DEVELOPMENT OF SUSTAINABLE ENERGY SUPPLY SOLUTIONS FOR FØNS, DENMARK

Master in European Construction Engineering 2012-2013

Group Project 2

Analyses and proposal for integrated heat and electricity supply in a 71 household community

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1. INTRODUCTION

1.1. INTRODUCTION

OBJECTIVE AND BACKGROUND OF THE RESEARCH

This research work aims at recommending a suitable renewable energy supply system for the inhabitants of a small village in Denmark called Føns. It involves studying of the different alternatives of renewable energy supply technologies which has been theoretically developed in the previous group project work entitled "System for Sustainable Energy Supply for a Small Village" for the production of heat and electricity, being the heat a priority because that is the inhabitant's desire. It is the hope of the research team that implementation of the output of this research work will liberalize the people of Føns community from using unsustainable, non-renewable energy sources such as fossil fuel as their main source of energy.

This project has arisen from the existing will of the community of Føns to be supplied of heating from renewable sources. A neighborhood association has been created to achieve this objective. Nowadays they are considering different alternatives and this report aims to help them in their choice.

During the research, possible alternatives of renewable energy system which can produce both heat and electricity will be exhaustively studied and evaluated from economic, social and environmental point of views. A refined analysis will also be carried out to look for the best combination of energy systems from among the plenty of renewable energy systems that are available and flourishing nowadays. By using a preset criteria tailored with the demand of the members of 'Føns' neighborhood, effort has been exerted to select, design and estimate the price of an appropriate energy supply system for the community to finally be independent of fossil fuels.

OVERVIEW ON BENEFITS OF RENEWABLE ENERGIES

In general, much has been said about the positive impacts of renewable energies on the environment. Yet, apart from this, renewable energies can contribute enormously to insure energy security. It can substitute fossil fuel at best in terms of secured and endless supply of energy. The overall scenario on the supply of traditional sources of energy is multifaceted in its nature presenting governments and developers with various challenges such as extreme volatility in the oil and gas market, global oil supply restrictions due to the dominating bargain power of the supplier and many more. However, renewable technologies are by far devoid of such limitations and can guarantee secured energy supply to villages and towns.

Surely these days, it is impossible to think of life without energy supply. Nevertheless, it does not sound logical to worsen and affect the weather, cause harm to the environment by using conventional energy sources to satisfy these demands. Unlike conventional forms of energy which is one of the main contributors to global warming and climate change, renewable and sustainable forms energy do not cause acid rain, air pollution, water and soil contamination or cause to rapidly increase the temperature of the earth and generally cause minimal harm to the environment. The energy supply sector, which is responsible for the lion share of CO_2 emission and its devastating consequences could be switched to a “green sector” by using renewable energy sources.

From the point view of job creation and strengthening of local and national economy renewable energy can also play significant role by promoting low carbon economy. Currently, the development of several renewable technologies in solar photovoltaic, wind, hydropower, biomass, geothermal, etc. is attracting investments creating plenty of jobs to the sector. The project design and development, physical construction and installation of renewable technologies are areas which involve a number of job opportunities,

Unlike fossil fuels, another major advantage of renewable energy sources is their ability to replenish themselves through natural and continuous process. Making use of renewable energies systems will not only benefit the living generation but also for the future generations to come. Hence, the question of meeting the needs of the present without compromising the ability of the future to meet its own need will ultimately be addressed by using and promoting renewable and sustainable energies.

PROJECT SUMMARY AND FACTS

As mentioned in the objective, this research work focuses on recommending the most suitable renewable energy system to produce heat and electricity for the community of ‘Føns’. ‘Føns’ is a small village located in Denmark, specifically situated in the Middelfart municipality.

The members of this community seek to use renewable energy in place of the conventional, non-renewable and environmentally polluting fossil fuels. Hence, the research team designed a way to study the overall need of the society as well as the existing realities of the community so as to propose a renewable energy supply scheme that is technically, socially, legally and environmentally appropriate.

The research team has paid a visit to the subject site to visually inspect the insulation capacity of the dwellings as well as the potential areas to develop the energy scheme. Furthermore, discussion has been held with some of the representatives of the community so as to have a clear understanding of the demands of the community.

To aid the visualization and realization of the project, numerous Maps of different kind such as topographic showing geographical features, environmental maps, maps for each energy supply scheme, and other aerial photographs are produced and gathered from different sources and are attached as Appendix to this report.

PROJECT FACT SHEET

Research Title	Development of Energy Supply Solution for Føns (Denmark). Analyses and proposal for integrated heat and electricity supply in a 71 household community.
Location	Føns, Denmark.
Currency	The currency in Denmark is “Danish Krone” (DKK) and its exchange rate has been accepted as 1€ = 7,46046DKK.

Research Objective	To propose integrated heat and electricity supply system for Føns.
Research team	Students of Master Program In European Construction Engineering (2012/2013).
Research Duration	January 07, 2013 until March 22, 2013.
End users	The Community of Føns.

LIMITATIONS

This reach has suffered from several limitations:

- Lack of time to perform an accurate research.
- Professional background of research team. The team is composed by: civil engineers, architects and building engineers. Therefore, not professionals in energy field.
- Linguistic barriers. Most of the information was in Danish.
- Difficulty in finding data has led to the use of secondary data, even from other countries.

1.2. LAYOUT OF THE REPORT

The present report is structured in four main parts:

- Building study: An exhaustive analysis of the current state of the buildings has been developed in order to obtain the energetic requirements and heat losses of each dwelling and the total needs to be supplied.
- Phase 1: Different alternatives for both heating and electricity supply are studied either for collective or individual solutions. Feasibility studies have been developed to make a first filtering.
- Phase 2: This phase deals with different solutions combining heating and electricity alternatives developed on Phase 1. This phase is divided in "Scenarios" and "Individual Solutions."
  - Scenarios: This section provides five different scenarios that will supply energy to Føns. The scenarios have been developed fixing first a heating solution and then the best electricity choice for that heating solution.
  - Individual Solutions: This section provides different individual solutions to supply energy to Føns. These options will be useful in case some houses are isolated and it is not feasible to apply a collective solution. The report will provide the guidelines, for choosing the best option.
- Conclusion: A benchmarking analysis of all the systems studied along the report with the main economic aspects has been developed so as to obtain the most suitable solutions. Besides, a multi-criteria analysis has been executed so as to take into consideration environmental and social aspects. This all will lead into a final chapter of advices for the users to be able to choose the best option according to their needs.

At the outset of the project, feasibility study has been undertaken to choose the appropriate solution from among the preliminarily suggested solutions for heating and electricity before making a regress analysis. Thus, for heat production, biomass and CHP and ground source energy were appraised whereas for electricity production, solar energy and wind power were studied.
The output of the thorough feasibility study on the possible renewable energies has led to a more refined and detailed analysis subdivided into different scenarios. The scenarios are divided in to two major categories; these are Individual systems and collective systems. The former, as the name implies is targeted towards devising an individual energy supply system for each of the 71 households in the community. In this category, the individual solutions for heat and electricity production were separately studied. Pellet boiler and solar assisted ground source heat pump with water tank seasonal storage has been studied as an individual heating option. Wind and solar energies were considered and studied as an alternative electricity production for individual housing.
The other major scenarios discussed in this report are the collective energy supply system to the community at large. In addition to supplying both heat and electricity from a centralized plant the system has been developed in such a way to supply the required amount of energy to the community as a whole. Under this major section, detailed analysis has been carried out on systems such as solar assisted ground source heat pump with boreholes seasonal storage and windmill, straw, CHP sterling woodchips, ground source heat pump and biogas and solar thermal and biogas. As part of the collective heating solution, this report also deals with district heating mechanism starting from production plant, distribution network up to individual house installation.

2. LOCATION OF THE PROJECT AREA

2.1. SITUATION

Føns is a small village in located in Middelfart municipality on the western Fyn located at the base of the peninsula Fønsskov. The village belongs to the Region of Southern Denmark.

