Marina Power Distribution Hub - Final report

1. Project details

Project title	Marina Power Distribution Hub
Project identification	Energinet.dk project no.: 10662
Name of the programme which has funded the project (ForskVE, ForskNG or ForskEL)	ForskEL
Name and address of the enterprises/institution responsible for the project	Danish Technological Institute
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2. Executive summary

There are more than 2600 pleasure motorboats in the river Gudenaa and connecting lakes. The majority of the boats are located in the 19 km river section from Ry to Silkeborg which is a closed system that only very small boats can sail away from; other boats must leave by road. There is no central registration of boats in Denmark and therefore no credible numbers have been found for motorboats in Denmark but it is assumed by the project that the high concentration of boats in the Silkeborg – Ry area may represent 3% to 10% of all the Danish leisure motorboats and as such allow for a very rough extrapolation to a national scale.

The project has in this limited geographic area assessed the energy potential with respect to leisure and tour boats, which could be electric without performance degradation, and the energy that would shift from fossil fuels to renewable electric energy. The national energy target on becoming independent of fossil fuels sets the expectation that most leisure boats will be powered by electricity in 2050. Assuming that the transition from Internal Combustion Engines (ICE) to batteries and electric motors had not yet started, the project idea was to analyse if and how the future electric boats can support the SmartGrid control necessary to achieve 100 % independence from fossil fuels in the Danish electric power supply network. The project is focusing on 3 areas:

1. **looking for the number of boats that are suitable for electrification**
2. **Some electric boats may have PV-panels for sailing, with a surplus production.**
3. **Optimise use of renewable energy by smart exchange of energy locally in marinas and reduce load both on the grid and the marina power feed connection.**

These areas can simplified be formulated as three hypothesis to be validated.

The project hypothesis no. 1

Few boats are now propelled electrically but many of the boats have the potential to become powered by renewable electric energy in the future.

- Has a transition towards electric boats started? Are there any indicators as to when it might peak?
  [*no transition started yet; A transition peak is more than 5 years away*]
- Find the number of motorboats that are readily feasible for electric propulsion powered by batteries.
  [*52% of the motorboats never leaves the area meaning approximate 1300 of the boats could be electric without range problems*]
- What is the size of the related electric power/energy needed from a charging infrastructure? *[1300 boats charging at the same time with 1 kW would require two full standard size 10/0.4kV substations that are typically used for a couple of hundred houses. The average time needed for charging the boats would be fairly short – very few hours only meaning that with a proper charging management the actual continuous power required may be reduces by a factor 20 to 50.]*

Project hypothesis no. 2

Many of the future battery powered boats will have Photovoltaic panels (PV-panels) to charge the battery and extend the range. If the use frequency of most leisure boats are very low the PV-panels will be idling already few hours after last tour. Assuming that PV panels can in most applications produce much more power than the battery can hold if not in use.

- Can it be estimated how much solar energy could be "wasted" on a typical solar powered leisure boat?
  [*example: 3kWh per day not used in the summer on a SunCat21(appendix D)*]
- What is the typical leisure boat use frequency?
  [*the boats are only away from the harbour 2-8% of the time and 59% sail less than weekly*]

Project hypothesis no. 3

If the surplus solar energy from PV-panels on battery boats could help charge other battery boats and contribute to the marina and the electric grid it would support the national energy strategies very well.

- Analyse boundary conditions for establishing a local energy hub system (model) to handle energy from
    1. a PV boat to a) battery boat; b) Marina club house; c) the grid (only surplus energy from the PV-array)
    2. a battery boat to b) Marina club house; c) the grid
    3. a land based PV system to a) battery boat; b) Marina club house; c) the grid
- To examine the potential and efficiency in balancing local energy exchange in a sort of local energy-hub at e.g. a marina build a small scale system consisting of at least one electric boat with PV and one electric battery boat exchanging energy with local renewable energy sources and the grid.
- Establish a land based PV-array or other renewable energy source (on or near the local marina) that via the energy hub should be linked to battery and solar powered boats on the piers of the local marina and members club house.
- Further to demonstrate the energy hub energy exchange idea put up some artistic elements with PV-panels that can draw attention to the else hidden energy challenges.

The project process
To find information for hypothesis 1 and 2 on actual boat use frequency and how the boats where used a survey targeting motorboat owners was carried out.
Over a three month period the project was luckily able to invite all owners renewing yearly registration of motorboats in the river Gudenaa to answer a survey on their boat and the way it is used. 841 users completed the survey – more than 40% - which was way over the 40 to 80 answers the project had optimistically hoped for.
The survey showed that a transition to electric propulsion has not yet started and it is unlikely to expect a rapid change within near future – the next 5 years.
The knowledge and acceptance of the new electric technology is fairly low. 30% find that electric boats are slow and 60% do not know. 11% think electric power is more expensive than fuel but 66% admit not to know. In spite of this 8% consider buying an electric motor when 18% consider buying a new ICE (The interest for electric motors may be as an additional motor for trolling fishing). 27% of the boat owners are looking for a new fuel powered boat while 8% consider buying an electric boat.
The classic and reasonable excuse for not considering electric propulsion is: "The battery may not be big enough if I should want to use the boat on open water". The short distances in this central part of the river Gudenaa system can be negotiated easily with batteries and electric propulsion. The survey showed that half the leisure boat fleet never leaves the river which means approximate 1300 of the boats could be electric without fearing range problems. This should give potential for a local electric boat service/business.
The average age of a motorboat is much longer than for a car and owners of motorboats want to maintain the value of their investment. It seems fairly normal that a boat can be repowered with a new engine. Therefore it seems likely that there should be room for some kind of business offering electric repowering on motorboats in good condition and in this way maybe even extend the active life of the boat.

The local tourist passenger boat company Hjejleselskabet, welcomes a possible study into electrical repowering their fleet of diesel powered boats using approximately 40000 litres of diesel per year (less than a citybus in a year). The old original steamboat Hjejlen uses 40 tons of coal per year, but this boat is not a candidate for electric repowering. The passenger service is only active in the summer months power for a full day is required and occasional also evening service. A canal tour boat in Copenhagen has been repowered with batteries and electric propulsion with success – removing engine related noise and emissions completely additional to lower operational cost. A main challenge is a very high initial cost on a technology with little references.

The power consumed by the leisure motorboats in the Silkeborg – Ry area is not significant enough to call for large investments in intelligent charging infrastructure. The yearly fuel consumption by the local leisure motorboats equals two citybusses. The amount of fuel sold directly to boats in Silkeborg and Ry is known but many motorboat owners bring their own fuel canisters filled elsewhere. The assessment by the local boat clubs is that they sell less than half the gasoline used but a larger share of the consumed diesel. The diesel sold directly to boats in Silkeborg and Ry is marine diesel without biofuel. Normal road-diesel with added biodiesel can create growth of problematic biofilm in the diesel tank.

A citybus consumes around 45000 litres of diesel per year. The Marinas in Silkeborg and Ry claim that the fuel consumption is fairly stable from year to year. In 2007 the two Marinas sold around 16800 litres diesel and 12170 litres gasoline. In the 2011 user survey the boat users estimate a total yearly fuel consumption between 52000 litres and 95000 litres which suggest that the sold amount of fuel should probably have a factor 2.5 to 3 instead to get to a realistic level. Still the fuel consumption by leisure boats seems insignificant in a national context. The Hjejle passenger boat fleet of 9 boats use 0.0016% of the total annual Danish diesel consumption. Comparing the fuel consumption to road transport the emissions should give little concern even though the engines have a very high average age. All new engines feature low emissions and the numbers suggest that engines are getting updated at reasonable rate.
Even though the fuel consumption and emission may not be an environmental issue avoiding diesel smell, exhaust smoke and other emissions including noise would be well received by tourists and others using the river and lakes.

The hypothesis 3 may sound right but the Denmark is not ready for it. It ended up being not impossible but unrealistic to implement the hub due to protective feelings for different parts of harbour and the geographical area in combination with a very effective set of national regulations ensuring that any energy flow from one owner to another can be taxed.
It has been essential for the project to find local people or organisations that will take ownership and responsibility for maintenance when the project is closed down.

The artistic sculptures with PV-panels were very well received by many local people but not all. Even after several iterations with new ideas and a local manufacture of steel structures that offered to help build the sculptures the ideas were not fully supported. From past experience the local people seems to understand that touching the atmosphere around the harbour can easily arouse conflicts.

Placing a PV array on the Marina was not easier. The marina club house has a very special roof design with a less optimal orientation towards the sun and with trees and other element casting shadows on the panels. Therefore it seemed ideal to place the PV-array on a south facing 45° slope up to an elevated railway just behind the club-house – also the only suitable area near the clubhouse. Since this land was owned by the Danish railway infrastructure company the power from the PV array could not be balanced against the consumption in the marina. The marina owns the land under club house and most of the piers which added to complication. You are not allowed to let power cross outside the limit of your land unless you are registered as a power producer with your own dedicated production meter and grid connection. You are only allowed to balance your PV-power (up to 6 kW) against your own consumption within your own single registered slice of land – else you must buy a separate meter and connection to the grid and sell the PV power at 0,60 DKK/kWh. When you buy it back you must pay around 2,00 DKK/kWh including tax and VAT.

A boat floating in water cannot be considered part of any slice of land – even it is moored at your own private pier. Therefore it is unpractical to share any energy between boats or between boats and land. Each boat that could source any power must have its own registered connection and meter to sell power to the grid. This can never be economical feasible meaning that the surplus clean power from PV panels on boats will never be utilized. This is directly counterproductive to the national strategy of reducing waste and making use of economical and clean renewable energy.

The back-up solution for the energy hub was to place a PV-array on the Ferskvands Museum at Siimtoften in Ry. The museum and the land are owned by the Municipality of Skanderborg. They also own the harbour and the toiletbuilding at the harbour. They also agreed that a charging post could be placed on their land at the harbour. The electric power is currently supplied via two different meters but in principle the Municipality could decide to supply all electric installations on their land via just one meter and therefore be allowed to balance the Distributed Energy Resources (DER) against the actual consumption. To visualize the electric energy flow remote reading has been established of the meters for the toiletbuilding , charging post and Ferskvands Museum. In the Ferskvands Museum a video display is continuously running a power point presentation of the project and the partners, the national energy flow from EnergiNet.dk, the local energy flow and production from the PV-array.

One of the partners, Solbaaden, has agreed to take over the maintenance obligation at project closure.

The marina in Ry has at its own initiative put up electric supply on all piers. The connection is standard 13A CEE connectors as used by camping caravans also. It is not SmartGrid charging post for electric boats but just 230V AC supply for whatever power equipment aboard. The consumed power is metered and an energy payment system has been set up by the marina. Each outlet can be switched off pending payment. Now the power is typically used for comfort equipment and charging the service battery after a day on the lakes with comfort equipment running. Adding up all the theoretical maximum load from all power outlets at the same time would exceed the power feed capacity to the marina by a factor more than 10. The energy consumption to comfort equipment seems to be increasing so that the marina may be facing problems shortly if many boats come home with semi empty service batteries and want to charge simultaneously. If just a few boats becomes battery powered and need to charge at the same the marina will need to shift some loads in time to stay within the allowed feed current.

Conclusions:

The project is early relative to the motorboat owners that seem to be fairly conservative. A transition to electric power is not exactly welcomed by the marina representatives because they fear that politicians may be tempted to force specific solutions without respect for the large investments done in the current leisure boat fleet.
That half the leisure boat fleet never leaves the lakes means that they are suitable for being propelled electrically and powered by batteries.
The power consumed by the leisure motorboats are marginal compared to road transport. The leisure motorboat fleet seems to consume less diesel fuel than two citybusses on an annual basis. This small fuel consumption per boat distributed on the full fleet cannot justify any investments in e.g. new SmartGrid charging equipment.

The lacking knowledge on electric boats suggest that a campaign towards motorboat owners and potential boat owners. From Electric Vehicles the lesson is clearly that you need to try for yourself to change your attitude. It could be relevant to demonstrate repowering on some boats and let boat owners win a trail period for free.

A future project could be to optimize a marinas load shift regime without SmartGrid connection to the boats but based on previous experience in combination with trend analysis. It could also be possible to supplement by a Wi-Fi or mobile app conveying the boats required energy to exploit the full feed capacity without overloading.

A relevant future project could be to look into an electric repowering of the Hjejle passenger fleet. They have currently 8 diesel powered boats that will need to have new engines within the next years. It is relevant to analyse/quantify potentials:

- Technical requirements for repowering: motor system size, auxiliary systems, battery capacity, charging capacity, power supply from grid
- Economy in repowering – investment, operational cost, future battery replacement
- Reduced noise and emissions, reduced risk of pollution of water
- Possible ancillary services exploiting the huge battery capacity during nights and winter?
- Other additional benefits from battery operation or in relation to repowering?

3. Project results

The funding to carry out this project has been granted by EnenergiNet.dk in the 2010 ForskEL program. The project partners have greatly appreciated the EnergiNet.dk financial support as well as active help from EnergiNet.dk in resolving questions on electric system regulations and presenting the project relevance in the future Danish and European electric energy system at a conference arranged by the project.

3.1 Project back-ground and challenge

There are more than 2600 pleasure motorboats in the river Gudenaa and connecting lakes. The majority of the boats are located in the 19 km river section from Ry to Silkeborg which is a closed system that only very small boats can sail away from; other boats must leave by road. There is no central registration of boats in Denmark and therefore no credible numbers have been found for motorboats in Denmark but it is assumed by the project that the high concentration of boats in the Silkeborg – Ry area may represent 3% to 10% of all the Danish leisure motorboats and as such allow for a very rough extrapolation to a national scale.

The project has in this limited geographic area assessed the energy potential with respect to leisure and tour boats, which could be electric without performance degradation, and the energy that would shift from fossil fuels to renewable electric energy. The national energy target on becoming independent of fossil fuels sets the expectation that most leisure boats will be powered by electricity in 2050. Assuming that the transition from Internal Combustion Engines (ICE) to batteries and electric motors had not yet started, the project idea was to analyse if and how the future electric boats can support the SmartGrid control necessary to achieve 100 % independence from fossil fuels in the Danish electric power supply network.

The project is largely focusing on 3 areas:

1. **looking for the number of boats that are suitable for electrification**
2. **Some electric boats may have PV-panels for sailing, with a surplus production.**
3. **Optimise use of renewable energy by smart exchange of energy locally in marinas and reduce load both on the grid and the marina power feed connection.**

These areas can simplified be formulated as three hypothesis to be validated.

The project hypothesis no. 1

***Few boats are now propelled electrically but many of the boats have the potential to become powered by renewable electric energy in the future*.**

- Has a transition towards electric boats started? Are there any indicators as to when it might peak?
- Find the number of motorboats that are readily feasible for electric propulsion powered by batteries.
- What is the size of the related electric power/energy needed from a charging infrastructure? [1300 boats charging at the same time

Project hypothesis no. 2

Many of the future battery powered boats will have Photovoltaic panels (PV-panels) to charge the battery and extend the range. If the use frequency on most leisure boats are very low the PV-panels will be idling already few hours after last tour. Assuming that PV panels can in most applications produce much more power than the battery can hold if not in use.

- Can it be estimated how much solar energy could be "wasted" on a typical solar powered leisure boat?
- What is the typical leisure boat use frequency?

Project hypothesis no. 3

If the surplus solar energy from PV-panels on battery boats could help charge other battery boats and contribute to the marina and the electric grid it would support the national energy strategies very well.

- Analyse boundary conditions for establishing a local energy hub system (model) to handle energy from
    1. a PV boat to a) battery boat; b) Marina club house; c) the grid [only
    2. a battery boat to b) Marina club house; c) the grid
    3. a land based PV system to a) battery boat; b) Marina club house; c) the grid
- To examine the potential and efficiency in balancing local energy exchange in a sort of local energy-hub at e.g. a marina build a small scale system consisting of at least one electric boat with PV and one electric battery boat exchanging energy with local renewable energy sources and the grid.
- Establish a land based PV-array or other renewable energy source (on or near the local marina) that via the energy hub should be linked to battery and solar powered boats on the piers of the local marina and members club house.
- Further to demonstrate the energy hub energy exchange idea put up some artistic elements with PV-panels that can draw attention to the else hidden energy challenges.

3.2 The project process

To find the information necessary for confirming or rejecting the hypothesis 1 through 3 the project was divided into a number of work packages with participation of various project partners.
The project was divided into four main Work Packages. The specific findings are elaborated below disseminated on their respective work packages.

3.2.1 General description of work packages

Table 1. Overview of activities, responsibilities

WP/Task	**Activity**	**Responsible**	**Partner**
WP 1	**Analyse potential of transition to smart grid for electric boats w/o solar cells**	**Teknologisk Institut**	
1.1	Possible link to existing initiatives such as Edison and ECO Grid	Teknologisk Institut	EnergiMidt
1.2	Analysis of boat usage patterns	Solbaaden	Teknologisk Institut and the Municipalities of Skanderborg and Silkeborg
1.3	Analysis of energy / power balance and potential	Teknologisk Institut	EnergiMidt and Solbaaden
1.4	Availability and technical stage of commercial PV products	EnergiMidt	Teknologisk Institut
1.5	Identification of potential PV locations near the marina	EnergiMidt	Kvickly
1.6	Billing and taxation schemes	EnergiMidt	Teknologisk Institut, Kvickly and Hjejleselskabet
1.7	Identification of potential for Danish boat owners and further business possibilities	Teknologisk Institut	EnergiMidt, Solbaaden and the Municipalities of Skanderborg and Silkeborg
WP 2	**Establishment of a prototype marina power distribution hub at the harbour of Ry**	**Solbaaden**	EnergiMidt and the Municipalities of Skanderborg
WP 3	**Compilation and dissemination of experience gathered**	**Teknologisk Institut**	EnergiMidt, Solbaaden, Visit Skanderborg and the Municipalities of Skanderborg and Silkeborg
WP 4	**Recommendations for future activities**	**Teknologisk Institut**	EnergiMidt, Solbaaden, Kvickly and Hjejleselskabet

3.3 Analysis - Potential of transition to smart grid for electric boats

3.3.1 Possible link to existing initiatives such as Edison and ECO Grid

Visits to Marinas and dialogue with boat clubs has given a reasonable impression on the present state regarding electric energy supply to the current fleet of leisure boats and the existing electric power distribution systems for boats. This is the background for assessing relevance of possible knowledge transfer from previous and current SmartGrid projects.
Batteries in boats can be charged like battery electric vehicles but a market for charging at SmartGrid charging posts like for EVs are unlikely to develop for boats. In most marinas and at private jetties standard electric plugs are available for charging service battery and powering all auxiliary and comfort equipment while the boat is in harbour. Standard connectors of type CEE seems to be the default connection method across boats and camping caravans. The payment regimes can be very different from flat rate to actual metered payment – prepaid or drawn from a credit card. Most marinas can offer also guests access to electric power. Since an infrastructure for providing electric power is already in place for most boats with comfort equipment charging of electric boats will be using the same. It is not realistic to supply comfort equipment from one connector and a second for charging propulsion batteries. Therefore experience from Edison is less relevant for the individual charge post but handling the mobile nature of the boat might be relevant. Leisure boats want constant supply to auxiliary equipment while battery charging may in most cases be postponed. The boat as an electric load is more similar to a house rather than an EV. But because of the mobile nature of a boat and that the DSO has no individual meter for each boat the normal control structures are not suitable. If a larger group of marinas join forces to develop an energy management system for marinas, it could be relevant to also look to projects like e.g. EcoGrid.EU and DREAM.

