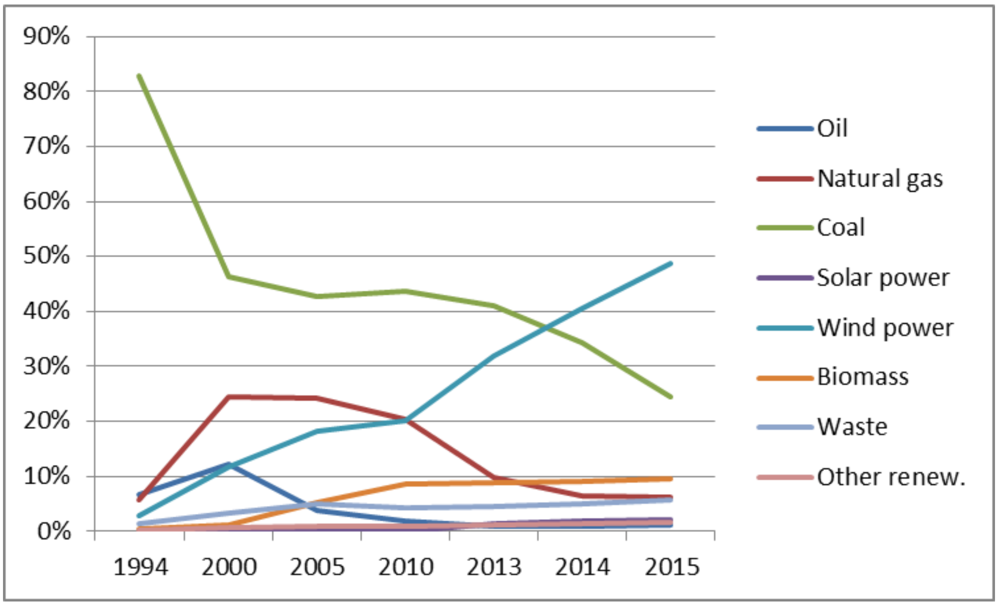
By 2015, renewable energy (wind power, biomass and solar power) represented about 62% of the Danish electricity production, while waste incineration and fossil fuels (coal and oil) represented 6% and 32%, respectively. Figure 2 shows how the distribution of the electricity production by energy sources has developed from 1994 to 2015. This shows how the Danish electricity system has changed from being primarily based on power production in centralised condensing power plants based on fossil fuels (partly as combined heat and power plants, CHPs) to a system with a much greater mix of different sources, with wind power being the main source. Following this transition, the electricity production is much less based on condensing power plants, and the integration of renewables have re-delegated many of the condensing power plants (centralised as well as

[5] http://reports.weforum.org/global-energy-architecture-performance-index-2014/global-rankings/#view/fn-10 Accessed: 04.11.2016.

decentralised) to primarily playing the role of power back up for the energy system (typically on windless days) and suppliers of heat for district heating.

The intermittency of especially wind power has become a major concern in Danish energy planning and policy-making. Today, this is partly handled through international trading (e.g. selling surplus electricity to Norway on windy days and buying hydro power-based electricity from Norway on windless days) and using condensing power plants a reserve capacity.

Figure 2: Distribution of electricy production by energy sources (1994-2015)



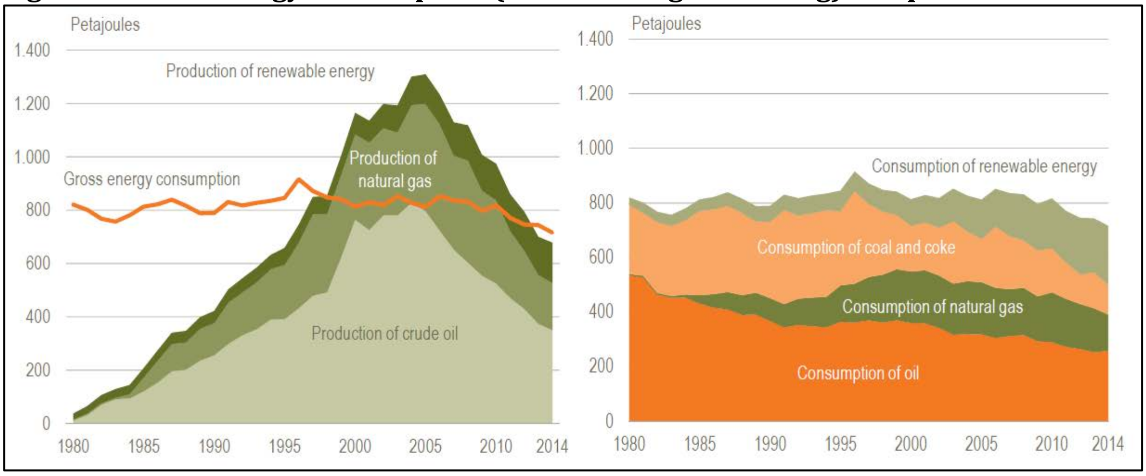
Source: Danish Energy Agency, 2017

Space heating is to a high degree based on district heating. Almost two-thirds (64%) of the Danish homes are heated by district heating, while 25% of the homes are heated by oil or natural gas burners (this is typically homes outside larger towns/cities), 5% have direct electric heating and 2% have heat pumps (Statistics Denmark, 2017). District heating is often based on biomass (wood and straw) as energy source, which represents 35% of the fuel consumption for district heating in 2015. Other major sources are natural gas (24%), coal (15%) and waste incineration (20%). Central CHP plants represents 40% of the total heat energy production, typically supplying the district heating in larger cities, while heating plants (only providing heating) represent 28% and decentralized CHP plants represent 12%. The latter typically provide energy for district heating in towns and smaller cities. In addition, about 20% of the heating supply is based on "surplus" heat from other production facilities (e.g. industries). (Statistics Denmark, 2017)

With regard to transport, the penetration of electric vehicles is very low in Denmark. During the period 2003-September 2016, the total number of new registered EVs was 8,286 passenger cars (Statistics Denmark, 2016b). In comparison, the total number of new passenger cars registered in 2016 alone was 222,475 (statistics Denmark, 2017)

Denmark's gross energy consumption is calculated as the consumption of oil, natural gas, coal and renewable energy, and is adjusted for import and export of electricity. Denmark has been self-sufficient in energy since 1998 thanks to an increasing extraction of crude oil and natural gas from the North Sea and the production of renewable energy. Due to a gradual decline in the extraction of oil and natural gas, a major drop in the Danish energy production has occurred since the mid-2000s (cf. figure 3 below). The energy production dropped below the gross energy consumption in Denmark by 2014 (Statistics Denmark, 2016c).

Figure 3: Gross energy consumption (not including bunkering) and production



Source: Statistics Denmark, 2016c

The production and consumption of renewable energy in Denmark has increased substantially for all renewable sources since 1990, but in particular for wind power and biomass (cf. table 1). In 2015, wind power represented 42% of the Danish electricity supply.[6] In addition, waste used for heat and power production based on incineration has also increased considerable.

[6] http://energinet.dk/EN/El/Nyheder/Sider/Dansk-vindstroem-slaar-igen-rekord-42-procent.aspx. Accessed: 03.11.2016.

Table 1: Consumption of renewable energy in Denmark (in 1.000 GJ)

	1990	2000	2014
Gross energy consump., total	**1 461 040**	**1 903 508**	**1 830 087**
Renewable energy	**45 509**	**78 541**	**191 086**
Wind power	2 197	15 268	47 083
Wood pellets	1 575	5 145	37 093
Waste, renewable	8 524	16 715	21 095
Firewood	8 757	12 432	18 413
Straw	12 481	12 220	18 409
Wood chips	1 724	3 049	16 660
Bio oil	744	49	9 669
Heat pumps	2 267	3296	7 245
Wood waste	6 191	6 895	6 686
Biogas	752	2 912	5 143
Solar power	0	4	2 144
Solar heat	100	331	1 227
Geothermal	96	116	166
Water power	101	109	54

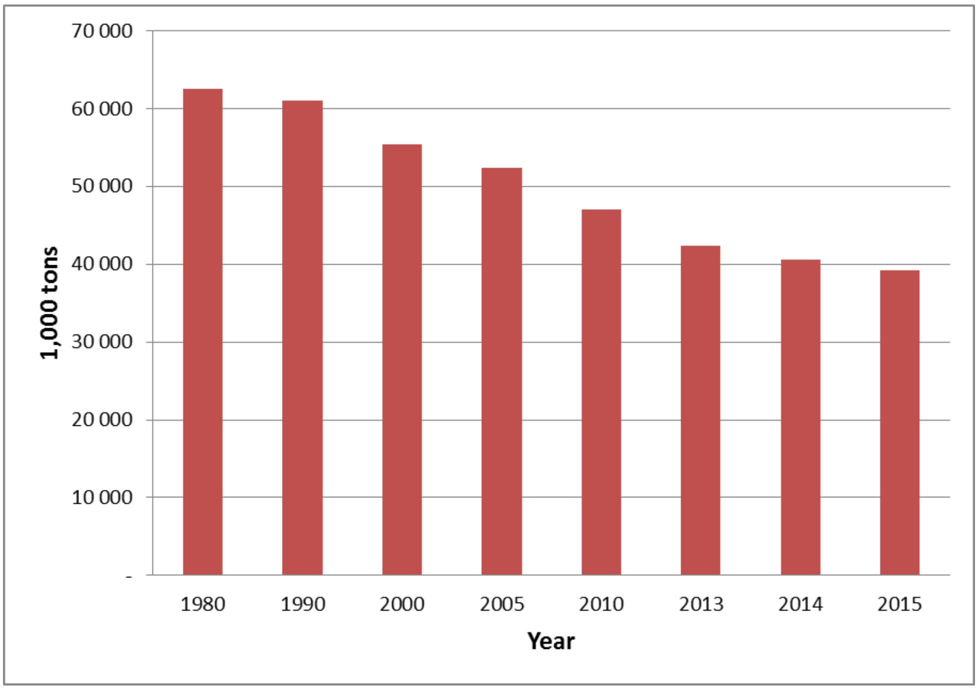
Source: Statistic Denmark, 2016a

Denmark is often mentioned as a 'frontrunner' regarding innovation and regulation within fields such as energy efficiency in buildings, energy retrofitting, renewable energy and smart grids (Winston, 2013), but still, the country's average CO_2 emission per capita is slightly above the EU average: In 2013, the Danish CO_2 per capita emission was 6.8 tons/year, compared with the EU average of 6.7 tons/year. However, the Danish emission is somewhat below the emission of Norway (11.7 tons/year) and Austria (7.4).[7]

As Figure 4 shows, the total CO_2 emissions from the Danish energy consumption has been reduced from about 62 million tons in 1980 to about 39 million tons in 2015 (a reduction of 36%). The reduction has mainly been realised through higher energy efficiency, massive extension of district heating since the early 1980s and phasing in renewable energy (especially wind power).

[7] The World Bank: http://data.worldbank.org/indicator/EN.ATM.CO2E.PC?year_high_desc=false (accessed 2017-02-15). These figures only includes national carbon dioxide emissions from the burning of fossil fuels and cement manufacture. Thus, it leaves out emissions of greenhouse gases from agricultural and forest activities, as well as emissions of CO_2 due to the embodied energy consumption related to import of products consumed in the countries.

Figure 4: CO_2 emissions from Danish energy consumption (1980-2015)



Source: Danish Energy Agency, 2017 (emissions are corrected for heating degrees variations)

However, some of the savings realized through increased energy efficiency has been outbalanced by rebound effects such as increased comfort and larger housing facilities. Especially if greenhouse gas emissions related to other consumption and production areas than energy are included, the Danish per capita emission is among the highest in the world, which to a high extent reflects the high living standard and the intensive agriculture production (Larsen et al., 2017).

According to the *Climate Change Performance Index 2015*, prepared by the German NGO *Germanwatch* and the European *Climate Action Network Europe*, which is an index that evaluates and compares the climate protection performance of countries, Denmark ranks as number 1, primarily because of a high ranking with regard to emissions development (the ongoing reductions) and ambitions of the energy and climate policies (Germanwatch & Climate Action Network Europe, 2014). However, with the 2017 index, Denmark dropped down to rank 13, even though it still "remains in the 'good performance' group" (Germanwatch & Climate Action Network Europe, 2016:14).