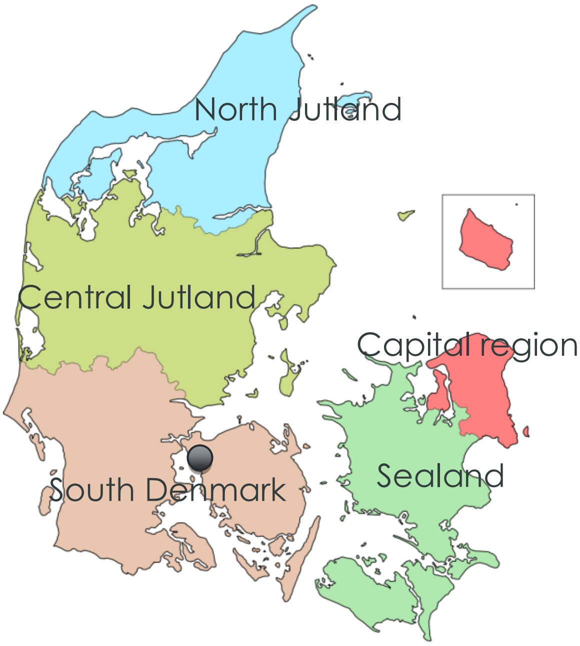


Figure 2.1_1: Føns location within Denmark (Lonelyplanet, 2013)

On the following figure the area included in the project can be seen with dark red. For more detail see appendix 7.2.

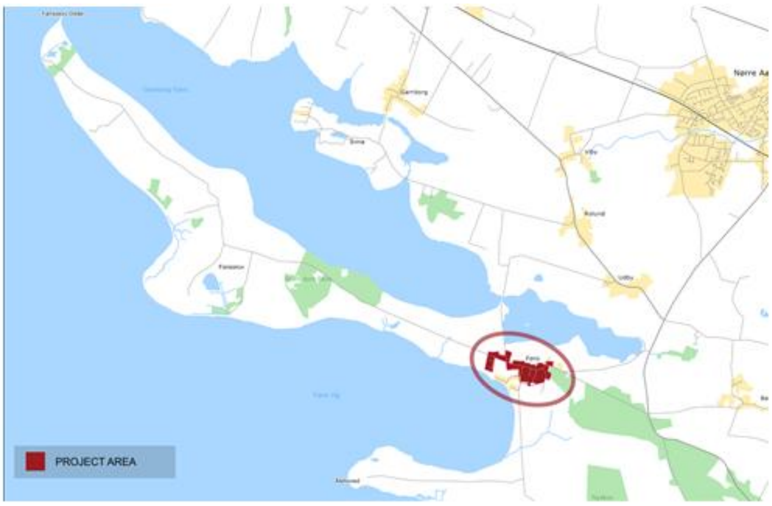


Figure 2.1_2: Project area location within Fønsskov peninsula [see Appendix 7.2]

3. DATA COLLECTION ABOUT HOUSES

3.1. INTRODUCTION

To develop a complete project, a data collection process has to be carried out in order to obtain as much information as possible of the buildings that are going to be involved.
The more information gathered about the actual status of the buildings, insulation, actual heating systems, position in the plot, the more accurate the calculations and the final solution will be for these future users.

3.2. EXISTING BUILDING STUDY

Føns is composed of a main settlement area where the majority of the buildings are close together and a peninsula. In some places along this peninsula there can be found isolated houses.
As for this project is concerned, based on the limited time and resources, only the main settlement area has been analysed. But as many building typologies has been analysed, there will be no problem to extend this analysis to other houses that fit inside the typological parameters studied.
In this specific case of supplying energy for a small community, the selection of the buildings to integrate in the analysis was made based on the supposed boundaries of a district heating, having into account that the district heating should have very well defined limits not to reach an unreasonable installation cost.
Having that into account, some buildings may have fall outside the project because their situation regarding the main installation. However, as the district heating is supposed to be a decision of the community, is that community who has to decide if the price of getting the installation to all the neighbours interested is affordable for the village or not.
This project will also have into account individual solutions that would not be conditioned by the district heating boundaries, but as a starting assumption due to time and resources those were the buildings studied.
Within this frame, 76 buildings have been analysed. From which 71 have been chosen as selectable. The others were rolled out due to their use or typology, e.g. church, summerhouse or due to their actual heating system based on renewable energies.
To perform this study, there have been used several information sources, from the existing information of the Danish government open databases, to a fieldwork (January 26th) based on visual recognition and photographic collection of the buildings. (Energigruppen Føns og omegns lokaludvalg, 2012; Energistyrelsen, 2012; Danmarks Miljøportal, 2013; Geodatastyrelsen matrikelinfo, 2013; Middelfart kommune, 2013; Ministeriet for By, Bolig og Landdistrikter, 2013; SKAT, 2013; Offentlige Informationsserver , 2013; Vedvarende Energy, 2010)

A database has been generated in order to include it in GIS maps and provide them with this information. This database will not be included in this report by itself, because it was a mean to complete maps in specific software.

Instead of this database, a series of record cards have been created with all the relevant information to catalogue every building. (Appendix 7.4)

With this information was possible to calculate accurately the energetic demand of each building. Also for every building the heat losses have been estimated, based on an insulation study accompanied by the building information gathered.

To obtain the heat losses information, a process has been followed:

Starting from the data collected during the visit to Føns on January the 26th, and the previous study to determine the composition of the closings of homes,

With regards to the design temperature, it has been established 2°C as a design outdoor temperature and an amount of 3466 heating degree-days. The heating degree-days indicate how winter weather affects building heating energy use. Both data have been collected from the DMI -Danish Meteorological Institute- Technical Report 99-5 (Vaarby, E., Sjølin, R., Cappelen, J., 1999).

Concerning to fuel type inputs, the study of the existing buildings in Føns showed us electricity and fossil (solid and liquid) fuels as the main energy sources for heating.

Electricity has a price in Denmark of 0,41DKK/kWh and a 99% of furnace energy, whereas fossil fuels have a price of 5,67DKK/kWh and a 59,5% of furnace energy (Europe's Energy Portal, 2013).

With these data as a starting point, and taking into account area and R-value inputs of ceilings, walls, doors & windows, floors and slabs, as well as house volume and air changes per hour, the tool developed by Built-It-Solar (Build it Solar, 2013) has been used in order to obtain:

- Design Heat Loss in kWh. The total heat loss from each house per hour when the outside temperature is at the Design Outdoor Temperature that we established as an input.
- Total yearly heat loss in MWh. This is a rough estimate of the total heat loss from each house for a typical year. It is based on the number of Heating Degree Days we defined.
- Total yearly cost for fuel in DKK. This is the cost of the fuel to heat each house based on the previous total yearly heat loss, and the fuel type, fuel cost, and furnace efficiency we defined.
- Total ten year cost for fuel in DKK. This is the cost of fuel for 10 years with the assumption that fuel costs will rise 10% each year of the 10 years.
- Tonnes of CO_2 gas emissions for heating each house (yearly). For electricity, we have assumed that the electricity was generated at an average rate of 0,00075 tonnes CO_2 per kWh.

Finally, in the record card of each building it is shown a graphic representing these infiltrations, gains and heat losses for ceilings, walls, windows, floors and slabs.