3.3.2 Analysis of boat usage patterns

In 2010 the Gudenaa-committee decided that all boats with engines sailing in the Gudenaa river system were obliged to have a sailing permit which could be obtained for 200 DKK by registering the boat through the committee's website. The register's launch date was set to 1st of May 2011 and all boat-owners were required to register before 1st of August 2011 in order to have a valid permit to legitimately sail in the Gudenaa River in 2011. This meant that all boat-owners using the Gudenaa River were to access their website to complete the registration. The project group reached an agreement with the Gudenaa-committee that all boat owners that successfully completed the online registration were forwarded to an online voluntary questionnaire designed by the project group. Thereby all registered boat-owners were offered to participate in the project's questionnaire.

To analyse the boat usage pattern it was necessary to define which specific information was needed to complete the task. This process resulted in six boat-centred topics for which information was gathered:

1) General information (Q1-Q3 in questionnaire): General information about boat specifications; type, length and weight. This data will give a good indication of the boat-size in the Gudenaa fleet as well as it is a potential causal indicator for answers to other questions.

2) Sailing and usage pattern (Q4-Q11 in questionnaire): From a "utility perspective" it is important to know what time of day and how frequently the boat is being used. Information about trip duration is also requested as it will give an indication of the energy consumption related to boating in the Gudenaa.

3) Engine (Q12-Q23 in questionnaire): Information about engine type, mounted location, size, top speed, engine hours and year of production are requested as these, eventually coupled with *general information*, will give the project group possibility to find clusters of boats that are homogenous. The specifications included in the engine-topic will give basis for calculations on emissions and reference calculations on energy consumption. Questions about considerations towards acquiring new engine and/or new boat are included to get an indicator of the current state and get insight whether a shift in trajectory in e.g. propulsion system is incumbent or more long-term.

4) Energy related costs (Q24-Q25 in questionnaire): Information about costs of engine maintenance and annual fuel consumption. This will give an indication on cost of ownership as well as a reference towards answers on trip frequency and duration.

5) Electricity (Q26-Q30 in questionnaire): Information about electricity consumption and connection; connection-type, electrical units, electricity generation and consumption.

6) Impression and experience (Q31-Q46 in questionnaire): Subjective questions about the positive and less positive experiences about recreational boating and test of owners' perception on electrical propulsion in terms of cost.

This resulted in a questionnaire with a total of 46 questions. To ensure a high completion rate only two questions in the questionnaire were obligatory to be answered. The questionnaire is attached in APPENDIX B and answers in appendix C (in Danish).

3.3.2.1 Expected results from questionnaire

Prior to questionnaire-launch discussions were with the organized boating clubs as well as internally in the project group about the analysis expected findings.

- Boat-usage:
  It is expected to be confirmed that the vast majority of the boats are docked at the wharf/marina most of the time as they are not being used. The expectation is also that when the boats are being used they are sailing very few hours at the time. It is expected to be concluded that the median frequency of usage is limited – maybe as low as once a week – and that the trip-duration is low. If these expectations are met it will support the argument that electrically powered boats already today can replace most fossil powered boats.

- Usage of electricity:
  It is especially interesting to see how high share is connected to on-shore electricity while the boat is docked at the wharf. The share is expected to be low as only the larger boats are assumed to be connected. This correlation is expected to be confirmed. Another aspect included is what kind of electrical consuming units are being used by the boat-owners. It is expected to be mainly refrigerators, water-heaters and entertainment systems.

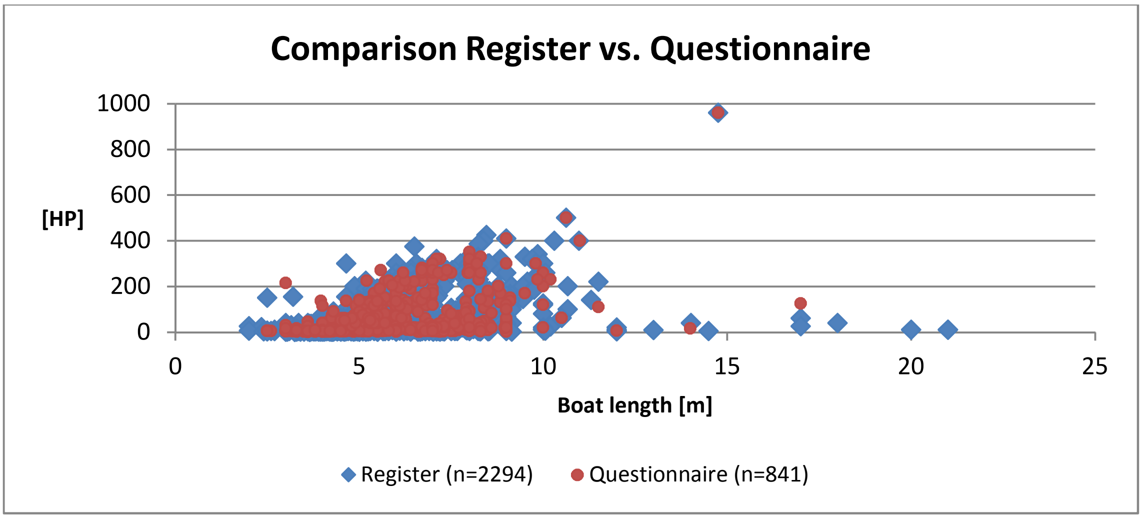
- Considerations towards changing engine or boat:
  It will be very interesting to see the difference between the owners' consideration in terms of whether they are more likely to acquire a new/used engine or acquire a

new/used boat, and more importantly if it will be electric or petrol/diesel. It is expected that a relative low share are considering to acquire a new/other engine/boat, and this could potentially give an initial segmentation of the boat-owners in terms of their preferred choice of vessel.

- Electric boats:
  It is expected to see that the boats usage pattern measured on trip duration, frequency and energy consumption can be fulfilled by the electric boats that exist today.

3.3.2.2 Questionnaire participation

In the period from 1st of May to 1st of August 2011 a total of 2.004 boats were registered in the official register and 841 of these answered the questionnaire resulting in a 42% response rate. Even though the official registration deadline was 1st of August there have been additional registrations and on 1st of January 2012 the total was close to 2600 registered boats. Using this latest known number the questionnaire's response rate is 32% of the total registered fleet in the Gudenaa-River and it is statistically tested to be valid with a 95% confidence interval.
The official register's boat-specific information is low-level and only two boat-specific variables are applicable for representation test purposes; boat-length and engine-power and a chi-squared test is conducted for Goodness-of-Fit.



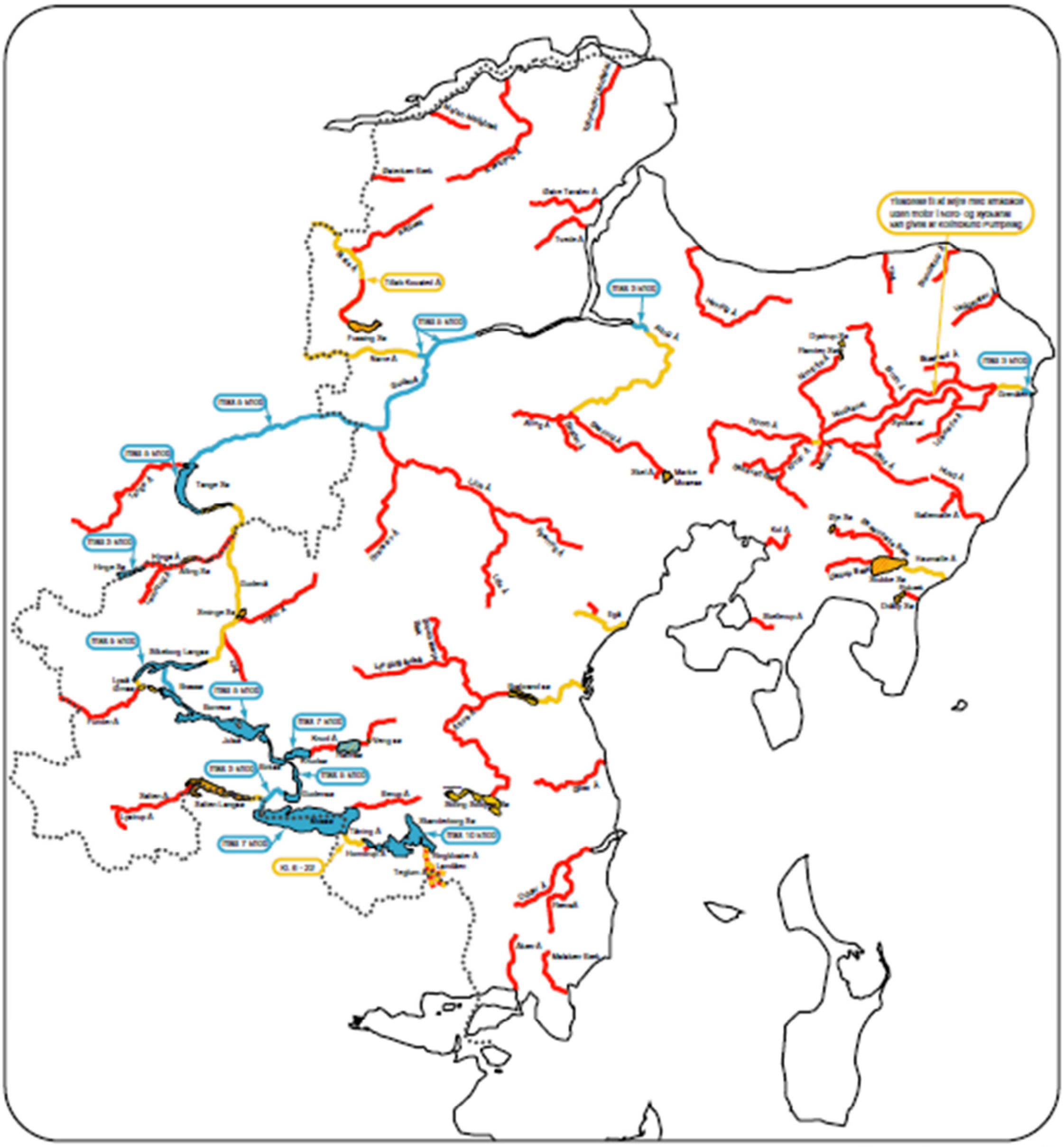
Figur 1 Comparison of boat registrations and survey answers

Mean comparison	Length [meters]	Engine [HP]
Register	5,75	50,91
Questionnaire	5,73	54,12

On basis of the chi-square test the hypothesis that there is a significant difference between the boat length observed in the questionnaire and the official register can be rejected. This is also the case for the engine size variable.
However there is still a difference on the mean engine size and third quartile on the questionnaire is at 60HP while it is at 55HP in the register. This indicates that there is a slight over-representation in the register of boats with large engines but this difference is not statistically significant and is not of importance for the complete analysis

3.3.2.3 Gudenaa River and boating

The Gudenaa River is in total 160km long and throughout the system there are speed limits which vary from as low as 3 knots but they never exceed 8 knots, as shown in Figur 2



Grundmateriale: KMS Copyright

Sejlads forbudt	Boats not allowed
Sejlads tilladt med småfartøjer uden motor	Only small boats wothout motor allowed
Sejlads tilladt med motordrevne fartøjer	Motorboats allowed
Småfartøjer uden motor kun for bredejere, andre efter tilladelse af bredejere og tilsynsmyndighed	Small boats without motor allowed for local landowners and with special permission.
Motordrevne fartøjer kun for bredejer, andre efter tilladelse af bredejere og tilsynsmyndighed	Motorboats only allowed for local landowners and with special permission.

Figur 2 River Gudenaa and lakes in the Eastern part of Jutland.

For boat-owners the most popular section of the waterway is the route between Silkeborg and Ry where especially Himmelbjerget near Ry is notable as an estimated 250.000 people visit there annually making it one of Denmark's top15 attractions.

3.3.2.4 Marinas and berths

There are three larger marinas in the waterway between Ry and Silkeborg, which the organized boat clubs operate. Silkeborg motorbådsklub has 900 members and Silkeborg Sejlklub has 120 members and they share 344 docking berths while Ry-bådlaug has 200 members and 160 docking berths. There are around 60 docks variously equipped and in size in the Gudenaa and approximately 30 of them are owned and maintained by the organized boat clubs and only accessible through club membership.
A total of 32 per cent of the boats in the official register do not inform a docking berth and according to the organized boat clubs they expect that these are the boats that are stored on trailers at various locations and are only in the water when actively sailing.
The active boating season is mainly from May to September but the freshwater inland waterway is prone to seasonal changes and if the winters are cold enough most of the waterway will freeze. Therefore practically all boats are located on-shore during winter-season. From the project point of view this complicates the accessibility to these boats as they most likely are located on-shore at various privately found locations and not in clusters at the marinas.

Boats in the Gudenaa system

The approximately 2600 private boats registered in the official register but the total number of vessels is higher. Since only boats with engines are required to be registered an unknown number of kayaks, rowing boats and other non-engine boats are to be added to get the total population. However these vessels are not included as the analysis focus in this project is the engine-powered boats in the Gudenaa system.

The boats engine type and their mounted location (inboard or outboard) uncovered significant indicators that are used for further fragmented fleet-analysis.

Categorisation engine-type	2-stroke gasoline	4-stroke gasoline	Diesel	Electrical engine	Hybrid	Other
Inboard	1,2%	**13,1%**	**19,2%**	0,1%	0,1%	0,1%
Outboard	**27,2%**	**32,9%**	0,1%	4,8%	0,1%	0,2%
I+O (both)	0,0%	0,4%	0,2%	0,1%	0,0%	0,0%

The four highlighted categories account for 92,9% of the boat population and not only do they have a significant size but a high degree of homogeneity was uncovered since causality was found between answer and engine-type in many of the other questions included.
This has made it possible to create boat profiles using means for each of the four main groups and this uncovers e.g. that it is the inboard 4-stroke and Diesel which account for the largest boats in the system since they are significantly longer, heavier and more powerful than the other boat-groupings as shown in the table below.

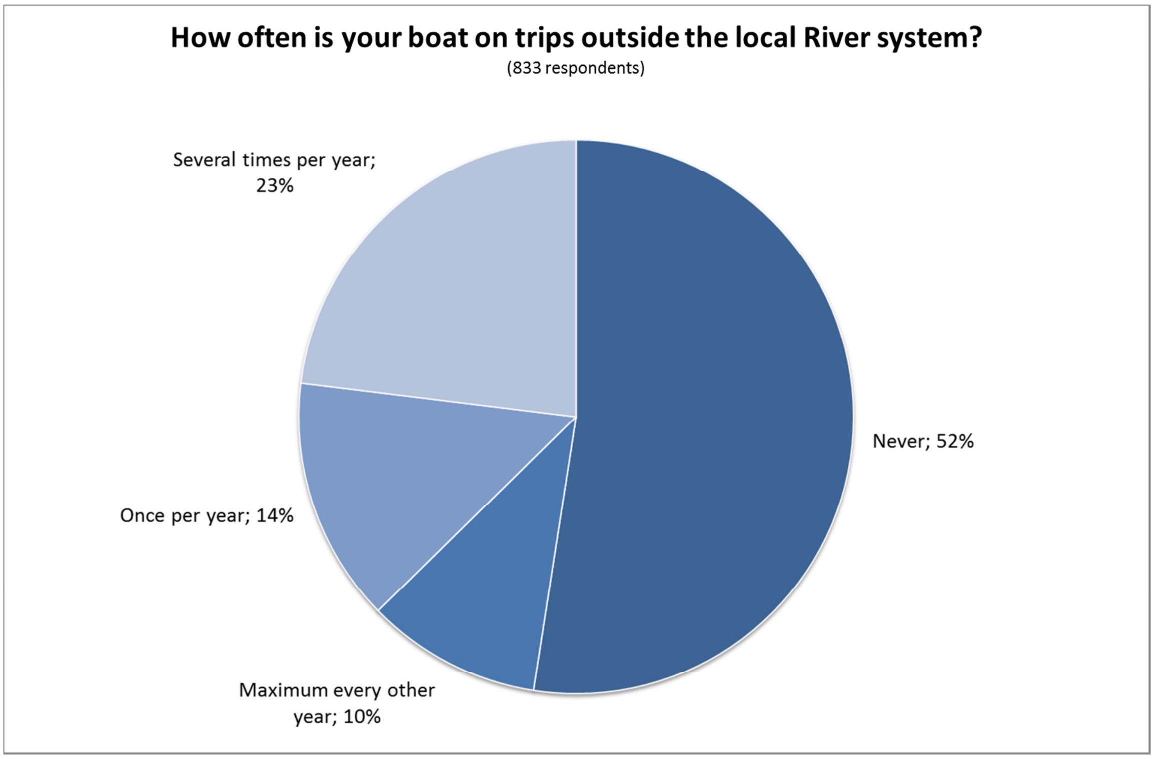
Boat-profile using categorical means	Outboard engines		Inboard engines	
	2-stroke, gasoline	4-stroke gasoline	4-stroke gasoline	Diesel
Engine size [HP]	22 HP	38 HP	159 HP	60 HP
Engine-age [years]	18,0	6,0	16,6	25,0
Length [meters]	4,96	5,04	6,41	7,54
Weight [kg]	448	540	1490	2546
Share of total	27,2%	32,9%	13,1%	19,2%

The average age is highest for diesel engines at 25 years old while outboard 4-stroke engines are newest with an average age of 6 years. The most powerful boats are the inboard 4-

stroke grouping whose engines more than two times more powerful than the inboard diesel grouping which has the second largest engines. The smaller boats are in the two largest groupings, outboard 2-stroke and outboard 4-stroke which account for 60% of the total boats in the questionnaire.