1.3 Policy and regulation of the energy market

Denmark's long-term energy goal is to become fully independent of fossil fuels by 2050. In 2011, the Danish government published *Energy Strategy 2050*, which is a detailed and ambitious policy paper that, building on existing policies, proposes a range of new energy policy initiatives to transform Denmark into a low-carbon society (IEA, 2011). To reach the target, all parties in the Danish parliament (except for one smaller party) made an energy agreement with the overall aim of reducing the Danish CO_2 emissions by at least 34% in 2020 (compared to emissions in 1990) and with the long-term aim of making the Danish energy system 100% based on renewables by 2050. The plan includes specific measures covering the period of 2012-2020, including the goal of increasing the share of electricity production from wind to 50% by 2020 (Energy Plan 2012). The following table shows the targets set by the Danish government and the Danish parliament, and how in particular major development of wind energy is in focus.

Table 2: The political goals for the transition of the Danish energy system

100% renewable energy in 2050	25% reduction of fossil fuels from 2010 to 2020
100% renewable energy for electricity and heat in 2035	50% reduction of fossil fuels for electricity and heat from 2010 to 2020
All oil-fired burners removed in 2030 (mainly to be substituted by heat pumps)	No oil-fired burners allowed in new buildings from 2013
Wind power shall produce 50% of electricity consumption 2020	Wind power shall produce 50% of electricity consumption 2020

Source: Sorknæs et al., 2013

The Danish Government and energy sector anticipate demand-side management as fundamental to reaching the target for a complete transition. Therefore, consumers' flexibility to time shift their electricity demand is regarded as essential in order to accommodate a renewable energy system by 2050 (Danish Government, 2011; 2013b). See also section 1.5 for more information on the Danish smart grid strategy.

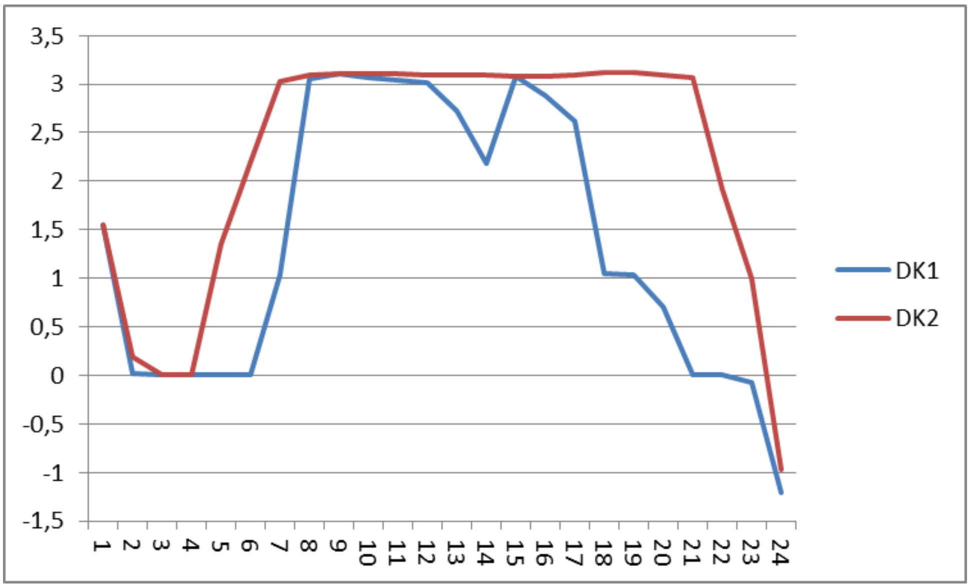
As in other EU countries, the market regulation in Denmark is strongly influenced by EU regulation. Thus, with the EU market liberalization directives and the EU Energy Packages, the Danish consumers have been able to choose their electricity supplier since January 2003. (Aarhus Universitet, 2017)

1.4 Market structure and energy consumption

As already mentioned, the Danish electricity grid is divided into two separate grids (an Eastern and Western); both are part of the Nord Pool day-ahead spot market, but are separate price areas.

The prices on the Danish spot markets fluctuate from even negative prices (in cases with a surplus production of wind power due to high wind speeds and low domestic consumption) to relatively high prices in case of low wind speeds and high domestic consumption. In 2016, the average spot market price were 0.199 DKK/kWh (2.7 euro cent/kWh) on the Western market (DK1) and 0.219 DKK/kWh (2.9 euro cent/kWh) on the Eastern market (DK2). But as the example in Figure 5 shows, the prices vary a lot from hour to hour and day to day. On this particular day, the prices in Eastern Denmark (DK2) were in general higher than on the Western spot market (DK1). Also, prices went below 0 euro cent/kWh in the late evening/night.

Figure 5: Spot market prices on Monday 2017-02-20. Euro cents/kWh by hour.



Data source: Nord Pool website (data retrieved: 2017-02-20)

The actual customer price is much higher than the electricity market prices mentioned above. For small consumers (4,000 kWh per year), the average customer price in the fourth quarter of 2016 was 2.32 DKK/kWh (31 euro cent); the retail price was only 0.28 DKK, while the main components of the customer price were the electricity tax (0.89 DKK), VAT (0.46 DKK), the net tariff for distribution (0.24 DKK) and the Public Service Obligation PSO (0.22 DKK) (Energitilsynet, 2017). The Public Service Obligation (PSO) was introduced in 1998 and covers expenses for subsidies related to renewable energy production, decentralized CHPs and research and development in energy technologies and energy efficiency. However, following a political agreement in the Danish parliament of November 17, 2016, the PSO will be gradually phased out during the period of 2017 to 2022. As a result, the electricity customer prices will be reduced with about 10%, and renewable energy installation and energy research will be funded by the state budget (i.e. regular taxes) in the future.

The Danish *transmission system operator* (TSO) is Energinet.dk, which is an independent public enterprise owned by the Danish state. In addition to the national gas transmission system, Energinet.dk owns the 400 kV electricity transmission system and is the co-owner of the international electricity connections to Norway, Sweden and Germany. (IEA, 2011)

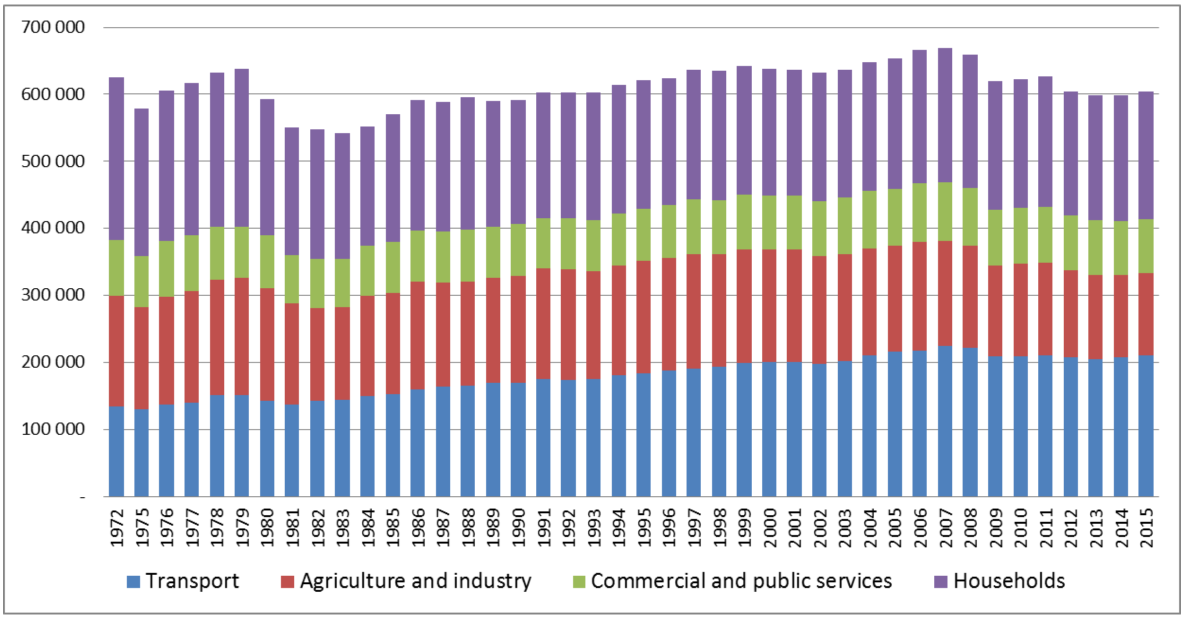
The primary *power producing* companies in Denmark are the Danish Dong Energy (which in November 2017 changed name to Ørsted) and the Swedish Vattenfall. They own the main coal or gas-fired CHP plants in Denmark (many of these currently being phased out due to increased wind power production or changed to biomass as fuel) and much of the wind power capacity. In addition, there are about 250 decentral CHP plants, typically supplying a small or medium-sized town or even village with district heating in combination with power production for the grid. These are often fuelled by natural gas, waste (incineration) or biomass. Some of these are owned by multi-national companies like E.ON, but most are either owned as co-operatives (typically with the district heating customers as the owners) or by municipalities. In addition, a minor share of the renewable power production is owned by private citizens either as privately-installed PVs or through shares in wind power cooperatives.

There are about 50 *distribution system operators* (DSOs) in Denmark (Bogetoft et al., 2014). They hold the monopoly on the physical delivery of power to customers (it is a geographical monopoly). They also have the responsibility for providing energy saving advices to the customers. The DSOs are owned by municipalities, co-operatives (with the customers being the owners) or act as commercial companies. They differ in size from

DSOs covering smaller cities or rural areas to the largest DSO, the commercial company Radius, which covers Copenhagen and Northern Zealand.

Finally, there are a number of *electricity suppliers* (retailers) who offer electricity to the customers. This is a market of competition and the customers can choose between about 50 retailers. In 2015, 7.3% of the Danish customers changed to another electricity supplier, which was a record compared to previous years (Dansk Energi, 2016). Some of the retailers offer specialized products to customers with “green” or renewable electricity, although it does not appear to have reached a significant market share.

Figure 6: The Danish final energy consumption by sectors (TJ), 1972-2015. Corrected for heating degree variations (climate) and not including energy consumption for non-energy purposes.



Data source: Danish Energy Agency, 2017 (data retrieved: 2017-04-27)

Figure 6 shows the development in the Danish final energy consumption from 1972-2015 (distributed by sectors). This shows that the final energy consumption of 2015 is more or less the same as in 1972. Throughout the period, there have been some variations (mainly as temporary reductions following economic crises; the first and second energy crisis in 1970s and the financial crisis in 2007-08). Overall, the energy consumption for transport has been steadily increasing, while the energy consumption for agriculture and industry as well as for households has been decreasing. In the case of households, there has been a reduction of 22% (2015 compared with 1972). Energy consumption for commercial and public services has been more or less constant throughout the years.

1.5 The Smart grids landscape in Denmark

In April 2013, the Danish Ministry of Climate, Energy and Buildings published a smart grid strategy (Ministry of Climate, Energy and Building, 2013). Together with a number of other strategies and analysis papers covering energy-related topics, the smart grid strategy supplemented the previously mentioned energy agreement from 2012. Thus, the smart grid strategy should support the realization of the ambitious goal of introducing 50% wind power in the electricity system by 2020 and making the energy system entirely based on renewable energy by 2050. In the foreword of the strategy, exactly the challenge from increasing wind power capacity (together with solar power) is highlighted as a main reason for preparing the strategy. Another main reason is the expected electrification of transport and heating. Thus, the core problem identified in the current Danish smart grid strategy relates to the balancing challenge of intermittent renewable electricity production; “… large amounts of wind power, and an increasing amount of solar energy, require more flexible electricity consumption" (ibid.: 5). And later: "An energy system with a smart grid design requires greater exploitation of the energy from wind as soon as it is produced, for example by heat pumps and electric cars. This will allow for greater exploitation of cheap wind turbine electricity, and it will mean less need to expand the electricity infrastructure to meet new electricity consumption." (Ibid.: 7) In other words, flexibility and demand-side management (demand response) is the key focus area for the Danish smart grid policies.

The main initiatives of the smart grid strategy are presented in Table 3.

Table 3: Main initiatives in Danish Smart Grid Strategy and status by Medio 2017.

