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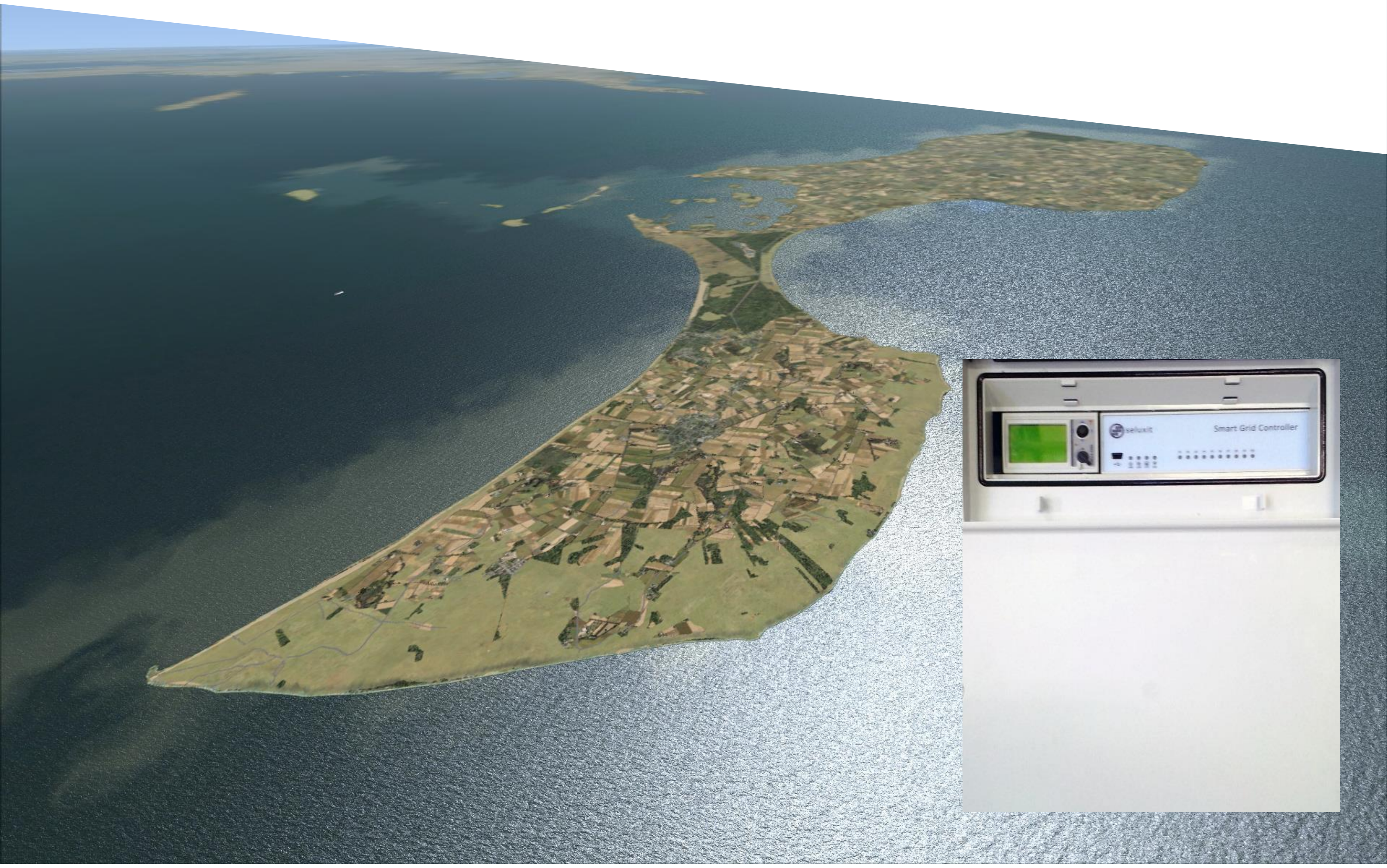
Smart Grid in agriculture on Samsoe

April 2015



Smart Grid in agriculture on Samsoe

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Projekt nr. 2012-1-10753

Samarbejdsteam:

BK Automation ApS

VE-Net

NRGi

ENERGI AKADEMIET

seluxit

TEKNOLOGISK INSTITUT

Bidrag til projekt:

mjk a xylem brand

Lars Hansen
Teknologisk Institut
April 2015

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1 SUMMARY

The basis of the project idea was formulated and prepared by BK Automation and Technological Institute where the agriculture on the island Samsoe should be the centerpiece and demonstration site. Furthermore it fit nicely with NRGi's replacement of all their power meters in the supply area, including Samsoe, to meters that could be read remotely on an hourly basis and with a simple function build in so that the meters could receive commands via Powerline. This feature and protocol could be used to turn off and on power-consuming appliances and devices to be included in a Smart Grid. NRGi should themselves develop software model and management strategy with ideas anchored in the organization so that it not only was a model that was developed for the project but as close to reality as possible. It was a success and the result can steer-res in Annex 1.

The project team was established with the purpose "to refine and define the project." However, it soon became clear that NRGi was not be able to offer that their Powerline system could be used for communication in the project and we therefore chose to take advantage of the Internet, which subsequent will be more open to further development of the unified platform. Power Line therefore was deselect in favor of a more open standard, which can be used across the supply areas and business boundaries. This refers to that when an aggregator in the future will use the developed Smart Grid platform it will be possible without the need for the power utility's form of communication in the current area.

After the first project meeting LIAB was replaced with Seluxit who could offer a Smart Grid control box with 10 relay outputs for the project. Measurement and data collection was based on Technological Institutes proven platform using a flexible data logger that handles, with software extensions, all input signals and protocols. The data logger is based on operating system Linux, an open standard, and therefore anyone with knowledge of Linux, c, c ++, can further-develop and customize the system measurements as needed. Collected data is automatically sent to a server located at TI. The transfer is done via normal Internet. See the following system and block diagram containing the setup at Soerendens pumping station and the new project setup and design.

BK automation and the Samsoe Energy Academy is located on the island Samsoe and has a vast knowledge of the local community and thereby Brian Kjaer found 5 farms that had an interest in participating in this project. Via a short visit specific farms were selected and entered in the project application.

The project had selected the following sites before the project started:

Farmer Henning Madsen, Tværvej 1 Langmarkskolen
Farmer Aage Madsen, Herring Balle 35 Besser
Farmer Peter Baltic, Byvejen 25 Hårdmark
Director of the local feed company, Lars Balslev
Samso Wastewater A / S

In the demonstration phase the pumping station Soerenden (Samsoe Sewage A / S) and Peder Oester (Ice bank) were used and the result is described later in this report.

Through the project NRGi has developed and documented their internal solutions of a software model that could be the basic intelligence to a comprehensive Smart Grid control. Appendix 1 describes the function and all communications interfaces in the model.

System and block diagram - Soerenden Pumping Station:

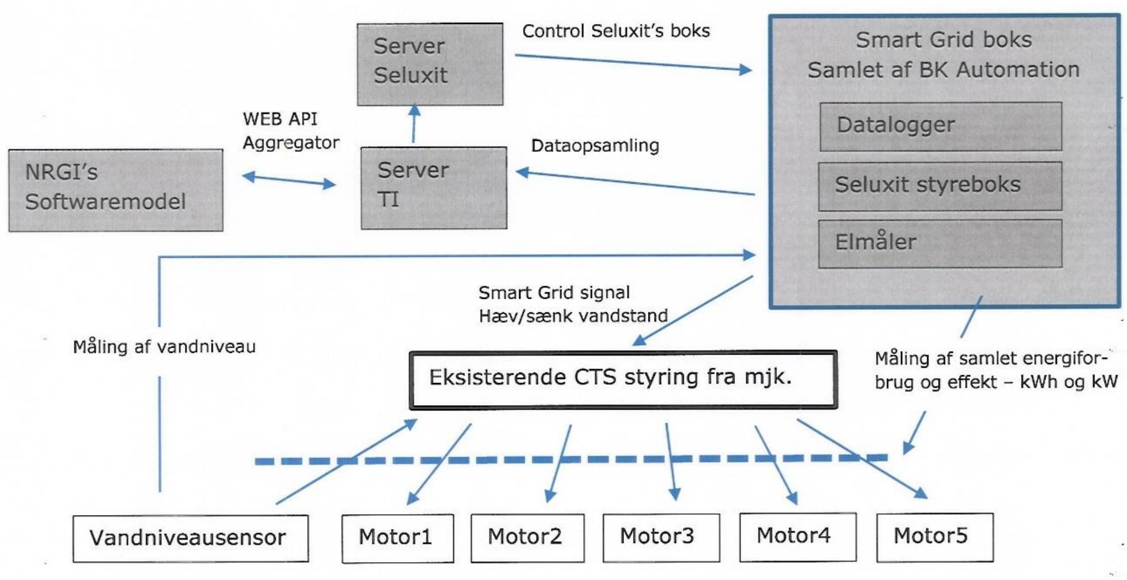

Figure 1

CTS from mjk - shows the status of Smart Grid signals. The picture below shows the 3 modes that we had the opportunity to put the pump station in, low, high and normal water level.

Figure 2 Gray blocks in the above block diagram are blocks that the project has developed

and implemented to connect devices like ice banks and pumping stations to the project Smart Grid technology. The white blocks already existed before the project started. The pumping station pumps about 360m3 of water per hour and flexibility occurs by changing the set point of the water level in the inlet to the pumping station.

The focal point and the main emphasis in this report is of a technical nature including:

1) Structure of the overall Smart Grid Platform - Hardware
2) NRGis software model - Annex 1
3) Analysis of the individual units

The project team has placed great emphasis on solving practical problems and challenges that have been underway in the project so that we ended up with a practical, workable and running platform. Via the moving platform a series of case studies describing the test on different devices have been prepared.

2 CONCLUSION

Agriculture in Denmark consumes considerable amounts of electrical energy and can help to realize the Smart Grid technology in Denmark. There is a lot of work to identify the single units concerning operation, usage patterns and security before the extent of flexibility can be found and thus determine if the business case is profitable.

The project team has developed and designed a robust Smart Grid Platform that in the future can be used for specific Smart Grid controls and possibly be implemented directly in larger systems and appliances and thereby making them Smart Grid Ready. It is furthermore possible to adjust the software model and thus align a management strategy depending on whether one is utility or future aggregator and what aims the control must have. The market plays both a great and decisive role in relation to the resources accruing to the end user when a final system is expanded in Denmark. This refers to if the price of electricity falls or other benefits that could accrue to the end-user, if any. The future deployed Smart Grid strategy can therefore easily be implemented in the project platform - it will be about software adjustments in the underlying software model.

The idea of NRGi's software model is that you e.g. send out a 'stop for power consumption' to a unit. Then a measurement is made and data are saved for statistics of how much power the command represented in watts. Based on a large amount of issued commands it’s therefore possible to start looking at what experience tells about the device and thus make a qualified guess about the, at any time, flexibility the unit has for on, off and normal mode in the system. When this experience is collected across the devices it is now possible to look at the individual aggregator - what flexibility does the aggregator contain and its part of the grid. In this way you can stick to a simple description of the individual units - such as peak powers, medium powers, etc. and ignore whether it is an ice bank or a pumping station. Collected data furthermore take into account user patterns. This strategy is excellent when different units are gathered and controlled according to the same strategy.

The model is described in Annex 1.

5 cases described and tested:

1. Pump station
2. Onions drying 1
3. Onions drying 2
4. Grain Drying 1
5. Grain Drying 2

All 5 cases have been described theoretically and measuring equipment has been implemented. Based on the initial measurements we performed a risk analysis and created guidelines to minimize any risks. In the first 2 cases, cases where closed with a real demonstration phase. In the 3 remaining cases the risk factors where considerable high. This does not mean that it can not be used on a national scale. It simply means that there should be implemented a security setup but this was out of the scope in this project.