3.3.2.5 Boat-usage analysis

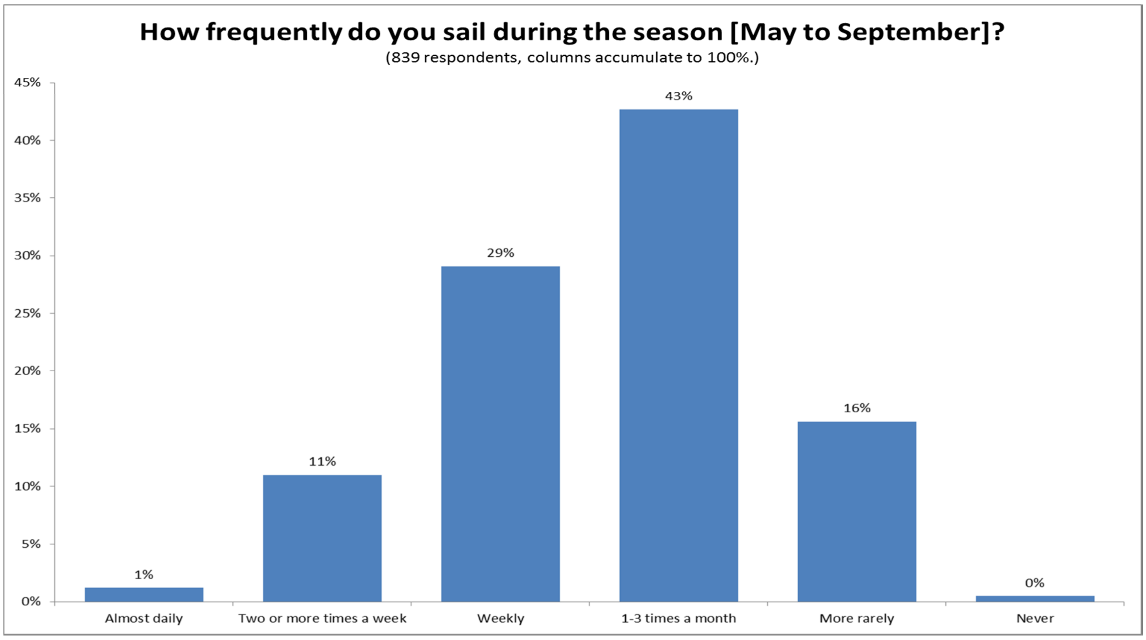
Besides sailing on the Gudenaa River system 48% of the boats are on trips outside the local River system at least every other year, as depicted in Figur 3.



Figur 3 Frequency og boat visits outside the river system.

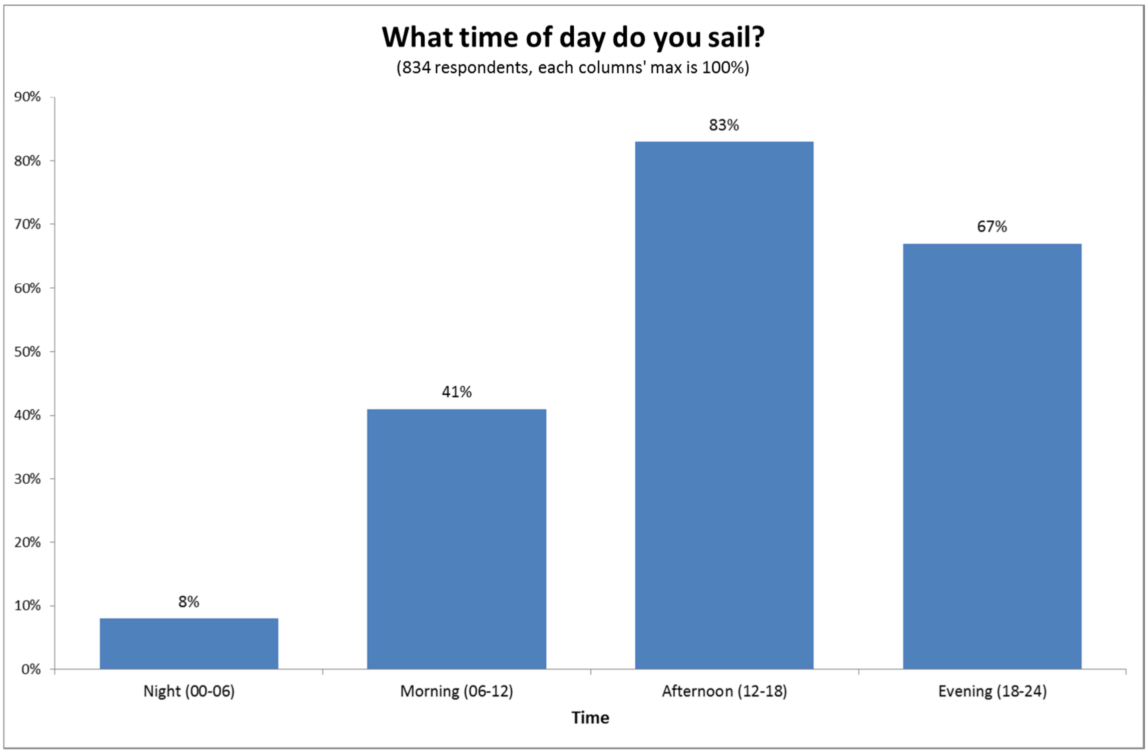
More interestingly this means that 52% of the boats only sail in the River system and besides seasonal lay-up these are never located outside the system.

The boat usage is very low as only 41% of the boat owners state that they sail weekly or more frequently as depicted in Figur 4.



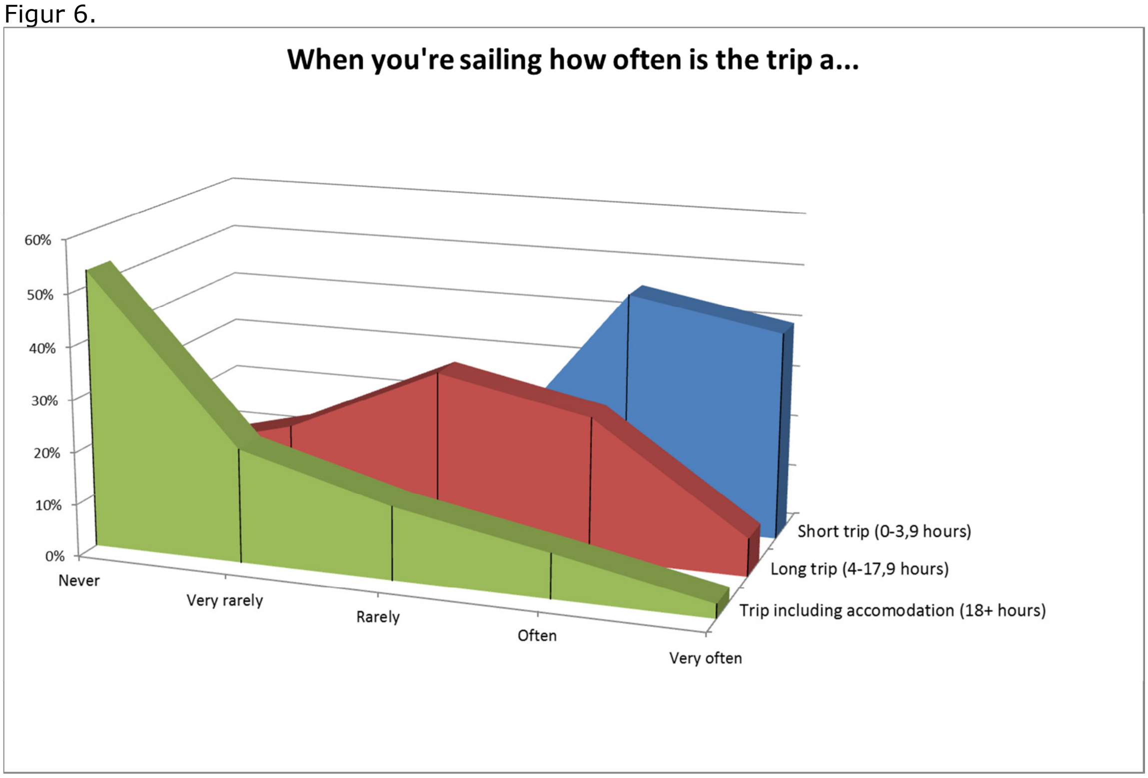
Figur 4 How often is the boat used?

When the boats are being used, the time of usage is mostly in the afternoon or evening, as depicted in Figur 5 below.



Figur 5 The time of usage- time of day

When the boats are being used it is mostly for shorter trips as indicated with the blue area in Figur 6.



Figur 6 The time of usage - how long - how often?

Most of the trips are shorter than 4 hours in duration while very few are of longer duration. This is not surprising since sailing from one end to the other (Silkeborg to Ry) takes approximately 2 hours.

The low usage frequency and the short trip duration essentially mean that the boats are located at their berth the majority of the time. Applying this to the whole 5-month season the boats are in average only sailing 2-7% of the time as shown in Tabel 1 below.

Tabel 1 Time away from harbour vs engine type

Usage over a season (3650 hours; 5 months)	**Outboard, 2-stroke**	**Outboard, 4-stroke**	**Inboard, 4-stroke**	**Inboard, Diesel**
Time away from dock [hours]	76,6	102,3	107,1	272,4
Boat usage time	2,1%	2,8%	2,9%	7,5%

This means that from May to September a boat could be docked at a marina as much as 98% of the time and this could prove beneficial if they were equipped with battery and were a part of a system for storage in the energy system.

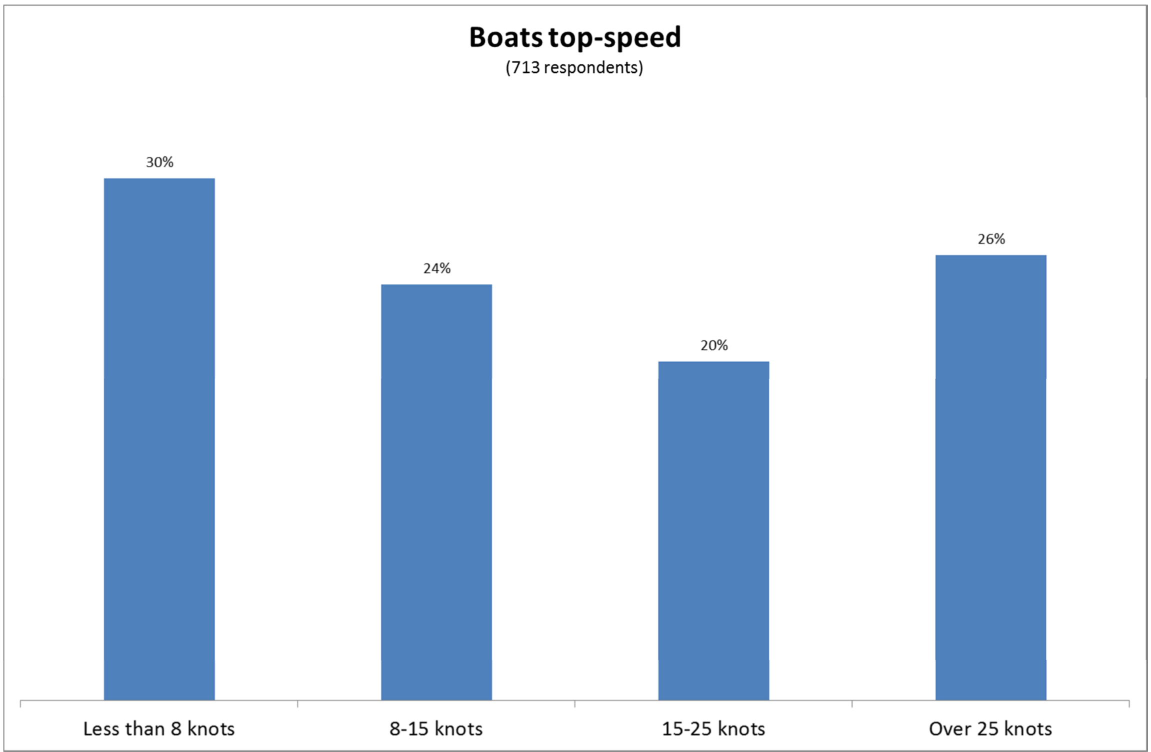
3.3.2.6 Peak docking activity

Unlike e.g. Electric Vehicles the usage of private boats in the Gudenaa is not for transportation purposes but more for recreational use and the pattern is thus dependent on other things than day-to-day logistics. Through the season the usage is highly weather dependent and on a sunny weekend day many boats are sailing, especially Sundays. 83% stated that they sail in the afternoon and according to the boat clubs the highest concentration of boats returning to dock is on Sunday afternoons.
However the highest occurrence of boats in the river is during special events such as Riverboat and Silkeborg Regatta. The regatta is held over four days and the organized boat clubs estimate that there could be as many as 1000 boats sailing in the system at the same time but this is just their estimate. The boat clubs state that these special events don't amplify the concentration of boats returning to their marina as their existing users are already frequent sailors' and the additional boats are not docking at their marina but are either taken on-shore after a trip or scattered to dock at various smaller and temporary berths.

The worst case scenario for usage-peak is that all 41% that sail weekly or more frequently would sail the same day and that 83% of them that sail in the afternoon would dock at the same time, and if all these boats were electrically propelled, this scenario would mean 34% of all the boats in the system would connect to the grid at the same time.

3.3.2.7 Energy and emissions - Energy consumption

The speed limit in the Gudenaa never exceeds 8 knots but the boats can achieve much higher speeds as depicted in Figur 7.



Figur 7 Boat speed capability

70% of the boats can achieve speeds higher than the speed limit at 8 knots and 26% even have a top-speed exceeding 25 knots.
The boats are thus sailing at very low speeds compared to their performance capability and depending on waterline length (LWL) and hull type several boat-types do not reach hull speed and thus use excessive energy to displace the water they're sailing through. Furthermore the speed limits force boats to sail with a very low engine-load to not exceed 8 knots and we are aware of at least one example where a private boat-owner had to acquire a smaller propeller to meet these demands. These factors indicate that boat engines are not being operated in an optimal load-pattern in the Gudenaa River.

The boats are mostly sailing short trips and by using the average profile grouping the energy usage per trip can be calculated and this is shown in the table below.

Energy usage dispersed on type of trip	Outboard, 2-stroke	Outboard, 4-stroke	Inboard, 4-stroke	Inboard, Diesel
Short trip (0-3,9 hours) [liters] - 2 engine hours	1,0	1,4	4,1	3,6
Long trip (4-18 hours) [liters] - 4 engine hours	2,1	2,9	8,2	7,1
Incl. accommodation (18+ hours) [liters] - 4 engine hours	2,1	2,9	8,2	7,1

Not surprisingly the largest energy demand is to be found within the inboard engine-groups as they also represent the largest and most powerful boats in the system.

Only 15% of the boats are connected to on-shore electricity and their electricity consuming units are refrigerators, water heaters, entertainment systems, navigational equipment and lights. The owners' average electricity usage in a season is 35 kWh according to their entered information.

Total energy consumption in the Gudenaa River
Three data sources are used as offset for finding the total energy consumption in the Gudenaa River:

1. **Maritime gasoline and diesel sales from pumps located at marinas in Silkeborg and Ry**
2. **Questionnaire: Energy consumption informed by the respondent**
3. **Questionnaire: Calculated from respondents sailing frequency and trip duration**

Using these offsets three different calculation methods are applied; one using the known sales figures from the pumps, one using the respondents informed energy consumption and the third by transforming the respondents' answers to sailing frequency (Q5), trip-length (Q7-Q11), and boat engine-size (Q16) to quantitative fuel consumption. The results based on the questionnaire input are multiplied with a factor which is found by dividing total registered boats with 841, which is the number of questionnaire respondents.

Total fuel consumption	Extrapolated from pump-sales	Questionnaire: Informed	Questionnaire: Calculated (reference)
Gasoline [liters]	36.000	265.532	64.195
Index	56	413	100
Diesel [liters]	90.400	94.918	101.532
Index	89	93	100

*The final results include commercial operators known energy consumption of approximately 40000 litres/year.

The obtained results for gasoline consumption vary with more than factor 7 from lowest to highest and this raises questions. The highest result stems from question 25 in the questionnaire: *"What is your annual fuel-consumption measured in litres?"*; the validity of the answer is highly doubtful as most boat-owners do not know their correct fuel-consumption but still state an answer (Mcknight, 2007).

The results for total Diesel-consumption across the three methods only vary from 90-101.000 litres of diesel.

(According to StatBank Denmark The Danish energy use by household and industry total 88068622 GJ of diesel in 2009 equalling 2.54×10^9 litres of diesel of which 0.0016% is used by the Hjejle passenger boat fleet)

3.3.2.8 Energy and emissions - Emissions

The demand for less emissions are increasing and as shown in table below the limit for NOx in tier III is set to be reduced by 95% in 2016.

Tier	Date	NOx Limit, g/kWh		
		n < 130	130 ≤ n < 2000	n ≥ 2000
Tier I	2000	17.0	$45 \cdot n^{-0.2}$	9.8
Tier II	2011	14.4	$44 \cdot n^{-0.23}$	7.7
Tier III	2016†	3.4	$9 \cdot n^{-0.2}$	1.96

† In NOx Emission Control Areas (Tier II standards apply outside ECAs).

EPA7IMO REFERENCE (find original website/report)

For recreational boats tier III is to be enforced already from 2013 for engines over 37 kW and in 2014 for the smaller engines.

IMO regulation for recreational boat engines

Engine effekt	2009	2010	2011	2012	2013	2014	2015	2016
< 37 kW			Tier 2				Tier 3	
≥ 37 kW								

EPA7IMO REFERENCE (find original website/report)

Estimating accurate emissions from the leisure motorboats is not possible with the available data. An attempt has been made to give some indicative figures based on average engine age and average engine power rating. Since the tolerance on fuel consumption is significant and average engine power rating is much bigger than actual operating power for most engines the resulting emission figures gives a very uncertain emission number – not to be used for analysis of boat fleet cumulative emissions. A more accurate estimation of emissions would require more detailed information from boat owners on the engine and the boats power need at 5 and 8 knots.
Anyway - to find specific data for the Gudenaa emission data vs. engine types is found in table from MST emission report. To find somewhat relevant table values the average engine power and average engine age is used within each category.