Initiative	**Status for "small consumers" (by summer 2017)**
Provide consumers with the option of settlement by the hour (i.e. time-of-use pricing) – and in relation to this promote the rollout of hourly-read meters (smart meters)	Still, only very few small consumers have time-of-use pricing schemes. More than 50% of the Danish households have smart meters installed, and according to Danish regulation, the rollout of smart meters should be completed by 2020.
Stronger price signals (time-of-use pricing) should strengthen the incentive of consumers to move electricity consumption to off-peak hours. This could be variable net tariffs or specific "flexibility products" offered on the retail market (i.e. price savings in return for offering regulating power to the grid companies, e.g.)	Time-of-use pricing not introduced yet and no "flexibility products" have been developed for the retail market.
Wholesale model (electricity-trading companies being the only players with direct access to consumers) is envisioned to make greater competition and, through this, to increase the number of tailored smart grid products offered customers.	So far, there has not been any visible increase in the diversity and number of "smart grid products" offered small consumers
Integrating the electricity sector with other sectors: It is envisioned that the "next step" in the development of the smart grid is to utilise and store wind energy in other energy sectors "and thus render the entire energy system smart". Using electricity to produce heating (e.g. via heat pumps) in the district heating system and hydrogen (via hydrolysis) for the gas system are mentioned specifically.	Some R&D projects have been funded within this area. The integration of sectors are not realised as such.
Establishment of partnership with broad participation from the energy sector.	Has been established (called the *Smart Energy Networks*)

The development of the smart grid (or smart energy) system is still primarily happening within the R&D and demonstration field. Yet, no large-scale market-based solutions targeted small consumers have been rolled out on the market. Even electric vehicles, which in some countries like Norway and the Netherlands have got some diffusion and "mainstreaming", are still only representing a marginal share of the market (as mentioned earlier). Thus, the smart grid continuous to be more of a visionary idea among energy planners, politicians, engineers and energy companies than a "reality" experienced among regular customers.

However, there have been many R&D and demonstration projects in Denmark within the smart grid field within recent years. These have been funded by both national and international (primarily EU) programmes.

A review of Danish smart energy projects and the state-of-the-art within the smart energy field was published in 2015 (Mathiesen et al., 2015). It shows that within the period of 2005-2015, almost 8 billion DKK (1.1 billion euro) has been granted for energy research in Denmark; hereof, about 1.5 billion DKK (0.2 billion euro) has been granted the smart energy area (covering all energy sectors; electricity, heat and transport). The review identified 225 projects. Projects related to the electricity sector have received the majority of the funding, while the thermal sector received the lowest level of funding. While focus in the beginning was almost entirely on the electricity sector, the review finds a tendency within recent years to focus also on other sectors and on cross-sectorial projects (i.e. looking into synergies between sectors).

The review also finds that very few projects focus solely on non-technical aspects of smart energy (5 in total), although non-technical aspects are part of several “technical” projects. When it comes to projects including non-technical aspects, most of these are feasibility studies, second most focus on socio-economic analyses and third most on user/consumer behavior (if measured by size of total granted budget). In particular, very few projects focus on issues related to ownership or the role of institutions and organisations. Within funding for electricity-sector projects, most funding goes to ICT and development of appliances, and in particular the system challenge of balancing demand and supply has been in focus. Overall, the review identifies the low level of research into the integration and interaction of different energy sectors as the most significant research gap.

With regard to the integration of households in the smart energy system, the review concludes that there has been a limited success so far; “[t]his raises the question whether the previous approaches to households have been relevant” (ibid.: 20). Later, the review concludes that more research is needed into how “the development of Smart Energy systems can improve the development of possibilities of local citizens, local communities, and local businesses as well as local and regional authorities. There is an increasing requirement for concrete collaboration and coordination procedures between the state level, municipalities, producers and owners of renewable energy plants, consumers and producers of heat, biomass and power, and also in a learning process of the democratic base, the households.” (Ibid.: 20)

Also in 2015, and partly based on the above-mentioned review, the Smart Energy Networks published a revised *Vision for smart energy in Denmark: Research, Development and Demonstration* (Smart Energy Networks, 2015). With regard to small consumers, the vision specifically mentions “inadequate end-user engagement and insights” as one of the main challenges on the socio-economic level. Another important challenge is the lack of incentives “among system owners, building owners, authorities and end-users for flexible consumption” (ibid.: 5).

2 Danish case studies

The three selected Danish cases represent different solutions related to the future smart energy system, even though there are also similarities between the cases with regard to the aspects addressed and the approaches pursued. Two of the cases are focusing on the general transition of a geographical area to a post-carbon energy system; these cases are *ProjectZero* in Sønderborg municipality (close to the German border) and the *Renewable Energy Island* of Samsø (an island between Zealand and Jutland). In both cases, the aim is to facilitate a thorough transition of the energy system to make it based entirely on renewable energy. Also, in both cases, an independent organisation plays a key role in facilitating this transition (ProjectZero in Sønderborg and Samsø Energy Academy on Samsø). Finally, in both cases, there is a wide range of activities covering both the energy consumption and production side. However, in our empirical study, we have chosen to focus on slightly different types of activities (socio-technical configurations) for each case. Also, ProjectZero and the Renewable Energy Island of Samsø differ with regard to the size of the geographical area and population they cover each, among other things.

The third case studied – *Innovation Fur and the GreenCom* project – differs from the previous two cases by having a much more thematically focused approach; the GreenCom case is targeted households and aims to create demand response and load control through micro-generation (rooftop PVs) in combination with various smart energy solutions (heat pumps, home battery storage and Home Monitoring and Control). In the GreenCom case, the local DSO Eniig is a key stakeholder in setting up the demo, which is located on the island of Fur (placed in the Liim Fiord in Nothern Jutland).[8]

Table 4. Danish cases in comparison (our study of case 2 and 3 did not cover all activities of ProjectZero and Renewable Energy Island Samsø, respectively, but focused on specific activities)

	Case 1	Case 2	Case 3
Name	Innovation Fur/GreenCom	ProjectZero (Sønderborg)	Renewable Energy Island (Samsø)
Main focus	Test area for developing future smart grid	Transition to a post-carbon energy system	Transition to a post-carbon energy system
Type of consumers	Households	Households, SME, community buildings	SME, community buildings
DSM	Demand response	Increase energy efficiency, building energy management systems	Increase energy efficiency
Micro generation	Rooftop PV systems	PV systems, waste heat recovery	
Storage	Stationary battery storage	(Car batteries)	

The case sites differ with regard to size of population and area. Fur is a small island, while Samsø is a medium-sized island. However, both are primarily rural areas. The same goes for much of the area of the Sønderborg Municipality, although its main town (Sønderborg) is a medium-sized, Danish provincial town. Being a test and demonstration site for energy transition is a relatively new thing to the island of Fur, while there is a

[8] ProjectZero, Samsø Energy Academy and Eniig are all MATCH project partners as well as research subjects (with regard to their role in establishing the socio-technical configurations) in the following case studies. They have all had the opportunity to comment on the ongoing research and previous drafts of this report, but the final outcome is the sole responsibility of the authors.

longer history of (renewable) energy initiatives in both Sønderborg and (in particular) on Samsø. These site-specific characteristics are detailed further in the following presentations of the case studies.

The three cases were originally selected because they represent some of the most innovative and comprehensive (smart) energy initiatives in Denmark for the time being. Also, they in total cover the three solution areas originally outlined in the analytical framework for the national case studies (see MATCH deliverable D1). Two of the cases (ProjectZero/Sønderborg and Renewable Energy Island/Samsø Energy Academy) were originally partners of the MATCH project, while the third case (and partner, Eniig) was chosen later because of the relevance of their demand response approach for the MATCH study.

The empirical work of the case studies was carried out by the Danish Building Research Institute (Aalborg University) and was primarily based on qualitative methods; i.e. field trips with visual observations and informal as well as formal, semi-structured interviews with local experts, demonstration project participants, project owners etc. Interview guides were developed before the start of the case studies and used across all three cases (although, of course, adapted to each case and interviewee). The semi-structured interviews were recorded, transcribed and later coded in the programme NVivo. In total, 22 semi-structured interviews were carried out and – in addition to these – a few informal interviews. Below some more details on the empirical work of each site.

Innovation Fur and GreenCom

A field trip to the island of Fur was made in the end of September 2016 and included visits to and interviews with in total 9 households taking part in the GreenCom trial. Households with PVs in combination with either heat pumps or batteries were selected (although, due to miscommunication, it turned out that one of the households neither had batteries or heat pumps in combination with their PVs). Further, in the selection of households, we aimed at some diversity of the sample regarding household size, age and occupation. The interviews typically lasted about an hour, with one lasting only 40 minutes and three lasting about 1½ hour.

ProjectZero (Sønderborg)

We had two field trips to Sønderborg. The first took place in the end of October 2016 and focused on households (taking part in the ZERObolig programme; see section 2.2) and local sports centres (taking part in the ZEROsport programme; see section 2.2). Households with a combination of rooftop PVs and electric vehicles were selected (four households in total), while we chose two rather different sports centres (one relatively big centre, which had been through a thorough energy renovation, and one relatively little centre, a rowing club, which had been subject to a more modest energy renovation). Again, the household interviews lasted about one hour (except for one lasting almost two hours), while the sports centres interviews lasted about 45 minutes and 1 hour and 45 minutes, respectively.

The second field trip took place in the middle of July 2017 and included visits to two supermarkets taking part in the ZERObutik programme (see section 2.2). Interviews were made with the supermarket manager at each site and lasted about one hour. In addition, the ZERObutik programme leader at ProjectZero was interviewed (lasted about ½ hour).

Renewable Energy Island of Samsø

A field trip to Samsø was made in late October 2016 and focused on local SME's taking part in the energy saving programme NightHawks. A supermarket, a local community centre and a hotel & restaurant were interviewed. In addition, two project managers from the Samsø Energy Academy were interviewed about the role of Samsø Energy Academy in the local energy transition. All interviews lasted about 1 hour each (except one lasting about 1½ hour).

A second field trip to Samsø was made in late March 2017 and included visits to more sites and some informal interviews with local shopkeepers etc.

2.1 Case 1: Innovation Fur and the GreenCom project

2.1.1 Background and project characteristics

The island of Fur is placed in the Liim Fiord in Northern Jutland. It has a modest area of 23 km^2 with 771 inhabitants (2017) and about 424 residential homes and 500 summer-houses. Fur is located in the Municipality of Skive with about 47,000 inhabitants (2017), and which belongs to the regions of Denmark experiencing a general decline in number of inhabitants and economic activity.[9] The population on Fur has halved since the beginning of the 20th century, and declined by 19% since 2000.[10] Fur is connected to the mainland via a small ferry (the crossing takes about 3 minutes). Since the beginning of the 20th century, there has been an extraction and local production based on Moclay in two factories on the island. The material resource Moclay (in Danish *moler*) is a diatomitic sediment of the Lower Eocene Epoch. The factories produce products for the international markets within heat resistant materials and tiles (the *Skamol* company) and cat litter, fodder additives etc. (the *Damolin* company, recently changed to *Imerys Industrial Minerals Denmark*). The two companies occupy about 70 employees.[11] Other important commercial activities on Fur are agriculture and tourism (the estimated annual number of tourists on Fur is about 250,000).[12] The island appears to have strong local networks among the inhabitants, often organized in various associations or working groups. Due to the size of the community, many people know each other from associations, meetings, the local grocery etc.

Innovation Fur is a private-public partnership (established in 2011) between the Fur citizens, the Municipality of Skive and the local electricity utility and DSO company (EnergiMidt, now *Eniig*) aiming to create a mini model on Fur of the future sustainable and energy-efficient welfare state. The initiatives on Fur focus on how modern technology, digitalization and energy-efficient solutions can support Denmark's vision on energy and welfare. The ambition is to make Fur carbon neutral in 2029 (originally by 2020) through various initiatives. The specific initiatives so far include information meetings, free energy consultation visits to approx. 145 households, involvement of local craftsmen, energy consultancy to businesses, free courses about energy forms, heat pumps, solar cells, solar heating, biomass boilers, energy consultancy and district heating[13], education about pros and cons of technologies, different kind of subsidies to energy saving, PV demonstration projects and a range of other information and education initiatives. The core target areas are energy saving/efficiency (with a particular focus on heat saving in permanent residences) and individual supply from PVs, and increase the installations of heat pumps and wind turbines.[14]

Innovation Fur was originally a spin-off of a citizen-led project called *Branding Fur*, which aimed at bringing the decline in population size of Fur to a halt and make it more attractive for people to move to the island. In this way, Innovation Fur is also by the local

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[9] Statistics Denmark, http://www.statistikbanken.dk/10021 (accessed 28-07-2017)

[10] Statistics Denmark, http://www.statistikbanken.dk/BEF4 (accessed 28-07-2017)

[11] http://furnyt.dk/4/index.php/component/k2/item/1940-moler-pa-fur and http://www.furnyt.dk/4/index.php/component/content/article/34-artikler/artikel/466-skamol-fra-moler-til-faerdig-braendt-sten (both accessed 28-07-2017)

[12] https://da.wikipedia.org/wiki/Fur (accessed 28-07-2017)

[13] In 2014, an under-water pipe connection was established to a Skamol factory on the mainland, thus utilising the excess heat from their production for district heating on Fur. This was not directly an activity of Innovation Fur, but contributes to the decarbonization of the island.