We must recognize that the selection procedure of units that would be involved in the demonstration phase of the project was underestimated and later it turned out that we should have devoted more time to this process and analysis on the devices. Several of the specific demonstration site proved to be difficult to control with on / off / normal signals and the project ended with that 2 out of the 5 selected units successfully could be connected the Smart Grid and project control device. E.g. it would be too risky to turn on and off for 600 tons of onions at Brdr. Kjeldahl in case of system failure. Therefore, this process was only analyzed theoretically. The case about the dairy describes how this process could be solved successfully. This case has been prepared by the Energy Academy.

Security and risk of error by controlling the cold storage (Brdr. Kjeldahl) and the grain drying process (DLG) was after the measurement period deemed too high and these were discarded in demonstration phase but was analyzed theoretically so that the result is in total assessment of the Smart Grid platform.

Although the platform proposes a control of many different devices, we can see that a grouping and control of pools of similar devices will make it possible to optimize and streamline the control. In addition, for example, a review of the milk cooling process at farmer a probably could be reused at farmer b. An approach like this could be used in connection with that an aggregator planned that the agriculture could be interesting as a business and would base its IT infrastructure on the Smart Grid platform of project.

Always use the default security on the Internet to ensure the platform's interface as possible. Appendix 4 is an example of a layer of security that can be placed on the platform if the technologies of Microsoft are utilized.

3 BACKGROUND

Over the years Denmark has gained considerable international recognition of the handling of large amounts of renewable energy, decentralized energy production and energy efficiency.

When other countries look for examples of intelligent integration of renewable energy and Smart Grid they look towards Denmark and the island Samsoe.

Samsoe's reputation as a renewable energy island is not only a good story. It is also the story of how an entire population have had a target to become self-sufficient with renewable energy. The project started in 1998 and the goal has succeeded so well that today it has achieved 100% self-sufficiency of electricity from wind turbines and about 70% of heat consumption with straw and solar heat. Finally the entire transport consumption equals the surplus of the offshore wind power generation.

In the future, smart solutions will contribue to resolve the anticipated challenges with fluctuating renewable energy from e.g. wind turbines, and even if Samsoe is not isolated in respect of energy, it is important to be prepared. Because of that the Energy Academy together with NRGi Seluxit and Technological Institute participated in this project which had the purpose to find out how agriculture and other major electricity consuming devices could be part of a smart electricity system with the ability to control the consumption.

4 PROJEKT DESCRIPTION

This describes the project setup and the essential subject to work with for the project team. The idea was to use the agriculture on Samsoe as location and to test whether the agriculture could contribute with consumption and flexibility for future Smart Grid. The utility company should be in charge of software model and the underlying control strategy (Annex 1). The figure below shows the project structure which consists of 9 Work Packages:

Nr	Name	Description	Responsible
1	Projekt Management		DTI
2	Analysis of user needs	Contact to farmers on Samso	Samsoe Energy Akademy
3	Analysis of control needs, hardware, signals and protocols	Clearing and choice of signal types and protocols	BK Automation
4	Survey of energy consumption in agriculture	Analysis of energy consumption in agriculture	Samsoe Energy Akademy
5	Adjustment of steering box	Customizing the Smart Grid platform	DTI
6	Hardware Installation	Construction and installation of the control box at the farms	BK Automation
7	Software for the smart grid control box - including iPad / iPhone application	Development of software model and documentation	NRGi
8	Running Smart Grid	The demonstration and testing phase	DTI
9	Dissemination activities	Dissemination of project results	VE-NET (TI)

Table 1

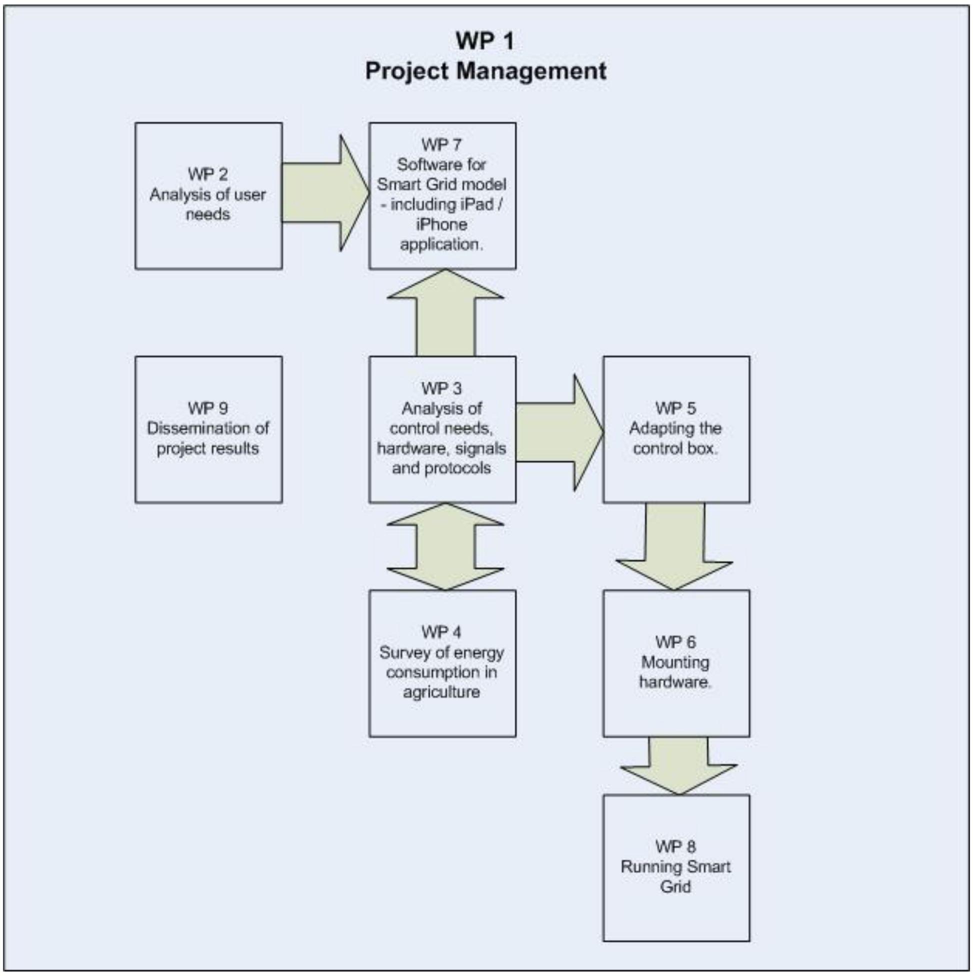

Figure 3

The responsibility for the work was delegated according to the above table. Those responsible should also report to the project management in WP 1. It gave the project an excellent workflow and more work packages could start in parallel. BK Automation and Samso Energy Academy was responsible for the local contact on the island with farmers MJK and Samsoe Sewage A / S.

5 AGRICULTURE ON SAMSOE AND IN DENMARK

Energy use in agriculture
According to the report "Survey of energy consumption in enterprises", prepared in 2015 for the Energy Agency of Viegand & Maagøe, the distribution of energy consumption on the main types of energy is as shown in the figure below.

As shown motor fuels form approximately 40% of the total energy consumption. It also shown that about 36% of the total energy is used for heating and CHP. Finally, that the electricity consumption is approximately 24% of the total energy consumption.

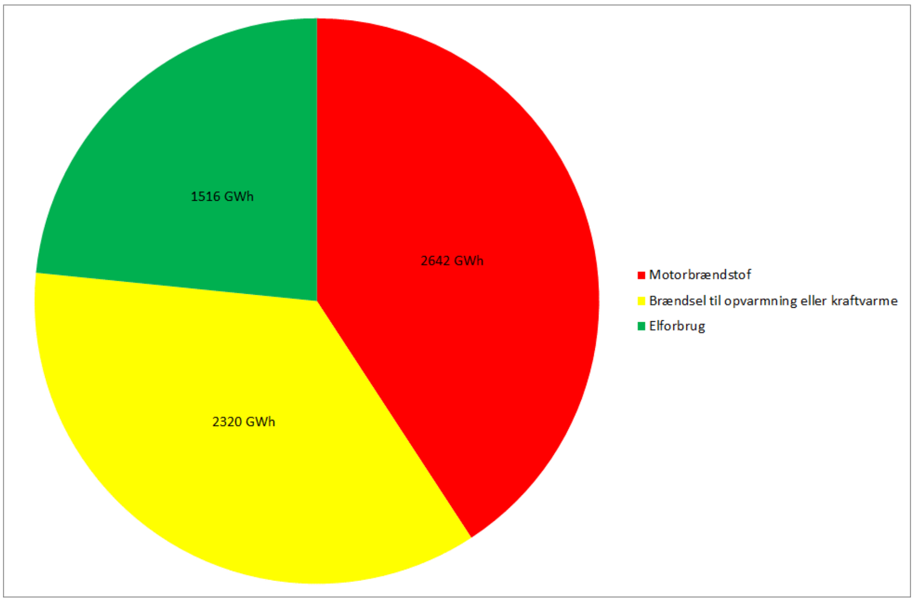

Figure 4

Fuel consumption in agriculture
As shown liquid fuel (heating fuel and motor fuel) forms approx. 62% of the total fuel consumption. It also shown that renewable energy represents about 12% of the total fuel consumption. Solid fuels account for about 12% of the total fuel consumption. Finally, the electricity consumption constitutes about 24% of the total fuel consumption.

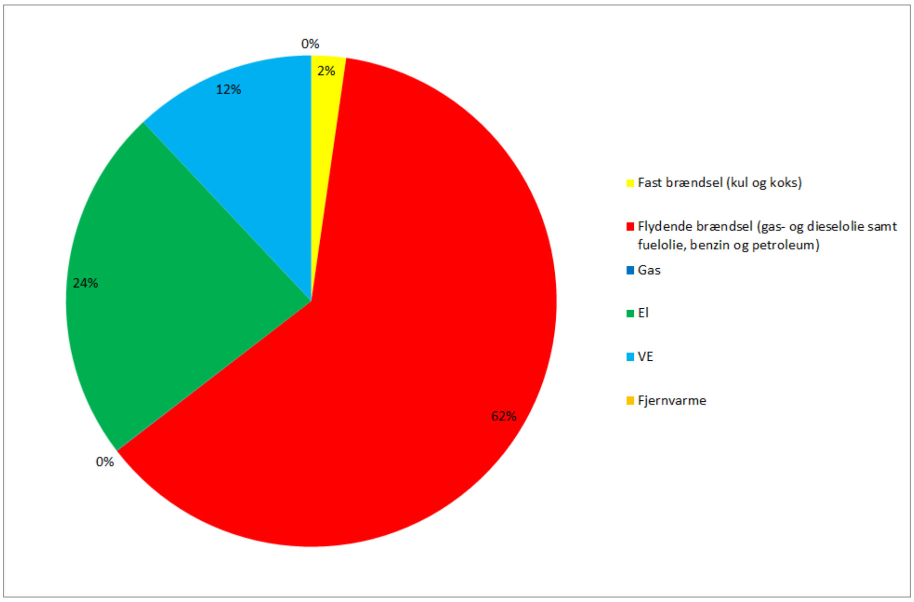

Figure 5

Power consumption in agriculture in 2012 – 1.516 GWh

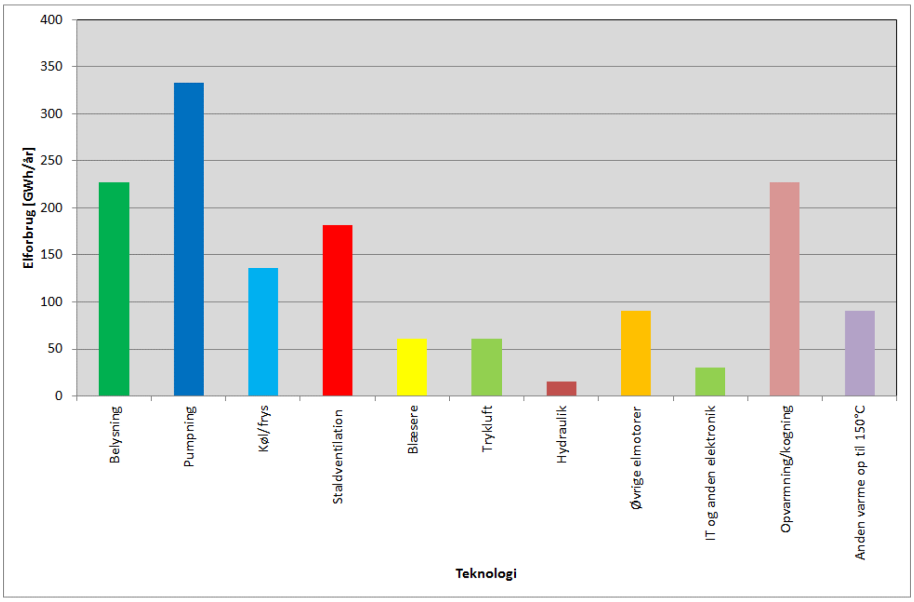

Figure 6

In the figure above a survey of the power consumption in the agriculture is showed. Power consumption for pumping forms, as seen, the largest single consumption. Consequently, the consumption is approximately 334 GWh per year equal to 22 % of electricity consumption in agriculture. 9 % of the power consumption is used for pumping water and manure internally in the agriculture and irrigation accounts for 13% of power consumption.