Emissions, table values	Outboard, 2-stroke gasoline	Outboard, 4-stroke gasoline	Inboard, 4-stroke gasoline	Inboard, Diesel	Commercial, diesel
HC [g/kwh]	156	20	20	1,36	0,6
CO [g/kwh]	310	455	455	6,79	2,2
NOX [g/kwh]	1,6	10	10	9,38	14
PM [g/kwh]	3,7	0,06	0,06	0,98	1,05

*www.mst.dk/udgiv/publikationer/2002/87-7944-963-8/html/kap02.htm

CO2 emissions

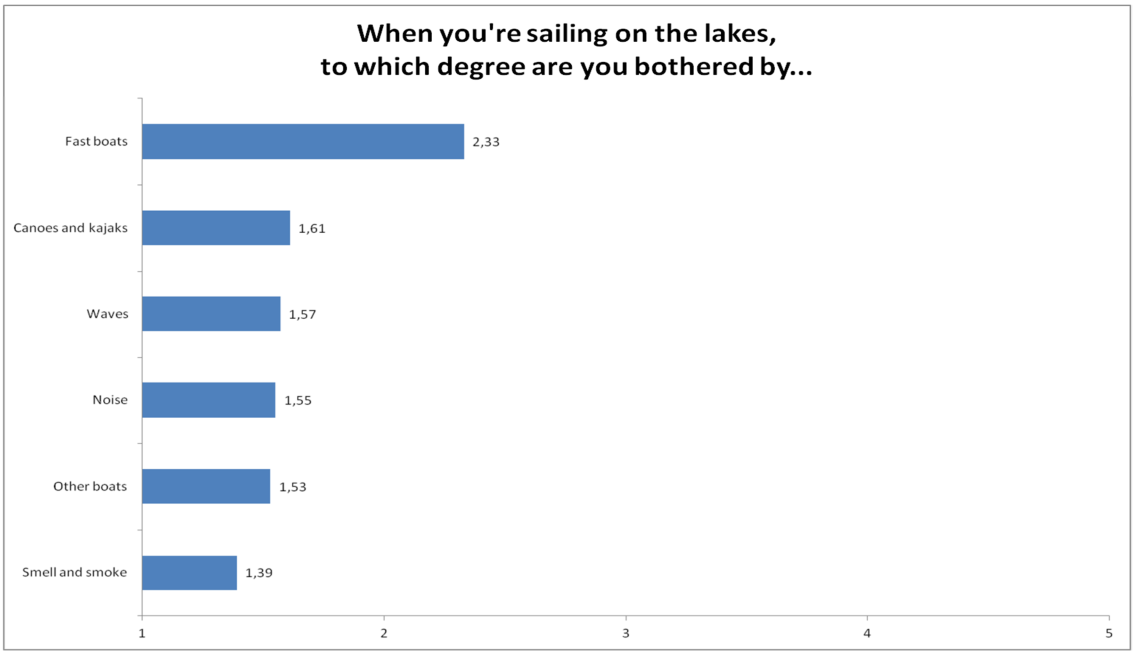
Using the index 100 method as basis the total emissions of CO2 can be calculated as the CO2 emission for gasoline is 2,41 kg per litres while it is 2,695kg per litres for diesel. Due to the previously mentioned conditions the variation on the final result here is from 330 to 895 tons of CO2 annually.

Total-Emissions	Out-board, 2-stroke gasoline	Outboard, 4-stroke gasoline	Inboard, 4-stroke gaso-line	Inboard, Diesel	Commer-cial, diesel	Total
HC [tons]	55,6	19,3	35,1	0,3	0,08	**110,3**
CO [tons]	110,5	439,6	798,7	1,3	0,31	**1.350,1**
NOX [tons]	0,6	9,7	17,6	1,8	1,96	**29,5**
PM [tons]	1,3	0,1	0,1	0,2	0,15	**1,7**
CO2 [tons]	28,6	50,7	77,1	171,3	107,8	**327,8**

Comparison with whole transport segment emissions in Skanderborg (153.000 tons and Silkeborg Municipality area. Boat emissions represents below 0.1 per cent of total emission!

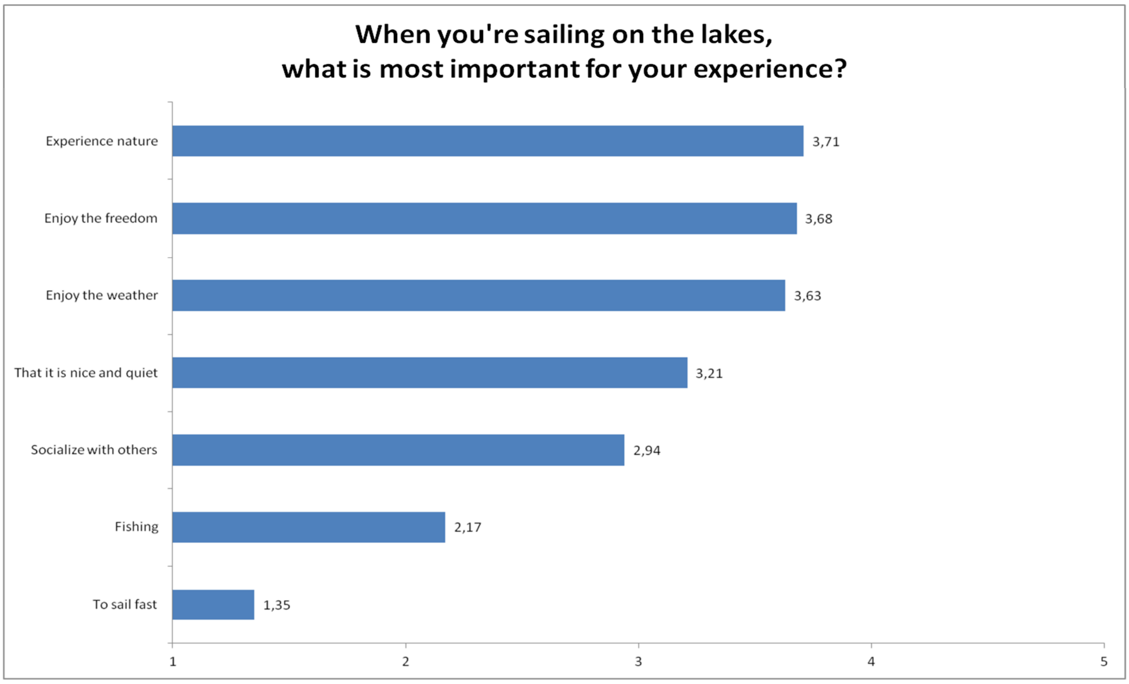
3.3.2.9 Boat-owners subjective perception

When the boat owners were asked about what bothered them the most (Q31-Q36 in questionnaire) "fast boats" got the highest score while the other five categories were rather insignificant.



Figur 8 Annoyances

Both *noise* and *smell and smoke* score low and this means that these do not bother the boat owners at the moment.
On the positive side the boat-owners appreciate (Q37-Q43 in questionnaire) to *experience nature*, *enjoy the weather*, *enjoy the freedom* and *that it is nice and quiet*.



Figur 9 Important for the leisure experience

A share of 27% of the respondents are considering acquiring a new/other gasoline/diesel boat and 18% are considering acquiring a new/other gasoline/diesel engine (Q20-Q23 in questionnaire).

Considering acquiring a new/other...	Gasoline/Diesel	Electric
...Engine	18%	8%
...Boat	27%	8%

For electric propulsion the considerations are 8% in both engine and boat and this is considerably lower than the gasoline/diesel responses. A natural user-driven transition to electric propulsion does not seem incumbent at this time.

3.3.2.10 Gudenaa potential for electric boats replacing fossil powered boats.

52% of the boat-owners state that they never sail outside the local river system and the findings have shown that it's mostly shorter trip durations that are being endured. This means that the energy demand per trip is low and as the boats are only away from the dock 2-8% of the time and 59% sail less than weekly there should not be any complications in terms of time for charging.

3.3.3 Analysis of energy / power balance and potential (WP1.3)

The survey has showed that a transition to electric propulsion has not yet started and it is unlikely to expect a rapid change within near future – the next 5 years.

The knowledge and acceptance of the new electric technology is fairly low. 30% find that electric boats are slow and 60% do not know. 11% think electric power is more expensive than fuel but 66% admit not to know. In spite of this 8% consider buying an electric motor when 18% consider buying a new ICE (The relatively high interest for electric motors may be as an additional motor for trolling fishing). 27% of the boat owners are looking for a new fuel powered boat while 8% consider buying an electric boat.

The classic and reasonable excuse for not considering electric propulsion is: "The battery may not be big enough if I should want to use the boat on open water". The short distances in this central part of the river Gudenaa system can be negotiated easily with batteries and electric propulsion.

The power required to travel at the standard speed limits in the river system vary extremely with the different boat designs. The speed limit of 5 knots in narrow and sensitive areas can be made by most even small boats with a relative low power required.
The 8 knots maximum speed in all other parts of the river system without lower limits requires much more power. The power versus speed is very unlinear and depend on hull shape , load, position of thrust, wind etc. Many smaller boats cannot reach 8 knots.

Two examples (based on data from www. Solbaaden.dk):

- The solar powered SunCat 21 has a catamaran hull designed for low power. It is 6.5 m long and 2.53 m wide; 1100kg. With the 3.2kW electric motor it can go 6 knots maximum. With 1 kW it can do 4 knots in 10 hours on the 48V 220A Lead-Acid gel battery (10.5 kWh).
- The solar powered Aquabus 850 is 8.5 m long and 2.5 m wide; 2000kg. It has a traditional displacement hull. With the 8kW electric motor it can go 6 knots maximum. With 2.3 kW it can do 4 knots in 8 hours on the 48V 380A Lead-Acid gel battery (18.2 kWh AGM-type).

The survey showed that 52% - half the leisure boat fleet - never leaves the river which should give potential for electric propulsion on batteries. The maximum distance from Silkeborg to Ry is approximately 19 km or 10.5 nautical miles (nm)

The two solar powered boats will with a March speed of 4 knots need a battery of at least:
SunCat21: 5.5 kWh
Aquabus 850: 12 kWh

The battery size for a day's sailing at leisure speed is not critical and can be fitted in most boats. There are currently only two types of batteries recommended.
The long life gel based lead-acid batteries tend to have the lowest initial price.
Of all the different new lithium based batteries only the very robust batteries like Lithium ferro Phosphate type are considered. The risk of a fire if something should go wrong is much lower that high energy density Lithium Cobalt or similar technology. Reducing risk of fire is always important on boats. Lithium titanium oxide batteries are also very safe but have a initial cost but also a very long life.
A major difference between Lead Acid batteries and lithium batteries is that the lithium battery always needs a battery management system BMS, to ensure balance and protect against abuse. The lithium battery advantage is 3 to 5 times higher energy content per kg and the volume is also reduced significantly. Additionally the lithium battery can cope with more than thousand 80% discharge cycles while a lead acid battery prefer to work at charge rates over 50% especially at heavy load currents. The3 lead acid can not easily handle high loads when State of Charge (SOC) is under 50% where the lithium is nearly unaffected until empty.

An electric motor does not need the normal transmission. It can stop completely and reverse without clutch and gear. Most electric motors do need a reduction gear to fully exploit the high energy density in an electric motor at high speed.

It is possible to repower most boats to handle 5 to 8 knots but there are not yet good substitutes for the high powered outboard motors. For inboard motors the engine, transmission and clutch is dismounted together with cooling system, exhaust and fuel system.
Often the electric motor/ gear assembly come on a frame that can be mounted in the same brackets as the original fuel engine. An elastic coupling connects the gear output to the propeller drive shaft.
Sometimes it can be useful to change the propeller to a type with less incline.

Experience from other projects show that the electric motor can be much smaller than the ICE. The electric motor has capacity for short time overload in manoeuvring while it must have enough power for the needed march speed.

The average age of a motorboat is much longer than for a car and owners of motorboats want to maintain the value of their investment. It seems fairly normal that a boat can be repowered with a new engine. Therefore it seems likely that there should be room for some kind of business offering electric repowering on motorboats in good condition and in this way maybe even extend the active life of the boat.

The local tourist passenger boat company Hjejleselskabet, welcomes a possible study into electrical repowering their fleet of diesel powered boats using approximately 40000 litres of diesel per year (less than a citybus in a year). The old original steamboat Hjejlen uses 40 tons of coal per year, but this boat is not a candidate for electric repowering. The passenger service is only active in the summer months power for a full day is required and occasional also evening service. A canal tour boat in Copenhagen has been repowered with batteries and electric propulsion with success – removing engine related noise and emissions completely additional to lower operational cost. A main challenge is a very high initial cost on a technology with little references.

The power consumed by the leisure motorboats in the Silkeborg – Ry area is not significant enough to call for large investments in intelligent charging infrastructure. The yearly fuel consumption by the local leisure motorboats equals two citybusses. The amount of fuel sold directly to boats in Silkeborg and Ry is known but many motorboat owners bring their own fuel canisters filled elsewhere. The assessment by the local boat clubs is that they sell less than half the gasoline used but a larger share of the consumed diesel. The diesel sold directly to boats in Silkeborg and Ry is marine diesel without biofuel. Normal road-diesel with added biodiesel can create growth of problematic biofilm in the diesel tank.
A citybus consumes around 45000 litres of diesel per year. The Marinas in Silkeborg and Ry claim that the fuel consumption is fairly stable from year to year. In 2007 the two Marinas sold around 16800 litres diesel and 12170 litres gasoline. In the 2011 user survey the boat users estimate a total yearly fuel consumption between 52000 litres and 95000 litres which suggest that the sold amount of fuel should probably have a factor 2.5 to 3 instead to get to a realistic level. Still the fuel consumption by leisure boats seems insignificant in a national context. The Hjejle passenger boat fleet use 0.0016% of the total annual Danish diesel consumption.

Comparing the fuel consumption to road transport the emissions should give little concern even though the engines have a very high average age. All new engines feature low emissions and the numbers suggest that engines are getting updated at reasonable rate.

3.3.4 Availability and technical stage of commercial PV products (WP 1.4)

PV is the abbreviation for "Photovoltaic", which describe the phenomena that under certain circumstances an electric current can be generated in materials when exposed to light.

Through the photovoltaic effect electrons are transferred between different bands within the material, resulting in the build-up of a voltage between two electrodes.
In most photovoltaic applications the radiation is sunlight and for this reason the devices are known as solar cells.

Modern solar cells are optimized to produce as much power as possible by providing different layers in the cells with different characteristic - popularly speaking with surplus of electrons respectively holes - in what is denoted the p-n junction solar cell.

The photovoltaic effect was first observed by the French physicist Alexandre-Edmond Becquerel in 1839. The first practical use of solar cells were seen in satellite and space investigating equipment, in which the motive could justify the relatively high cost of PV at the time in question.

As consequents of the energy crises in early 1970'ties, research and development regarding utilization of PV in terrestrial application were launched, which forms the basis for the current deployment of commercially available PV systems in various sizes.

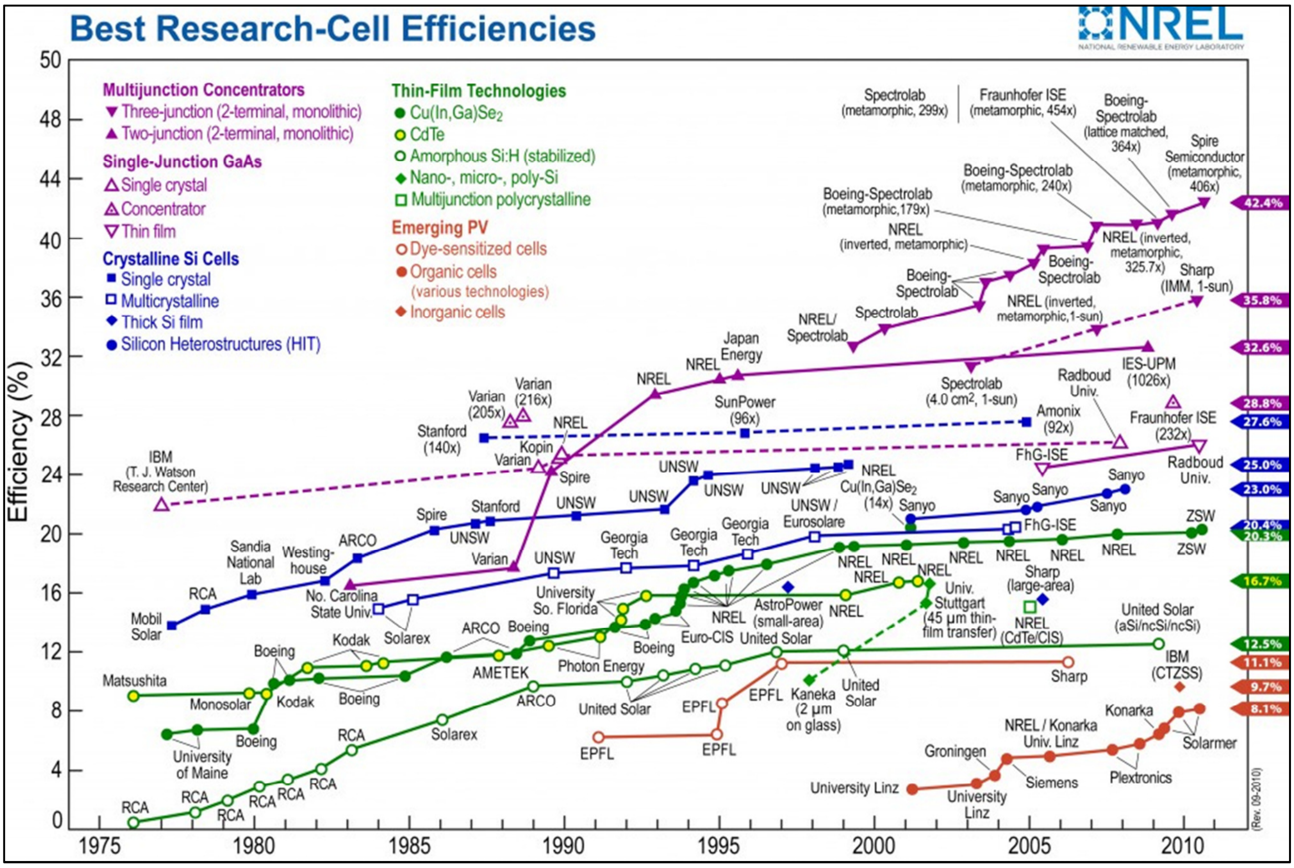
The development in PV has regarded technical as well as economic aspects. With respect to the technical side, efficiency of the cells has increased significantly over the years, and the best mass-produced solar modules now has a converting efficiency of 21 %.

In the figure below the development in efficiencies for research size cells is shown. Efficiency of cells in commercially available PV modules is approx. 5 % lower than in these small size research cells; however the figure provide an overview of the variation and potential between the different technologies.

Solar cells used in commercial application have traditionally been silicon based crystalline types, and these still account for approximately 80 % of production. According to the production process, either mono-crystalline or poly-crystalline is manufactured. The dark blue or black mono-crystalline type is slightly more efficient than the light blue poly-crystalline type.

The thin-film types cover the remaining 20 % of the marked. These are divided in 3 main types according to the active material utilized in the absorber layer of the cells:

- a-Si and a-Si/µc-Si. The oldest and least efficient, however also relatively cheap.
- CIS and CIGS. The most efficient thin-film type.
- CdTe. Mainly for large-scale plants, the cost leader among all PV technologies.



Figur 10 Research cell efficiencies, published by US federal National Renewable Energy Laboratory (NREL). More information on the website: www.nrel.org

The thin-film technologies are new compared to crystalline modules and hold some benefits over these. Usually they have a more uniform surface, which have made them rather popular among architects, whom traditionally have not been very fond of the visual appearance of especially poly-crystalline PV modules.