[14] See e.g.: https://www.information.dk/indland/2013/08/fur-dur and http://voresomstilling.dk/projekt/innovation-fur/96.

community seen as part of an overall strategy of ensuring the future development of the island (including attracting newcomers). (Ministeriet for By, Bolig og Landdistrikter, 2013)

Innovation Fur aims at developing innovative processes in cooperation with private and public actors. The core concept is based on accommodating sustainable transition and consumption change by bottom-up processes facilitated by user involvement. The project's green and smart solutions are thus ideally developed in close collaboration with the citizens living on Fur in order to secure that the initiatives/smart solutions are based on what the citizens/consumers consider meaningful and important. The citizen perspectives are achieved through working groups, courses, workshops and information meetings. The latest annual climate account for Fur (for 2013) shows significant drops in CO_2 emissions and heat consumption for homes and summer houses, increase in renewable energy shares from wind turbines and PV energy, and that the number of heat pumps is increasing. This led to a reduction in total energy consumption for electricity, heating and transportation of 16% compared to 2010. (Innovation Fur, 2016)

One of the projects affiliated with Innovation Fur was the EU-funded demonstration project GreenCom, which has been using Fur as an international test area for developing the future smart grid (the project was concluded in 2016). The goal of GreenCom was to "utilise the flexibility and intelligence in the low-voltage demand and local supply side infrastructure to create increased regulation capacity and reserve power in the centralised power grid by extending the means to effectively and securely manage and control the demand and supply within defined boundaries". In other words, the project aim was to "balance the local exchange of energy at the community microgrid level"[15]. By combining smart grid and IT technologies, GreenCom tested the balance in the energy system through technological equipment installed in "The Intelligent Home" coupled with strategies to increase user awareness. The demonstration included 33 households; of these, 19 were equipped with a home monitoring and control system (HMC), 11 had heat pumps installed (7 air/water, 1 air/water and 3 air/air heat pumps), 20 had PVs installed and 5 had batteries installed with Intelligent Energy Storage (IES) monitoring equipment. The overall experiences from GreenCom were that it is possible for private households to be flexible with PV systems and batteries and PV systems and heat pumps, and that the house owners are interested and cooperative in being flexible if it can help the local DSO. (GreenCom, 2016)

In 2017, a new EU-funded project, Storage4grid, which primarily continues the analysis on electricity storage provided by the 5 installed house batteries, has started.[16]

In the MATCH case study, we have focused only on GreenCom households with PVs in combination with home batteries and heat pumps, respectively. In the GreenCom project, the main actors involved was the GreenCom consortium (in Denmark represented by the energy provider and DSO Eniig), funding agencies (EU and a national R&D programme) and the local citizens (particularly those participating as trial homes). The latter had partly been selected based on their connection to the same "last mile" power line. In this way, they were only partly self-opted. Participants in the trial would acquire the tested technologies with significant subsidies, which made it attractive to participate.

2.1.2 Socio-technical configurations applied in the project

In our study of the Fur case, we specifically focused on two socio-technical configurations, both targeted households and both part of the GreenCom project. The first includes households with a combination of solar power (PVs) and home batteries (for local stor-

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[15] Quotes from project website, http://www.greencom-project.eu/ (accessed 28-07-2017)

[16] http://www.storage4grid.eu/pages/index.html

age), while the other includes households combining solar power (PVs) with heat pumps. It should be noted that all households (except one) also had Home Monitoring and Control (HMC) systems installed. In addition, the heat pumps of the second configuration were installed with Heat as a Service (HaaS) equipment and control, which means that the heat pumps could be remotely controlled in order to utilise them as a flexible load for the grid operation. However, except of a single calibration test of the remote control (to get data on the thermal characteristics of the buildings and how fast the buildings cool down when heat is turned off), this was not tested in "real life" due to technical challenges – and we will not go into further detail with this here. Similarly, the HMS system was never used on a broader scale by the participating households due to a number of technical issues and a low interest among the homeowners.

	PV + home battery	PV + heat pump
Technical elements	Low-voltage grid PV panels (~ 6 kWp each) Home batteries (4,5 kWh storage capacity each) IT control unit of charging of home batteries (Intelligent Energy Storage, IES) User interface for monitoring battery charging via smartphone app or internet browser	Low-voltage grid PV panels (~6 kWp each) Heat pumps (air/water) HaaS control equipment for the heat pumps
Social elements	5 households Households own PVs Batteries own by DSO (project owner) Information meetings related to demonstration R&D funding (EU and national) Subsidies for households (PV and batteries) Loyalty & commitment to demonstration project Gendering in household members' interaction with technologies Account settlement scheme (hourly net metering)	11 households Households own PVs and heat pumps Information meetings related to demonstration R&D funding (EU and national) Subsidies for households (PV and heat pumps) Loyalty & commitment to demonstration project Gendering in household members' interaction with technologies Account settlement scheme (hourly net metering) Family status (children or not) Developing new (embodied) routines for time shifting consumption Weather (annual/daily sun cycles)

Both configurations relate to the low-voltage grid (as the overall focus of the GreenCom project was to test new technologies and their possible use for managing the local low-voltage grid) and include PV rooftop panels (owned by the households). Also, both configurations depend heavily on external funding from EU and, partly, national funding from the Danish ForskEL programme, some of this funding being transferred to the households as subsidies for acquiring PV panels and heat pumps. The batteries were the ownership of the DSO. Further, loyalty and commitment to the demonstration project was found among the participating households in both configurations, i.e. that they were in general committed to follow the instructions and recommendations (scripts) conveyed by the project owners through information meetings and participant workshops. Finally, both configurations share a relatively strong gendering with regard to which household members who engage most actively in the new technologies and are planning consumption according to their own production of electricity from the PVs (as will be elaborated further in the Discussion section).

Zooming in on the specific configurations, the first combines PVs with batteries. This was part of the GreenCom project's focus on exploring the potential for an Intelligent Energy Storage (IES) business model; both seen from a household perspective (making it possible for households to consume a larger share of their own PV generation and, in this way, save money) as well as from the perspective of the DSO (by reducing grid load peaks by covering some of the peak consumption by electricity delivered from the battery). Thus, focus was on the implications of the battery + PV constellation on how the households act as a load on the low-voltage grid (GreenCom 2016). In order to optimize the performance of the battery, an IT control unit (Intelligent Energy Storage, IES) controlled the battery charging, making sure that the battery would only be recharged during periods with a surplus PV generation (i.e. when the household is consuming less power than is produced by the PVs). Conversely, the battery would discharge during hours with higher consumption than PV production (in this way replacing some of the power that would otherwise be drawn from the grid). Finally, a user interface was offered the households (run via a smart phone app or an internet browser) that enabled them to monitor the battery charge status and energy flows of the home on a near-real-time basis. However, only one of the interviewed households had managed to make this work (or figured out how it worked).

In the final analysis, the GreenCom project partners conclude that the PV + battery configuration significantly increases the level of self-sufficiency by about 50%; increasing the average self-sufficiency rate[17] from about 20% without batteries to about 30% with batteries.[18] Measured by the rate of utilization of the PV power generation, the PV + battery combination almost doubles the utilization rate from about 30% for direct energy consumption to about 60% including the battery. Also, it is concluded that the PV + battery combination typically reduces the peak load with 35-70% for 1,5-2 hours in the peak period. However, the data also shows great seasonal variations with relation to both self-sufficiency rate and peak load reduction, as the battery is typically fully recharged every day during the summer months, while it during the winter months might not even be recharged at all (due to limited solar influx). Regarding the business case, the demonstration shows that without subsidies like those in the GreenCom, it is not yet profitable for households to invest in the PV + battery combination, primarily due to batteries still being too expensive.[19] Also, the solution is not yet profitable to the DSO because of battery prices still being high and because of a general over-capacity of the local, low-voltage grid. (GreenCom, 2016)

The second configuration combines PVs with heat pumps. This was part of GreenCom's exploration of the Heat as a Service (HaaS) business model, i.e. remote control of heat pumps via a HaaS control unit in order to offer different flexibility services to the DSO. The ideal is that the household will benefit from entering a HaaS contract by getting a reduction in their electricity bill in return of offering flexibility within certain limits defined by maximum and minimum acceptable indoor temperature levels, while the DSO will get the possibility of controlling the load on the grid (through the flexibility offered by the households). The DSO can control the performance of the heat pump remotely via the HaaS unit, which is connected to the heat pump. However, the HaaS concept was not

[17] I.e. the share of the residential electricity consumption covered by electricity from the PV (either consumed directly or stored in the battery for later delivery to the household)

[18] It should be noticed that these figures are not based on a full year, but the period from Mid-August 2015 to Mid-May 2016, leaving out the summer months of June and July. Therefore, the actual, annual self-sufficiency might be expected to be somewhat higher.

[19] With the subsidies of the GreenCOM project, the use of the batteries were free of charge to the households, which means that the households in the project saved money by increasing their rate of self-sufficiency (for each extra kWh consumed locally instead of sold to the grid, the households would save about 1,5 DKK).

tried out in real-life in the demonstration project, although one calibration test was run for each of the seven households taking part in the trial (GreenCom, 2016). In the final analysis, GreenCom (2016) concludes that the HaaS method potentially can be used for load shaving and in this way help the grid operator.

With regard to the social elements, the interviews show that the households taking part in this configuration were sensitive to the type of account settlement scheme (hourly net metering), as this in general incentivised them to shift parts of their electricity consumption from evening/night hours to daytime hours in order to utilize their own PV power generation the most (saving them on average 0.20 euro for each kWh shifted).[20] It was primarily dishwashing and laundering that the households shifted (manually or by use of timers on the appliances), while none of the households shifted their heat consumption. Those who actively time shifted their electricity consumption appeared to develop new, routinized (embodied) habits in relation to this (detailed further in the following section), which to some extent were built on day-to-day observations of the weather (whether the sun would shine or not during the daylight hours). Finally, it appears as time shifting was most prevalent among households without children living at home, which indicates that the degree of flexibility regarding time shifting consumption is lower for families with younger children.

2.1.3 Discussion: Success and outcomes

Seen from the perspective of GreenCom project (and the project consortium), the demonstration succeeded in providing concrete experiences with new smart grid solutions, including combinations of PVs with heat pumps and battery storage, respectively. Thus, measured by the R&D goals, it was a successful project. However, at the same time, it also showed the existence of both technical and non-technical challenges related to setting up complex systems like these. In particular, with current investment costs related to PVs and batteries, and current electricity costs, the battery + PV combination is not yet profitable seen from the perspective of households or the DSO (neither for optimising the utilization of the PV generation or as part of a load management strategy in general). Another key finding of the demonstration was that the capacity of the low-voltage grid on Fur (and in Denmark in general) is oversized. This means that even with a high penetration of new technologies like PVs, EVs and heat pumps, the DSOs are in general not expected to face grid capacity problems related to peak loads. In other words, the Danish DSO member of the GreenCom project lost some of its initial interest in the prospective future use of DSM solutions throughout the demonstration. However, the GreenCom project, being an international project, discovered that this might differ from many other European countries, as “many of the European LV [low-voltage] grids are not as heavily over dimensioned and strong as the Danish LV grid” (GreenCom, 2016: 4). Interestingly, this also points to the importance of the physical characteristics

[20] Depending on when the PVs were installed, Danish household accounts are settled according to two different net metering schemes: the original net metering scheme from 2005 was based on annual net metering, which means that, e.g., surplus PV production in the summer months is deducted from surplus consumption during winter months (as the account is only settled one time a year). With falling prices on PV installations, this net metering scheme became increasingly profitable for private household, which spurred a take-off in installations of privately-owned PVs in 2011. This threatened to undermine the tax revenue from electricity consumption. In response, the Danish parliament passed a new bill in December 2012 that changed the net metering to be hourly based, which stalled the installations of new PVs in private households (Wittrup 2016). With the new scheme, the account is settled every hour, meaning that for each hour the amount of electricity delivered to the grid (in case of higher PV generation than on-site consumption) is deducted the amount of electricity delivered from the grid to the household. If the resulting figure is positive (i.e. the household has consumed more electricity from the grid than it has delivered to the grid), the household pay the ordinary electricity price for the net consumption. If the resulting figure is negative (i.e. the household has been a net exporter of electricity within the hour), the household gets a fixed price per kWh for the net export. However, the household gets only 8 eurocents per kWh delivered to the grid, while it pays about 30 eurocents per kWh (including taxes) consumed from the grid. Thus, with hourly net metering, there is a strong economic incentive to consume as much of the PV power on site, and within the hour of production, as possible.

of the existing electricity grid, including the history related to the level of investments in, and original capacity design criteria of, these grids.[21]

The households were in general happy with participating in the demonstration. Their acquisition of new technologies was partly subsidized by the project, which likely influenced both their initial interest in enrolling for the trial and their satisfaction with being part of it. Even if they did not necessarily have exact numbers on their energy costs before and after the installation, the households in general believed that they had benefitted economically. Also, the households with heat pumps were happy about their new heating system (the heat pumps replaced previous systems such as oil or biomass burners). They experienced a higher indoor comfort and also experienced the heat pump to be a reliable technology that did not require much attention (e.g. compared to biomass burners). In both cases, this indicates the importance of convenience in relation to heat pumps.