Power consumption for stable ventilation represents 182 GWh or 12% of the power consumption while electricity consumption for blowers for drying crops and blowers for grain transport accounts for 61 GWh or 4% of power consumption.

Power consumption for cooling forms 136 GWh per year equal to 9% of power consumption. The power consumption is used for cooling of milk at the farms before pickup and cooling of various vegetables such as onions.

Electricity consumption for other kinds of heating up to 150 °C is 91 GWh per year equal to 6% of power consumption. The power consumption is used for heating lamps used for heating in piglets corners in maternity wards, heat fans used in climate stables (used by now no more) and water heaters used to heat the cleaning water for e.g. milking equipment and tempering of drinking water to calves. The power consumptions for the three objectives seen in the figure below.

Power consumption for heating/boiling represents 227 GWh per year, equal to 15% of power consumption. Power consumption is mainly used for infrared lamps in barns.

Power consumption for fans and blowers and other kinds of heating up to 150 ° C and heating/boiling

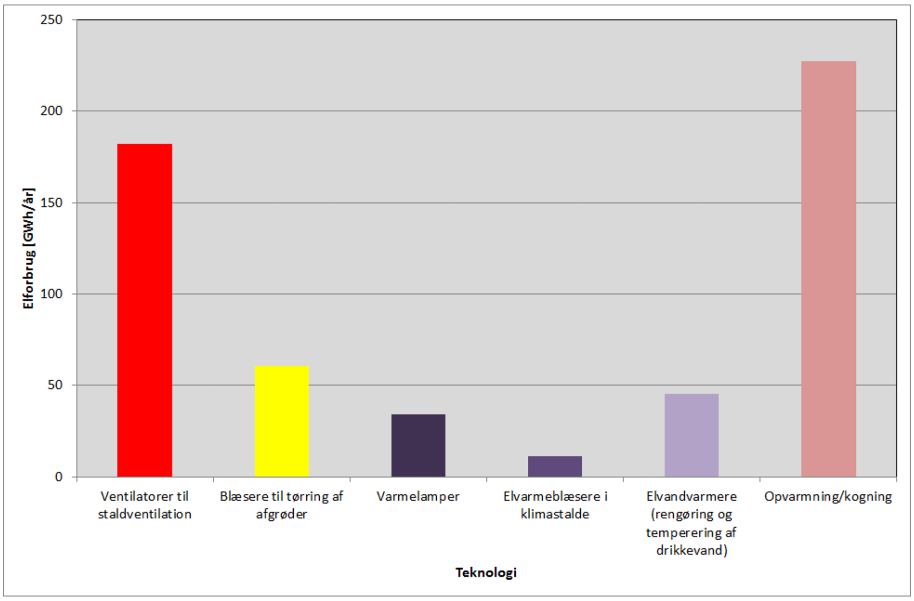

Figure 7

The figure above shows the power consumption for fans and blowers and other heating up to 150 °C and heating/boiling. This is a form of process equipment in the stables. The figure shows that about 45 GWh is used for hot-water tanks.

Electricity demand as "movable" - 381 GWh (25%)
The figure below shows the power consumption for pumps for irrigation, water heaters for cleaning and tempering of water and cooling/freezing. The total power consumption for the three technology areas represents 381 GWh. For these technology areas, the consumption can "be moved". This means that the consumption can be moved to times when there is a surplus of power and electricity is cheap.

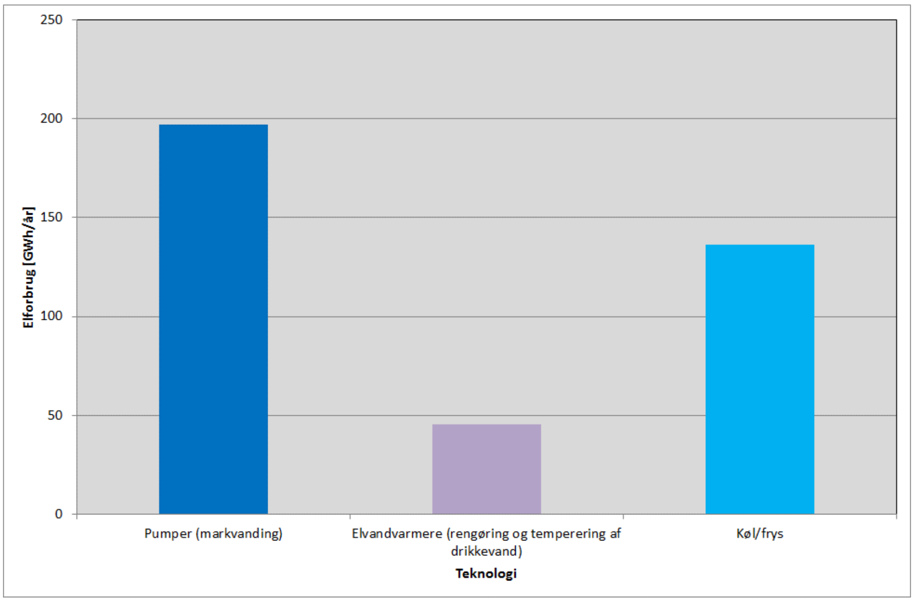

Figure 8

Heat for processes

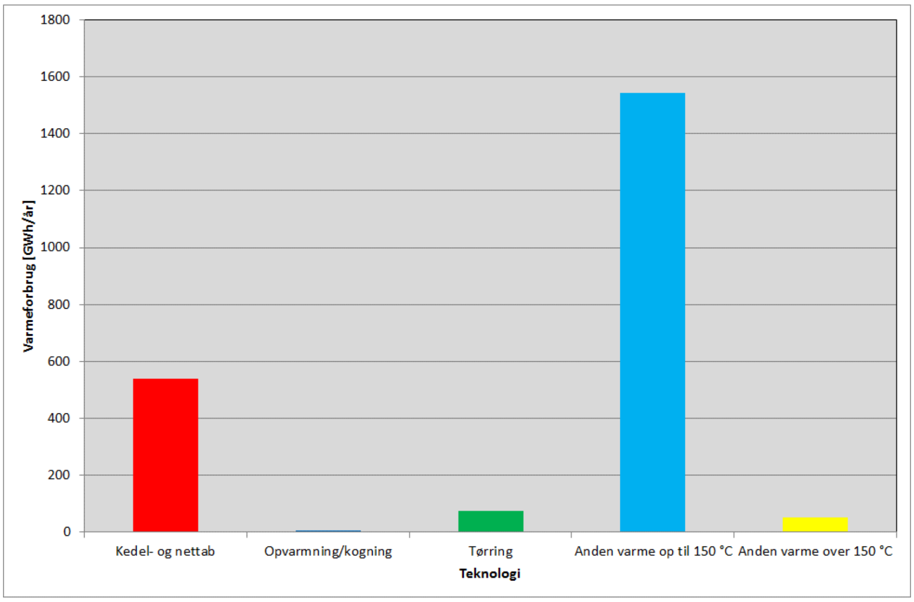

Figure 9

In the figure above a mapping of heat consumption processes in agriculture is shown. The heat consumption for the other kinds of heating up to 150 °C form, as seen, the largest single consumption (1.544 GWh).

This is the heat to shed heating in pig farms (primarily for maternity and piglet wards) and chicken houses. This heating depends on housing systems, bedding, over-coverage/caves etc. The heating of barns and chicken houses is primarily using heating oil. An opportunity to utilize excess power will be to use electricity as warm-up source at night and at other times when it is cheap.

6 DEMONSTRATION AND TEST ON SAMSOE

6.1 The farmer – Peder Øster

Milk cooling

Immediately after milking, the milk must be cooled from 38 °C to 4 °C and maintained at this temperature, until it is picked up. The milk can be cooled in different ways and in some cases, the cooling takes place in a cold storage or ice tank. The most common design of the ice bank is the so-called ice-on-tube where the ice formed on the outside of a tube bundle. Another option is an ice ball store where the cooling energy is bound in ice, which is encapsulated in the balls.

Figure 10

Figure 11

Regarding smart grid the use of a cold storage is a really good idea, as the cold storage can be recharged at times when there is a surplus of power.

Milking of the cows always happens at the same time and therefore the cold storage has to be fully charged at this time. One should therefore be aware of how long the charging time is for the cold storage, so that the charging does not start too late.

Points to be aware of (summary)

- How long is the charging time for cold storage (ice bank)?
- What is the storage capacity (Wh or kg ice)?
- What is heat loss of the cold storage (linked to the bullet above)?
- What is the maximum milk flow (kg/s or kg/h)?
- How many liters of milk has to be cooled per day?
- At what times does the milking happen?

Control signals

- After milking in the morning, the charging of the cold storage is delayed until a time when there is not a great demand for power. Charging should take place at a time when the necessary charging is reachable (charging time). Milking typically happens at 3 pm.

- After milking in the evening the charging of the cold storage is delayed until night time. The refrigeration plant of to the cold storage unit will be put into operation at a time between 10 pm and 3 am. Milking typically happens done at 4 am or 5 am.

On some farms, milking happens three times a day, e.g. at 5 am, 1 pm and 9 pm. There are also some farms with automatic milking - or milking robots, where the cows themselves decide when they want to be milked. These cows are milked 2 - 3 times a day. In these cases, charging of the cold storage has to be fit into this milking rhythm. This impends however, the use of ice storages when the exact milking time is unknown.

Case

On the company Peder Øster a herd of 165 cows are milked twice a day. Milking is carried out at 5 am and 5 pm. The cows provide a total amount of 1,8 tons of milk per year per milking. Milking of the cows takes about 3.5 hours.
Cooling of the milk quantity per. milking requires the following amount of energy:

$Q_{cooling}$ = 1.800 kg · 4,2 kJ/kg °K · (38 – 4) °C = 257.000 kJ = 71 kWh

If this amount of milk has to be cooled in an ice storage, the required amount of ice in the storage is:

M_{ice} = 257.000 kJ/334 kJ/kg = 769 kg

Since a milking takes about 3 hours it requires a cooling capacity of about 24 kW (71 kWh / 3 h). A refrigeration plant typically operates with a COP at about 3,5, therefore the power input of the compressor will be about 6,7 kW. This means that it's possible to move an electrical power of approximately 6,7 kW at that company.
The charging of the ice storage takes 3 hours, therefore it is possible to move around on the hours of charging in relation to the hours of milking.

The figure below shows the power input of the refrigeration plant for charging of the ice storage and milking and at the same time cooling of the milk in the storage tank. As seen the power input of the refrigeration plant is about 6,7 kW when charging the ice storage. The ice storage therefore is sufficiently charged to cope with the cooling of the entire amount of milk from 38 to 4 ° C. Start of "charging the ice" is made by the control signals to the platform.