Føns urban plan:

To complete the database information, the local urban plan has been studied in order to preserve the protected buildings and points of interest. (Føns lokalplan, 1981)

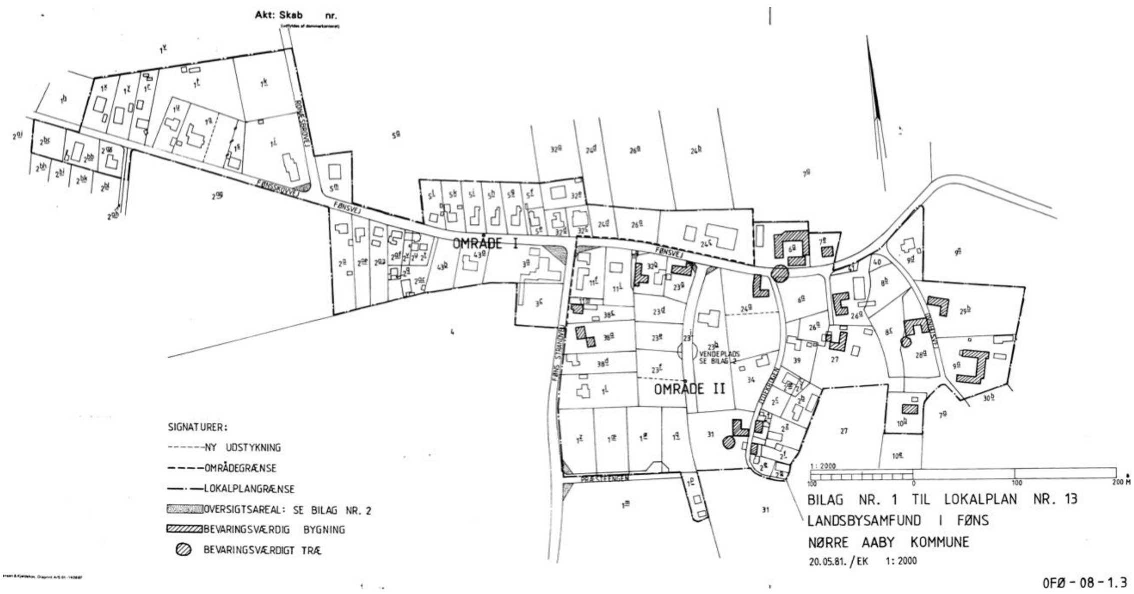


Figure 3.2_1: Føns local urban plan

As it is shown in the map, the striped hatches indicate a protected building or a protected tree (round hatches).
For future modifications based on this work, those protected elements have to be respected, it is important to notice that not only buildings are protected but also trees.

3.3. BUILDING CONSTRUCTION STUDY

Due to the high number of houses in Føns and the impossibility of knowing the exact materials used, the help of Professor Torben Lundberg from VIA University have been used, and other data (Danske Bygnings Modeller, 2013) to simplify the constructive solutions.

Thereby it has been established the three following types of housing.

- Building type A: Contemporary construction (1960 – 2000)
  - Roof: Asphalt Shingles + 3x100 mm Mineral Wool
  - Wall: Brick layer + Air space + 2x125mm Mineral Wool + Gas concrete block layer + Gypsum
  - Slab: Insulated.

- Building type B: Refurbishment / Brick walls structure (1920 – 1960)
  - Roof: Asphalt Shingles + 3x100 mm Mineral Wool
  - Wall: 2x100mm Exterior Insulation + Gas concrete block layer / Brick layer + 1x100mm Mineral Wool + Gypsum
  - Slab: No insulated.

- Building type C: Refurbishment / Wood structure (1850-1920)
  - Roof: Wood Shingles + 3x100 mm Mineral Wool
  - Wall: Reed/Plywood layer + 2x100mm Mineral Wool + Brick layer + Gypsum
  - Slab: No insulated.

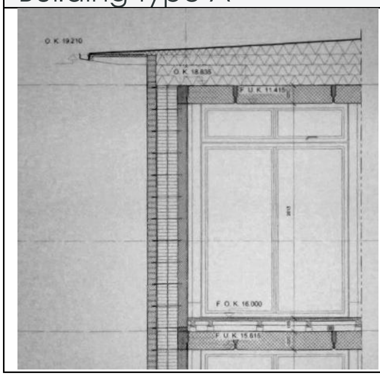
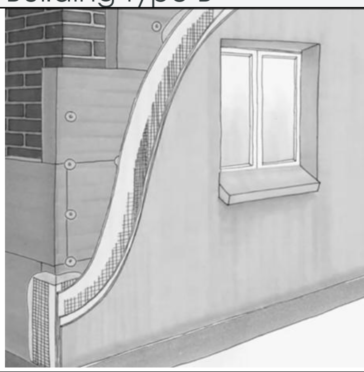
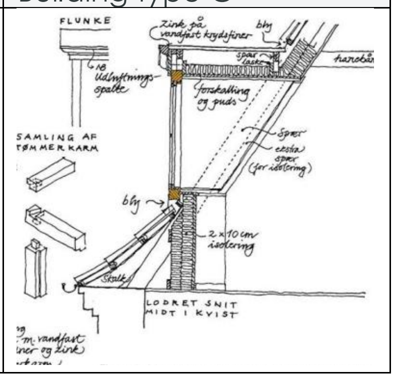
Building type A	Building type B	Building type C
		

Figure 3.3_1: Building types

Starting from these housing inputs, they have modified depending on the data provided by the website ois.dk and the one collected by means of the visual inspection on the fieldwork in Føns (carpentry status, exceptions, and so on).

The R-value is a measure of thermal resistance used in the construction industry. In order to determine the R-values of the different closures, the method "Wall Assembly R-Value" has been used (All Wall System, 2012) by adding the R-Values.

3.4. CONCLUSION

The estimation of the energy needs for the town of Føns has been made from the study of the different houses that configure the town. These data are shown in Appendix 7.4 and from these, the present report will pose and develop the different possible solutions. Therefore, these proposals are based on the current needs of Føns.

However, it is important to note that a poorly insulated house needs more heat production to maintain its temperature, increasing its energy consumption.

For this reason, we have considered necessary to make a detailed study, for each one of the houses, the heat losses that take place in each of the four following building elements: ceilings, walls, windows and doors, and foundation slabs, as well as the infiltrations which are carried through the overall surface of the housing.

The final values of heat loss for the total numbers of studied homes in Føns are:

Total yearly heat loss	154,6 MWh	100%
Heat loss through ceilings	154,6 MWh	8%
Heat loss through walls	110,7 MWh	6%
Heat loss through windows and doors	383,8 MWh	20%
Heat loss through slab	169,2 MWh	8%
Heat loss due to infiltrations	1131,6 MWh	58%

Figure 3.4_1: Heat losses

The values obtained in each of the houses have allowed us to simplify the results in the following chart. Here, we show the total yearly heat loss in MWh of three houses with similar surface (180 m2), but different date of construction, and therefore, with different constructive solutions. Such differentiation corresponds to the types of insulation defined in the previous point.

Year of construction	**2008**	**1960**	**1900**
Total yearly heat loss in MWh	19,3	30,8	49,4
Percentage of heat loss through ceilings	13%	8%	7%
Percentage of heat loss through walls	4%	6%	4%
Percentage of heat loss through windows and doors	10%	22%	13%
Percentage of heat loss through slab	<1%	9%	6%
Percentage of heat loss due to infiltrations	73%	55%	70%

Figure 3.4_2: Houses values

In any housing in general, and those which construction is prior to 1980 in particular, small improvements in insulation can lead to economic and energy savings of up to 30% on heating. Since roofs are those that constitute the surface where most heat is lost in a home, improving insulation can reduce up to 35% on heating costs.

The composite wood and fibreglass or polyurethane are simple solutions that require little manpower. So too are special paints that deflect the heat to another point.

We must stress that in homes built prior to 1980, replacing the existing carpentries with other ones more efficient thermally, would be a significant reduction in heat loss that take place through doors and windows (to about half). The insulation of foundation slabs would lead to a reduction of heat loss even greater, about 80%, depending of the house.

But enhancements do not end here. A state of the art developed in appendix 7.14 about Low Temperature District Heating has shown that high-energy efficient dwellings would allow the reduction of the circulating water temperature in the DH network from 90 to 70 degrees Celsius.

For this reason, we would like to emphasize that we understand that the data obtained for the different housing should be considered as an additional tool to guide the Føns inhabitants to decision making of energetic nature. This means that we believe that the final decision of the Føns inhabitants should not be restricted to the choice of one or another kind of electricity and heating system, but also taking constructive solutions to improve the construction quality of housing and, in this way, reduce energy demand.