With regard to the influence of the demonstration on the everyday life and consumption patterns of the households, the interviews show that many households to various degrees incorporated new routines of time shifting their electricity consumption (this in particular apply to the households with PVs + heat pumps). In particular dish washing and laundering were shifted to daylight hours in order to optimize the consumption of the PV generation. The time shifting was motivated by mainly two reasons: First, the project partners had through information meetings and workshops conveyed the message that the householders would save most money by time shifting their electricity consumption. This – in combination with the householders' general commitment to the trial – appeared to influence their daily habits. Second, the hourly net metering scheme was mentioned by many as a reason for time shifting, as this would save them most money. In addition, the notion of "consuming one's own electricity" also appears to have an influence on the householders' motivation with regard to time shifting. Typically, the households would develop new routines in relation to time shifting their consumption. In a few cases, the households even had developed more "advanced" and reflexive practices related to monitoring PV generation and planning the time shifting of everyday practices. In all these cases, it was the male adult member of the household who had developed these routines (although the performance of the routines also depends on communication with their spouse, e.g. in relation to plan the timing of laundering). Interestingly, the motivation for time shifting consumption was less prevalent among the households with home batteries; these households to some extent delegate the activity of balancing (synchronizing) PV generation and consumption to the batteries and the IES control unit.[22]

On a more general level, it appears as the GreenCom demonstration project strengthens already existing local ties and networks among the citizens on the island. This happens in two ways: First, the information meetings and workshops held by the project owners worked as a setting for people to meet (an additional setting to the other settings on this island, e.g. in relation to the islanders' participation in local associations). Second, some of the participants explained how they on an informal basis exchanged personal experiences with the new technologies with their neighbours or work colleagues when meeting these. In particular, production data of the PVs was something that was shared, partly – it appears – as a friendly "competition" among households with regard to who produces the most electricity (e.g. on a sunny day). Again, it was only male interviewees who told about this kind of habits. In this way, these technologies – and the trial setting – appear to invite to informal knowledge exchange (and perhaps even shared learning) within the local community. Further, the media coverage of the trial and frequent visits of external professionals within the electricity sector might also have contributed to a general positive image and "branding" of the island similar to that of Köstendorf (although not at all

[21] These observations and conclusions only relate to the use of load management (demand response) for managing potential grid capacity problems. Demand response might also be interesting in relation to balancing the consumption side with (intermittent renewable) electricity generation; however, this was in focus in the GreenCom project.

[22] See Christensen et al. (2017) for a more detailed analysis and examples of how the households time shift consumption.

on the same level of size). In this way, one can argue that the GreenCom demonstration contributes to the overall aims of the original *Branding Fur* and *Innovation Fur* initiatives.

In summary, and with reference to the MATCH framework, the main findings of the case study in relation to technology, markets and actors are:

- Technology: The GreenCom demonstration provided important R&D insights in relation to smart grid solutions in homes. It was shown that the PV + battery combination reduces peak loads significantly (35-70%) as well as increases the level of self-sufficiency at the household level. And even though the remote control of heating in the PV + heat pump combination was not tested under ordinary operation (due to technical challenges), the calibration tests indicated a potential flexibility of 1 kW in load demand per household (i.e. 1 kW that can be shifted from peak hours to other hours). However, due to a general over-dimensioning of the low-voltage grid in Denmark, grid capacity is not expected to become a major challenge in the near future (even with more EVs and PVs). Therefore, demand response is not expected to become needed for grid capacity management.
- Actors: The DSO to some extent lost interest in the technical solutions due to the above-mentioned over dimensioning of the LV grid. The households were in general happy with participating in the trial and believed they had benefitted from it economically. Also, some saw the trial as part of the larger vision of a renewable energy system and the branding of the Fur island. Further, several householders were actively engaged in time shifting their electricity consumption (mainly dishwashing and laundering) in order to optimise the utilisation of the PV generation. Also, the community of the island might have benefited from the trial in more general terms through strengthened local networks and publicity in Danish media.
- Market: As mentioned above, the tested solutions (business models) were not commercial viable without public subsidies (the funding of the project). The households benefitted economically from participating in the trial through increasing their level of self-sufficiency (saving money on the electricity bill) and by getting new equipment to reduced prices. More generally, the hourly net metering scheme has a positive influence on households' motivation and engagement in time shifting (some of) their electricity consumption.

2.2 Case 2: ProjectZero in Sønderborg – ZEROhome, ZEROshops & ZEROsport

2.2.1 Background and project characteristics

The municipality of Sønderborg is located in Southern Jutland (close to the German border). The municipality covers 496 km^2 with the island of Als representing 321 km^2 of this. The island is connected to the mainland by two bridges. The number of inhabitants in the municipality of Sønderborg are 75,000 (by 2017), of which 28,000 live in the main city Sønderborg. The municipality of Sønderborg belongs to the declining regions of Denmark, although the decline in population is less marked here as in other declining regions. Thus, the number of inhabitants dropped by 2% from 2010 to 2017, but with a slight increase from 2016 to 2017.[23]

Industrial production holds a strong position within the Sønderborg area, with the largest company being *Danfoss* (developing and producing mechanical and electronic components and system solutions). Danfoss is an international company with about 24,000 employees worldwide. The head office is placed on the northern Als and employs about 5,000 people (at the head office and the factory).[24] In addition, there are other manufacturing companies in the municipality. Agriculture is also an important business (as in

[23] Statistics Denmark, http://www.statistikbanken.dk/BEF4 (accessed 28-07-2017)

[24] http://www.danfoss.dk (accessed 01-08-2017)

most regions of Denmark outside the major cities). Compared to other declining regions, there is a higher share of knowledge-based industries and jobs. Similarly, and partly due to the local technology-advanced companies, there is a number of educations in Sønderborg, including a local branch of University of Southern Denmark.

ProjectZero was founded in 2007 as a public-private partnership between the local DSO and energy provider SE, the Bitten & Mads Clausen Fund (related to Danfoss), the Danish energy company DONG Energy (now *Ørsted*), the Nordic bank Nordea and the Municipality of Sønderborg. The aim of ProjectZero is to promote and facilitate a transition of the municipality of Sønderborg to a CO_2-neutral community by 2029 through a variety of initiatives facilitated by the ProjectZero Secretariat. In 2009, a masterplan for this transition was published (ProjectZero, 2009). The goal only relates to CO_2 emissions (not other greenhouse gases, e.g. methane). Further, only CO_2 emissions from direct energy consumption within the Sønderborg area as well as related to imported/exported energy are covered by the ProjectZero vision and strategy (i.e. CO_2-emissions related to import of goods, e.g. food, and transport outside of the area, e.g. citizens on holidays, are not included). The end goal of CO_2 neutrality in 2029 is complemented by mid-term CO_2 reduction goals; 25% reduction by 2015, 50% by 2020 and 75% by 2025. The baseline year is 2007. In addition to the climate goal, the vision also aims to create new and keep existing work places within the "knowledge-intensive business". This is thought of as a spin-off of the activities related to the realisation of the CO_2 neutrality vision. In other words, work creation is also central. More generally, the vision is anchored within a market-driven and growth-based paradigm, as also stated on the website of ProjectZero: "We will show, how a market-driven and growth-based energy and climate transition to a CO_2 neutral society in 2029 can be done in practice"[25].

According to the masterplan, the realization of the vision is going to happen through three overall approaches: 1) Substantial energy efficiency measures, 2) transition to renewable energy within the energy supply and 3) transition to a dynamic energy system. The latter relates to the interaction between energy sectors and the goal of balancing intermittent RE production with the consumption side. The latter approach is specifically emphasised as being "essential for a sustainable energy system" (ProjectZero, 2009:8).

The ProjectZero initiatives are facilitating new business concepts, new partnerships and new solutions that are climate friendly. The initiatives are strengthened by involvement and participation of local citizens, shops, institutions, businesses, craftsmen and others, which through cooperation aim to create local "green" jobs and economic growth. Hence the strategic efforts to reduce CO_2 emissions through energy efficiency improvement and smart grid solutions are based on participation from local stakeholders. Moreover, energy retrofitting, conversion to district heating, installation of PVs and heat pumps comprise some of the pivotal solutions to accommodate the reduction.

The specific initiatives are being developed and detailed in the so-called Road Maps, each covering a specific time step in the transition. So far, two road maps have been published (in 2009 and 2013).[26] The 2013 road map identifies six strategic areas for the efforts until 2020:

- Citizens (focus on energy reduction, e.g. through a network of local energy consultants)
- Companies (focus on providing access for companies to knowledge about energy saving, transition and CO_2 reductions)
- The public sector (focus on making the Sønderborg area into a test site for new and smart energy and climate solutions that create growth, jobs and CO_2 reductions)
- Intelligent Energy (a new business concept, which aims at optimising the energy consumption and increase the RE share)

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[25] http://www.projectzero.dk/da-DK/TopPages/Om-ProjectZero/Hvad-er-ProjectZero-.aspx (accessed 01-08-2017)

[26] See: http://www.projectzero.dk/da-DK/Publikationer/City/Roadmaps.aspx (accessed 01-08-2017)

- Bio energy (focus on facilitating an optimal utilisation of the local biomass resources)
- Green Transport (focus on optimising public transport, commercial transport, reduce transport in urban areas, increase ride sharing and support a transition to transport based on electricity and biogas)

By 2016, the total CO_2 emissions from the Sønderborg area had been reduced by 36% (compared to 2007), while the energy consumption had been reduced by 18% (ProjectZero, 2017). As the 2015 mid-term goal was a 25% CO_2 reduction, this shows that the realized reductions are far ahead of the projected. The main reasons behind the reductions are a combination of increased energy efficiency and a shift to less CO_2-intensive energy forms or renewable energy (e.g. conversion to district heating and the phase in of biomass and solar heating in district heating). It should be noted that part of the reduction is caused by the national decarbonization of the electricity supply (primarily through new wind power capacity).

In the MATCH case study, we have focused on three of the ProjectZero initiatives: ZERObolig (in English: ZEROhome), ZEROsport and ZERObutik (in English: ZEROshop). As indicated by the names, ZERObolig targets the residential sector, ZEROsport the local sport centres and sport facilities and ZERObutik the local shops. All initiatives are primarily focusing on promoting energy saving.

ZERObolig motivates homeowners to energy retrofit their homes (partly by offering free energy consultant visits)[27]. However, in this study we focus on homes, who have invested in PVs in combination with electric vehicles (EVs) and heat pumps. ZEROsport aims to make the sport facilities in the municipality more energy efficient and green by engaging sport facility associations. Together with the Leisure Department in the municipality, the secretary has developed the ZEROsport-programme, which is a two-years certification targeting sports facilities and clubhouses working to reduce their energy consumption and CO_2 emissions. The initiative's purpose is to increase awareness and daily energy management in the buildings through active participation of the users in their leisure time. The core assumption is that the network around leisure activities have a crucial impact on consumers' energy awareness and activities in general. The ambition is also that the activities at the sports facility site should inspire the local citizens (the users) to change behaviour in their own everyday life outside the sports facility. Finally, ZERObutik offers a certification of local shops according to the size of their realized energy saving. The shops can get different types of certificates, ranging from a white certificate (10-20% reduction) to a green certificate (more than 70% reduction). At regular public events, the certificates are handed over to new members of ZERObutik. Typically, it is the mayor of Sønderborg Municipality that presents the certificates. So far, about 135 shops have got a certificate. None have got the green certificate yet, while only a few groceries (convenience stores/supermarkets) have got the gold certificate (51-70% reduction). As part of the ZERObutik programme, the shops are offered a free visit by an energy consultant (a so-called "ZERObutik partner"), which is done by local electricians who have followed a course in energy advisory. The most typical measure done by the shops is replacing traditional light spots with LED spots. However, some shops also do more comprehensive measures like changing the heating system.

2.2.2 Socio-technical configurations applied in the project

Three socio-technical configurations have been identified related to ZERObolig, ZEROsport and ZERObutik.

[27] Since 2007 approximately 16,800 home owners have energy retrofitted their houses.