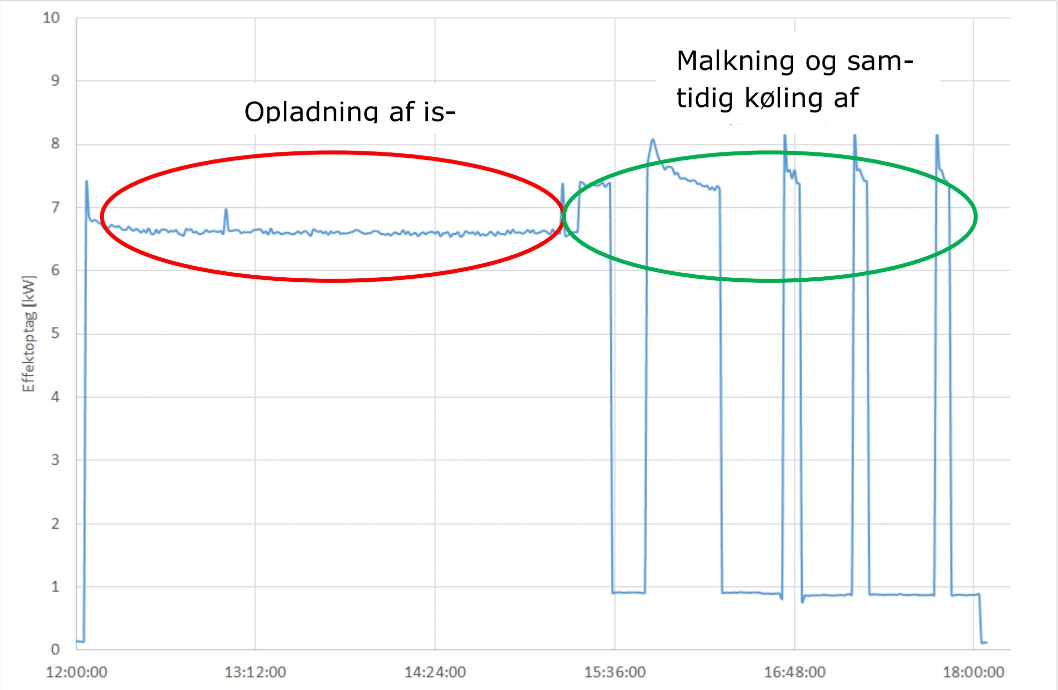

Figure 12

In a large part of the Danish dairy farms the cooling of milk volume does not only happen through mechanical cooling. The cooling is often made by that the hot milk is cooled from about 38 ° C to about 20 ° C by means of a water circuit in a first heat exchanger (pre-cooler). The water in the water circuit, which is further heated, is used to clean milking equipment and cooling tank. The milk is then cooled via mechanically cooling from 20 ° C to about 4 ° C. This is also the case for the above described company, but to show the possibilities of moving power consumption the water circuit was disconnected.

Upscaling

In Denmark around 4.5 billion liters of milk per year is produced. Cooling of this amount of milk requires the following amount of energy as it is estimated that the use of pre-cooling of milk occurs at about 50% of milk cooling plants.

$Q_{cooling}$ = (2.250.000.000 kg · 4,2 kJ/kg °K · (38– 4) °C) +
(2.250.000.000 kg · 4,2 kJ/kg °K · (20– 4) °C) = $4{,}725 \cdot 10^{11}$ kJ = 131.355.000 kWh

As a refrigeration plant typically operates with a COP of about 3, the power consumption for mechanical cooling is about 43,785,000 kWh per year.

6.2 Pump Station Sørenden

Mark drainage (pumping)

The agriculture dewatered/drain to get the excess water away from the root zone, so that there is the necessary oxygen to the roots, and so that the crop is not drown. The drainage happens when water from the fields via drainage pipe, flows into a stream, where it is pumped away through the pumps at a pumping station. The pumps typically are controlled by using a simple level control, i.e. they operate on/off

Figure 13

The result of the project is the development of intelligent controllers for pumps, which ensures that the pumps, as far as possible, is only in operation when access to power is highest (i.e. offshore windfarms produces most) and electricity prices are low.

Points to be aware of (summary)

- The level in the stream must not be too high, but how high it must be (100 - 200 m stream is emptied when levels become too high in the current case)?
- Length of the stream/volume (7 - 8 km in the current case)
- What happens if a cloudburst occurs and the stream is almost completely filled?
- Exploiting of weather forecasts?
- Utilization of meadow land as reservoir (flood or excavation)?
- Environment - leaching of nutrients (should it?)

Control signals

• The pumps run continuously in the period from 10 pm to 6 am.

•?

Case

The figure below shows simultaneous measurements of the level in the stream and power consumption of the pump. As seen, the pump starts when the level in the stream reaches its allowable or desired maximum. The pump stops again when the level in the stream reaches its allowable or desired minimum. During the day, the pump is, as seen, in operation in an estimated 70 - 75% of the time. As seen, it’s not possible to accumulate such large amounts of water in the stream.

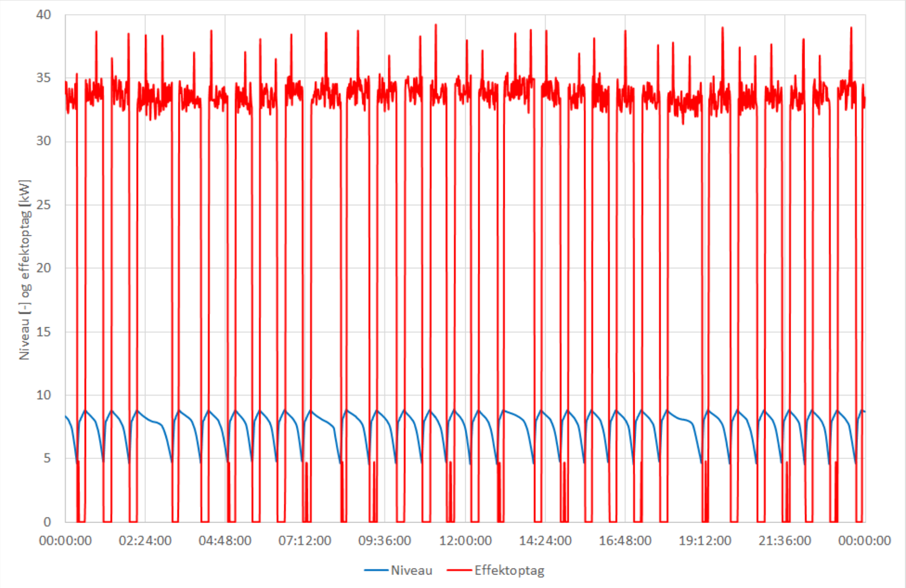

Figure 14

When the pump is in operation, it provides a flow of about 500 m3 of water per. hour. As the pump is in operation for approximately 70% of the time it can be calculated that on average, the flow to the stream is around 360 m3 of water per. hour.

Smart grid

In order to change the pumps' use pattern with regard to smart grid, i.e. move consumption to times of excess of power, it is necessary that the amount of water that is drained from the fields can be accumulated at certain times of the day. One option could be to accumulate a part of the amount of water in the streams, which in principle means raising the level at certain times. Another option could be to establish an accumulation possibility in the form of e.g. a reservoir. Below is an example of the first option by raising the level of streams.

The figure below shows the attempt to let the level rise in the streams. The figure shows the level in the stream and the power consumption of the pump. From 0.00 am to 8.00 am (green ellipse), the pump operates in normal condition. There is zoomed in on this in the following figure.

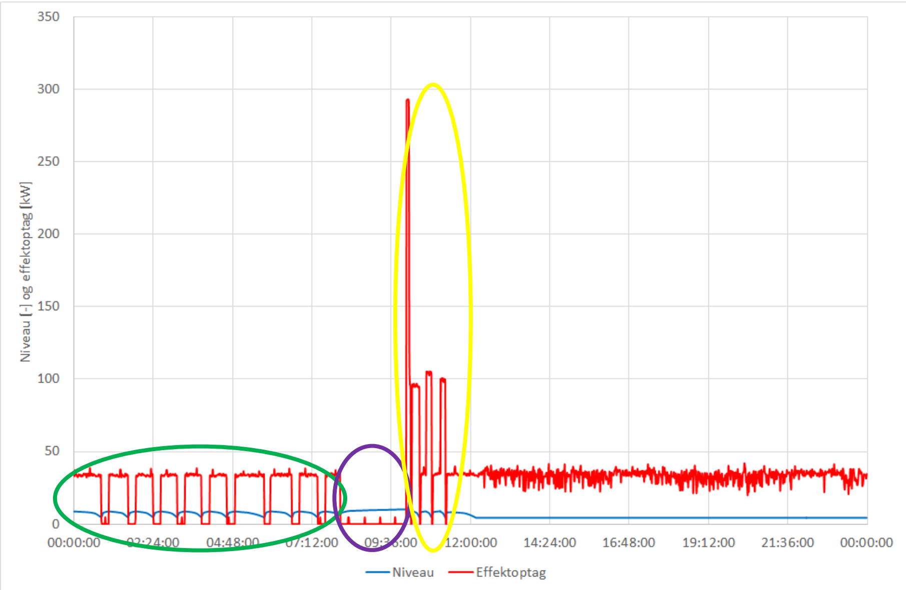

Figure 15

The figure below shows the pump in normal operation during the period from 0.00 am to 8.00 am. As it can be seen, the pump starts when the level in the stream is increased to the maximum value. Once the level has decreased to the minimum value, the pump turns off.

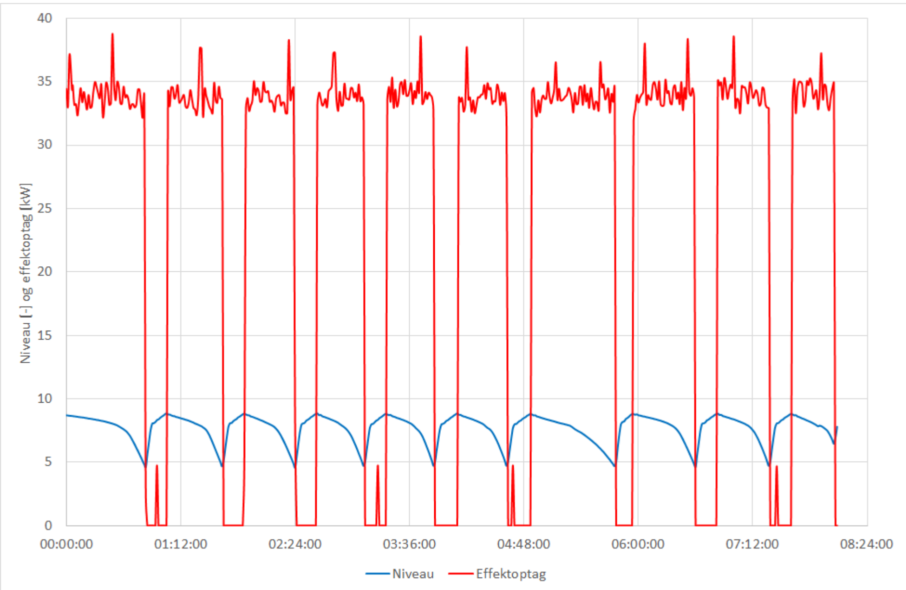

Figure 16

The figure below shows the level of the stream and the power consumption of the pump during the period from 8:00 am to 10:00 am (purple ellipse). As seen the level in the stream rises from about 8 am to about 10 am while the pump is off. The four peaks shows the power input for other equipment plugged into the same power grid. As the pump is in operation for approximately 70% of the time, the average power input during the time from 8:00 am to 10 am is approximately 25 kW. In the two-hour period, it is therefore possible to accumulate an energy consumption of about 50 kWh.