4. ALTERNATIVE STUDY

4.1 INTRODUCTION PHASE 1

The following information gathers the different alternatives studied to provide Føns village of heating and electricity supply. This section includes all the relevant information necessary to develop the collective and individual solutions on phase 2.

First of all, some common assumptions must be taken in order to be able to carry on with the study. The information below is presented in Appendix 7.4, where it is found the different studies developed to arrive at the following final data:

- The number of houses is set in 71
- The total need of heating is 1.965.835 kWh per year
- The total need of electricity is 315.000 kWh per year

Secondly, the full covering of the heating and hot water demand for the 71 dwellings will be studied. Different fuel solutions will be considered in three main scenarios: The implementation of individual biomass boilers, the implementation of a district heating net, and the implementation of a district heating net powered by a cogeneration plant. The study that permits the use of this information is in section 5.3.

GENERAL ASSUMTIONS HEATING

- Heat supply considerations. (See Appendix 7.4)
    - ANNUAL HEAT DEMAND – 1.965.835kWh/year
    - ACTUAL AVERAGE ANNUAL HEATING COST – 29.721 DKK/year, +3% annual increases. (1 house, oil boiler)
    - TOTAL HEAT PEAK DEMAND – 639KW
- Annual heating period considered - 9 months, (September to March).
- District heating distribution net.
    - TOTAL ESTIMATED INVESTMENT – 2.797.600 DKK
    - ANNUAL MAINTENANCE COST – 51.500 DKK

Finally, as each alternative will provide estimation on the return of the investment that each user should do. There are some assumptions that must be taken into account:

- The price for selling electricity is 0,35 DKK/kWh (Plan Energi, 2012)(notice that solar systems will apply the new energy regulation regarding price for selling and buying electricity).
- The price for buying electricity is 2,2 DKK/kWh
- Bank loan:
    - Interest rate at 3%
    - Initial payment per user of 45.000 DKK
    - Annual payment per user of 18.000 DKK
- VAT of 25%
- Exchange rate from DKK to Euro of 7,46046
- Electricity inflation 3%

The study of the different alternatives starts below. The first section is destined for heating alternatives while the second is focussed on electricity.

HEATING ALTERNATIVES

This section defines the different alternatives in accordance to heat supply in Føns. First of all, Biomass and Cogeneration systems and secondly Geothermal alternatives that will work thanks to different combinations.

ALTERNATIVE 1: BIOMASS AND CHP

The following part develops the study of 6 different alternatives. These scenarios can be divided into three groups. The first one refers to the proposal of an individual solution based on a pellet boiler; the second one studies a district heating plant considering as possible fuels wood-chips, straw and biogas; the third solution studies the implementation of a cogeneration plant considering two fuels woodchips and biogas.

ALTERNATIVE 2: GEOTHERMAL

The study included in this part is compound by the development of 4 different alternatives based on ground source heat pump solutions.
The first three ones refer to the proposal of individual heating supply solutions. The alternative 1 and 2 focus on individual solar assisted heat pump. The former considers a water tank seasonal storage system whereas the latter is based on boreholes seasonal storage. The alternative 3 deals with an individual heat pump with boreholes without being assisted by solar collectors.
To conclude, a collective solution is developed. The last alternative studies a district heating plant considering a collective solar assisted heat pump with boreholes seasonal storage.

ELECTRICITY ALTERNATIVES

This section defines the different alternatives in accordance to electricity supply in Føns. First of all, Solar power and then, wind power.

ALTERNATIVE 1: SOLAR PANELS

In this part the analysis of the different options regarding solar systems will be analysed. Both individual and collective installations will be considered, taking into account the differences regarding the current energy regulation in Denmark, recently changed to favour collective systems.

ALTERNATIVE 2: WIND POWER

The following part develops two different alternatives related to wind power. The first alternative considers the execution of a wind turbine that will create enough energy to supply Føns village while the second alternative considers for each house a wind turbine located in the garden's area. Both alternatives are going to be taken into detail below.

4.2. HEATING ALTERNATIVES FEASIBILITY STUDY

4.2.1. ALTERNATIVE 1: BIOENERGY

INTRODUCTION

In this part of the feasibility study, the full covering of the heating and hot water demand for the 71 dwellings will be studied. Different fuel solutions will be considered in three main scenarios: The implementation of individual biomass boilers, the implementation of a district heating net, and the implementation of a district heating net powered by a cogeneration plant.

ASSUMPTIONS

- Three possible heating solutions will be considered:
    - The implementation of an individual heating system.
    - The implementation of a collective heating system.
    - The implementation of a collective heating and electricity production system.
- The cogenerations systems proposed will be focused on fulfilling the heating demand of the households, while the electricity surplus produced will be considered as a secondary production.
- Considering the conclusions gathered on previous reports (Alberdi Pagola, Alvarez Anton, Andersen, Awugya, & De Vivo, 2012), a list of options will be rejected due to economic and technical considerations.
- For the options considered, the economic aspects, regulations and social aspects, technical and environmental considerations will be studied to select the most suitable solution.

OPTIONS REJECTED

The following solid biomass-based systems will be discarded, considering the conclusions obtained on previous research (Alberdi Pagola, Alvarez Anton, Andersen, Awugya, & De Vivo, 2012).

- Firewood – For individual and collective systems, this solution requires a high initial investment; while it's low performance and high fuel cost do not compensate this investment.
- Briquettes – For individual and collective systems, this solution requires a high initial investment; while it's low performance and high fuel cost do not compensate this investment.

- Charcoal – For individual and collective systems, this solution will not be considered due to the high fuel cost and the low efficiency of the system, on developed countries this fuel has been rejected for new installations.
- Forest Chips – For individual systems, this solution has been discarded due to the high initial investment and complexity for the loading system and boiler, which cannot be compensated with the actual fuel cost.
- Straws – For individual systems, this solution has been discarded due to the high initial investment and complexity for the loading system and boiler, which cannot be compensated with the actual fuel cost.
- Grain – For individual and collective systems, this solution has been discarded due to the high initial investment and complexity for the loading system and boiler in the case of individual boilers, which cannot be compensated with the actual fuel cost. In the case of collective boilers, the price of grain (wheat, corn…) makes the solution less interesting compared with other fuels (straws, woodchips…), while the initial investment would be similar.

The following biofuel-based systems will be discarded, considering the conclusions obtained on previous research (Alberdi Pagola, Alvarez Anton, Andersen, Awugya, & De Vivo, 2012).

- Biodiesel – For individual and collective solutions, the use of biodiesel boilers will not be considered, as the fuel price reaches the same values as diesel fuel and do not compensate the initial investment.
- Bioethanol – For individual and collective solutions, the use of bioethanol will not be considered, because the actual market price makes the investment not feasible.

OPTIONS CONSIDERED

Installing an individual system for each user.

- Individual pellet boiler.

  The solution will consist on the installation of an individual boiler, with a nominal power of 12,5KW. It will consist on an automatic boiler with integrated feeding system and manual loading, including a pellet container of 150-200l. Considering the model *HPK-RA 12,5 "CLIBER-GILLES"*.

Installing a collective heating system.

The distribution net is based on the district heating net mentioned on heating assumptions.

Collective heating solution

- District heating with Wood-Chips boiler.

  This solution will integrate a wood-chips feeding system, which will power two 300KW wood-chip boilers, considering the model *HPKI-K 300 "CLIBER-GILLES"*. The system will count with 4 buffer tanks of 800l.
- District heating with Straw boiler.

This solution will integrate a straw feeding system, consisting on a conveyor belt combined with a loader, which will power a 600KW adapted straw burners, considering the model *HTHW HHF600 "DANSTOKER"*. The system will count with an auxiliary gas-oil boiler, which will be used on peak demand days and during the maintenance of the main boiler. The system will count with 4 buffer tanks of 800l. The loading of the straw bales will be manual, considering the purchase of a second hand minilader.