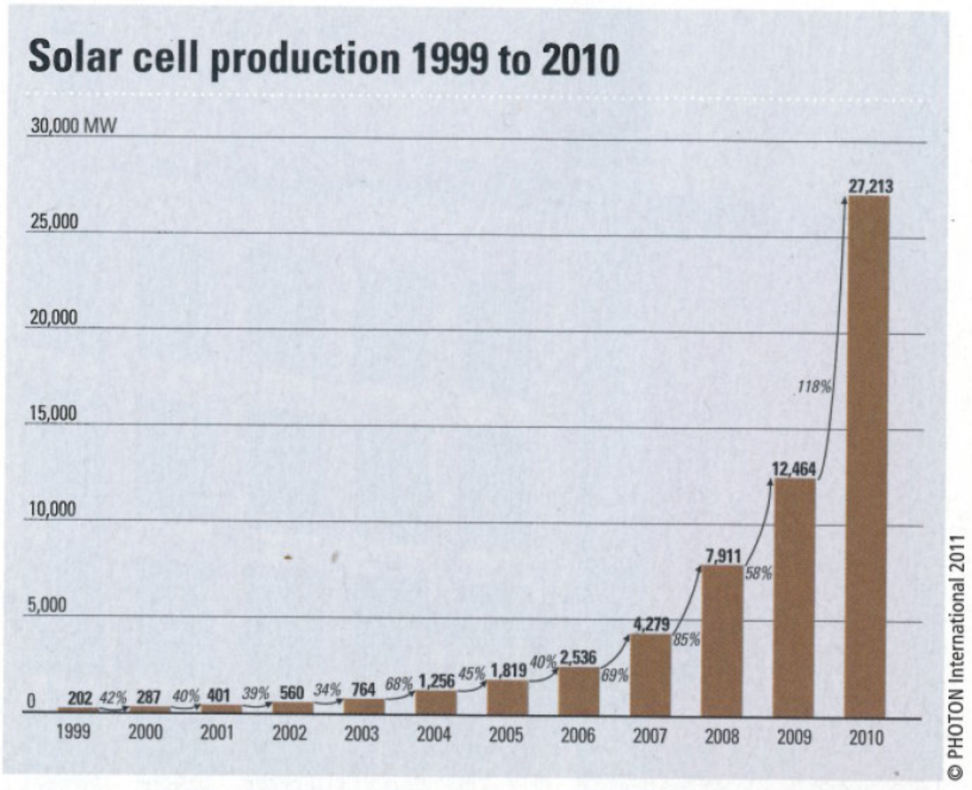
Furthermore the specific price per Wp is usually cheaper, which, however, to some extend is counterbalanced by the fact that efficiency is lower and thus more space as well as mounting equipment and – time is needed to provide a certain yield.

In the table below typical efficiencies for various PV modules are shown and compared. It is worth notice that a-Si modules require more than twice as much area compared to the crystalline-based types.

Table 1: Module and cell efficiencies for thin film and crystalline base PV modules

Technology	Thin film photovoltaic				Crystalline based	
	Amorphous silicon a-Si	a-Si/µc-Si	CIS - CIGS	Cadmium telluride CdTe	Mono crystalline	Multi crystalline
Cell efficiency, %	5 - 7	8	7 -13	8 - 11	16 - 19	14 – 15
Module efficiency, %					13 - 15	12 – 14
Area needed pr. kW_p, m²	15	12	10	11	App. 7	App. 8

The development in utilization of PV in global perspective has been steadily increasing in the last decade with growth rate typically in the magnitude of 40 %. The tendency is shown in the figure below taking from the periodical "Photon International". Especially in 2010 a very high increase were seen. For 2011, most experts expect a growth rate in the same size as for 2009.



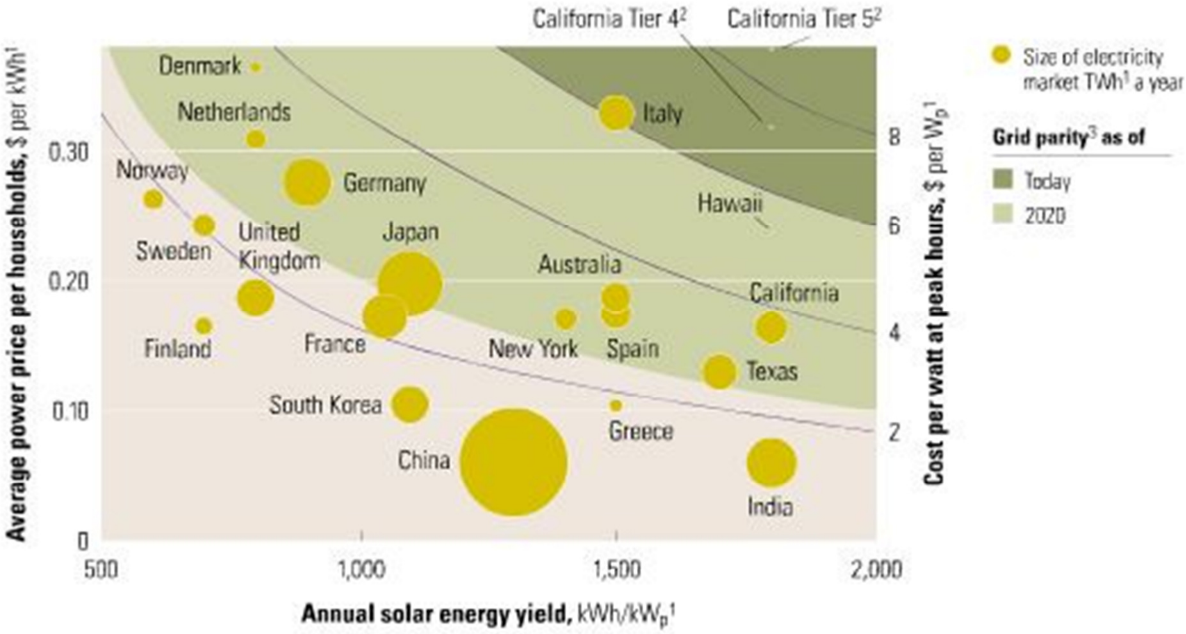
Figur 11 Solar Cell production 1999 to 2010

When looking at Denmark, the deployment of PV has not been anyway near the international level. According to the annual report for the IEA PVPS for 2010, a total installed capacity of approx. 7 MWp was estimated to have been installed in Denmark at the end of 2010.

In specific numbers, less than 1 Wp per inhabitant is installed in Denmark, whereas the corresponding number in neighbouring country Germany is close to 200 Wp, although the climatic condition for exploiting PV is almost comparable.

In 2011, however, a very significant raise in the national interest in PV were seen, probably due to a combination of increasing cost for electricity bought from the power company and steep decrease of the costs for PV systems. This tendency is shown in the figure below, showing the expected development in price equilibrium between electricity sourced from the grid respectively PV various countries[1].

[1] Source: http://peakenergy.blogspot.com/2008/06/mckinsey-on-economics-of-solar-power.html

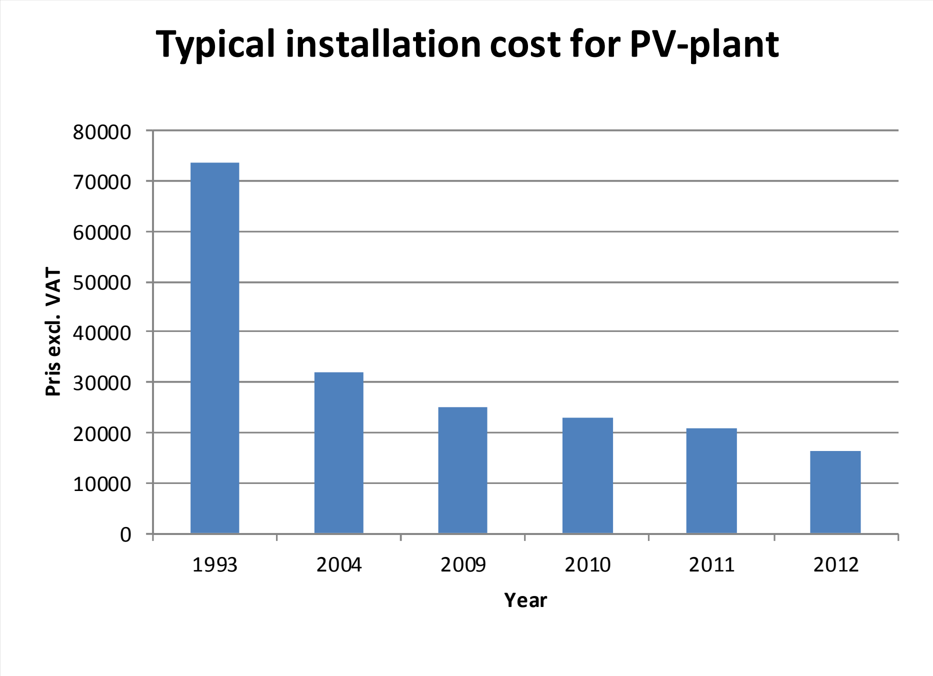


Figur 12 Annual solar energy yield vs price

Previously the payback time of a PV plant established under Danish conditions exceeded 20 years, and although the lifetime of the system is longer, an investment in PV could not be considered beneficially in traditional, economic terms.

The main reason for purchasing a PV plant were instead connected with attitudinal signals and environmental concerns as well as the wish to partly supply once own energy; which – although sympathetic - limited the number of potential investors.

The development over the last 4 years in typical costs for purchasing and installation of a PV plant in Denmark is shown in the figure below. For comparison, typical prices for the 1993 and 2004 are also inserted. The prices are based on experiences gathered at EnergiMidt A/S.



Figur 13 Typical installation cost for PV-plant

As consequents of the development in prices for electricity and cost of PV systems, approx. 10 MWp of installed PV capacity in Denmark is expected to be added in 2011 according to the branch organisation for PV related companies in Denmark (www.solcelle.org),

Although this is very positive, there is still a long way to go, before the deployment will reach a level, that have a significant influence on the national power grid. If high concentration of PV is present in local areas, however, this can in some case cause challenges for the local power grid, and therefor a growing attention regarding the possible influence from PV systems is observed among the grid operators.

3.3.5 Identification of potential PV locations near the marina (WP 1.5)

A site visit to areas and buildings at and nearby the marina in Ry has been carried out in order to identify the most suitable places for a PV plant that eventually could cover the electricity consumption at the marina.

For start, however, only a minor PV plant will be installed for demonstration purpose, and the optimal location for this was also identified at the site visit.

It most be noticed, that the identification of sites and sized is done from a strictly technical point of view, not taking into account if and how the legal framework affect the attractiveness of the solutions. These aspect is covered in the next chapter – Billing and taxations schemes.

Consumption

To decide on the PV capacity necessary, consumption figures for Ry marina has been provided for the period from March 1994 to April 2011. The consumption figures are presented in the table below.

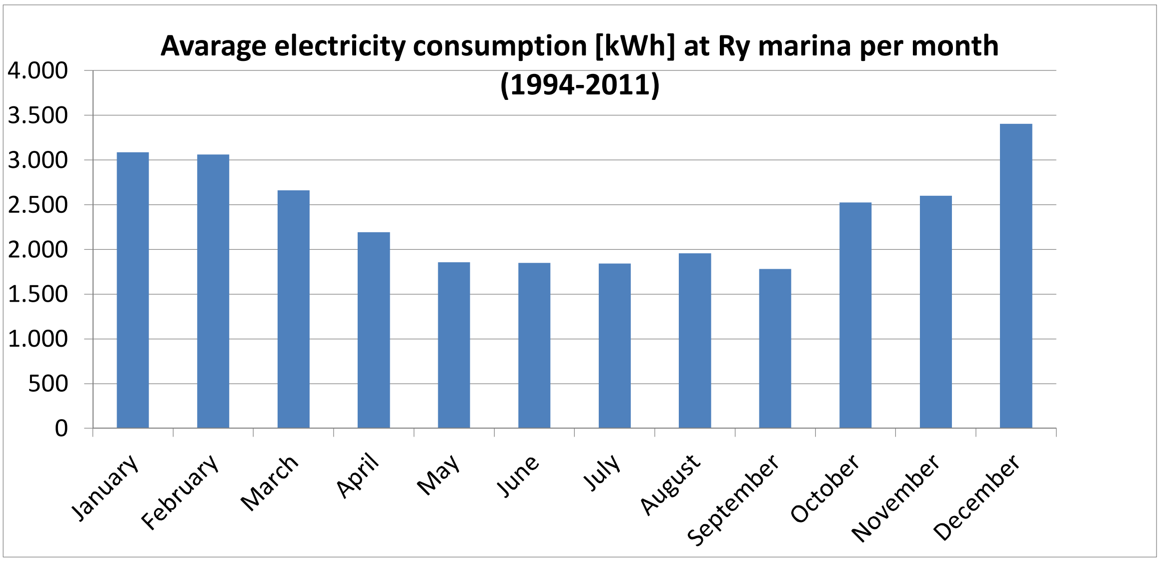
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
January		3.776	2.608	3.676	3.910	3.485	3.071	2.741	3.151	3.822	2.901	2.494	3.237	2.580	2.667	2.779	3.002	2.528
February		3.384	3.395	3.904	2.860	3.445	3.681	3.364	3.378	4.348	2.501	3.032	2.813	2.073	2.410	2.212	2.978	2.247
March	3.567	3.834	3.693	2.907	2.497	3.559	2.435	2.801	2.775	1.408	2.202	2.225	3.251	2.432	2.252	1.606	2.136	2.321
April	2.550	2.099	1.825	2.502	2.449	2.576	2.072	2.745	1.589	1.958	2.652	2.180	2.327	1.014	2.379	1.877	2.354	2.321
May	1.728	1.512	1.919	1.882	1.790	1.707	794	1.224	1.938	2.246	2.129	2.055	2.222	2.257	1.891	1.892	2.396	
June	1.709	1.679	1.591	1.223	1.434	1.200	1.386	2.172	2.018	1.653	1.831	2.374	2.126	2.956	1.901	1.888	2.272	
July	712	1.116	1.332	1.664	1.836	2.173	1.928	1.734	1.257	1.796	2.424	2.383	2.770	1.620	1.790	2.003	2.742	
August	1.324	1.048	1.288	1.641	1.492	1.722	1.461	1.965	2.108	2.346	1.840	1.487	2.264	2.037	3.676	2.817	2.742	
September	1.461	1.189	1.166	1.478	2.003	1.503	2.223	1.606	1.476	1.687	2.070	2.168	2.582	1.779	1.457	2.048	2.370	
October	2.158	1.560	2.330	2.822	2.564	2.281	2.100	2.548	2.517	3.185	2.210	2.095	3.127	2.872	2.712	2.815	2.989	
November	2.503	1.731	3.255	2.726	3.391	2.523	2.662	2.563	3.469	2.078	2.619	2.948	3.127	2.477	2.205	1.832	2.066	
December	3.533	5.599	3.597	2.726	4.272	3.887	2.522	2.563	3.280	3.123	3.181	2.506	3.929	3.174	2.862	3.040	4.066	
Forbrug Ialt	**21.245**	**28.527**	**27.999**	**29.151**	**30.498**	**30.061**	**26.335**	**28.026**	**28.956**	**29.650**	**28.560**	**27.947**	**33.775**	**27.271**	**28.202**	**26.809**	**32.113**	**9.417**

Based on this, the average annual consumption is calculated to 29.993 kWh (only full year included).

From the data it can also be calculated, that the month with lowest average consumption is July with a figure of 1.840 kWh. When this number is known, it is possible to calculate the size of a plant that minimize surplus production and thereby usually create the most favourable economic business case.

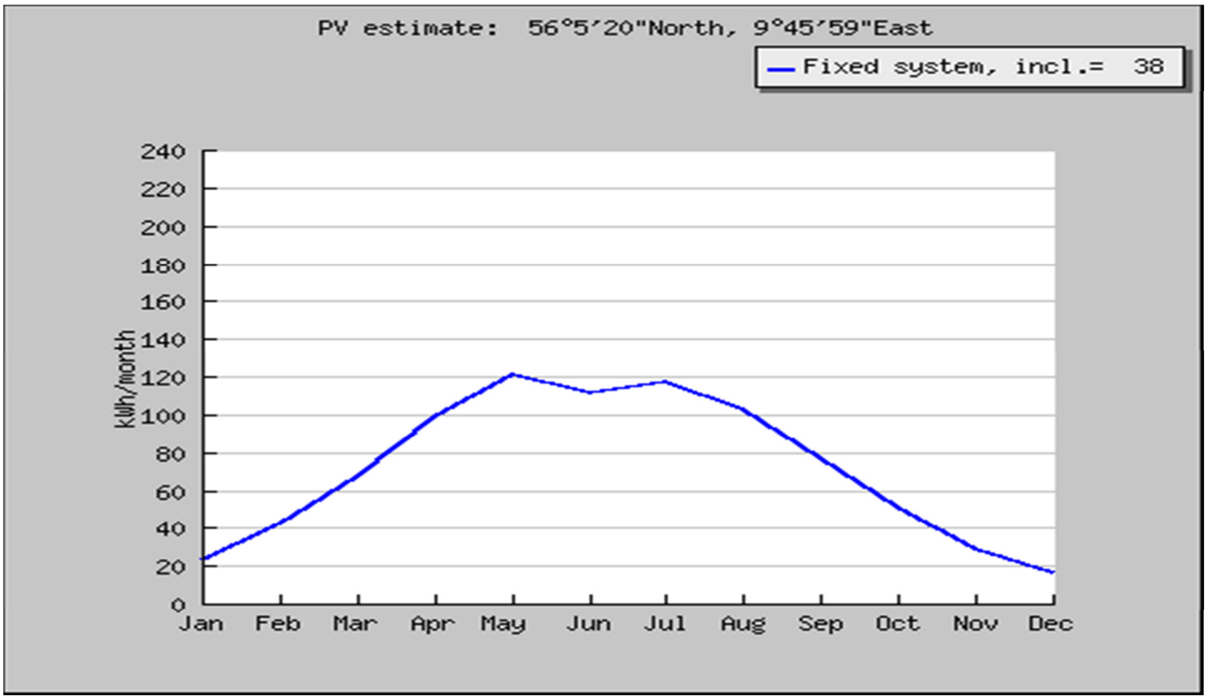
In the diagram below, the average electricity consumption in each month in the period is shown. The different between the months with the lowest (July) respectively highest (December) consumption is 1,85.

The relatively high consumption in the wintertime is – besides energy for lighting - due to the fact that heating is provided through electrical radiators, whereas the main part of the electricity in the summertime is used to supply the boats plugged into the marina grid.



Figur 14 Average electricity consumption at Ry mrina

In next diagram, the production profile of a 1 kWp PV plant in a typical year is shown (www.re.jrc.ec.europa.eu/pvgis) .