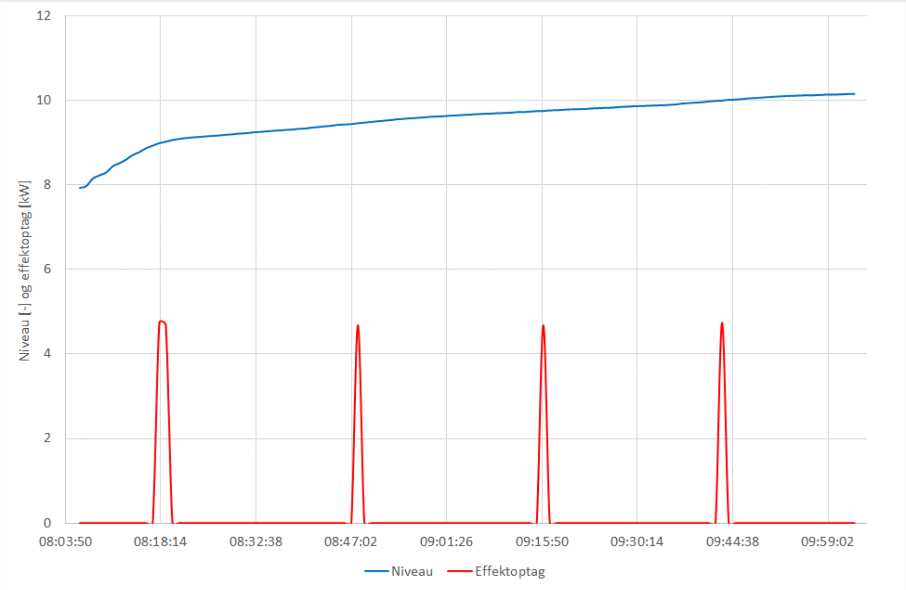

Figure 17

The figure below shows the level of the stream and the power consumption of the pump during the period from 10:00 am 12:45 pm (yellow ellipse). As seen in the figure, this relocation of the set point for the maximum level in the stream results in that all pumps in the pump station starts to pump the accumulated water away.

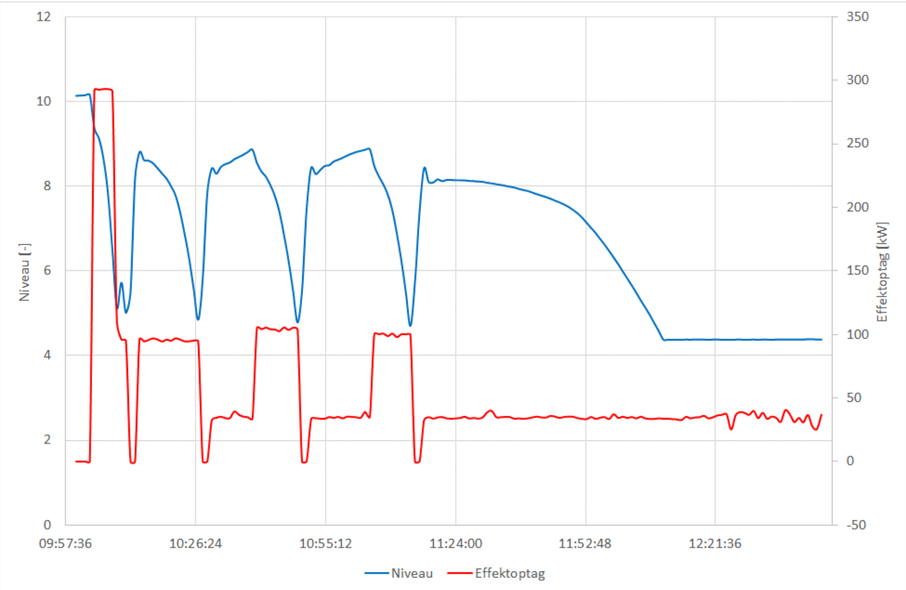

Figure 18

This was obviously not the intention. The intention was that the pump should now run normal operation just between levels 8 and 10. However, it would require the re-programming of the pump control, which unfortunately was not possible within the framework of this project.

One must be very careful not to use this method of accumulation, as there is a risk that the level of the streams becomes so high that there is no drainage of fields. This will destroy the crops.

As previously mentioned, an estimated amount of 360 m3 of water per. hour is flowing to the stream. If the water should be accumulated in the period from 6 am to 10 pm, it would require the construction of a basin with a volume of about 5,800 m3. It corresponds, e.g. to a basin with a diameter of 70 m and a height of 1.5 m. During the 16 hours, it would therefore be possible to accumulate an amount of energy of about 400 kWh.

6.3 DLG – Grain drying

Grain drying

Grain is harvested when it is "mature" i.e., when the seeds are fully developed and the moisture content of the grain is down to about 14 - 15%. If the water content is higher, e.g. because there is rain and humid weather at harvest time, the grain urgently has to be dried down to 14 - 15% water after harvesting, to make it shelf stable and prevent fungal or grain burn (heat).

Figure 19

Regarding smart grid it is therefore, when the grain is harvested, not possible to wait with the drying process to the point where access to power is highest (i.e., when the offshore wind turbines produce most) and electricity prices are low.

Time for grain drying
Grain drying without heat should be carried out in the period from 9:00 am to 19:00 pm. This is because the air-humidity rises at night as a result of that, the air is cooled. The humidity will in the summer and in the period from 07:00 pm to 9:00 am be about 100% relative humidity. Proper drying of the grain reduces or eliminates the need for heat for the drying process.

Humidity control
It is important that the blower for the grain is moisture controlled. It is expensive for farmers to over dry the grain because of the energy consumption and the lack of weight of grain that is settled.

Use of heating
Grain drying with heat therefore has the greatest effect in the period from 9:00 am to 07:00 pm. Whether it is most worthwhile to dry at night or during the day depends on how much the temperature of the inlet air is increased by heating. Be critical with the use of heat. Only at humid conditions and low temperatures heat is usually required. If the fan is too small or work not optimally the demand for heat increases.

As the grain quality should be maintained throughout the storage period, that may extend for up to a year, it is important that the storage conditions are good. This means that the grain must be kept under observation for possible temperature increases.

Points to be aware of (summary)

- Development of mold and harmful molds growing up, if grain are not dried properly
- The grain can "burn out" if it is not dried properly
- How is the outdoor air and heat input to the storage controlled?
- Is a humidity control used so that the grain is not over dried?
- For how long time is the grain usually dried (hours / days / weeks) until it is shelf stable?
- Can you interrupt the drying periods - how long? (One must be very careful with it, because the grain can be damaged)
- Could it be an idea to use electrical heat fans at night?

Control signals

- Aeration at certain times 2 - 3 times in the period from 6 am to 10 pm
- Full aeration/drying during the night (from 10 pm to 6 am)

Smart grid
For possibly to be able to alter the drying process, it is necessary to look at the times the drying process is going on and on the kind of heating (the fuel used for heating the dry air). As mentioned earlier, when the grain is harvested, it is not possible to wait for the drying process to the time where access to power is highest (i.e., when the offshore wind turbines produce most) and electricity prices are low. The risk of damaging the grain, by waiting is too big.

An opportunity to utilize excess power will be to use electricity as heating source at night and at other times when it is cheap.

The drying of the grain occurs, as seen in the above image (bottom right) using portable heaters, which heat the air using gas oil. The heated air is blown towards an inlet of a fan and after that blown into the storage (typically a silo). If you also need to use electricity as heating source, it requires that the heater is both able to heat the air using liquid fuel and electricity. However, it will be quite difficult.

For new constructions the possibility of using multiple fuels, should be incorporated in the design- and project phase.

Upscaling
In Denmark, the consumption for drying of grain and seeds is around 74 GWh per year. The energy consumption consist of different fuel types. Drying of the grains could, as previously described in the section, happen using electric heating at certain times.

6.4 Brdr. Kjeldahl - onion drying and storage

Storage of goods in cold storage (onions)
Drying the onions finishes with a cooling process. To avoid condensation, it is important that the onions be cooled down slowly, preferably by lowering the temperature by 0.5 ° C per. day. For this to be practiced, a computer-controlled facility that provides for the gradual reduction of the temperature is required. When the onions have been dried as desired and are storage firm, they should be stored at low temperature and low humidity - max. 80 to 85 per cent. relative humidity - to ensure the quality for sale. Maximum retention is achieved by cold storage at 0 to 1 ° C.

Figure 20

Things to be aware of (summary)

- What is the optimum storage temperature?
- What is minimum and maximum storage temperature (limits)?
- What is the maximum mass of goods?
- How does the mass in the cold room vary (e.g. from September to July)?
- What is the minimum mass of goods?
- Can the temperature in the storage be lowered to the optimum temperature?
- How quickly does the temperature in the storage and in the goods increases if the cool-ing is stopped?
- Can the goods can withstand temperature variations (what can the temperature may vary in between)?

Control signals

- For a period between e.g. 10 pm and 6 am forced cooling is used. In this period, the temperature in the cold room is lowered, for example 0 - 1 °C. The cooling system is stopped when this is temperature is reached

- When the temperature in the storage is increased, for example to 3 ° C, the refrigerant plant is started again. If there is cheap power available before the temperature has risen to 3 ° C the refrigeration plant will be started and the room temperature is lowered to 0 to 1 ° C.

Case

The figure below shows a weeklong recording oof the temperature of the storage. The temperature varies as seen between 1.5 and 3.5 ° C. The variations in temperature in the storage is, as seen in the following figure, closely linked to the variations in the outside temperature. When the outside temperature rises, the temperature in the storage rises too.

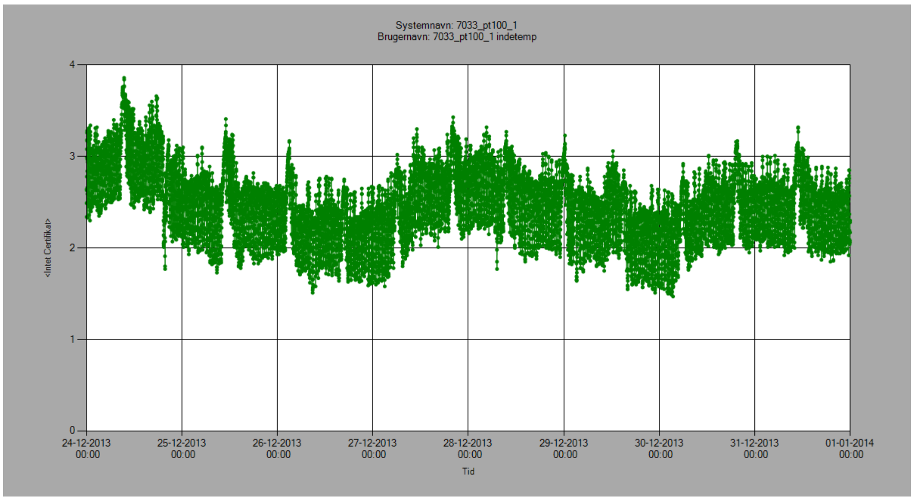

Figure 21

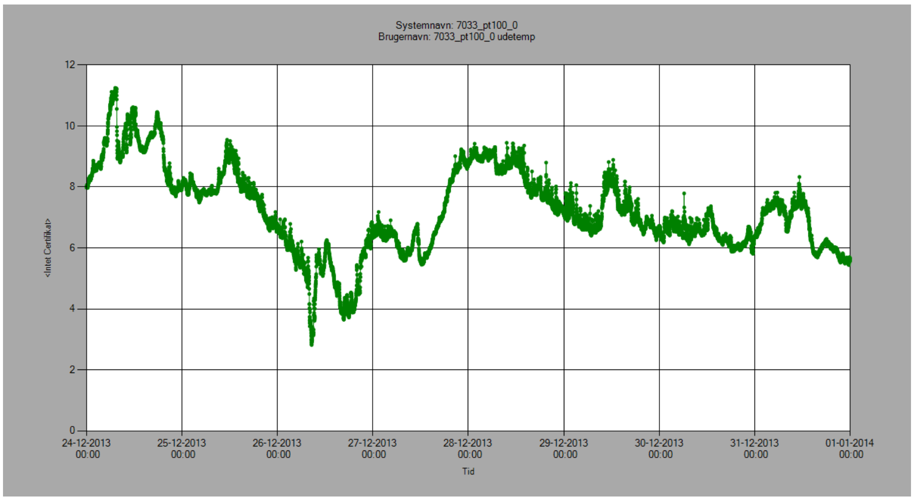

Figure 22

The possibility of lowering the temperature in the storage by 1 °C during the night should be examined further. For 600 tonnes of onions calculations show that there can be accumulated 2.5 million kJ in the onions by lowering the temperature in the cold room by 1 degree.