- District heating Biogas.

  This solution will integrate a biogas tank of 25m3, which will power two 310KW biogas burners, considering the model *Logano Plus SB 615 "BUDERUS"*. The system will count with 4 buffer tanks of 800l.

Collective heating and electricity production system

- District heating Wood-Chips + Cogeneration.

  This solution will integrate a wood-chips fueled gasification boiler, which will power 5 gas burners, each one combined with a Stirling engine. This solution will be dimensioned to reach a power of 700KW of heating production and 175Kw of electricity output. The model selected for the 4 boilers will be: *35kW SD4 engine "Stirling DK"*. The solution will integrate four buffer-tanks of 800l.
- District heating Biogas + Cogeneration.

  This solution will integrate a biogas tank of 30m3, which will power 5 gas burners, each one combined with a Stirling engine. This solution will be dimensioned to reach a power of 700KW of heating production and 175Kw of electricity output. The model selected for the 5 boilers will be: *35kW SD4 engine "Stirling DK"*. The solution will integrate four buffer-tanks of 800l.

Cogeneration proposed options are very innovative and there are still few producers. It is currently being researched and improved; few projects have already been realized. Despite what it is supposed to be the leading company in the world, located here in Denmark, it has not been possible to get any direct and real precise budged or cost reference. Therefore it has only been possible to do an estimating with figures from a report (E. Podesser, 2005). Despite this lack of information this modern systems surely are the future of Biomass cogeneration in small scale.

CONSIDERATIONS

TECHNICAL ASPECTS

For this analysis, it will be considered the technical feasibility of installing and running the system, considering the previous proposals. An estimated budget for the installation cost and annual maintenance will be added, in order to compare the options analytically on the economic analysis.

FUEL	LHV	Cost (DKK/GJ)	Cost (DKK/MWh)	Yearly variation
Wood Chips	13.320 KJ/Kg	38,10	137,16	+5,22%
Pellets	19.000 KJ/Kg	71,40	257,04	+1,00%
Straw	18.000 KJ/Kg	39,06	140,62	+ 1,67%
Biogas	35.900 KJ/Nm3	115	414	± 0,00%

Figure 4.2.1_1: Fuel considerations. Source: (Ea Energy Analyses, 2010) (WIP Renewable Energies, 2012)

* Yearly price variation has been estimated considering the Danish Energy Agency cost forecast from 2010 to 2020.
* Biogas variation will be considered as ±0%, considering the establishment of a fixed feed-in tariff by the Danish Government from 2012 to the year 2020.
* All the inflation estimations are considered up to the year 2020, before this there will be considered a steady rate, as doing a prediction is not possible

SYSTEMS AND EQUIPMENT

- **Individual pellet boiler.** (Gilles, 2012) (Burdeus, 2012) (Negarra, 2012)
    - Power – 12,5Kw
    - Temperature range
        - Impulsion – 70°C
        - Return – 50°C
    - Performance – 85%
    - Annual consumption – 30.382KWh/year
    - Annual maintenance cost – 1.250 DKK/year
    - Installation cost – **176.669 DKK**

DESCRIPTION	COST (DKK)
Pellet boiler *(HPK-RA 12,5 "CLIBER-GILLES")*	*105.500 DKK*
SHW -tank 75l *(Logalux ER 75 "BUDERUS")*	*4.700 DKK*
Extraction system *(COAXIS W "NEGARRA")*	*1.200 DKK*
Installation and connection (10%)	11.500 DKK
TOTAL INSTALLATION COST	**122.900 DKK**
GC+IB (9%+6%)	18.435 DKK
Total cost	**141.335 DKK**
VAT (25%)	35.334 DKK
TOTAL	**176.669 DKK**

Figure 4.2.1_2: Cost analysis of the individual pellet boiler system

* These costs refer to the estimated costs for the implementation of the solution into a house heated by a combustion based method. The internal installations concerning emitters will not be included.

- **Collective wood-chips boiler.** (Gilles, 2012) (Burdeus, 2012) (Negarra, 2012)
    - Power – 2X 300KW
    - Temperature range
        - Impulsion – 95°C
        - Return – 40°C
    - Performance – 90%

- Consumption – 2.157.213Kwh/year
- Annual maintenance cost – 35.000 DKK
- Installation cost – **4.852.684 DKK**

DESCRIPTION	COST (DKK)
Wood-chips boiler X2 *(HPKI-W 300 "CLIBER-GILLES")*	*2.107.700 DKK*
Loading system*(HPKI-K/R/W "CLIBER-GILLES")*	*28.950 DKK*
Storage silo *(63m3 "CLIBER-GILLES")*	*355.970 DKK*
Buffer-tank 800l X4 *(PSM 800 "CLIBER-AUSTRIA")*	*25.200 DKK*
Extraction system *(GC-25 ALU PLUS "NEGARRA")*	*41.980 DKK*
Site building (100m2, industrial)	560.000 DKK
Installation and connection (10%)	255.980 DKK
TOTAL INSTALLATION COST	**3.375.780 DKK**
GC+IB (9%+6%)	506.367 DKK
TOTAL COST	**3.882.147 DKK**
VAT (25%)	970.537 DKK
TOTAL	**4.852.684 DKK**

Figure 4.2.1_3: Cost analysis of the collective wood-chips boiler system

- **Collective straw boiler.** (Danstoker, 2012) (Burdeus, 2012) (Negarra, 2012) (Gilles, 2012)
  - Power – 1X 600KW + 1X125KW
  - Temperature range
    - Impulsion – 95ºC
    - Return – 40ºC
  - Performance – 87%
  - Consumption – 2.231.600KWh/year
  - Annual maintenance cost – 140.115 DKK/year
    - Annual maintenance cost – 85.800 DKK/year
    - Annual Gas-oil consumption – 33.690 DKK/year
      * Considered price 11.230 DKK/l (Plan Energi, 2012)
  - Installation cost – **4.928.171 DKK**

DESCRIPTION	COST (DKK)
Straw boiler *(HTHW HHF600 "DANSTOKER")*	2.300.000 DKK
BACKUP SYSTEM	
Gas-oil boiler *(Logano SK 645 "BUDERUS")*	56.200 DKK
Gas-oil tank (3000l)	11.250 DKK
Loading system *("DANSTOKER")*	32.000 DKK
Charging machinery *(CAT "216B")(2nd hand)*	90.000 DKK
Buffer-tank 800l X4 *(PSM 800 "CLIBER-AUSTRIA")*	25.200 DKK
Extraction system *(GC-25 ALU PLUS "NEGARRA")*	41.980 DKK
Site building (200m2, industrial)	560.000 DKK
Installation and connection (10%)	255.663 DKK
TOTAL INSTALLATION COST	**3.116.630 DKK**
GC+IB (9%+6%)	467.495 DKK
TOTAL COST	**3.593.125 DKK**
VAT (25%)	898.281 DKK
TOTAL	**4.491.406 DKK**

Figure 4.2.1_4: Cost analysis of the collective straw boiler system

- **Collective biogas boiler.** (Burdeus, 2012) (Gilles, 2012) (Negarra, 2012)
    - Power – 2X 310KW
    - Temperature range
        - Impulsion – 95ºC
        - Return – 40ºC
    - Performance – 99%
    - Consumption – 1.961.103KWh/year
    - Annual maintenance cost – 12.500DKK/year
    - Installation cost – **1.315.481 DKK**

DESCRIPTION	COST (DKK)
Biogas boiler X2 *(Logano Plus SB 615 "BUDERUS")*	360.200 DKK
Pressurized Biogas tank 25m3 (superficial)	150.000 DKK
Buffer-tank 800l X4 *(PSM 800 "CLIBER-AUSTRIA")*	25.200 DKK
Extraction system *(GC-25 ALU PLUS "NEGARRA")*	41.980 DKK
Site building (100m2, industrial)	280.000 DKK
Installation and connection (10%)	57.738 DKK
TOTAL INSTALLATION COST	**915.118 DKK**
GC+IB (9%+6%)	137.267 DKK
TOTAL COST	**1.052.385 DKK**
VAT (25%)	263.096 DKK
TOTAL	**1.315.481 DKK**