	Households (ZERObolig) *PV + EV + heat pump*	Sport centres (ZERO sport) *Local sports centre*	Shops (ZERObutik) *Supermarket*
Technical elements	PV panels (~ 6 kWp) Electric vehicles (EVs) Limited EV driving range Heat pumps (air/air, ground/water)	Complex energy system and controls (PVs, solar heating, heat pumps, ventilation systems with heat regeneration etc.)	Various conventional energy saving solutions like replacing incandescent bulbs with LEDs Heat recovery of "waste heat" from cooling
Social elements	Annual vs. hourly account settlement schemes Local network for knowledge sharing, support & inspiration Independence and resilience Test an EV campaign	Advanced skills for managing the system Funding (and skills for raising funding) Dedicated volunteers ProjectZero certification scheme National competitions and prices Partly demonstration project	Local (informal) network Danfoss company (the supermarket being a test site for new solutions) ZERObutik certification scheme (publicity/branding) Partly demonstration project Energy supply contract with local district heating National tax rules on selling "waste heat"

For the first configuration (the households), the PVs, EVs and heat pumps are obviously core technical elements. In addition, two households combine the heat pump with wood-stoves and one with a masonry stove.[28] Also, all households combine the EV with a regular combustion engine car (due to limited driving range of the EV). Typically, the EV is used primarily by one of the adult household members (typically for daily commuting and shorter trips), while the combustion engine car is used for longer trips (e.g. visiting friends or relatives in other parts of Denmark) or when they need to use a car trailer. The households do not think that their transport needs can be covered by EVs only; it is in particular the limited driving range per battery charge that is regarded as limit to EVs. Two of the four interviewed households had also two cars before they acquired their EVs, and in these cases the EVs are replacing combustion engine cars. The two other households did not have two cars before they got the EVs.

Furthermore, for two of the interviewed households, the excess of electricity from the PVs worked as a motivation for acquiring the EV. This relates to the type of account settlement (featuring as a social element in the table above): All households, except for one, were on the annual net metering scheme (see also previous footnote no. 12). This means that if the households have an annual surplus of electricity (i.e. the PVs are generating more electricity that the household consume on an annual basis), there is an economic incentive for the households to use the "surplus" electricity generation, as they typically get only about 8 eurocents per kWh of surplus electricity delivered to the grid. Thus, the additional electricity costs of adding new electricity-consuming products like EVs or heat pumps are minimal (at least until the added electricity consumption equals the annual surplus PV production). This shows how the old scheme (annual net metering) promoted increased electricity consumption; an indirect effect that resembles the so-called rebound effect. However, this has changed with the new hourly-based scheme (hourly net metering). One of the interviewed households was on the new scheme, and

[28] In the household with the masonry stove, the air/air heat pumps are actually used more as supplementary heating to the stove. This household also have solar heating for combined hot water and central heating (space heating).

they did time shift various electricity-consuming activities on a regular basis (especially during the summer), including dishwashing, laundering, tumble drying and – to some extent – baking. This was in order to save money by increasing the degree to which they consume the generated PV electricity within the same hour as it is produced.

Other social elements: In particular two households emphasised the role of local (informal) networks for knowledge sharing, mutual support and inspiration. Further, ideals of energy independence and resilience (for instance from rising energy prices, blackouts due to supposed terror attacks on vital infrastructures or being resilient to "the turmoil around the world") were mentioned by two households as motivations for investing in PVs and for their general interest in acquiring home batteries in the future (if the prices on batteries fall enough). Finally, two households had previous experiences with driving EVs from a national EV "test pilot" campaign called "Test an EV", which ran across Denmark a few years earlier. In this campaign, households could borrow and "test" an EV for three months. It appears as the participation in this campaign had "demystified" the idea of acquiring an EV for these households.

The second socio-technical configuration relates to sport centres being part of the ZEROsport initiative. We visited two sites (a rowing club and a local sports centre). However, in this analysis we focus mainly on the sports centre as this represents the most ambitious and advanced example of an energy renovation. The sports centre is called *Diamanten* and is placed in the town Fynshav on the eastern part of the island of Als. Originally, the sports centre was a traditional Danish sports centre with a main hall for sport activities (like playing hand ball), showering facilities and a cafeteria. In the mid-2000s, the volunteers behind the centre decided to work on getting an extension to the existing hall (they needed a place where people could warm up before matches etc.). In other words, a relatively simple project with no specific focus on energy issues. However, a contact at the local municipality made them aware of a funding call from the so-called *Lokale og Anlægsfonden* (in English: The Room and Facility Fund), which is a Danish fund supporting construction works within the sports, culture and leisure time sector. They decided to apply for support, and as part of the project description they also put emphasis on energy efficiency (this was partly inspired by ProjectZero suggesting them to make energy saving a pivotal element of the refurbishment proposal). They got funding[29], and then followed some hectic years for the volunteers with a lot of work related to obtaining additional funding from other funds and programmes. According to the interviewees from the Diamanten, an important reason for their success in getting funding was that one of the volunteers was competent in preparing applications. The total budget was 37 million DKK (5 million Euro), which was funded by the municipality, external funds and loans. The design of the renovation (including considerable extensions) was facilitated by external architectural and engineering companies. The design process continued for two years and involved several meetings and workshops for the volunteers. The volunteers were organized in several working groups. The renovation took place during 2009-10. Despite an increase in the total floor space of 1300 m^2, the energy costs were reduced by almost 60% with the new centre. The energy saving initiatives include (among other things): Insulation of the original hall, low-temperature heating system, solar heating (70 m^2 on rooftop), PV panels (90 m^2 on rooftop), LED lighting, ground-source heat pumps and a low-energy ventilation system based on natural ventilation, heat recovery and air-cooling based on heating cold tap water (intended for being used as hot water), natural overhead lighting, etc.

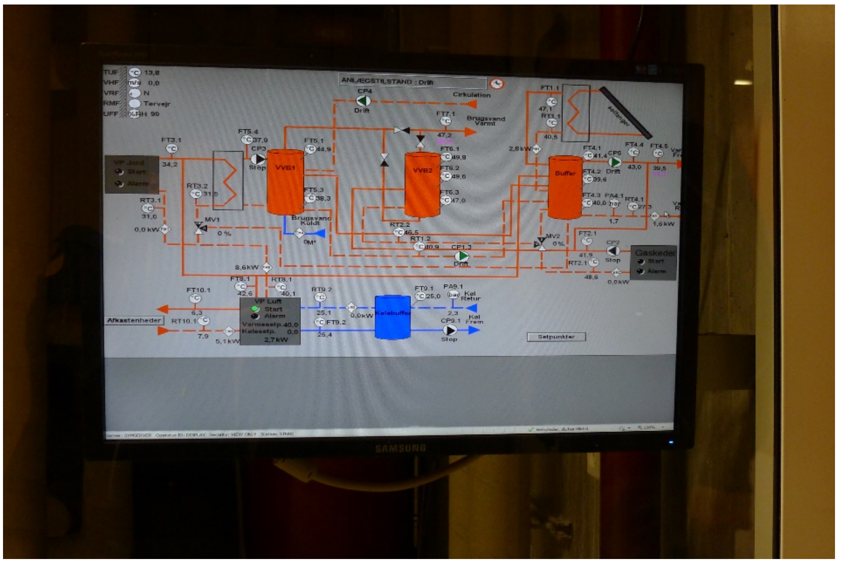
Main focus has been on optimising the (internal) energy flows of the building and to use "waste energy" from some subsystems for heating in other subsystems in order to minimize the energy consumption of the building. The example of pre-heating hot tap water by using the cold water for cooling the intake of air (in the summer period) is an example of this. The use of the electricity produced from the PV rooftop panels (6,6 kWp) for run-

[29] http://www.loa-fonden.dk/projekter/2010/diamanten-idraets-og-kulturcenter-i-fynshav/ (accessed 01-08-2017)

ning the installations (e.g. circulation pumps, heat pump etc.) is another. In that sense, this is a “smart” designed and controlled building, although the aim has not been to make the building interact with the external grid in any “smart” way.

The sports centre Diamanten

The main hall (this is the old, now refurbished, hall). Notice the natural lighting from above.



The energy system is mainly controlled via a control board. This screen shows an overview of the system and its energy flows.

Many elements of the solution were quite innovative and new, at least for sports centres in general in Denmark – and some turned out to work less effectively than others. For instance, the initial idea was to include a thin-layer PV material to be integrated with the outdoor construction materials. However, they turned out not being effective in generating electricity and were eventually skipped.

Overall, the technical system is rather complex and involves flows of energy between different subsystems. The daily maintenance and monitoring is carried out by the daily manager (who is one of the two employees at Diamanten). This person, who has a background as a carpenter, has developed a knowledgeable insight into the system and how it works over the years. This knowledge was developed during his participation in the planning and development phase as well as through his daily interactions with the system in the following years.

Diamanten is often used by ProjectZero as a demonstration case; thus, about twice a month, ProjectZero staff come by to show the centre to their visitors. Also, the sports centre on a regular basis submit energy consumption data to ProjectZero (part of the obligations to be ZEROsport certified) and they take part in quarterly meetings for all ZEROsport members. ProjectZero has been a good help with regard to getting publicity around the Diamanten and their refurbishment. Finally, it should be mentioned that the sports centre won the national 2014 Refurbishment Price[30].

The third socio-technical configuration, the ZERObutik initiative, is studied on basis of experiences from two ZERObutik certified groceries. Both are local branches of the large Danish grocery chain called COOP. In the following, focus is on the largest of the two groceries (called the “Supermarket”), as this grocery shop had done the most advanced and comprehensive measures in order to reduce their energy consumption. The supermarket is a middle-sized grocery (while the other ZERObutik COOP shops are smaller). Due to a fire in 2010, they had to make a thorough renovation of the shop. As part of this, they decided to replace the old cooling system (a central cooling system for the refrigerated counters) with a new one based on CO_2 instead of Freon (as the old one). The chairman of the association (formally owing the shop) did also work at the Danfoss company, and as they specialize in larger cooling systems (among other things), he suggested that the Supermarket should collaborate with Danfoss in order to develop a solution that would utilize the waste heat from the cooling system for the space heating system. This could entirely cover the needed space and water heating of the supermarket. Danfoss was interested in the collaboration as this offered them an option for pilot testing a new system they were developing at a location within convenient distance of the company (and its development unit). Other initiatives, in addition to the heat recovery system, included installing rooftop PVs to supply electricity for the grocery and sliding covers for the cooling counters (has become quite standard in many Danish shops nowadays). More recently, they have also decided to replace existing spot lights with LED spots, and got connected to the local district heating in order to sell excess heat from the heat recovery system to the local district heating company. The latter was also originally suggested by their contact at Danfoss. Thus, the Supermarket has turned the costs for heating (previously based on an oil-fired burner) into an income from selling excess heat. However, due to national rules, taxes were put on the sale of the (excess / waste) heat from the Supermarket to the local district heating company. This made it less attractive for the district heating company to buy the heat and also caused a lot of difficult paper work for the Supermarket. However, the Supermarket got help from the central administration of COOP to solve this and figure out the tax rules.[31] The solution of recovering the heat from refrigeration for space heating and delivering to the local district heating grid has now spread to other supermarkets in the Sønderborg area, including also su-

[30] http://renover.dk/om-prisen/tidligere-vindere/ (accessed 01-08-2017)

[31] Lately, the tax rules have been changed making it possible for companies to sell excess (waste) heat from their production activities to other customers (like district heating) without taxation.

permarkets related to the other major supermarket chain called *Dansk Supermarked Group*.[32]

ProjectZero did not originally play a role in relation to the initial decisions and implementation, but the Supermarket later became a ZERObutik member and received the first "gold certificate" issued by ProjectZero (for 51-70% energy savings). Also, ProjectZero has used the Supermarket as a "best case" in relation to press releases, news on their website and visits by externals. Thus, ProjectZero helps providing publicity about the initiative. Similarly, Danfoss has also often visited the supermarket in order to show prospective customers and other contacts the technical solutions. Now, the Supermarket uses the ZERObutik certificate actively in their advertising; thus, the certificate is always displayed in connection with their weekly adverts in the local newspaper etc.[33]

2.2.3 Discussion: Success and outcomes

In terms of realized energy savings, both the Supermarket (the ZERObutik configuration) and Diamanten (the ZEROsport configuration) demonstrate impressive results. Surely, both sites represent "best cases" within each configuration, and most of the other sites taking part in these configurations have demonstrated much smaller reductions. For instance, many of the shops in ZERObutik have only received a white certificate (indicating 10-20% reductions). However, with more than 130 shops already having received a certificate, this indicates a rather successful spreading of the ZERObutik initiative among the local shops.