Figur 15 the production profile of a 1 kWp PV plant in a typical year

It is notable, that the profile of the production is opposite the one showing the consumption. This clearly indicates, that unless net metering is available, some measures have to be taking in order to improve economic conditions.

In this context it would improve the fit between production and consumption, if the energy source for some of the boats situated in the marina were converted from diesel and gasoline to batteries, since this will increase the consumption in the summertime where the boats are plugged into the grid of the marina.

Giving a certain share of the boats have their own electricity source, the electricity consumption of the marina would be more evenly shared over the year. Contrariwise, if these electricity-propelled boats also were equipped with their own PV system to charge the batteries, it would increase the difference between summer and winter electricity consumption of the marina.

Calculation of plant size

The necessary size of the PV plant is calculated in two situations:

1. For a plant, that can provide the total yearly electricity consumption at the marina, and
2. For a plant, that can provide the electricity consumption in the month with lowest average consumption (July).

1. A PV plant covering the total consumption

To calculate the necessary plant size, a calculation is done in a web simulation software developed by the Joint Research Centre of the European Commission called PVGIS (www.re.jrc.ec.europa.eu/pvgis).

According to this, a PV plant in Ry with an installed capacity of 1 kWp will have a yearly production of 855 kWh providing the plant is situated in optimal position with respect to slope (38°) and orientation (south). The monthly figures are shown in the table below .

Fixed system: inclination=38°, orientation=2°				
Month	E_d	E_m	H_d	H_m
Jan	0.73	22.8	0.87	27.1
Feb	1.50	42.0	1.82	51.0
Mar	2.15	66.8	2.69	83.3
Apr	3.29	98.7	4.26	128
May	3.90	121	5.25	163
Jun	3.72	112	5.05	151
Jul	3.77	117	5.14	159
Aug	3.32	103	4.51	140
Sep	2.54	76.3	3.35	101
Oct	1.65	51.1	2.08	64.3
Nov	0.97	29.1	1.18	35.4
Dec	0.53	16.4	0.63	19.5
Yearly average	**2.34**	**71.3**	**3.07**	**93.5**
Total for year		**855**		**1120**

E_d: Average daily electricity production from the given system (kWh)

E_m: Average monthly electricity production from the given system (kWh)

Based on the yearly yield of 855 kWh/kWp and the annual consumption of approx. 30.000 kWh, the necessary size in kWp can be found to:

30.000 kWh / 855 kWh/kWp = <u>35,1 kWp</u>

If utilizing typical modern PV modules of 200 Wp each, 175 modules is needed. Since each module typically measure 0,8 m x 1,6 m, the needed areal is:

0,8 m x 1,6 m x 175 = <u>224 m^2</u>

2. A PV plant covering the consumption in July

In July, the average electricity consumption of the Marina is 1.840 kWh. From the table above, it can be seen that the production from a PV plant of 1 kWp in July on average is 159 kWh. Thus the necessary installed capacity needed is:

1.840 kWh / 159 kWh/kWp = <u>11,6 kWp</u>

It the same module type is uses as in the calculation above, it can be found that 58 modules is needed, following the necessary areal will be:

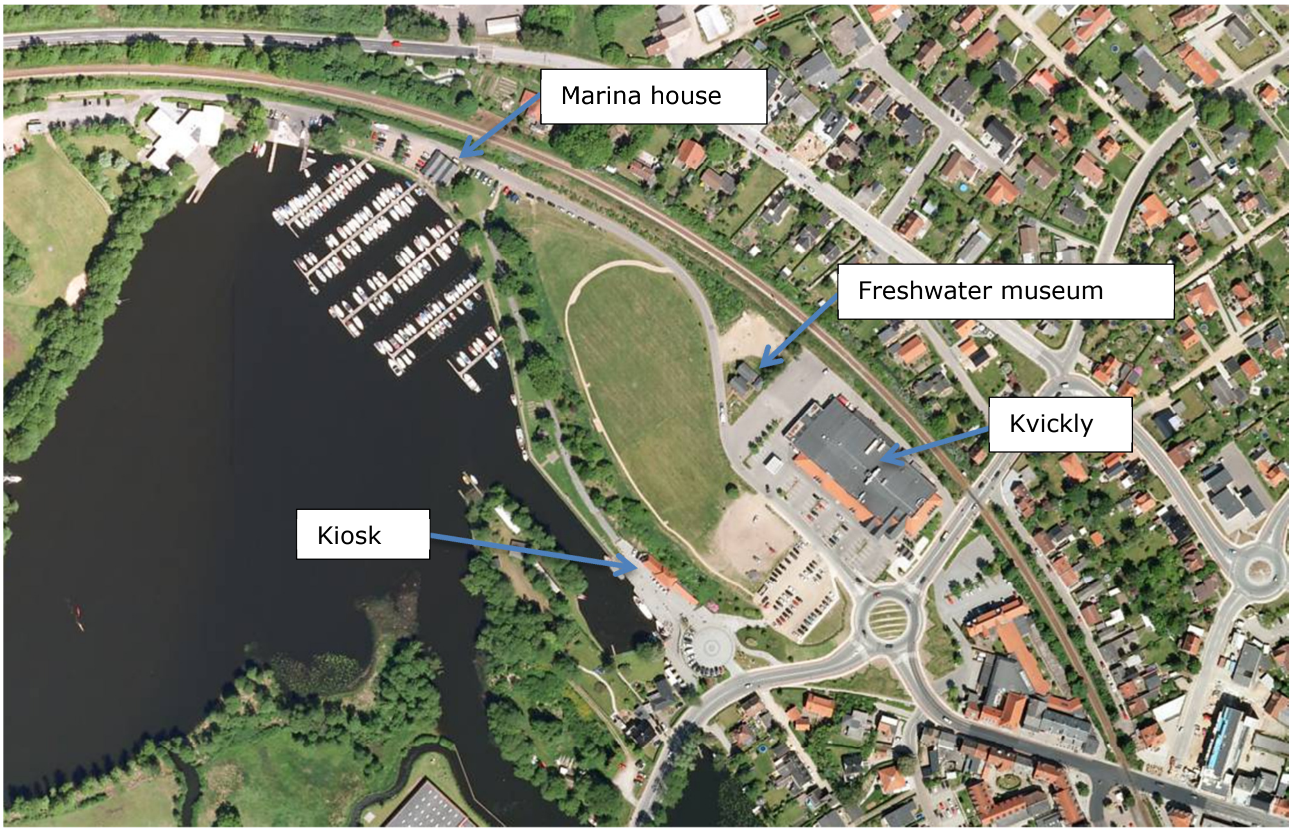
0,8 m x 1,6 m x 58 = <u>74,2 m^2</u>

On annual base, a plant this size will cover approx. one third of the total electricity consumption of the marina, giving it will be:

11,6 kWp x 855 kWh/kWp = 9.920 kWh

Possible locations

As part of the project, possible locations for PV plants have been investigated at – or nearby – the Marina. The area and locations in question is shown on the sketch below.



Figur 16 Possible locations for PV-system near Ry habour

If possible, the most obvious place to install the plant would be on the building belonging to the marina. This building is shown on the photo below.

Figur 17 Ry Marina - club house - notice trees and mast.

Unfortunately the building is not suitable for PV for several reasons:

- The size of the roof does not provide the areal needed, and besides this, the orientation is east-west.
- Parts of the roof are covered by shadows from trees etc.

The building was also judged to be unsuitable for the small-scale plant to be set up immediately for demonstration purposes, partly due to the above-mentioned reasons and partly because the building is situated rather isolated.

The next building investigated was the kiosk situated at the entrance to the marina area. In many respect, this building could be suitable for PV: The areal would be sufficient to cover at least a 10 kWp plant and since many people visit or pass the kiosk, it would also serve as an interesting place for the small-scale demonstration plant.

It was, however, decided not to use is due to the fact that:

- Part of the roof is exposed for shadows, which is clearly visible on the picture below.
- The building hold local historical value, and changing the visual expression with a PV plant would probably not be acceptable in the view of many of the inhabitant of Ry.

Figur 18 Kiosk and toilets at Ry Habour

The final building investigated was the Freshwater Museum situated to the north of the marina area. The museum is shown on the photo below.

Figur 19 Ferskvand Museum at Siimtoften in Ry

The museum consists of two identical buildings with a very steep roof facing south-west. As can be seen from the picture, the main part of the roof of the back building is shaded by the front building, which excludes this as suitable for PV.

The roof of the front building holds very good conditions for PV, the only limitation being that the flagpole seen to the right of the building has to be moved. If the entire roof surface of

the front building is covered with PV modules, approx. half the annual electricity consumption of the marina could be provided from this.
Although situated in the outer rim of the marina area, the Freshwater Museum has been chosen as location for the small-scale demonstration plant, since the physical conditions is excellent and a significant number of people pass the building.

The demonstration plant will have an installed capacity of 2,6 kWh and be installed as a narrow band on the top of the roof of the front building. In this initial phase of the project, the production from the plant will be utilized in the Freshwater Museum.

Other locations

Since none of the building describe above could host a PV plant of 35 kWp, another location has to be found or a combination of more buildings could be taking into consideration. With respect to other locations, some possibility could be to:

- Find a place suitable for a ground based PV plant.
- To utilize the flat roof of the nearby supermarket "Kvickly". Here, and area of approx. 2.500 m^2 is available, which could hold a PV plant sizing more than 300 kWp.

Another solution could be to make a distributed PV plant, which could be the case if PV plants were mounted on several boats harbouring in the marina. In many ways, this could be a nice and convenient solution, but it had, however, some major drawbacks.

First of all, as it is described in the next chapter, it will require a change in the legal framework in order to be implemented. Some more practical issues also have to be taking into consideration: In the season, the boats – and thus the energy sources – are often sailing on the lake system and therefore not available for the marina.

Also the fact that the marina in Ry is surrounding by high trees that occasionally cast shadows on the boats – as well as the boats casting shadows on each other – will potentially reduce the yields gained from boat based PV plants. In other marinas, these conditions might differ, and thus make it more feasible to consider this solution.

3.3.6 Billing and taxation schemes (WP 1.6)

In practice, the legal framework regarding billing and taxation of electricity produced by PV plants will be the main factor that determines whether a certain business model is realizable or not. Having this in mind, it was decided to include an analysis of the present situation on this important topic.

Initially, several models were developed, ranging from the simplest situation were a boat is docked at a bridge belonging to a private parcel to a much more complex, where a "PV energy symbiosis" between boats, marina and public and private enterprises in the Siimtoften area is established.

Afterwards the outcomes and findings from this analysis is presented and discussed.

Introduction to legal framework
In several European countries various incentive measures have been introduced to support deployment of PV. In the leading PV market, Germany, for instance, a feed in tariff for electricity produced by PV has been available since the mid 1990'ties.

In Denmark, support to PV is provided by the fact that electricity sourcing from PV – in general – is exempted from taxation when used by the producer.

The value this holds, vary considerably dependent of the producer/consumer category, since the main part of the energy taxes for electricity used in commercial enterprises is already deducted. In the table below[2], typical consumer prices and taxation are indicated (in Danish language).

	Private og ikke-moms reg. virksomheder: ~ 4.000 kWh/år	Små virksomheder: ~100.000 kWh/år	Let proces virksomheder: >300.000 kWh/år	Tung proces virksomheder: >300.000 kWh/år
Element:	[øre/kWh]	[øre/kWh]	[øre/kWh]	[øre/kWh]
Markeds elpris [1])	37,5	37,5	37,5 – 35,5¤)	37,5- 35,0¤)
Lokal nettarif	19,3	19,3	11,9 – 7,1*)	5,9 #)
Regional transmission	0,9	0,9	0.9	0,9
Energinet.dk transmission	7,4	7,4	7,4	7,4
PSO	6,0	6,0	6,0	6,0
Abonnem. & effektbetaling net	15,9	15,9	15,9	15,9
Abonnem. Forsyningspligt	2,7	2,7	2,7	2,7
Elpris i alt	89,7	89,7	82,3-75,5	76,3-73,8

[1]) Markeds elprisen kan svinge temmelig meget tidsmæssigt afhængig af elmarkedet, typisk i intervallet mellem 30-60 øre/kWh. ¤) ved store forbrug over 300-400.000 kWh kan opnås individuelt forhandlede rabatter, typisk 2-3 øre /kWh

*) tilsluttet 10 kV på enten en 10/0,4 kV eller en 60/10 kV station; #) tilsluttet 60 kV.

In the table below an overview regarding type of enterprises, energy taxes etc. are presented. The figures are valid as of primo 2012. All taxes are raised 1,8 % per year until 2015 due to inflation rate.

[2] Prepared by Peter Ahm, PA Energy.

	Private og ikke-moms reg. virksomheder	Liberale erhverv	Let proces (handel & service)	Let proces Lempet (landbrug m.v.)	Tung proces (proceslisten i CO_2 afgiftsloven)	Tung proces Lempet (efter aftale med Ens)
Afgift og pris:	[øre/kWh]	[øre/kWh]	[øre/kWh]	[øre/kWh]	[øre/kWh]	[øre/kWh]
Energiafgift	63,5	63,5	1,6	0	0	0
Elsparebidrag	0,6	0,6	0	0	0	0
Eldistributionsbidrag	4,0	1,0	1,0	1,0	1,0	1,0
Tillægsafgift	6,1	0	0	0	0	0
Energispareafgift #)	6,3	6,3	6,3	6,3	2,7	0,3
Afgift i alt *)	80,5	71,4	8,9	7,3	3,7	1.3
Elpris uden afgift ¤)	89,7	89,7	82,3-75,5	82,3-75,5	76,3-73,8	76,3-73,8
Elpris inkl. afgift	**170,2**	**161,1**	**91,2-84,4**	**89,6-82,8**	**80,0-77,5**	**77,6-75,1**
Moms	42,6	0	0	0	0	0
Værdi solcelle-el @)	**212,8**	**161,1**	**91,2-84,4**	**89,6-82,8**	**80,0-77,5**	**77,6-75,1**

*) i flg. elafgiftsloven; #) tidligere CO_2 afgiften; ¤) landsgennemsnit skønnet per 01.01.12; @) værdi for en virksomhed af solcelle-el der substituerer el fra kollektiv elforsyning

The value of electricity produced from a certain PV plant will usually not exceed the corresponding cost for the electricity it is substituting, hence the value is considerably higher for a private consumer, who will have to pay all energy taxes as well as VAT than for commercial costumer.

Another very important aspect when valuating PV electricity in a concrete situation is whether or not it is possible to time shift production and consumption. In this way, the public grid can be used to store production from period with higher production than consumption (daytime/summer) to the vice versa situation (night-time/winter) without cost.

The hitherto commonly used Ferraris meters literally counted downwards when the momentary production exceeded the consumption, which gave a very visual impression, which stimulated the consumer to save energy.

The regulation regarding using the grid as storing device without cost is administrated by Energinet.dk and denoted "Net metering category 6". In economic concern, this is a very favourable method that actually is more attractive than the German feed in tariff, which have successively been reduced over the years.

Net metering category 6 is, however, only allowed under certain circumstances, namely:

- For systems established on private households or public buildings
- The plant mush be fully owned by the owner of the building in question
- The maximum plant size is 6 kWp for a private household and for each 100 m^2 of public buildings
- If a plant is larger than 50 kWp (typically on a municipal building), all the production from this is imposed with reduced PSO taxation (at the moment less than 1 øre/kWh).

Once a year the account is settled and in case the production exceed the consumption, the plant owner receive a payment of 0,60 kr/kWh in the first 10-year period. This payment is reduced to 0,40 kr/kWh after 10 year and phased out after 20 year.

Private enterprises are not allowed to use net metering category 6, instead they can use either category 4 or 5. In both cases, the settling period is typically one hour and the differ-

ent between the two categories being that only in category 4 payment for surplus electricity is giving. The payment figures is the same as mentioned under category 6.
It is obvious, that using category 4 and 5 is less beneficial that category 6, since the possibility for time shifting productions and consumption is not present.

1.6.2 Ry marina – billing and taxation

In the initial phase of this project, several ideas regarding implementation or a symbioses between PV, boats with batteries and electricity consumption of the marina – in some scenarios also a number of the surrounding buildings and enterprises – were launched.

Afterwards some of these are described and the possibility to actually implement them is discussed. In this analysis, only grid-connected system is taking into consideration. Energinet.dk has kindly contributed with input regarding the legal situation of the various cases.

<u>Case 1: PV boat docked at a bridge on a private parcel</u>
In order to create a baseline, it was decided first to investigate the simplest situation, namely a private boat equipped with a PV plant docked at a private bridge at a private parcel.

Energinet.dk was asked, if it would be possible for the boat-owner to connect the PV plant of the boat to the grid in his/her house and then use the produced electricity from the PV system according to net metering category 6.

A bit surprisingly the reply was, that the boat owner is not allowed to use net metering category 6 for a PV plant installed on his boat. The reason is, that it is clearly stated, that the PV plant in question has to be installed on the same land register (matrikkel) as the installation in which the production is utilized, and the water – strictly following the law – do not belong to the land register.

<u>Case 2: PV plant on the building owned by the marina</u>
Another rather simple case would be, that the marina installs a PV plant on their own building and use the electricity produced in their own installation and thus the PV electricity substitute electricity purchased from the grid.

From the information obtained, it is clear that this setup will be legal. The marina, however, are not allowed to use the most attractive net metering category 6 (time shift of production/consumption), but instead category 4, in which momentary surplus production is sold to the grid for 60 respectively 40 øre/kWh.

As described in chapter 1.5, there is a significant difference between production and consumption profile, which in this case will reduce the economic feasibility in a PV investment.

<u>Case 3: PV plants on boats docked at the marina – supplying electricity to the marina</u>
Supposing a number of PV equipped boats docked at the marina were to supply electricity to the marina, it turns out that the latter has to pay energy taxes for the electricity in question. This is due to the fact, that the exemption for paying energy taxes is only valid, when the producer and consumer is the same person or legal entity.

If this model was to be implemented, the boats have to be connected to a separate energy meter administrated and owned by the local grid operator, since this is the only legal way to measure and charge the energy taxes.

Involvements of the grid operator cause a yearly payment, which - in the cases of small PV plants – easily will exceed the possible income from sell of electricity.

Case 4: PV plant on neighbouring building supplying the marina and/or boats docked in the marina

As discussed in chapter 1.5, the building owned by the marina is not particularly suitable for PV. A possible solution to overcome this barrier could be– if possible - to place the PV plant on a nearby building and supply the marina from here, either through 1) a direct cable or 2) the public grid.