Figure 4.2.1_5: Cost analysis of the collective biogas boiler system

- **District heating Wood-Chips + Cogeneration.** 4x35 kw Stirling engine wood chips* system. (Stirling DK, 2011) (E. Podesser, 2005) (Gilles, 2012) (Burdeus, 2012) (Negarra, 2012)
  *(*Wood chips of Austrian Önorm classification G50: moisture content of 35-55%)*
    - Power – 4X 35kWe + 140kWth (Total 140kWe & 560kWth)
    - Temperature range
        - Impulsion – 95ºC
        - Return – 40ºC
    - Performance
        - Gasification – 97%
        - Heat – 70%
        - Electric – 17%
        - Total system – 69%
    - Consumption – **2.808.335,7KWh/year**
    - Annual maintenance cost – **102.138DKK/year**
        - Annual maintenance cost boilers – 35.000DKK/year
        - Annual maintenance cost stirling – 33.448DKK/year
        - Annual Gas-oil consumption – 33.690 DKK/year
          * Considered price 11.230 DKK/l (Plan Energi, 2012)
    - Installation cost – **8.505.156 DKK**

DESCRIPTION	COST (DKK)
4x35 kw Stirling engine wood chips*system (STIRLING DK)	*5.222.000 DKK*
Storage silo	
Loading system	
Updraft gasification and combustion system	
Biogas boiler	
Buffer-tank 800l X4 *(PSM 800 "CLIBER-AUSTRIA")*	*25.200 DKK*
Extraction system *(GC-25 ALU PLUS "NEGARRA")*	*41.980 DKK*
BACKUP SYSTEM	
Gas-oil boiler *(Logano SK 645 "BUDERUS")*	56.200 DKK
Gas-oil tank (3000l)	11.250 DKK
Site building (200m2, industrial)	560.000 DKK
TOTAL INSTALLATION COST	**5.916.630 DKK**
GC+IB (9%+6%)	887.495 DKK
TOTAL COST	**6.804.125 DKK**
VAT (25%)	1.701.031 DKK
TOTAL	**8.505.156 DKK**

Figure 4.2.1_6: Cost analysis of the District heating Wood-Chips + Cogeneration

- **District heating Biogas + Cogeneration.** 4x35 kw Stirling engine biogas system. (Stirling DK, 2011) (E. Podesser, 2005) (Burdeus, 2012) (Gilles, 2012) (Negarra, 2012)
  - Power – 4X 35kWe + 140kWth (Total 140kWe & 660kWth)
  - Temperature range
    - Impulsion – 95°C
    - Return – 40°C
  - Performance
    - Heat – 70%
    - Electric – 17%
    - Total – 87%
  - Consumption –**2.808.335,7KWh/year**
  - Annual maintenance cost – **79.638DKK/year**
    - Annual maintenance cost stirling – 33.448DKK/year
    - Annual maintenance cost boilers – 12.500DKK/year
    - Annual Gas-oil consumption – 33.690 DKK/year
      * Considered price 11.230 DKK/l (Plan Energi, 2012)
  - Installation cost – **6.943.484 DKK**

DESCRIPTION	COST (DKK)
4x35 kw Stirling engine biogas system (STIRLING DK)	*4.177.600 DKK*
Buffer-tank 800l X4 *(PSM 800 "CLIBER-AUSTRIA")*	25.200 DKK
BACKUP SYSTEM	
Gas-oil boiler *(Logano SK 645 "BUDERUS")*	56.200 DKK
Gas-oil tank (3000l)	11.250 DKK
Site building (200m2, industrial)	560.000 DKK
TOTAL INSTALLATION COST	**4.830.250 DKK**
GC+IB (9%+6%)	724.538 DKK
TOTAL COST	**5.554.788 DKK**
VAT (25%)	1.388.697 DKK
TOTAL	**6.943.484 DKK**

Figure 4.2.1_7: Cost analysis of the District heating Biogas + Cogeneration

ENVIRONMENTAL ASPECTS

As biomass is considered legally zero balance carbon emissions energy, the environmental impact of this heating system is reduced to the limitation of the gaseous emissions on protected areas and living areas. The controversy of the neutral CO2 balance will be relegated aside, considering the official European outlook as the valid one for this analysis.

SOCIAL ASPECTS

On this section, all the actual regulations will be taken into account; in order to evaluate if it is legally feasible to execute the project. Furthermore, the existence of grants and government support will be studied, providing a better economic environment for the investment.

Individual pellet boiler

The implementation of this individual system has no legal problems, and there is needed just to ask for a work permit to the local authorities.
For heating purposes there are no grants, neither Danish nor European.

Collective systems

The implementation of this collective system requires the permission from the local legal authorities to implement the district heating net, the situation of the plant has to be studied according to national and local regulation (see Appendix n).
Grants:

- Collective wood chips boiler.
- Collective straw boiler.
- Collective biogas boiler.

For heating purposes there are no Danish nor European grants, that can be applied on the present project (see Appendix n).

- District heating wood-chips + cogeneration
- District heating biogas + cogeneration

For cogeneration systems there are Danish grants, that can be applied on the present project (see Appendix n)

ECONOMIC ASPECT

The economic considerations will basically take into account the cost of the initial investment, analyzing the long term-cash flow of the investment taking into account the annual consumptions and maintenance costs, energy productions and sells in case on the case of cogeneration systems and the financial costs of the operation. The comparison will be carried out considering the estimated investment of one owner.
All the heating solutions will be compared with the estimate annual cost of running a traditional heating system, which will be considered as 17.500 DKK/year, considering an annual increase of 3% on the cost (See heating introduction).

Individual pellet boiler

- Annual consumption – 32.574KWh/year
- Annual maintenance cost – 1.250 DKK
- Initial Investment – 176.669 DKK
- Annual fuel cost – 8.373 DKK
    - Yearly fuel inflation - +1,00%

Collective wood chips boiler

- Annual consumption – 30.764KWh/year
- Annual maintenance cost – 1.218 DKK
    - Annual maintenance cost installation – 493 DKK
    - Annual maintenance cost district heating – 725 DKK
- Initial Investment – 107.841 DKK
    - Initial Investment boiler – 68.348 DKK
    - Initial Investment district heating – 39.403 DKK
- Annual fuel cost – 4.220DKK
    - Yearly fuel inflation - +5,22%

Collective straw boiler

- Annual consumption – 31.825KWh/year
- Annual maintenance cost – 2.698 DKK
    - Annual maintenance cost installation – 1.973 DKK
    - Annual maintenance cost district heating – 725 DKK
- Initial Investment – 102.662 DKK
    - Initial Investment boiler – 63.259 DKK
    - Initial Investment district heating – 39.403 DKK
- Annual fuel cost – 4.475 DKK
    - Yearly fuel inflation - +1,67%

Collective biogas boiler

- Annual consumption – 27.967KWh/year
- Annual maintenance cost – 901 DKK
    - Annual maintenance cost installation – 176 DKK
    - Annual maintenance cost district heating – 725 DKK
- Initial Investment – 57.931DKK
    - Initial Investment boiler – 18.528 DKK
    - Initial Investment district heating – 39.403 DKK
- Annual fuel cost – 11.578DKK
    - Yearly fuel inflation - +0,00%

District heating wood-chips + cogeneration

- Annual consumption –39.554KWh/year
- Annual maintenance cost –2.164 DKK
    - Annual maintenance cost installation – 1.439DKK
    - Annual maintenance cost district heating – 725 DKK
- Initial Investment – 159.193 DKK
    - Initial Investment Cogeneration System – 119.790 DKK
    - Initial Investment district heating – 39.403 DKK
- Annual fuel cost –4.913 DKK
    - Yearly fuel inflation - +5,22%

District heating biogas + cogeneration

- Annual consumption –39.554KWh/year
- Annual maintenance cost –1.847DKK
    - Annual maintenance cost installation – 1.122DKK/year
    - Annual maintenance cost district heating – 725 DKK
- Initial Investment – 137.198 DKK
    - Initial Investment Cogeneration System – 97.795DKK
    - Initial Investment district heating – 39.403 DKK
- Annual fuel cost – 16.301 DKK
    - Yearly fuel inflation - +0,00%

CONCLUSSIONS

INDICATORS

The following economic indicators referred to the investment have been selected in order to compare all the scenarios proposed. For further information, check the cash-flow tables in Appendix 7.15.