On a more general level, the ProjectZero (with its many and varied initiatives), and the goal of Sønderborg becoming a CO_2 neutral area by 2029, appears to be rather successful. As mentioned, the overall CO_2 emissions have been reduced with 36% by 2016 (compared to 2007) and the energy consumption by 18%. In comparison, the national figures of CO_2 emissions related to energy consumption (all sectors) show a reduction of 31% from 2007 to 2015[34], while the final energy consumption shows a reduction of 11% from 2007 to 2015[35]. This shows that the reductions within the Sønderborg area is well above the national average (particularly on energy reduction), although it also demonstrates that much of the achieved local reductions can actually be attributed to the outcome of national energy policies. In other words, it seems fair to conclude that the initiatives in Sønderborg contribute to a local strengthening of the national trends of decarbonization and increased energy efficiency.

The interviewed shops and sports centres also regarded their measures as successful in the sense that they had realized significant energy savings – and thereby also economic savings (in the case of the Diamanten even despite a considerable extension and standard improvement of the facilities). The interviewees talked about economic savings as the primary motivation for implementing the saving measures, whereas environmental reasons were mentioned more sporadically.

For the shops and sports centre Diamanten, it is interesting to notice that competitions and rewards in several ways played a key role. The ZERObutik is built almost entirely on the idea of promoting action through the public recognition of energy saving actions by issuing certificates (typically handed over by the mayor at a public event with local media coverage). Also, it was originally a call (competition) for funding applications that played

[32] http://www.projectzero.dk/da-DK/Artikler/2017/Marts/Varmen-fosser-ud-af-Bilka-F%C3%B8tex.aspx (accessed 08-11-2017)

[33] However, this does not apply only to the Supermarket, but also all the other groceries being members of the local co-operative association, which organizes the local COOP supermarkets.

[34] Statistics Denmark, https://www.statistikbanken.dk/statbank5a/default.asp?w=1333 (accessed 02-08-2017)

[35] Calculated on basis of the annual national energy statistics from the Danish Energy Agency (*Energistatistik 2015* & *Energistatistik 2007*). https://ens.dk/service/statistik-data-noegletal-og-kort (accessed 02-08-2017). Notice that the energy consumption calculation includes all sectors, although only road transport in relation to the transport sector.

a key role in initiating the ambitions of creating a low-energy building at Diamanten. This indicates that competition, recognition and general publicity can motivate organisations like shops and sport centres to take part in energy saving initiatives.

With regard to the households, they also appeared to view the outcome of their investments and efforts as successful. Again, money savings were most often mentioned as a reason for doing the measures (even though the householders in general found it difficult to say how much they had actually saved), but also environmental reasons as well as considerations of being part of the overall energy transition were mentioned. In addition, some talked about developing individual solutions that would make them more energy-independent and resilient to external threats.

Compared with the households on the island of Fur, the awareness of time shifting electricity consumption in order to balance PV generation with consumption did not feature high in the Sønderborg interviews. It appears that the main reason behind this is that most of the Sønderborg households were on the annual net metering scheme, which does not incentivize time shifting economically (see previous on the difference between the hourly and annual net metering schemes). Interestingly, the only household on the hourly net metering scheme was also the only household reporting that they had changed daily habits in order to time shift consumption.

The households in general plugged-in the EV and started recharging upon home arrival in the late afternoon / early evening. This indicates a potential future systemic challenge as it adds additional power consumption to the already existing afternoon/evening peak (the "cooking peak") between 5 and 7 PM of households. Also, the EV recharging does not synchronize with the midday peak in PV electricity generation. Automated or remotely controlled recharging is often promoted within the smart grid field as a solution to this problem. However, the Sønderborg interviews indicate that these kind of solutions may face a challenge, as the habit of starting recharging upon home arrival also relates to a feeling of security associated with always being able to go for possible (unexpected) rides later in the evening. Finally, the limited driving range of EVs still means that the EVs in these households have not yet fully replaced the combustion engine car (used typically for longer-distance trips).

ProjectZero clearly plays a key role in facilitating, promoting and communicating the energy transition of the Sønderborg area. Based on the study of ZERObolig, ZERObutik and ZEROsport, it appears, however, that this role is less about *direct* consulting or implementation of measures, but more about supporting knowledge sharing, keeping energy savings and CO_2 neutrality on the local agenda and promoting publicity around measures taken by local actors. In a sense, a key contribution by ProjectZero is to ensure that "the pot is kept boiling". This is also seen in the stories of most of the visited sites (households, shops and sports facilities); in case of the households and the Supermarket, formal contact with ProjectZero was not in general made before the decision about energy saving measures had already been taken (and often not before their realization) – although it might be argued that the general awareness about the Sønderborg climate targets and ProjectZero might have influenced the decisionmakers indirectly. However, an exemption is Diamanten, where it was a central figure from ProjectZero, who originally suggested them to incorporate energy measures in the renovation project (but even in this case, ProjectZero did not directly engage in the sketching and realization of the project).[36]

[36] The direct influence of ProjectZero seems slightly more visible in relation to the ZERObutik sites more generally (except the Supermarket), as ProjectZero is active in reaching out to local shops (e.g. through personal visits) in order to make them interested in taking part in the ZERObutik initiative. However, also here, ProjectZero is not as such giving specific advices (offering consultations) to the shops, but instead provide inspiration through sharing best cases from other shops (e.g. via online newsletters and local media coverage) and in supporting the establishment of a local network of electricians (the energy consultants or "ZERObutik partners"), who can offer advices.

It is interesting to compare the role of ProjectZero with the role of Samsø Energy Academy (see later), where the active contribution by the latter appears to be much more "substantial" in the sense that the Energy Academy is often directly involved in developing and carrying out energy measures locally. ProjectZero identifies their own role and activities as being "transition management" or "transition leadership" (in Danish: Omstillingsledelse). In their own interpretation of this (Christiansen & Rathje, 2015), transition leadership incorporates a number of key skills and approaches, especially: Network building (engaging local actors and facilitate their mutual cooperation), being a catalyser for change (initiate and facilitate rather than design and control), bring the vision and strategies into focus and to debate locally, and create collaboration between universities (knowledge institutions), companies and authorities (the Triple Helix idea).

It was evident from our visits to the Sønderborg area that the vision of Sønderborg becoming CO_2 neutral was something that also "regular citizens" of Sønderborg had heard about and knew. In this way, ProjectZero has succeeded in creating and anchoring the vision within the local community as a shared vision.

In summary, and with reference to the MATCH framework, the main findings of the case study in relation to technology, markets and actors are:

- Technology: The solutions developed at Diamanten (ZEROsport) and the Supermarket (ZERObutik) were quite innovative and were in both cases developed in close collaboration with local companies. This shows the importance of the collaboration between companies and local consumers in the ProjectZero case, which also feeds into their vision of the green transition as contributing to local economic growth. The technical solutions applied in the households were not in a similar way innovative.
- Actors: Seen from the perspective of the actors, the initiatives were regarded as successful. Economic savings was in most cases reported as the main reason for engaging in these initiatives, although also considerations for the environment or the overall energy transition were also mentioned (and increased resilience through self-sufficiency with energy in some of the households). ProjectZero plays an interesting role in relation to developing and maintaining existing networks of actors and, in particular, nurturing the awareness of the CO_2 neutrality vision and goals.
- Market: Like on Fur, subsidies played a role in most of the studied examples (except for the ZERObutik sites). Thus, households got their investments subsidized through general tax exemption on EVs and favourable account settlement schemes (implying tax exemptions), while the sports centres received funding from private and public funds and programmes for their investments. In this way, most of the solutions studied are not "truly" commercial in the sense that they would work without subsidies of various kinds. But given these subsidies and external funding, the solutions were in general profitable to the households and sports centres.[37] However, the Supermarket is an exemption from this, as the technical solution (utilising "waste" heat from refrigeration for space heating) was profitable even without subsidies. This is also seen in that the solution developed at the Supermarket is now being implemented in other local supermarkets.

2.3 Case 3: Samsø – Denmark's renewable energy island and the NightHawks project

2.3.1 Background and project characteristics

The island of Samsø is located between the island of Zealand and the mainland of Jutland. It has ferry services to both Jutland and Zealand. The area of Samsø is 114 km^2

[37] However, it can be problematized to what degree the current market is successful in internalising the externalities of the economy, e.g. environmental and societal costs related to pollution, and in that sense is working as a "proper market". In other words, public subsidies can sometimes be seen as "corrections" to a failed market dynamic.

and it is the home of about 3,700 inhabitants (by 2017). The population of Samsø has almost halved since the beginning of the 20th century and is still in decline (was reduced by 12% between 2010 and 2017). [38] The island has its own municipality (the Municipality of Samsø). Agriculture and tourism are the most important businesses on Samsø. Among other things, the island is famous in Denmark for its “Samsø potatoes” (the Samsø potatoes are typically harvested earlier than potatoes from most other places in Denmark due to the mild climate on Samsø). The biggest town on Samsø is Tranebjerg (about 800 inhabitants) placed centrally on the Southern part of Samsø.

Energy saving and renewable energy transition has a long history on Samsø. In 1997, a group of islanders submitted an application for a competition of becoming the first Danish Renewable Energy Island project (applications from four other islands were also submitted). The competition was initiated by the Danish Ministry of Energy. Samsø won the competition with their plan on becoming fully self-sufficient with renewable energy within ten years. Then followed ten years of work on realizing this goal, which were to a high extent carried though by local NGOs and working groups of volunteering citizens. The goal was achieved by 2007, particularly through the following main measures: Installing new wind power capacity (11 x 1 MW onshore) owned by local citizens or windmill guilds (co-ops) and an offshore wind farm south of Samsø (10 x 2.3 MW wind turbines), expanding existing and creating new district heating areas based on local biomass and solar heating, helping homes outside district heating areas to save energy and convert to biomass-fired burners or heat pumps and installing new PV capacity. The key figures of the Renewable Energy Island (REI) Samsø initiative managed to engage a wide range of local citizens, businesses and organisations through what has been defined as “hope management”, which “focuses … on the careful building of a process taking individual or group stakeholders’ interests and worries as a starting point of situated negotiations” (Papazu, 2015: 197). Thus, even though the formal goal was to realize the REI plan, the transition was by the key initiators very much framed within the context of addressing local threats and challenges, such as local job creation, as a strategy to combat the decline in the island population. In this way, the initiative and transformation were flexibly adapted to the local citizens’ and stakeholders’ interests and aspirations. For instance, besides some idealistic viewpoints, the local farmers were encouraged by the economically-driven incentives related to owning land sites that were suitable for renewable production (wind power). In particular, cooperative ownerships have increased the acceptance of energy projects.

With the realization of the REI plan in 2007, the island had become self-sufficient, if measured by the annual, total renewable energy generation. However, there is still an exchange of energy with the mainland of Jutland through a sea cable, and the island is not as such “truly” independent of the wider energy system. Thus, on calm days, the island imports electricity from the mainland in order to cover the lack of local wind power generation. Also, the transport sector and some of the individual heating outside district heating areas are still fuelled by fossil fuels (even though this consumption can be said to be “offset” by the annual surplus of RE generation).

Thus, the new challenge of Samsø is to get entirely rid of using fossil fuels, i.e. in particular replacing fossil fuels for transport with renewable alternatives. On the national level, this is expected to be achieved in 2050 (see previous on Danish energy policies), but Samsø aims for reaching it by 2030, as a pilot project for the rest of the country. In relation to this, seven goals to realize the vision have been formulated. These were developed by the Samsø Energy Academy (see below) in collaboration with the Danish energy planning consultancy EnergiPlan and with input from the municipality, local citizens and other stakeholders (local businesses, associations etc.) through, among other things, so-called “open space” meetings, which is structured debates and brainstorm meetings. One of the seven goals is that half the local cars must be electric by 2020 (however, not likely to be reached in time, according to the Academy). Another goal is that heating in

[38] Statistics Denmark, http://www.statistikbanken.dk/BEF4 (accessed 28-07-2017)

local households must be reduced by 33%. Also, the Samsø Municipality, supported by Samsø Energy Academy (see next), are currently working on plans for a local biogas plant, which – on basis of local biomass resources – can produce biogas that could fuel the local public bus line or the ferries to Jutland.