> Ad. 1. If the marina made an agreement with for instance Kvickly regarding renting a part of the roof on this shopping centre and then established a PV plant here that was connected to the marina via a cable, it might be possible to be able to qualify for net metering category 4 if the plant is larger than 50 kWp[3].
>
> In the concrete situation, however, the economic feasibility of this setup will then be doubtful at best. The calculation in chapter 1.5 shows, that a plant sizing 35 kWp is sufficient to provide the yearly consumption at the marine at present, and due to this and the fact that time shifting of production/consumption is not allowed in net metering category 4, a large portion of the produced electricity will have to be sold to the grid for 60 resp. 40 øre/kWh.
>
> Ad. 2. If the public grid is used to transport electricity from for instance Kvickly to the Marina, it will be administrated as if Kvickly were the sole owner of the plant. Kvickly will then be able to use net metering category 4, but since this is a trading company, it is exempted from the major share of energy taxes, and thus the value of the PV production is limited.
>
> With respect to billing and taxations, it is not in any way legally possible to transfer a part – or the total – of the PV production from one entity to another, so in this case, the Marina will have to buy its electricity as it has always done.
>
> The only way the Marina could benefit from an arrangement like this, would be if for some reason Kvickly – perhaps as part of its marketing activities - would provide some kind of payment.

Case 5: PV plant supplying boats owned by a company

If for instance "Hjejle-selskabet" or a boat renting company established a PV plant where the production were used to charge batteries in electrical boats and/or to supply electricity to an administrative building, it would be possible to use net metering category 4.

As described in the situation for Kvickly, the value of the PV generated electricity will be limited, if the company are able to deduct some of the energy taxes applied. In this case, however, the marketing aspect is more obvious, since the company can claim, that there boast is generated by renewable and clean energy.

[3] This is according to information giving to Peter Ahm, PA Energy, in a telephone conversation with the Energy Agency. There is still some uncertainty regarding how this issue will be handled in the future, so in the end this solution can prove not to be valid after all.

If PV modules are also installed on the boats, they can be used to successively charging the batteries when the boat is sailing, but they may probably not be used to provide electricity to other boats or administrative purpose when docked, since this will qualify for taxation as described in case 1.

Note, that in this case, the company in question is not associated with the Marina or any other entities.

Conclusion

When observing the cases discussed above, it is reasonable to say that introducing a system for mutual utilisation of PV in a marina area, in the present legal regime is associated with far more challenges then actual possibilities.

Of the 5 scenarios described, only one turns out to be potentially interesting, namely the one when a PV plant is established to supply electricity to for instance "Hjejle-selskabet" or a private company owning a number of electrical boats.

If the physical situation has been different, it could perhaps also be interesting for the marina to establish a PV plant that covers a part of their energy consumption. In the present situation, however, neither a suitable location for the PV plant nor an optimal convergence between production and consumption exist.

It is, however, not unlikely that this situation will change in the not so distance future. At the moment, the billing regime surrounding electricity consumption and – production is the object of great interest, giving major changes has to be implemented if the forthcoming deployment of smart-grid functionalities shall reach the desired level.

A key element in the future electricity system is a massive escalation in deployment of electric vehicles, which – intelligently utilized – can provide a flexible disposal source for fluctuating renewable energy as well as providing a storing capacity.

In order to utilize these possibilities, the traditional billing scheme has to be reinvented and it is not unlikely, that this will provide improved possibilities for a Marina Power Distribution Hub as the one discussed in this project.

At the present stage, it is not possible to make any qualified estimations with respect to which solutions and scenarios, that can be implemented in the future. However, giving the present situation, it is very difficult to imagine that the possibilities could decrease in the forthcoming years.

3.3.7 Identification of potential for Danish boat owners and further business possibilities (WP 1.7)

Supposing a large number of boats in a certain marina is equipped with solar cells – and perhaps in combination with a landbased PV-system at the marina - it is interesting to understand, whether it will be possible to generate incomes in periods, where the produced electricity exceeds the local consumption.

One possible way could be, if the marina including boats, could be considered as a unit and functioning as a marked actor in the electricity marked, for instance by providing ancillary services to the power grid.

In order to understand the rather complex situation on the present power marked, a short introduction to the different parts of this is giving below.

As part of the gradual liberalization of the EU electricity industry, power markets are increasingly organized in a similar way, where a number of closely related services are provided. This applies to a number of liberalized power markets, including those of the Nordic countries, Germany, France and the Netherlands. Common to all these markets is the existence of five types of power market:

Bilateral electricity trade or OTC (over the counter) Trading: Trading takes place bilaterally outside the power exchange, and prices and amounts are not made public.

The day-ahead market (spot market): A physical market where prices and amounts are based on supply and demand. Resulting prices and the overall amounts traded are made public. The spot market is a day ahead-market where bidding closes at noon for deliveries from midnight and 24 hours ahead.

The intraday market: Quite a long time period remains between close of bidding on the day-ahead market, and the regulating power market (below). The intraday market is therefore introduced as an 'in between market', where participants in the day-ahead market can trade bilaterally. Usually, the product traded is the one-hour long power contract. Prices are published and based on supply and demand.

The regulating power market (RPM): A real-time market covering operation within the hour. The main function of the RPM is to provide power regulation to counteract imbalances related to day-ahead operation planned. Transmission System Operators (TSOs) alone make up the demand side of this market and approved participants on the supply side include both electricity producers and consumers.

The balancing market: This market is linked to the RPM and handles participant imbalances recorded during the previous 24-hour period of operation. The TSO alone acts on the supply side to settle imbalances. Participants with imbalances on the spot market are price takers on the RPM/balance market.

Ancillary services are connected to the regulation power marked, in which the TCO (in Denmark this is Energinet.dk) – usually by means of day-ahead auctions – has provided reserves needed to make the necessary adjustment in the power system to secure stable operational conditions.

Ancillary services vary between East and West Denmark due to the fact, that these areas – in spite interconnected through the Great Belt cable - are connected to different power systems. Whereas Eastern Denmark, i.e. east of the Great Belt (called DK2) is connected to the Nordic synchronizing area called ENTSO-E RG Nordic; Western Denmark, i.e. west of the Great Belt (called DK1) is situated in ENTSO-E RG Continental Europe synchronizing area.

At the moment, Energinet.dk purchases the following ancillary services:

- Primary reserves (DK1)
- Secondary reserves, LFC (Load Frequency Control) (DK1)
- Frequency-controlled disturbance reserve (DK2)
- Frequency-controlled normal operation reserve (DK2)
- Manual reserves (DK1 and DK2)
- Short-circuit power, reactive reserves and voltage control (DK1 and DK2)

In the table below, the main characteristics of these services are listed.

Ancillary services offered by Energinet.dk

	Area	Purpose	Regulation method	Requirements	Auction type
Primary reserves	DK1	1. Step in stabilizing the frequent of the DK1 grid.	Autonomous via local set-point and monitoring of actual values.	First half within 15 sec., the remaining within 30 sec. Maintained for max. 15 minutes and re-established within 15 minutes.	Daily auctions for the next day. At least 0,3 MW.
Secondary reserves, LFC	DK1	2. Step in stabilizing the frequent of the DK1 grid.	Autonomous via set-point send by Energinet.dk.	Shall be ready within 15 minutes and maintained continuously.	Offered on monthly basis.
Manual reserves	DK1 and DK2	Used to secure the balance between production and consumption.	On request by Energinet.dk	Shall be fully delivered within 15 minutes and maintained continuously.	Daily auctions for the next day. Bids have to be between 10 and 50 MW.
Frequency-controlled disturbance reserve	DK2	Compensation for large drop in grid frequents.		First half within 5 sec., the remaining within 25 sec. Maintained continuously.	Daily auctions for the next day. At least 0,3 MW.
Frequency-controlled normal operation reserve	DK2	Compensation for variation in grid frequents under normal operation.	Autonomous via local set-point and monitoring of actual values.	Shall be delivered within 150 sec. and maintained continuously.	Daily auctions for the next day. At least 0,3 MW.
Short-circuit power, reactive reserves and voltage control	DK1 and DK2	Stabilizing the grid.	On request by Energinet.dk	At present only provided by central power plants.	Offers are provided on weekly or monthly basis.

When observing the table it becomes obvious, that the role a MPDH can play in the present marked for ancillary service will probably be quite limited. The main obstacles are connected to size and availability, since the bids in the primary and secondary reserves in DK1 and the frequency-controlled disturbance/normal operation reserve in DK2 have to be at least 0,3 MW.

This means, that the PV plant has to be rather large to meet the necessary capacity to qualify to make a bid – even aggregating several into one large virtual plant. Besides this, bidding can only be made when the weather forecast is predicting the necessary conditions and when there is a certain guaranty that the necessary numbers of boats are sited at the harbour.

Also the requirements for response - and especially maintain time is critical and will require storing capacity or a secondary power source. In the case of LFC and Frequency-controlled normal operation reserve the provider has to be able to maintain the reserve continuously, which in practice will form a crucial barrier for the MPDH.

When looking at the manual reserves, the obstacles described above will becomes even more critical, since the minimum bid to this marked segment is 10 MW.

At the moment, providing short-circuit power, reactive reserves and voltage control in the TSO-regime is not an option, since these services can only be provided by central power plant connected to the high voltage grid.

In the future, this might change, and in any case these services can be provided to local distribution system operators (DSO). In this context it is interesting to notice, that high-end PV-inverters usually are capable of providing reactive power regardless of the PV array connected is producing power or not. In situations, where the PV cells provide no power, the necessary electricity instead is taking directly from the grid.

To establish a sound business case this of cause requires, that the incomes generated through sale of reactive power exceed the value of the power bought.

3.3.7.1 Future sceneries

Looking at the technical potential of the MPDH and the present power marked, the possibilities for generating incomes through providing ancillary services seems very limited; however, there are indicators suggesting that this situation might change in the future.

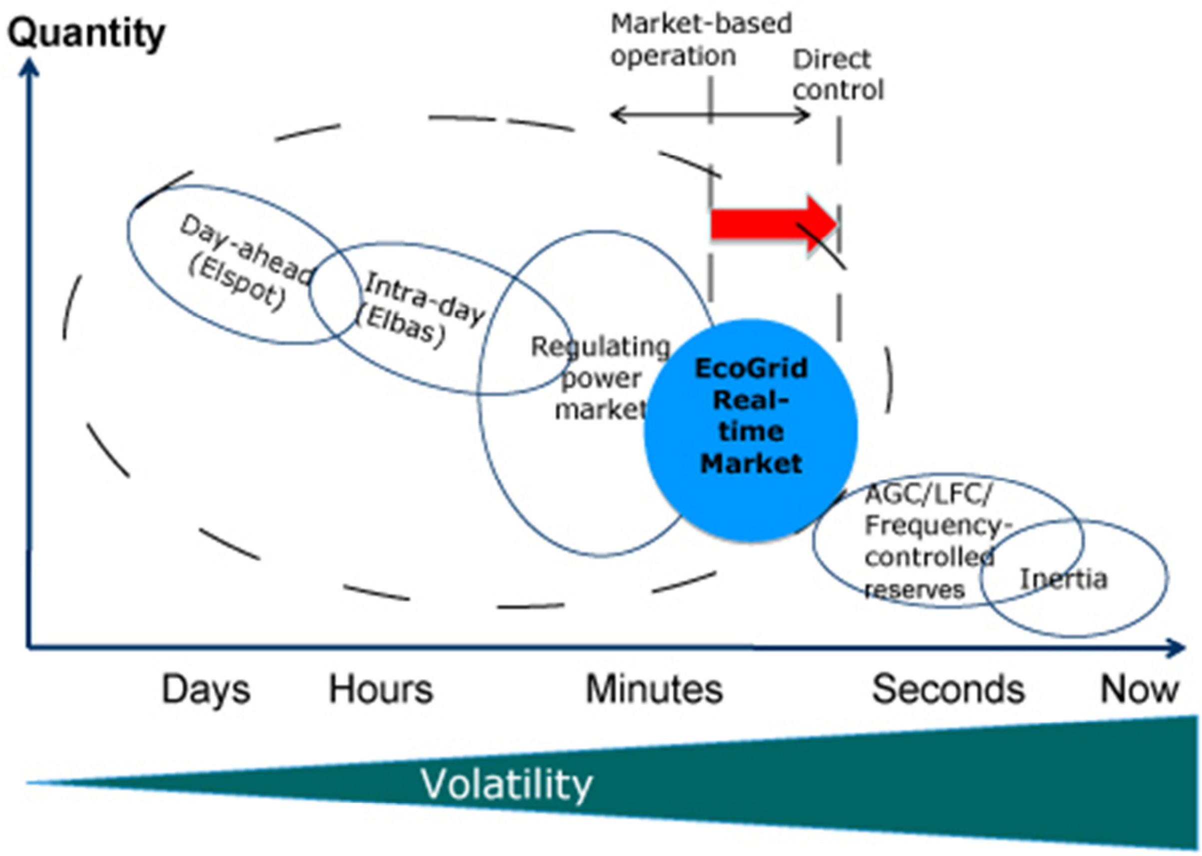
At the moment a number of research projects are carried out with the purpose of prepare the power grid for a future, where large percentage of the electricity consumption are based on fluctuating, renewable energy sources – this project being one of these.

In this project, the possibilities in the present marked are described, barriers are identified and recommendations towards useful steps are giving, whereas practical demonstration of the suggested solution is beyond the scope of this activity.

This, however, is not the case for the project EcoGrid EU, which seeks to develop and demonstrate a real time marked for small produces and consumer. The main measure of EcoGrid EU is to introduce a real-time price response that will provide additional regulation power from smaller customers with both reducible demand and excessive load in periods.

The system developed by the EcoGrid EU project is now being tested in real life conditions on Bornholm and is expected to play a significant role in designing of the framework for the future electrical marked. EcoGrid EU is supported by funds from the EU Commission and is carried out in a consortium holding national and international partners. Further information is available on the website of the project at www.eu-ecogrid.net

In the figure below the EcoGrid EU concept in the context of the current (Nordic) power markets and system operation is illustrated.



Figur 20 Grid auxiliary reserves

If – and when - the principle is adapted in the years to come, a MPDH could participate in this in the same way as a private producer/consumer (sometime named “prosumer”) and then the necessary regulatory framework will be available.

In this situation, it will be possible to sell excess power into the future real time marked, and – hopefully - by developing an intelligent operating strategy to generate a better economic situation than today, where the value of each kWh delivered will be 0,60 DKr./kWh (which must also cover metring and access-fee to the local DSO).

It is also not unlikely, that the possibility for providing ancillary services in the form of reactive reserves and voltage control to the TSO will be possible in the future, which will also expand the business potential of the MPDH.

3.3.7.2 Further business possibilities

It was originally the intention to present local enterprises for the opportunities identified and if relevant invite participation in a succeeding application. Based on the results obtained, the potentials for Danish boat owners as well as for further business possibilities are limited under the current set of regulation. Should some of the regulations retarding SmartGrid roll-out be adjusted as a result of on-going evaluations in the Danish Government it could be relevant to reassess the relevance of a local energy hub as a business opportunity.

Even without the energy hub idea electric propulsion may still have economic perspectives for boat owners. But electrification also holds some challenges.

It would make good sense for motorboat owners and marinas to join forces – setting up a task force to agree on common connection methods and intelligent charging at national level based on international standards. Where no relevant standards can be found the task force could look for inspiration in home automation and industrial energy management systems. It would also be relevant to look into SmartGrid projects like e.g. EDISON and EcoGrid.eu.

In a national perspective this amount is insignificant as the annual Danish dispersion of CO2 is approximately 50.000.000 tons.

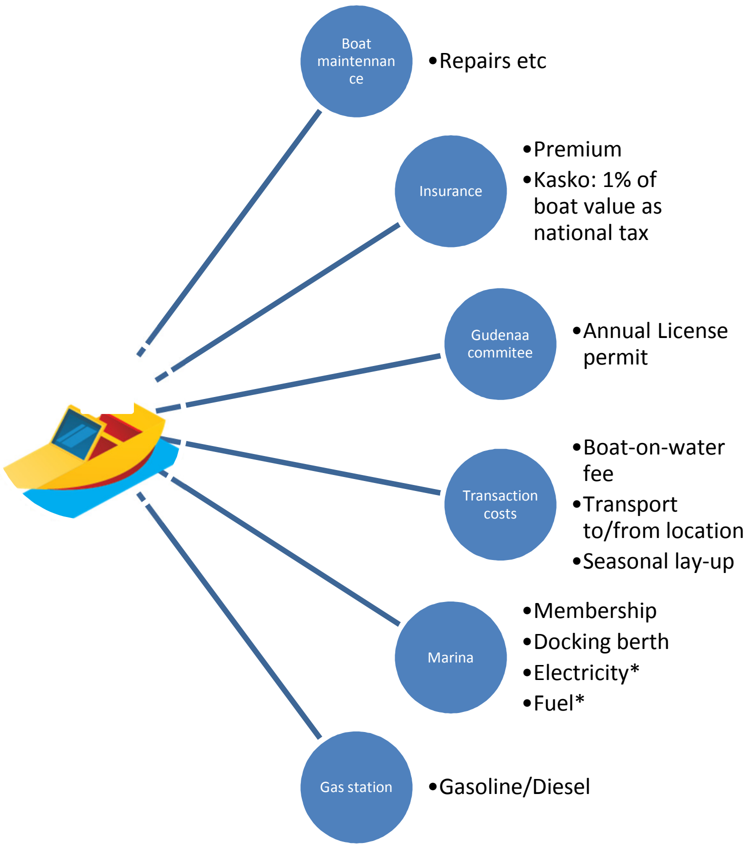
3.3.7.3 Business models

In order to theorize a business model that could support a shift of propulsion the existing financial flow needs to be mapped. This will uncover the financial transactions, actors and market size.

Mapping boat-owners expenses

For explanatory purposes the mapping process is operational and this mean a boat *has* been acquired and the costs are associated with the operational usage of the boat are the focal point for analysis.

Today's financial flow: financial activities clustered on boat owners' fiscal receiving entities.