It means that it is possible to accumulate energy equivalent to 58 kW over a 12-hour period.

6.5 Dairy

We have analysed a dairy farm in detail in order to understand better what the possibilities for load shifting are in reality. The farm is small such that it is manageable to analyze in a relatively short time.

The farm produces organic milk, butter and cheese with a certain weekly schedule. Table 2 gives an overview of the production. The size of the land is the most significant sizing factor, because it determines the milk quota and thus the number of cows. The total electricity consumption is 25 300 kWh per year, which includes the farmer's dwelling for two adults (4 300 kWh). The heating unit is a firewood furnace, and thus not counted in the electricity consumption.

Electricity consumption:	25 300 kWh
Direct cost of electricity (excl. subscriptions):	38 900 DKK
No of cows:	8
Size of land:	11 hectare
Cheese production:	4 tonnes / year
Butter production:	900 kg / year
Milk production:	40 tonnes / year

Table 2. Key figures that characterize the dairy farm.

As mentioned in the survey report (Jantzen, et al., 2015), the table provides enough information to calculate the expected electricity consumption. A spreadsheet calculation (Mortensen, 2007) returns an expected consumption of 13 900 kWh per year; thus the actual consumption is 1.8 times higher than expected. It seems high, but could be explained by the small size of the farm (it lacks economy of scale).

Figure 23 shows a rough estimate of the electric energy balance. The largest load is cooling and freezing, because the milk must be kept cold, and there are large amounts of cheese in a relatively cool storage room.

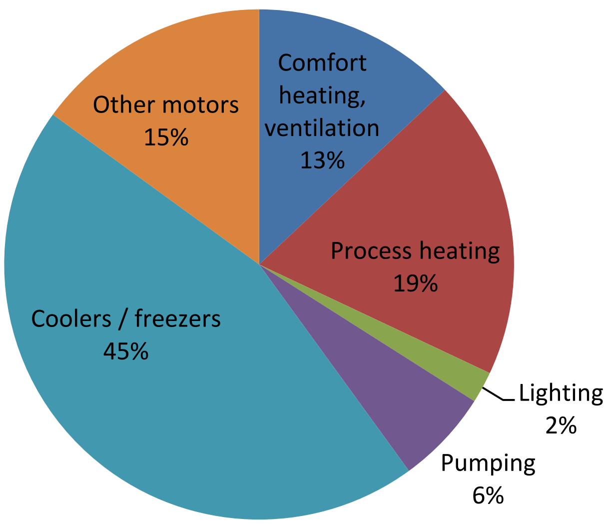

Figure 23. Estimated energy balance.

Figure 24 shows the electric energy consumption hour-by-hour on a particular Wednesday. It was possible for the farmer to identify three main events in the plot, namely: The milking of the cows early in the morning, cheese production in the dairy before noon, and cooking and dining in the dwelling later in the day. There are different patterns each day, depending on the kind of activity in the dairy.

There is also a distinct difference between work days and weekend days, as Figure 25 shows. Even the work days exhibit a pattern, because the production changes every day according to the following schedule: Monday, cheese; Tuesday, idle; Wednesday, cheese; Thursday, butter; Friday, cheese; Saturday and Sunday, idle. Clearly, the milk must be stored in a cool place until it is used in the production.

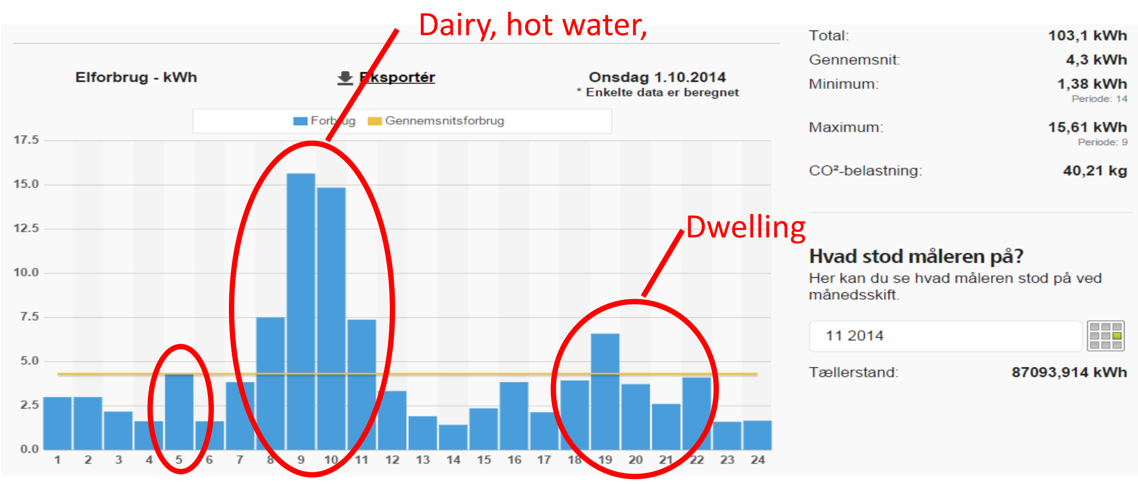

Figure 24. Smart meter screen shot of hourly electricity consumption on 1 Oct 2014 (Mit-Nrgi).

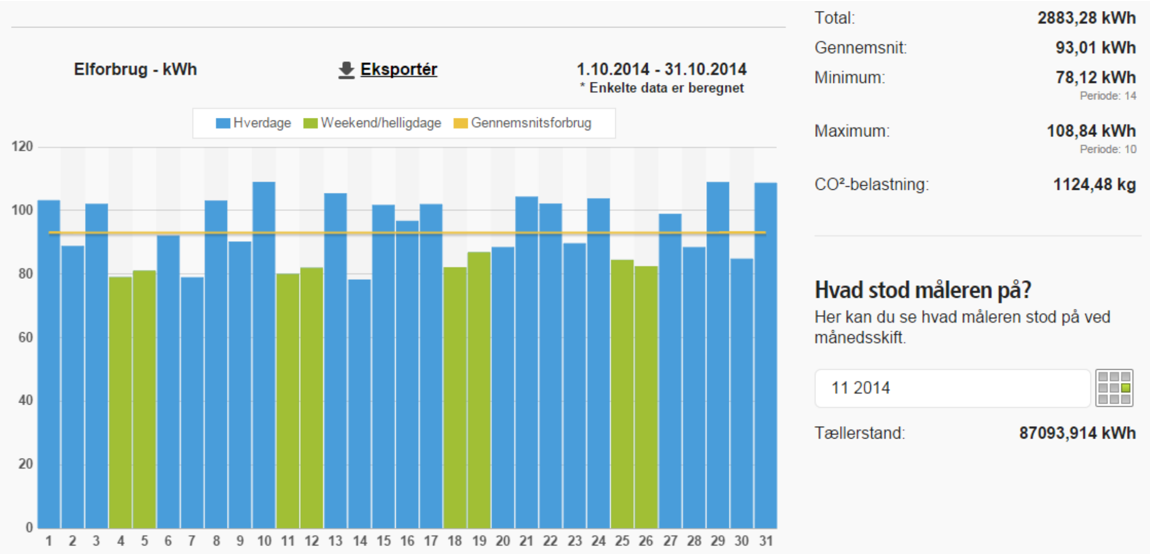

Figure 25. Smart meter screen shot of daily electricity consumption during the month of October 2014 (MitNrgi). The green columns are Saturday-Sundays where the activity is lower

There is even a seasonal variation, as Figure 26 shows. The consumption is largest during the summer, and lowest in February / March where there is a natural break, because the cows are giving birth. It is very likely that the electricity consumption depends on the outdoor temperature, because the chiller works harder during summer time.

From the figure we can tell that the idle consumption (in February) is about 900 kWh per month. Assuming that this amount does not depend on temperature, the annual consumption is 12 times that amount. Assuming that the dwelling consumes 4 300 kWh, which is normal for the size and two adults, the temperature-independent part of the consumption constitutes 26 % of the whole. This is just to show an example of the information we can extract from the smart meter records.

In order to investigate further whether the electricity consumption depends on the outdoor temperature, Figure 27 compares the hourly consumption on a winter day and on a summer day. During the summer day the electricity consumption is higher almost every hour during the whole 24 hour period. The morning peak is much higher during the summer.

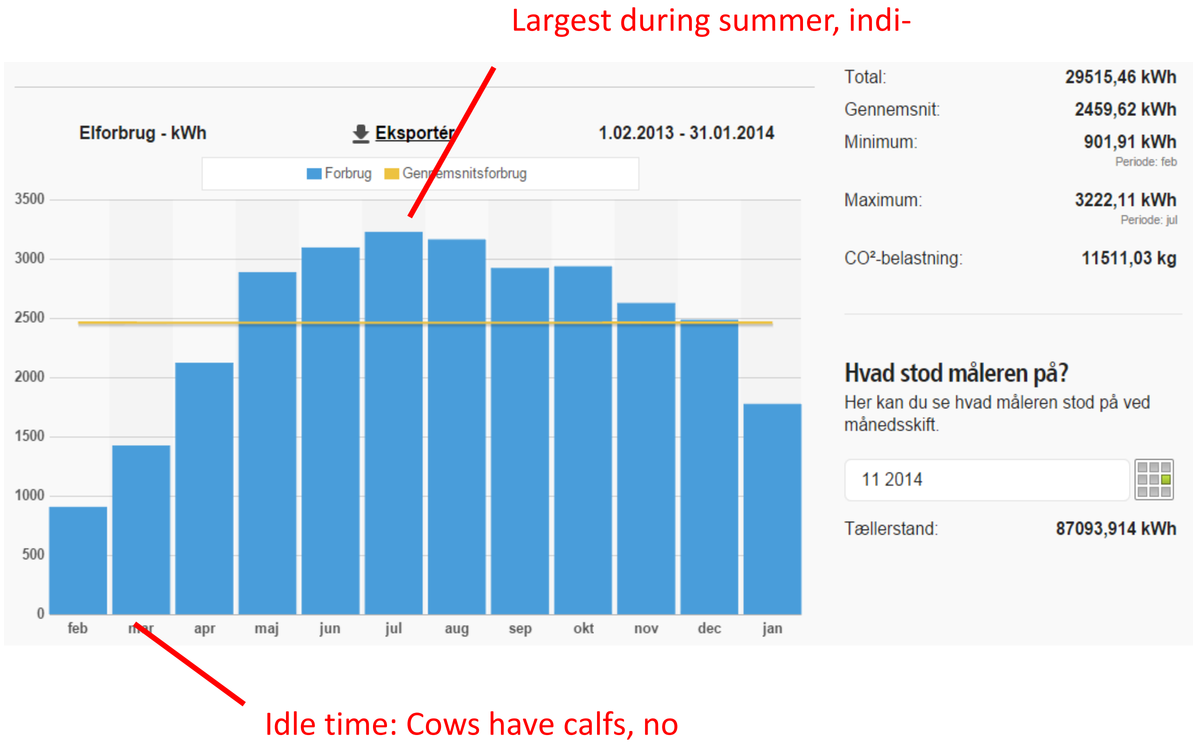

Figure 26. Smart meter screen shot of the monthly electricity consumption during 2014 (MitNrgi).