INDICATOR	I. PELLET BOILER	DH. WOODCHIPS	DH. STRAW	DH. BIOGAS	CHP. WOODCHIPS	CHP. BIOGAS
Initial investment	176.669 DKK	124.562 DKK	102.662 DKK	57.931 DKK	159.193 DKK	137.198 DKK
Loan period	9 years	6 years	5 years	2 years	8 years	7 years
Break-even point	8 years	4 years	4 years	4 years	2 years	2 years
Profit 10 years	42.494 DKK	150.415 DKK	157.008 DKK	157.221 DKK	274.689 DKK	274.689 DKK
Profit 20 years	398.120 DKK	550.891 DKK	537.674 DKK	490.328DKK	925.701DKK	907.627 DKK
Profitability 10 years	20%	120%	153%	271%	173%	200%
Profitability 20 years	225%	442%	524%	846%	581%	662%

Figure 4.2.1_8: Economical indicators

GRAPHICS

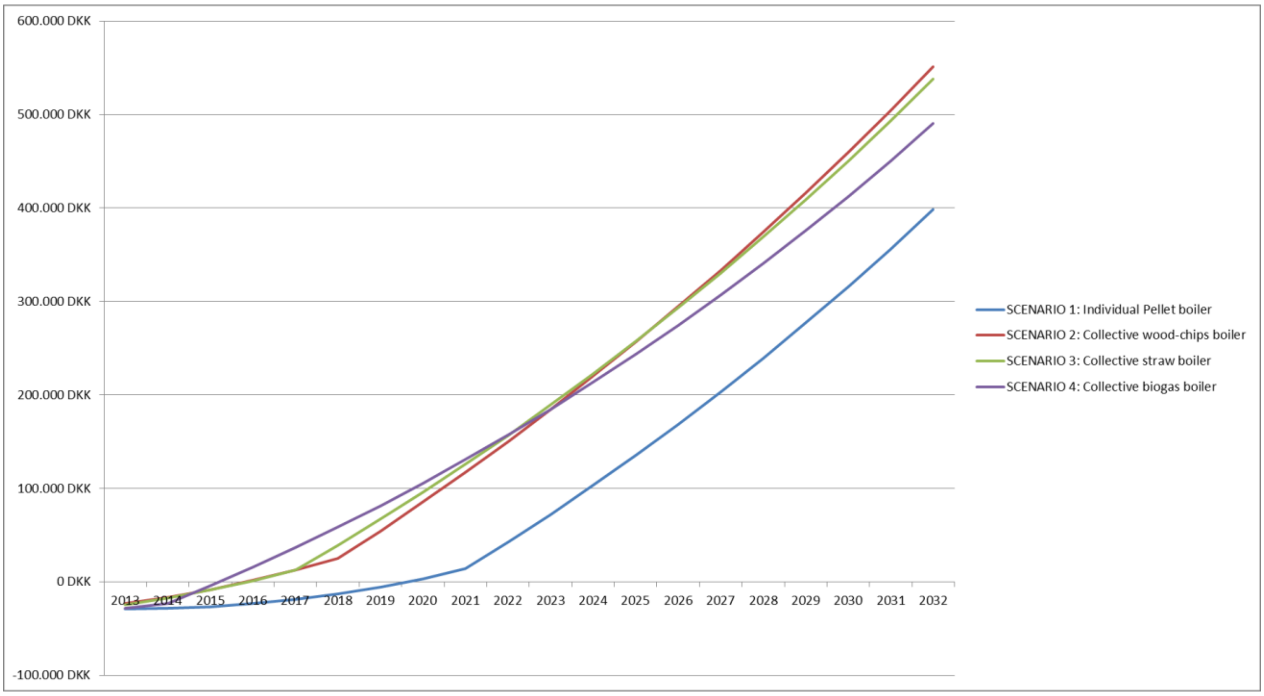


Figure 4.2.1_9: Compound Cash-Flow for individual pellet boiler and heating solutions