The Samsø Energy Academy (opened in 2007) is a demonstration and meeting place for local citizens, guests and visitors with a general interest in sustainable energy, community power and sustainable development.[39] Visitors particularly wish to hear about the island's experiences with anchoring projects through involvement of local citizens. Also, the Samsø Energy Academy (SE) works on many different projects related to the continuous development of Samsø to become a fossil-free island. The staff of SE includes about nine employees, who work on different projects typically funded by national or international programmes. Formally, SE is owned and managed by the association of the same name (Samsø Energy Academy) with the purpose to be "instrumental in the development of competencies within sustainable community development and the communication of knowledge about holistic processes of co-operation. The association is to promote and encourage co-operation between citizens, businesses, public authorities and research and educational institutions on the basis of Samsø as a sustainable local community."[40] The board of the association consists of 7-8 members elected among the members, although Samsø Municipality and Region Midtjylland (the local region) each appoints one member.[41]

Lately, the SE has set out a range of initiatives to reduce the energy demand. Some initiatives focus on installation of smart electricity loggers in buildings to identify unnecessary consumption, decrease heating demand and increase energy efficiency. Also, as part of an EU-funded international project called *NightHawks*[42], The Academy visited 16 shops and other local businesses during 2014-15, offering them consultancy about possible energy savings. Moreover, the business staff was offered education about energy saving. During the visits, temperature data-loggers were installed in different places in the buildings to gain information about the opportunities to reduce the heating or cooling. These visits have resulted in concrete advices to save energy and, all in all, reduced the average energy consumption by 11% since 2014.

In the following, we will focus on the shops and other local businesses taking part in the NightHawks initiative. In total, two shops (a supermarket and a convenience store), one community centre and a small restaurant & hotel have been visited as part of MATCH project.

The original idea behind the NightHawks project was to do so-called "night walks". As the project website explains: "Night walks are on-site energy surveys held at times when businesses are closed to the public. Energy experts conduct the survey with a view to identifying areas of energy waste within a business, in order that a bespoke action plan can be produced and implemented so as to enable direct and significant energy savings."[43] However, the SE slightly modified and adapted the concept to the local context on the island. First of all, they visited the businesses during day hours, which made it

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[39] The domicile of the Energy Academy houses in addition a variety of actors (e.g. researchers and scientists) running a broad spectrum of energy counselling services for commercial and private customers and organize guided energy tours, workshops, and seminars etc.

[40] http://arkiv.energiinstituttet.dk/71/ (accessed 08-11-2017)

[41] Before 2007, the energy initiatives – and the Renewable Energy Island project – was anchored to the association "Samsø Energy and Environment Office" (established in 1997) and the Samsø Energy Company, which was founded by the Samsø Municipality, the local Business Council, the local Farmers' Association and Samsø Energy and Environment Office. The Samsø Energy and Environment Office and Samsø Energy Company (established in 1998) had a close collaboration and shared secretariat. They were primarily financed by public money and project funding. Due to lack of funding the Samsø Energy Company closed in 2005. The Samsø Energy and Environment Office is now part of Samsø Energy Academy.

[42] See http://www.night-hawks.eu/

[43] Quotation from: http://www.night-hawks.eu/night-walks/ (accessed 03-08-2017)

possible for them to talk with the business owners and staff members about their daily routines etc. With regard to identifying areas of energy waste, SE instead used smart meter data and data from temperature data-loggers to map the 24 hours energy performance of the buildings. The latter were used to identify (unnecessary) high energy consumption and develop suggestions for energy saving measures. Focus of the site visits and the analysis of the measured data were in particular on options for energy optimising the heating system (e.g. by night set-back), cooling (e.g. by turning off bottle coolers during night hours) or replacing inefficient lighting with LEDs etc. In explaining the underlying approach behind the initiative, SE emphasises that it was important to come up with ideas that would not compromise comfort, sales or the daily work routines at the supermarket.

2.3.2 Socio-technical configurations applied in the project

Even though the sites visited as part of the MATCH project are rather different (a supermarket, a community centre and a small restaurant & hotel), they were all part of the NightHawks project and in this way part of the same socio-technical configuration. In the following, the key elements linking the sites together through the intervention of the Samsø Energy Academy are identified (the role of SE will also be explored separately in the following). Below, the supermarket is used as a through-going case, while comments/observations from the other sites are included when relevant.

	Energy savings in local business *NightHawks*
Technical elements	Monitoring consumption (smart meter data, temperature dataloggers) Conventional technologies (timers, LED lights etc.)
Social elements	The Samsø Energy Academy Trust Dialogue-based processes Local networks Funding

On basis of several site visits, dialogue with the staff and monitoring the smart meter data and profiles of logged temperature data, the SE came up with a variety of suggestions of energy saving measures in the supermarket (see the list of suggested measures in Jantzen et al., 2017, and the theoretical background in Jantzen & Kristensen 2014). The management of the Supermarket decided to apply a number of these measures. The SE calculated that the total savings of the implemented measures would account to about 7.5% of the annual energy budget of the shop, i.e. about 8,400 Euro/year or about 58,000 kWh/year. At the end, the management states that they had saved even more than the calculated.

One of the implemented measures was to lower the room temperature of the Supermarket during night hours (the shop is closed from 8 PM to 8 AM). The SE proposed a 1 °C reduction (from 20 to 19 °C), which alone should save about 8% of the total energy consumption for heating. This was realized by simply adjusting the control of the heating system of the building (i.e. no need for installation of new technology). However, it took some dialogue and negotiation with the staff to settle on the specific timing of when the night set-back should start and end. For instance, a cleaning worker is cleaning the shop during night, and some members of the staff (e.g. the butchers) are meeting early in the morning. In other words, the specific settings of the control had to be adjusted to the practices of the staff members. This exemplifies how prolonged dialogue is a key (social) element of the work of SE and the realisation of the suggested measures.

Closely related to this, trust is also a key social element. In general, the sites approached by the SE for the NightHawks project welcomed the SE and were happy to collaborate. Typically, they would provide the SE with the login credentials for the online access to their historic electricity consumption data (collected via smart meters). Also, the SE was generally allowed to walk around in the shops on their own while doing their observations and measurements (which implied many recurrent visits). In this way, the SE could more or less "come and go" as they liked. It is likely that this trust in SE to a high extent is based on the long history of the energy transition project on Samsø as well as that people in general know each other from other contexts (cf. the small population size of Samsø). Also, the key staff members of SE where also active within other arenas (e.g. local policy). All in all, SE and its staff members appear to have become household names to most people on Samsø. As several of the MATCH interviewees explained, they believed that the people from SE were the one's on the island that knew most about energy and energy savings – and they also trusted that advices from the SE would be impartial. Over the years, trust in SE has been built up, and is probably one of the most valuable "capitals" of the SE today.

When it comes to the technical elements, these are – as already indicated – rather conventional in the sense that none of the solutions included demonstration of (radical) new technical solutions (as was the case on Fur and in ZEROsport and ZERObutik, cf. previous). Instead, the "innovative" aspect of the NightHawks project (as carried out by SE) is more related to how the process of identifying and carrying out energy saving measures is organized and performed by SE. Here, SE works both as a facilitator of the process (e.g. directing the awareness of businesses towards the issue of energy saving) *and* is strongly involved in the realization of the measures. Thus, they frequently visit the sites to see if "things are working properly" and talk with the owners or staff members if there are any problems. In this way, SE continuous to be the "supervisor" to be contacted if the businesses experience any issues with the energy saving measures. This seems partly facilitated by Samsø being a small island and that the SE staff therefore often happens to "pass by" a site and "pop in" for a talk or to look at something. However, the exact role of SE is manifested slightly different from site to site. In the Supermarket, the SE staff is clearly ascribed a role as the energy experts. Thus, the new director does not really know much about what energy measures that have been carried out or how they work. Therefore, he relies almost entirely on the support of the SE for the continued monitoring and maintenance of these measures. Different from this, one of the key persons at the community centre (a volunteer who has retired from her work) is the one who is actively managing the energy and ventilation system. She originally got help from SE to figure out how the system works and how to make it more efficient (by adjusting the running hours of the system to the actual needs in the buildings), but is now the person who manages the system on a day-to-day basis (although she still relies on the SE if she encounters more complicated (technical) issues). Based on these observations, it appears as SE has developed an approach or practice that makes them flexible with regard to adapting their interaction and role to the characteristics and specific needs of the individual site.

Even though the (technical) solutions appear rather simple, it in many cases turns out to be more complicated to develop and carry out the saving measures. For instance, the energy consuming devices are in some cases third-party property. One example of this is some of coolers in the supermarket that are provided by the suppliers of, e.g., beverages. Typically, an agreement is made between the supplier and the shop, which gives the shop higher profits of the sales from the cooler. In return, the shop must accept that the supplier installs its own coolers with its logos etc. It is the responsibility of the supplier to maintain the cooler, but the energy costs are paid by the shop. This exemplifies the so-called principal-agent problem (Eisenhardt, 1989), i.e. an uneven distribution of energy saving investment costs and energy saving benefits between agents. In this example, the supplier has no incentive to provide the shops with energy efficient (but often more expensive) coolers, as the energy costs are paid by the shops themselves. Also, this type of arrangement complicates doing energy saving measures (e.g. controlling the cooling with timers turning of the coolers in the night or changing set temperatures), as tinkering with the devices potentially can violate a third-party property. For instance, the owner of the restaurant & hotel has not installed a timer on beer cooler because the supplier (a brewery) has told him that it must not be turned off.

Local networks and relations also play an important role for the development of this socio-technical configuration. First, the businesses participating in the NightHawks project were mainly chosen through the local network of the SE staff. Second, the energy saving measures are spreading between businesses via informal networks. An example of this is two smaller convenience stores, where the managers know each other privately and are exchanging experiences with different initiatives to save energy. Also, one of these managers originally contacted the SE for help and advices, because the chairman of the association behind the convenience store also was chairman of the local district heating utility and, through this, knew the SE people very well.

Finally, like in the previous cases, external funding also plays a key role for the development of this configuration. Partly through direct EU funding of the NightHawks project, partly through the general public funding of the SE, which makes it possible for the staff to continue their engagement in the businesses (even after the funding of the NightHawks project has concluded).

2.3.3 Discussion: Success and outcomes

Is the NightHawks project a success or failure? On one hand, it certainly appears as a success: Significant energy reductions were achieved through rather simple socio-technical solutions and typically with very small investments in new equipment (if any). Often, the savings were achieved simply by a more energy efficient management of the energy systems of the businesses. Also, the businesses taking part in the project appear to be happy about the interventions and believing that they save energy expenses. As discussed in the previous, the successfulness of the initiative appears to a high extent conditioned by the general history of the REI and, specifically, the trust in the SE that has been developed on the island over the years. However, this might also limit the extent to which the method and lessons learned from Samsø can be transferred to localities without the same level of trust in a local entity like SE.

On the other hand, it appears to be a relatively expensive method, as it requires many hours of work (of SE) to develop and implement the measures – as well as continued help and supervision afterwards.[44] At least if compared to solutions based on “do-it-yourself” check lists or instructions, although the latter methods might not be as efficient as the approach of NightHawks and SE. It is therefore an open question to what extent this could work on market conditions and without public funding.

A final comment on the character of the work carried out by SE: At first glance, the method employed by the SE might seem rather simple. However, the sites of intervention often turn out to be surprisingly complex. A site like the Supermarket, e.g., is a complex of interrelated practices and networks of actors. Even apparently small modifications like a temperature night-setback might interfere with practices of cleaning during the night or staff members meeting early in the morning. Similarly, installing timers on coolers might interfere with third-party properties (not to mention national regulations governing storage of foodstuffs).[45] Consequently, instead of being a “simple technical” intervention, it is rather a complex social and organisational task, which also means that a successful intervention in general depends on many actors’ active involvement.

[44] In the NightHawks project, this was financed by EU – and the consultancy was free to the participating businesses.

[45] See also Jantzen et al. (2017) for an example related to replacing traditional light spots with LED spots.

Finally, it should be noted that the case study shows differences between the sites (businesses). Compared with the community centre and the restaurant & hotel, the Supermarket appears to be the most complex site; both in terms of material and technical complexity (many relatively advanced energy systems, partly interrelated and interfering with each other) as well as organizational complexity related to the size of the staff (many practices and many people to involve), ownership models (e.g. coolers owned by third parties) and the role of the central office at the supermarket chain (of which the Supermarket is a branch). By contrast, the other sites typically had one person in charge of the energy system and the decision-making related to doing changes.

In summary, and with reference to the MATCH framework, the main findings of the case study in relation to technology, markets and actors are:

- Technology: Only “conventional” technologies were applied in this configuration, because focus was not on technology development as such. The innovative aspects of the NightHawks project were on the approach of identifying and realising (organising) energy saving potentials, for example by placing temperature loggers in the shops.
- Actors: Seen from the perspective of the actors (SE and the businesses), the initiative was rather successful. The relations between SE and the shops etc. are embedded within the local social networks on the island, and in particular shaped by the long history of the REI and SE (including a high level of trust in the SE).
- Market: Like on Fur and in Sønderborg, subsidies play a key role for this configuration. It is questionable if this initiative could have been realized without external funding. The realized energy savings can be considerable and do not require significant investments in new equipment or installations. However, the costs are mainly related to working hours connected with identifying, carrying out and maintaining the saving measures.

3 Literature

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