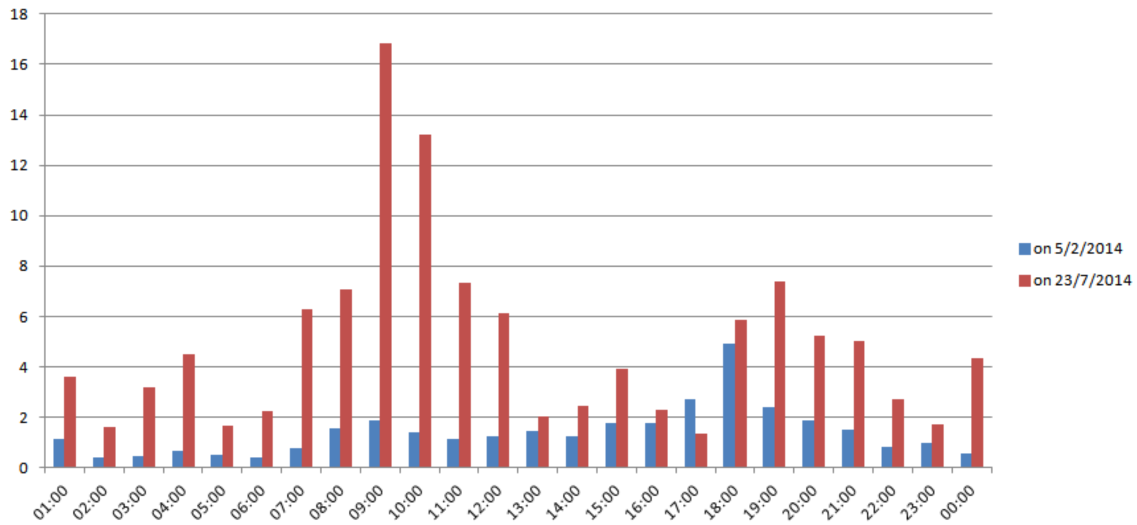

Figure 27. Hourly consumption on a winter day (blue) and on a summer day (red).

Figure 28 gives an overview of the proces flow in the production. To the far right in the figure are the final products: butter and cheese. Furthermore, on the right hand side, is the waste product, which is spread on the field as fertilizer. Whenever there is a storage, there is a theoretical possibility to shift an electric load, and therefore the diagram emphasises the storage opportunities. For example, the daily milk is kept in a tank, which can be filled to various extents. In principle, filling and emptying the tank could be shifted in time to match electricity tariffs, as long as the tank capacity is large enough.

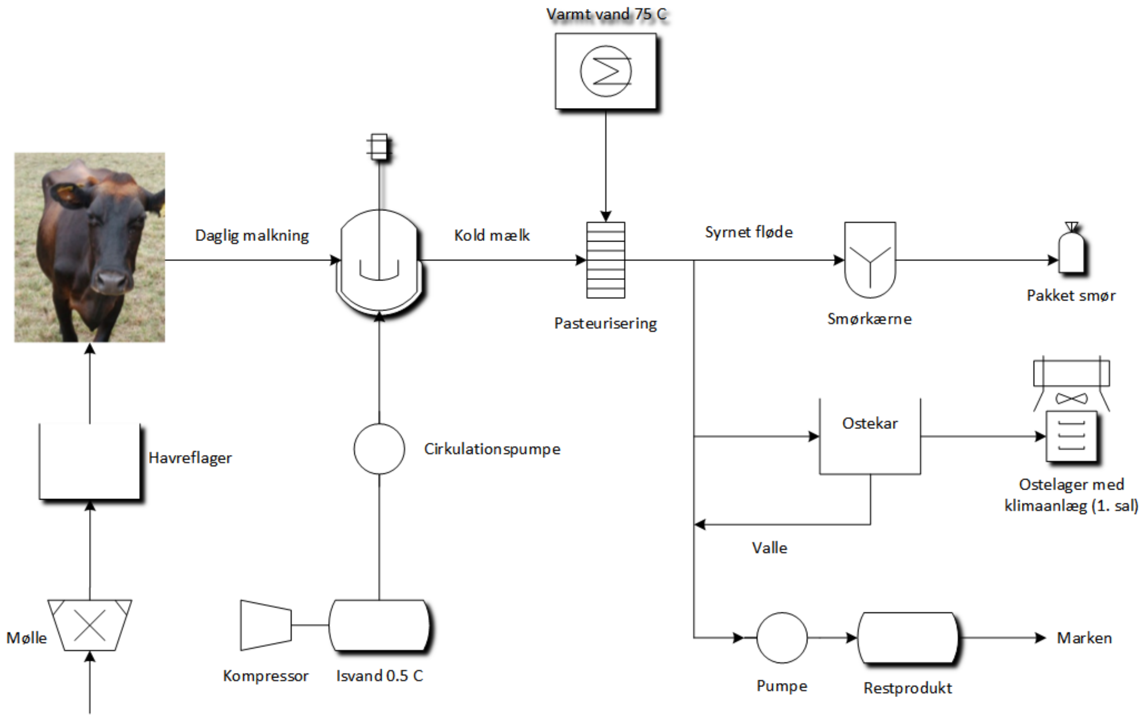

Figure 28. Proces flow diagram of the dairy production. Storages are emphasised by shadows.

Aided by the diagram we can identify several possible options for load shifting related to storages.

- Superheat hot water for pasteurisation, install a timer
- Preheat hot water for pasteurisation
- Superheat the building (winter), subcool the building (summer)
- Precool cooling water
- Subcool ice bank
- Keep cold milk in tank until electricity price is low
- Produce butter and cheese to storage when electricity price is low
- Defer washing and hosing, and thereby pumping to waste storage
- Compress air when price is low
- Produce fotter to storage when price is low
- Chop firewood to storage when price is low
- Consider using old car batteries for storage of electricity

Not all of this is possible in practice, but the point is to focus on the available storages, because they give the option to defer or speed up the processes that feed / empty the storages. An obvious example is the heating of hot water to 75 degrees C for pasteurisation. Modern hot water tanks are well insulated (losses are perhaps 30 Watt), so that the heating of hot water could be done ahead of time, for example during the night if the price is low.

Another advice is to replace the existing firewood heating unit with a heat pump, perhaps ground source heating. The heat pump runs by electricity, which makes it easier to control, and today it is often installed together with a hot water buffer tank. The heat pump has built-in options for control and scheduling, and the heating of hot water could therefore easily be set to operate at favourable times.

Speaking of renewable energy, this is in itself a motivating factor for the farmer to shift the electric load. Figure 29 shows the hourly consumption together with an imaginary photovoltaic plant. The PV plant produces most electricity around 13:00 (summertime). The farmer is willing to delay the milking, and thereby the whole production, several hours in order to match the electric production. The delay should be between 4 and 7 hours, and the morning peak will have to be flattened.

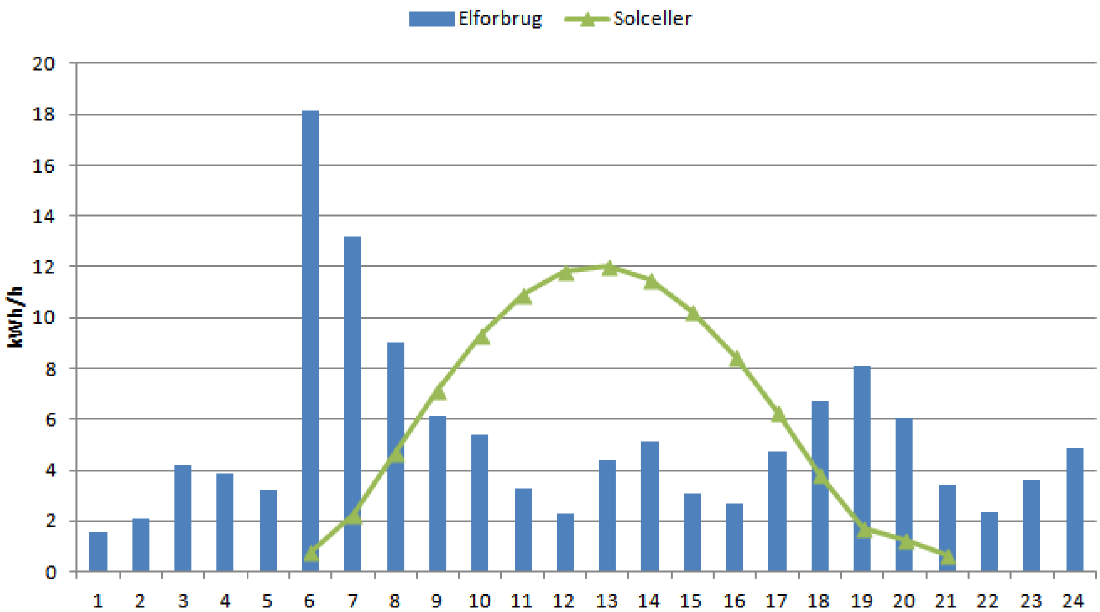

Figure 29. Typical hourly electric consumption (14 Jul 2014). The overlay (continuous curve) shows the nominal production from a 12 kWp photovoltaic plant.

6.6 Opting out of cases in the demonstration phase

The onion and grain drying processes were deselected due to the risk of control error and thus the risk of many tons of onions or grain being destroyed. However, an examination of the processes were carried out theoretically.

7 EXPERIENCE DERIVED FROM PROJECT - DEMONSTRATION AND TEST

Compared to the project more time should have been allocated in selecting the devices needed for test of the Smart Grid platform. The time was in any case necessary to spend, but subsequently it was not possible to devote more time to find new devices in the agriculture on Samsoe as user patterns showed that there would be minimal amount of energy that could be moved around. These extra resources, the project did not have. The result of NRGis software model was dependent on many devices and changes of mode. Therefore it is difficult to state how effective it will be. We discussed whether to run a larger simulation of the system with many devices but the project team prioritized that the platform would function in practice. NRGis development of a software model, which is the basis of the control strategy and the collection of experiences, is looking good. It takes into account the issues where the device does not react as desired according to the model. This is done by looking at diminished power before and after the envoy of changes of mode - see more in Annex 1.

If a larger project in the future will be defined with a greater number of participants, it is necessary to offer a "carrot" to each participant. This is in the form of, e.g., cheaper power. A gathering of customers with greater consumptions where you could contract hourly rate with the utility company and control the consumption for a lower total cost of consumption. Thus, a development project could offer the participants a lower electricity prices.

From the start, there should have been more focus on existing CTS system, e.g. at the Soerenden pumping station. The safeguards incorporated in the systems should not be changed by signals from the platform changing the control mode. E.g., the pumping station should not stop if the platform sends a stop signal while the water level is high. Therefore, as far as possible, existing CTS systems should be expanded with inputs for on, off, normal modes from the Smart Grid platform and within the CTS system it is ensured that all safety devices are complied. In some cases specific safety standards must be complied. The project solution by Soerenden pumping station exactly took into account this problem and needed MJK's help for the solution. MJK customized their software and signal inputs so that we could lower and raise the water level, respectively -10 and +10 cm and put the system in normal mode. At the ice bank BK Automation installed a knob which had 3 modes, on, off and Smart Grid. This meant that the farmer could override the platform signals. It will in a final installation of the system just mean that the software model will collect these statistics and experiences.

8 NRGI'S SOFTWARE MODEL

NRGi participate in the project "Smart Grid in agriculture on Samsoe" as it fits into the company's Smart Grid strategy by effectively utilizing the options of the intelligent Electricity-meter, and other derivative effects.

Through the project NRGi wishes to identify whether customers/consumers are willing to postpone power consumption over time so that the existing electricity grid can be utilized more efficiently and thereby avoiding large investments in grid reinforcement.

In one of their future scenarios NRGi can as a network operator, see a market of flexibility services, where end users, manufacturers, electricity traders, balance responsible and network companies act, to optimize their particular business, by exploiting the opportunities the other offers on the market.

NRGi can see a new and important role in this market of flexibility. A player that can offer to convey the needs of flexibility and tie the other players in the market along. This player will play the role of an aggregator. A role that NRGi has played in this Samsoe smart grid project, as there are some prospects in it to make it a commercial role/product.

Through the project, NRGi has spent a lot of time developing a model for how the role as an aggregator should be and how this role could fit in a system context. See the document 'NRGi Infrastructure - Project Samsoe - Løsningsforslag_21112013' (Annex 1) for the construction and operation of the aggregator model/system.