Figur 21 Conventional boat - cost elements

There are many boats in the system and there is a varying degree of usage of the above mentioned expenses. 32 per cent did not inform a designated docking berth in the user survey and thus do not necessarily have expenses to Marina as well as Insurance is not obliga-

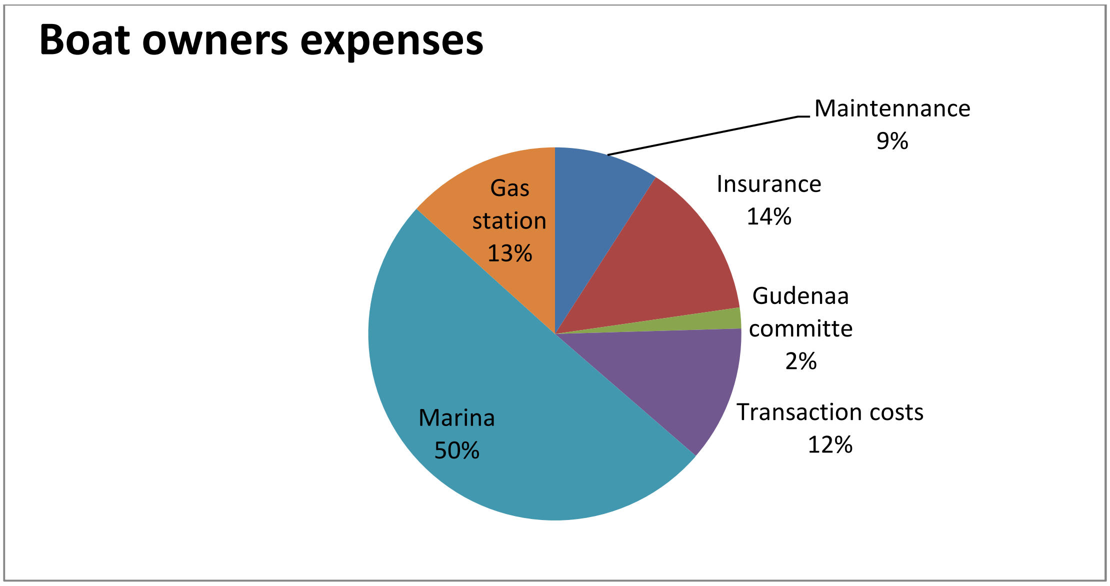
tory by law but if a full-coverage premium (kasko) is taken an additional 1% of the insured value is to be paid as state tax.
To further clarify the expenses specific boat examples need to be used as causal parameters for financial expenses are boat value, marina usage, fuel consumption and insurance type.
The example below is based on the diesel-category profiled mean from questionnaire: A Diesel powered boat with a value of 100.000 DKK, fuel use of 133 liter, docking berth in Silkeborg and minimum coverage insurance:

Post	Amount	Share
Repairs etc.	1000	9,1%
Annual premium, liability	500	4,5%
***1% state Tax (only kasko)**	1000	9,1%
Annual license	200	1,8%
Boat-on-water fee	300	2,7%
Transporting boat to/from location	400	3,6%
Seasonal lay-up	600	5,5%
Annual membership	790	7,2%
Docking berth	4750	43,2%
Electricity	0	0,0%
Fuel	1463	13,3%

For this example the docking berth is the highest singular expense and if this were a larger boat (wider than 2,75m) the annual cost for a berth would be 8.000 DKK. Looking outside the Silkeborg lakes there are berths easily being sold for 5-digit figures in eg Marselisborg marina and Egå Marina and this high cost is thus not special for Silkeborg.
The total amount of members at the marinas is approximately 1.000 boats and this means that a higher share are non-members furthermore it is unclear how many boats are insured and if these two categories are subtracted from the total expenses, the expenses become much lower.

Total annual expenses	11.003 DKK
Excl [Marina] and [Insurance]	3.963 DKK

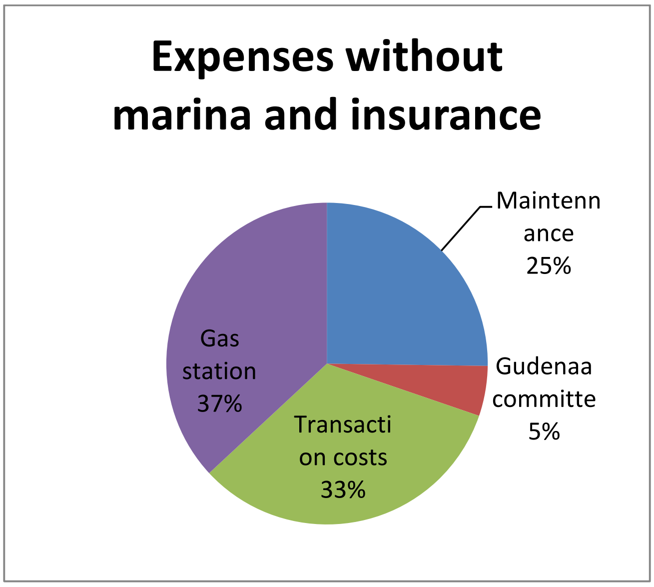
Looking at the boat owners expenses insurance, gas station and transaction costs follow marina in size, as shown in Figur 23.



Figur 22 Pie-chart Boat owners expenses

It is not known how many have and what type of insurance the boats in the lakes use. The annual state income of these 1% taxes was 116 million DKK in 2009 and this is from the pool of 57.000 recreational boats that are estimated to be in Denmark. If this is accepted as representative and directly scaled down to the 2.603 registered boats in the Silkeborg lakes they have contributed with 5,3 million DKK in taxes. This furthermore means that they are insured for a value of 530 million DKK and the average value a boat is insured for become 204.000 DKK and this can be questioned.
As uncovered earlier there are boats connected to the electricity grid today and some marinas distribute electricity to them as well as, in some cases, retails fuel. There is an unknown share of boat owners that purchase their fuel at regular gas stations are not known. In the following they are considered buying from to Gas station.

If the same diesel boat has no insurance nor has any usage of the marina the 3.963 DKK in expenses are distributed as shown in Figure X.



Figur 23 Pie-chart Boat owners expenses without marina and insurance

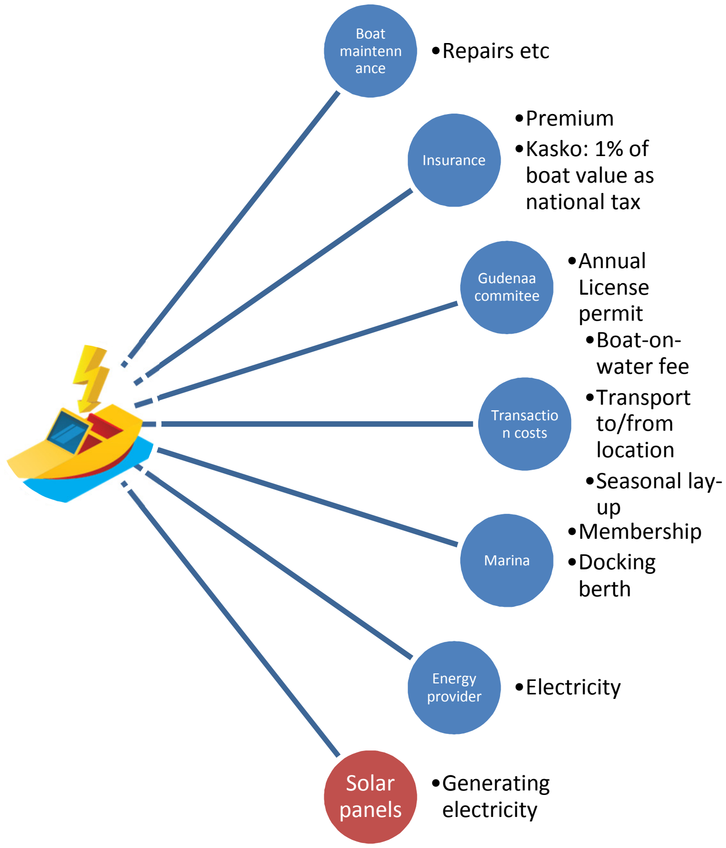
The cost of fuel becomes substantial, as well as the transaction costs of transporting the boat to the lake and the cost of launching the boat on the water. The maintenance is set at 1% of the boat's value and the annual fee to the Gudenaa committee is 200 DKK.
The usage of fuel for the whole fleet, including commercial operators is calculated from the questionnaire, and total value of this is shown in Table X.

Total fuel consumption	Calculated (reference)	Cost per liter	Total
Gasoline [liters]	64.195	12,00	770.340 DKK
Diesel [liters]	101.532	11,00	1.116.852 DKK

The fuel-market size here is at most 1,9 million DKK. This is the equivalent to the annual fuel consumption of 43 gasoline cars and 51 diesel cars. This could in *worst* case mean that the owners of the 2.603 registered boats may consume *more* fuel driving back and forth to their boats, than all the boats consume through a season.
A complete shift to electric propulsion would remove this revenue from the gas stations (& marinas) and although it is a small market these stakeholders have financial interests linked to the source of energy.

3.3.7.4 Usage model with an Electric boat

Usage model with an Electric boat - Dispersed on fiscal recipients



Figur 24 Electric boat - cost elements (optional solar power)

The only difference for a boat-owner is that the energy needed is now electricity and a provider is needed for this. However the marinas can distribute electricity through their systems today and therefore it can be questioned whether it is necessary for a provider to enact active retailing or if this role should continue to be handled by the marinas.

3.3.7.5 Repowering business

The user survey showed that half the leisure boat fleet (52%) never leaves the river which means approximate 1300 of the boats in the Gudenaa area. Most of these boats could be electric without fearing range problems. This should give potential for a local electric boat service/business.
The average age of a motorboat is much longer than for a car and owners of motorboats want to maintain the value of their investment. It seems fairly normal that a boat can be repowered with a new engine. Therefore it seems likely that there should be room for some kind of business offering electric repowering on motorboats in good condition and in this way maybe even extend the active life of the boat.

3.3.7.6 Usage model with an MPDH type construction

Due to the tight regulation for taxation of energy exchange across property boundaries, a business model will be very complex and with no positive economic incentive for boats owners. A leisure boats with a fairly limited energy consumption can never earn back the required installation costs and annual fees to the DSO for enabling any auxiliary service interface.
No further economic analysis has been made on a smart energy hub in this project.

3.4 Establishment of a prototype Marina Power Distribution Hub at the harbour of Ry (WP 2)

Compared to the projects first intentions the realisation of a Marina Power Distribution Hub (MPDH) turned out to be far more challenging than expected and several non-legal hurdles had to be negotiated to approximate the original objectives. Also the local societies have a lot of feelings at stake when it comes to the harbour area, seen by many as the cities primary touristic core value.

Establishment of a physical prototype hub was foreseen to facilitate equipment monitoring and distribution of energy but legal rules and tax restrictions on any exchange of energy reduced the energy hub ambition to data-monitoring. PV panels supplying green energy and drawing attention to the project has been established but in a fourth location after finding first there proposed positions unacceptable. A new charging post with monitoring of current flow in both directions is established next to the solar boat's home base, ready to accept solar power from a boat if the rules should change in future.
A planned Solar Tower and Solar Wells or Water "lilies" was not all well received by the parties intended to adopt ownership. After discussions of different new design proposals without broad acceptance the idea was put on hold due to lack of hours. A public real time display of hub related energy flows has been set up but in the local museum rather than directly in the harbour area. A project web-page has been running throughout the project period.

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Figur 25 Ry Harbour with proposed PV on house, solar tower and sun-wells floating on water

Ownership and contractual relationship
Public areas for the harbour and Siimtoften are owned by the Municipality of Skanderborg
The jetties of Ry Marina and the boat clubhouse are owned by Ry Bådlaug
Port kiosk is owned by Ry Håndværker- og Borgerforening
Part of the area is owned by the company Ry Kanofart.
Ferskvandsmuseum is owned by the Municipality of Skanderborg

Solbaaden APS has established the necessary agreements with the municipality of Skanderborg, Ry Bådlaug, Ry Håndværker- og Borgerforening and Ry Kanofart concerning the location of the physical elements of the charging station at the port.

Upon project completion and until the launch of a possible Phase 2, where an operating company could be established with relevant public and private partners, Solbaaden APS assumes ownership and responsibility for the operation of the charging station, as it is closely related to the company's activities with renting out solar powered boats and the creation of share-a-boat arrangements with solar boats from the harbour of Ry.

4. Utilization of project results

4.1 Compilation and dissemination of experience gathered (WP 3)

To bring information of the project's findings and results this final report is essential.

The project has arranged two information-meetings and a conference to disseminate the status and results of the project.

A Smart Marina project home page with project information; FAQ and contact details was set up very early in the project – hosted at www.co2neutralsejlads.dk

News letters has been sent out to interested and a large share of the participants in the user survey showed interest.

A PC with a 32" video display integrated nicely into a wall in the Ferskvands Museum runs a continuous power point show highlighting some information about the project. Live web pages are blended into the power point presentation showing:

- the Danish energy flow now (from EnergiNet.dk)
- the local energy flow at the Museum with the PV-system on the roof.
- Data on the solar boat that
- Link to the local tourist web-page and office for more information.

This project has shown that the leisure boat marked seems to react slowly to the new electric options – much like the automobile market's reaction on electric vehicles. Politicians and people preparing the electric grid to handle much more fluctuating renewable energy wants the electric vehicle market to take off. The actual reality is that the development in EV-sales in Denmark since 2009 has been even lower than the most pessimistic predicted before COP13 summit meeting. Car companies have developed both dedicated electric vehicles and electric versions of familiar models in an attempt to find the key to the EV-market.
The knowledge of electric vehicles may be marginally higher than knowledge of electric boat propulsion among the motorboat owners. Still it is the understanding between specialists that cars will be electric in the future and so will boats unless new massive reserves of easily accessible fossil oil becomes available.
For electric vehicles all people change their mental reservation when they have actually tried to use the electric vehicle instead of their own. Few develop a hate-love relationship with the electric vehicles because the car is so lovely to drive but you are always only few kilometres from running out of energy and need to plan all transport. The same reservations can surely be found among motorboat owners. Nearly all motorboats have a spare canister with fuel – just to be safe. It is likely that trying out a good electric boat could change the acceptance. A challenge might be that there are so many different types of boats.

Three proposed steps to get motorboat owners to consider electric propulsion:

1. Establish a demonstration project repowering a few typical but different types of motorboats.
2. Let families borrow a boat for two weeks or more –get them to present their experience in blogs and club magazines and workshops
3. Arrange workshops on "the water" with specialists, where owners of motorboats can get some input on suitable repowering options and battery type/size and maybe even get to try an electric outboard motor on their own boat.

Projectpartner Solbaaden selling solar powered boats found important information on the acceptance or lack of same in the motorboat clubs, which would normally be the natural marketing channel for boats. Instead it may be more interesting to address new potential boats owners, which may be attracted by the clean power concept in combination noiseless experience of pure nature.

VisitSkanderborg and the Municipality of Skanderborg now use the the new solar image and the solar boat and clean energy production in their promotion attracting tourists to the area.

5. Project conclusion and perspective

Conclusions on the three project hypothesis.

The project hypothesis no. 1

Few boats are now propelled electrically but many of the boats have the potential to become powered by renewable electric energy in the future.

- *Has a transition towards electric boats started? Are there any indicators as to when it might peak?*
  No transition started yet; A transition peak is more than 5 years away
- *Find the number of motorboats that are readily feasible for electric propulsion powered by batteries.*
  52% of the motorboats never leaves the area meaning approximate 1300 of the boats could be electric without range problems
- *What is the size of the related electric power/energy needed from a charging infrastructure?*
  1300 boats charging at the same time with 1 kW would require two full standard size 10/0.4kV substations that are typically used for a couple of hundred houses. The average time needed for charging the boats would be fairly short – very few hours only meaning that with a proper charging management the actual continuous power required may be reduces by a factor 20 to 50.

Project hypothesis no. 2

Many of the future battery powered boats will have Photovoltaic panels (PV-panels) to charge the battery and extend the range. If the use frequency of most leisure boats are very low the PV-panels will be idling already few hours after last tour. Assuming that PV panels can in most applications produce much more power than the battery can hold if not in use.

- *Can it be estimated how much solar energy could be "wasted" on a typical solar powered leisure boat?*
  An example: 3kWh per day not used in the summer on a SunCat21or approximately 750kWh (appendix D)
- *What is the typical leisure boat use frequency?*
  The boats are only away from the harbour 2-8% of the time and 59% sail less than weekly.

Project hypothesis no. 3

If the surplus solar energy from PV-panels on battery boats could help charge other battery boats and contribute to the marina and the electric grid it would support the national energy strategies very well.

- *Analyse boundary conditions for establishing a local energy hub system (model) to handle energy from*
  1. *a PV boat to a) battery boat; b) Marina club house; c) the grid (only surplus energy from the PV-array)*
  2. *a battery boat to b) Marina club house; c) the grid*
  3. *a land based PV system to a) battery boat; b) Marina club house; c) the grid*
- *To examine the potential and efficiency in balancing local energy exchange in a sort of local energy-hub at e.g. a marina build a small scale system consisting of at least one electric boat with PV and one electric battery boat exchanging energy with local renewable energy sources and the grid.*
- *Establish a land based PV-array or other renewable energy source (on or near the local marina) that via the energy hub should be linked to battery and solar powered boats on the piers of the local marina and members club house.*
- *Further to demonstrate the energy hub energy exchange idea put up some artistic elements with PV-panels that can draw attention to the else hidden energy challenges.*

The project is early relative to a transition towards electric powered boats and the motorboat owners seem to be fairly conservative. A transition to electric power is not exactly welcomed by the marina representatives because they fear that politicians may be tempted to force specific solutions without respect for the large investments done in the current leisure boat fleet.

That half the leisure boat fleet never leaves the lakes means that they are suitable for being propelled electrically and powered by batteries.

The power consumed by the leisure motorboats are marginal compared to road transport. The leisure motorboat fleet seems to consume less diesel fuel than two citybusses on an annual basis. This small energy consumption per boat distributed on the full fleet cannot justify any investments in e.g. new SmartGrid charging equipment.

A future project could be to optimize a marina's load shift regime without having a "Smart-Grid communication" with the boats but based on statistical indicators and past experience in combination with trend analysis. It could also be possible to supplement such a system with a Wi-Fi or mobile app conveying the boats required energy to exploit the full feed capacity without overloading.

Long term it is expected that boats will have electric drive lines with either battery energy storage or on-board electric generation e.g. from fuel cells supplied by sustainable hydrogen. If Danish boat industry or boat service industry should play any role in the expected transition from fuel based boating to electric drive, there will be a need for many demonstration projects. Demonstration projects where people can actually try out the technology will nurture an initial market that can grow into a business segment. Building demonstration projects are essential for the industry to build up the practical and technological competences need to support a transition. Some incentives might help moving the focus of a very traditional Danish maritime industry.

Being early in the transition toward battery powered electric boats there could be a chance of more advanced battery management systems being available, that can increase battery life and give better SOC and SOH information to the user and the owner respectively.

A very relevant future grid and boat project could be to look into an electric repowering of the Hjejle passenger fleet. There are currently 8 diesel powered boats in good condition that will need to have new engines within the next years. It is relevant to analyse/quantify potentials:

- Technical requirements for repowering: motor system size, auxiliary systems, battery capacity, charging capacity, power supply from grid
- Economy in repowering – investment, operational cost (fuel saving, maintenance saving, shorter preparation in the morning), future battery replacement
- Reduced noise and emissions, reduced risk of pollution of water
- SmartGrid control of main and spot charging
- Possible ancillary services exploiting the huge battery capacity during nights and winter
- Other additional benefits from battery operation or in relation to repowering

This pilot project was relevant and has uncovered several challenges needing political adjustments before effective use of small renewable energy resources will be attractive.