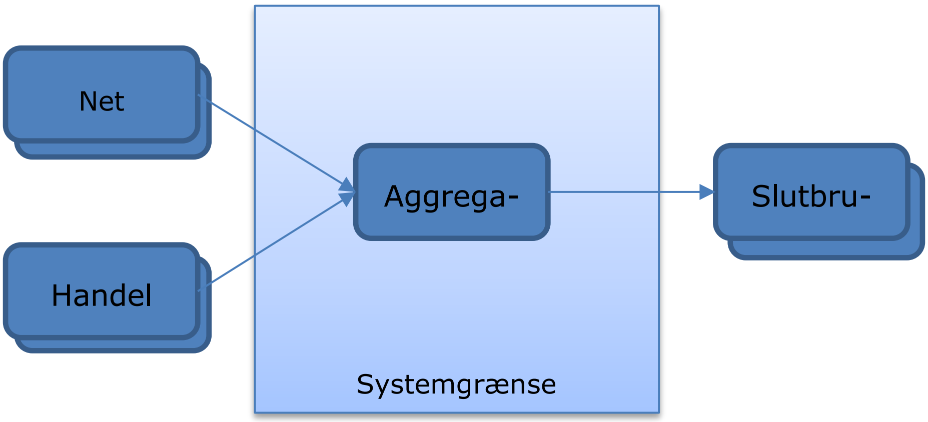

Figure 30

After the model was developed and specified, it has now been programmed and now stands as a SW model.

The model is now operating in a test environment at NRGi's IT supplier, and is ready to integrate to the project selected consumer units / end users / remotes.

The model has been presented in NRGi's organization, and we are now in the process of identifying where, in the long term, it will be most advantageous to place this aggregator system in NRGi, so that they commercially get the most benefit from it.

Appendix 1 is a technical documentation describing in details how the software model can be used.

9 SMART GRID BOX

9.1 Measurement system

Collected measurement data ends up in the database, which is located at TI. An example of 2 temperatures recorded at the ice bank of Peder Øster:

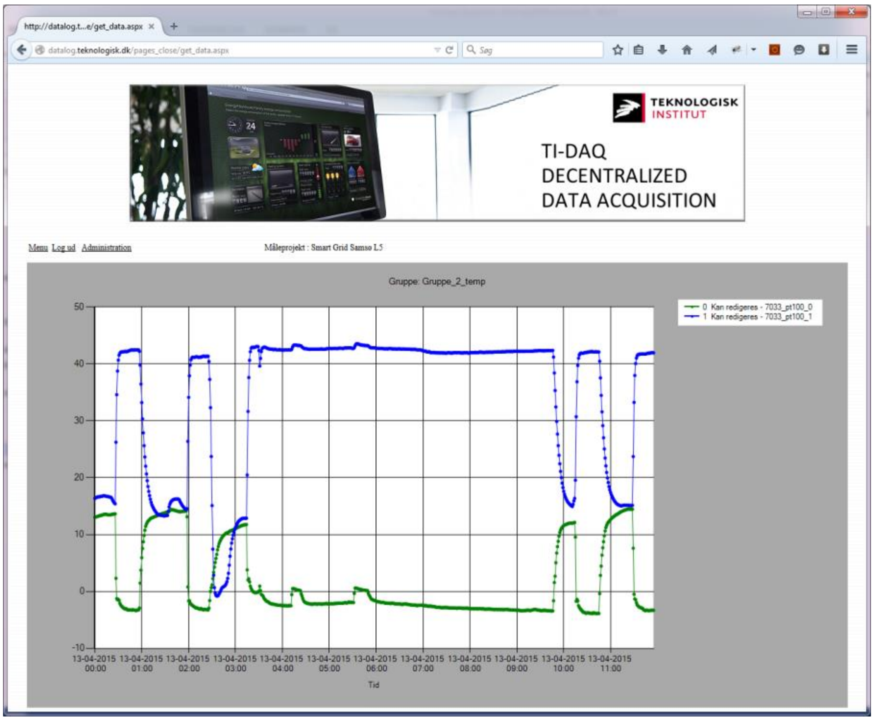

Figure 31

Here it is possible ti see the water level as a function of time at the inlet to Soerenden pumping station

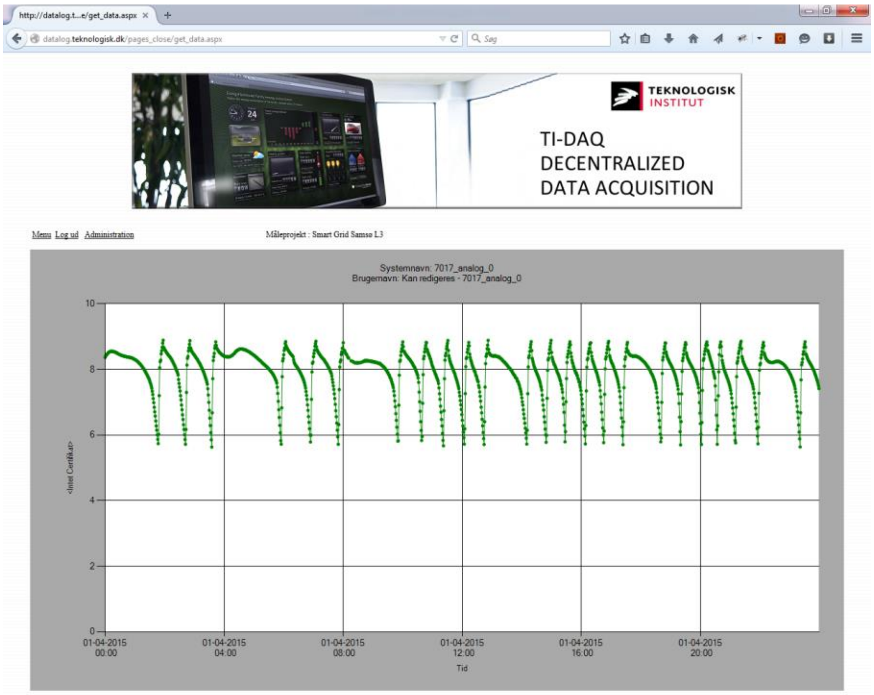

Figure 32

The power consumption synchronized with the above graph above the water level.

Figure 33

Data is stored in a SQL database and are used for communication via Web API. Examples of this could be reading out the actual power consumption of the pump station, see Appendix 1, how it is made technically.

Current sensors and measuring devices, which are incorporated in the platform:

3 phase electricity meter	: EM24 from Carlo Galvazzi
Temperature	: PT 100 sensor
Water Level	: 4-20mA – The own ultrasonic sensor of the pump station
Available	: 0-10V

The data logger communicates via USB / RS 484 with sensors and thus can be adapted to all types of signal converters such as ADC / DAC, 0-10V, 4-20mA and PT100 inputs. The conversion to the final units occurs at the server level. It is exactly this flexibility, that has made it possible to measure the different parameters of the devices and thus the Smart Grid platform has an extremely strong base in relation to the number of types of devices and installations, which exist in the agriculture. The dataloggers upload collected data, on a minute basis, to the server via the Internet and the screen shots above are examples of how data can be studied later.

9.2 Control box - Seluxit

Annex 2 describes the hardware and software protocols to be used to control the relay outputs.

9.3 Web API

Appendix 3 describes Web API, which is used when it is desired to control the connected devices remotely via toggle on, off, or normal mode.

10 PERSPECTIVES OF OVERALL SMART GRID PLATFORM

The future power system will be significantly different from the system we know today. Large and significant changes are needed, if the very large amount of renewable energy, primarily from wind turbines and solar cells, must be integrated and utilized optimally. The development of technical and economic solutions that ensure a balance between production and consumption between the various energy consuming devices and operators in the overall energy system is necessary.

In the future power system, "Smart Grid", there will be a need for significantly more flexibility from electricity customers, and that means that the interaction between the different energy systems (Smart Energy) should be used much more extensively than it is done today. Furthermore the customers must be involved in such a way that they become an important and useful "active" in balancing of the electrical system and efficient utilization of the fluctuating power generation from solar and wind.

"Production, supply and consumption of electricity must always be in balance in the future Smart Grid / Smart Energy System"!

On the production side, it is necessary to build in more intelligence in the grid, so that the grid can handle the fluctuations from the power production, e.g. wind power. On the consumption side, the power consumption has to be more flexible so that the flow is optimized. In its simplicity, it is about ensuring that the users can respond to price signals in the market. Information and communication technologies can make heat pumps, electric cars, etc. active resources for the power system. Specifically the intelligent network comprises of sensors and other equipment and software for controlling the grid, consumption and production. Some of the technologies already exist, but must be combined with IT- and communication technology in a new way and it involves a higher degree of digitization of the electrical grid, and high demands on communication networks like fiber connections.

Fortunately, we in Denmark and around us in the international community become more aware of both the need and the potential of the use of data communications across players, high as low, in the power system. This is a prerequisite for the Smart Grid.

11 DISSEMINATION

Activity Log:

Dato	Møde	Sted	Formål	Deltagere	Bemærkninger
12-03-2013	Start-up meeting	SE, Samsoe		SH, MIL	
04-04-2013	Samsø Association of Craftsman	Samsoe	Presentation	MK	
06-04-2014	Wind Association	Vingsted	Annual meeting		
11-05-2013	Electric car Theme Day	SE, Samsoe	Meeting	SH	
15-05-2013	Grundfos	Bjerringbro	Meeting	LSB, SH, MK, JJ	
10-06-2013	Allegheny College, 1 day	SE, Samsoe	Student project, sustainabi-lity	SH, MK	
29-06-2013	Renewable Theme Day	SE, Samsoe	Meeting	MK	
15-08-2013	Summary of interviews	Samsø	Report	MK	Energikontorer
18-09-2013	Next Practice, 2 dage	SE, Samsoe	Conference	Kasper, Stig	WP2
25-10-2013	Rowan Boeters, Delft, 1 week	SE, Samsoe	Student project, smart grid	SH, MK	
06-11-2013	Strategic energy planning	Region Midt	Meeting	SH, MIL, MK	
07-11-2013	Smart Grid	TI, Aarhus	Project meeting	MIL	WP9
08-11-2013	Smart Grid	SE, Samsoe	Local project meeting	MK	
12-11-2013	TU Delft Energy Club, 2 days	SE, Samsoe	Workshop, study trip	MK, Brian, Lars	
16-01-2014	Rowan Boeters, Delft	SE, Samsoe	Public meeting on smart grid	SH, MK, JJ	
20-01-2014	Fossil free island	SE, Samsoe	Meeting		
11-02-2014	Grundfos, 2 days	Bjerringbro	Pumps for farmers	MK, SH	
26-02-2014	Samso Electric car Association	SE, Samsoe	Founding meeting	MK, SH	
28-02-2014	Nicholas Urban, College of the Atlantic, USA, 1 week	SE, Samsoe	Student project, prepare meeting in autumn 2014	SH	
25-03-2014	Circular economy	SE, Samsoe	Workshop, Grundfos	MK, SH	
31-03-2014	Smart Grid	Samsoe	Meeting	MK, SH	
04-04-2014	The Green Organizations	Samsoe	Annual meeting, agriculture	MK	
11-04-2014	Smart Grid	Samsoe	Local project meeting	SH	
02-05-2014	Smart Grid	Samsoe	Meeting	MK, Brian, Lars	
15-05-2014	Farmers cooperative, seniors Samsoe	Samsoe	Presentation	MK	
15-05-2014	Smart Grid	SE, Samsoe	Project meeting	SH	
25-05-2014	Renewable energy, Energitjenesten	SE, Samsoe	National meeting	SH, MK, JJ, Lars, Brian	Referat
26-05-2014	Allegheny College, 2 days	SE, Samsoe	Student project	MIL, 45 pax	
31-05-2014	Samsoe Sustainable Festival, 2 days	SE, Samsoe	Citizen meeting	PC, SH	

12 Bibliography

"Survey of energy consumption in enterprises", prepared in 2015 for the DEA of Viegand & Maagøe

13 Annex

Annex 1 - NRGis solution description.
Appex 2 - Smart Grid relay box from Seluxit.
Annex 3 - Web API.
Annex 4 - Secure a Web API with Individual Accounts and Local Log in ASP.NET Web API 2.2.