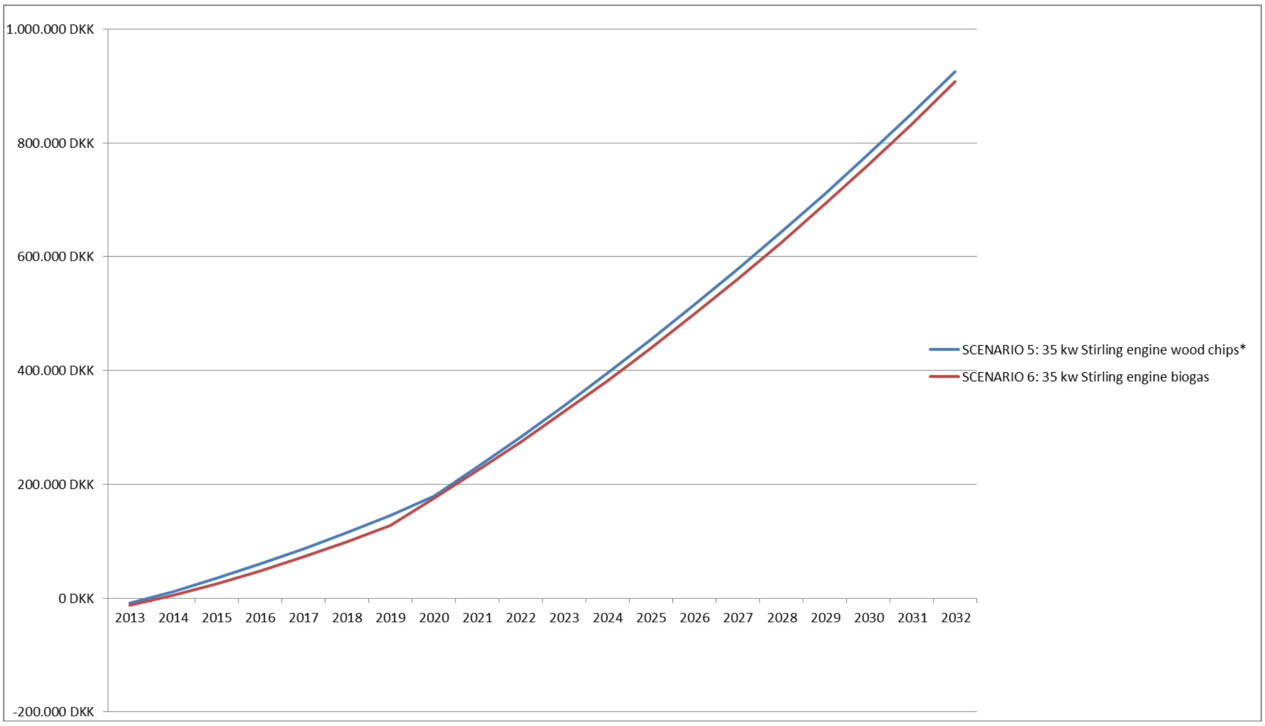


Figure 4.2.1_10: Compound Cash-Flow for cogeneration solutions

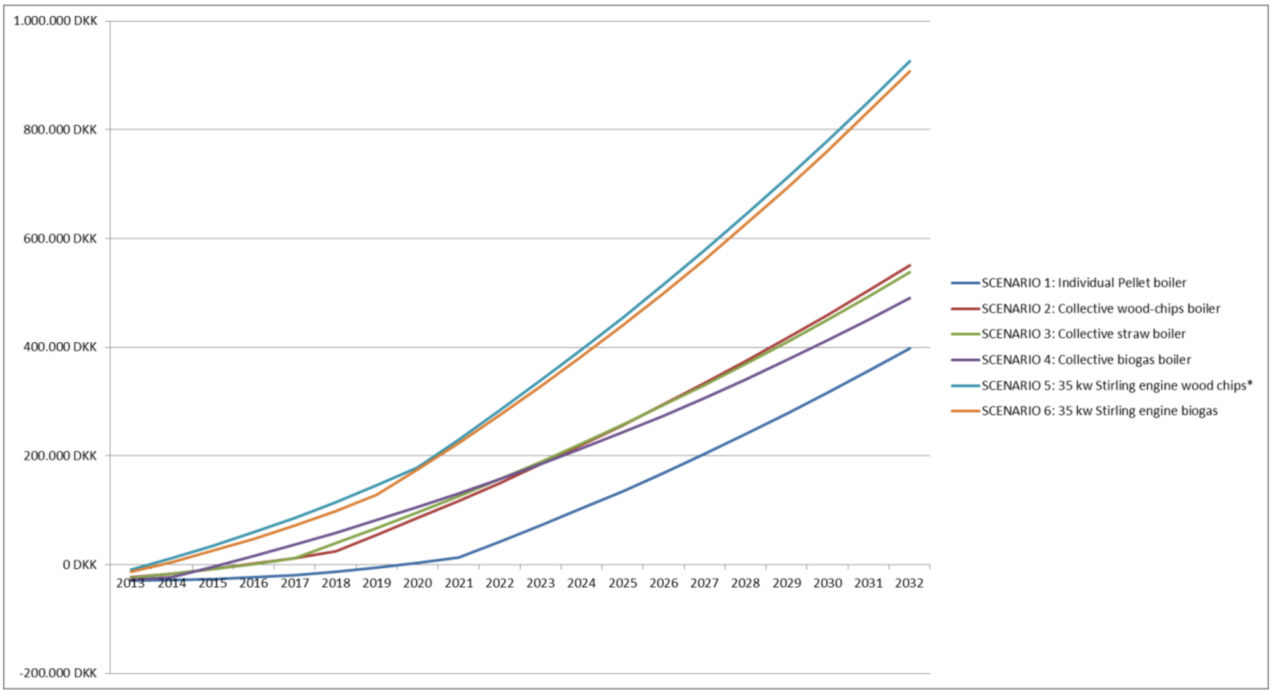


Figure 4.2.1_11: Compound Cash-Flow for all the solutions

INDIVIDUAL SYSTEMS

Once compared the economic data of the individual system with the investment on a district heating, the following conclusions can be assessed.

- The initial investment required per each neighbor is a 72% Higher, which requires an estimated loan period of 9 years compared to the 5 years of the most expensive district heating solutions.
- The yearly consumption is almost the double of the district heating solutions. This cost combined with a higher initial investment makes the investment to take 5 years to turn the cash-flow into positive numbers.
- Considering the overall balance of the investment at 10 and 20 years, there can be assessed that: The profits of the overall investment are a 66% and a 30% lower respectively.

Considering all these economic factors, there can be assessed that the investment on an individual heating solution is not worthy compared with the benefits of a district heating solution.

The implementation of this solution should be relegated just in case of impossibility of connection to the district heating net.

Considering these two points, there has to be remarked that this investment represents an investment with an average annual profit of 12%, with a lifespan of 20 years. And considering a period of 10 years reaches an annual profit of 3,5%, which may turn into a profitable investment though.

COLECTIVE HEATING SOLUTIONS

Concerning the collective solutions, depending on the interests of the investors, several solutions can be adopted.

- The biogas district heating plant represents the solution with the lowest initial investment required; this solution requires also the lowest loan period to be paid (2 years).
- The investment with the shortest break-even point (the one which go positive first) is the woodchips district heating plant, with a break-even point on the 3rd year.
- The district heating solution with a woodchips plant represents the investment with the highest benefits at 10 and 20 years, followed by the straw plant.

Having considered all these factors, and once analyzed all the solutions, there can be assessed that the **woodchips district heating** plant represents the best investment.

COLECTIVE COGENERATION SOLUTIONS

Regarding the accuracy of this study, the prices taken for the installation cost of Stirling systems has been taken from published numbers of leading company Stirling DK, maybe the only one currently offering updraft gasifier systems for converting woodchips into biogas. As the source referenced did not made any difference in price between woodchips systems and biogas system, a 20% discount has been applied to biogas system because this system is simpler.

Concerning the cogeneration solution, and comparing the results obtained with the ones gathered from the district heating solutions, there can be seen that this investment represents a higher initial investment but reaches higher profits with greater returns.

- The biogas cogeneration plant represents the solution with the lowest initial investment required; this solution requires also the lowest loan period to be paid (11 years).
- The wood-chips gasification plant is the investment with the greatest benefits at 10 and 20 years

Having considered all these factors, and once analyzed all the solutions, there can be assessed that the **woodchips cogeneration** plant represents the most interesting investment.

4.2.2. ALTERNATIVE 2: GROUND SOURCE ENERGY

INTRODUCTION

Heat Pumps have demonstrated that can achieve high efficiencies, in other words, they can both save money and reduce CO_2 emissions.

In the case of Denmark and its hard temperatures, if the heat pump takes the heat from the cold air, the efficiencies will not be good enough. Taking benefit of the steady and warmer (about 9 degrees) temperature of the ground, the efficiency of the system would be good enough to make it feasible.

These systems are not so rare in Denmark, mainly in individual houses heating. However, new developments and improvements of these systems are in progress, introducing new elements to the GSHP system, as solar collectors with or without heat storage, and also considering collective solutions.

Solar collectors

The solar collectors are used in order to store heat into the soil while the sun heat is available, mainly in summer time.

One of the reasons to include solar collectors in a ground source system is based on the fact of achieving higher heat pump efficiencies.
With the solar collectors and storage system, the input temperature of the heat pump can be raised, which means reaching better efficiencies in the system.

Individual / Collective system

As far as the system in general is concerned, collective systems have to be considered, because of the improvement of the efficiency and its other advantages. However, some houses and farms in Føns are not close to the others, so an individual system for these houses may be necessary.

Storage systems

Taking into account the brief description of the main typologies of storage systems gathered in the Group Project I report and in the appendix, some conclusion and assumptions have been made.

- Water tank could be considered as the most well- disposed storage system from a thermodynamic point of view and occupied a short space with the same heat capacity comparing it with other storage systems.

- One of the main advantages of boreholes storage system is its modularity, which could be a significant feature if new householders want to join to the district heating system.

The main point to combine solar panel and ground source heating is the season characteristic in north countries. Indeed, it is in summer that the reception of solar radiance is the highest although our energy need is lower than in winter. Therefore, the interest of that combination is to store the amount of energy collected in summer to use it in winter. Here, the way of storage is borehole in the ground, but it is existed different other methods detailed in Appendix 7.8.
Moreover, the point is that during the summer, the energy collected has to be used in order to avoid the water which circulates in pipes boils and damage the system. To prevent that problem, the owner has three solutions: paint the panels in white to reduce their efficiency, to heat the house even if it is not necessary (heat waste) or store it in the ground to make the water circulate by storing the energy for cooler seasons.

ALTERNATIVES TO BE STUDIED

Taking into account all the considerations gathered in the appendix, it has been made the decision of studying the next alternatives.

Alternative 1: Individual solar assisted heat pump with water tank seasonal storage

- Individual heat pump
- Individual solar collectors
- Individual storage in a water tank

Alternative 2: Individual solar assisted heat pump with boreholes seasonal storage

- Individual heat pump
- Individual solar collectors
- Individual boreholes storage.

Alternative 3: Individual heat pump with boreholes

- Individual heat pump.
- Individual boreholes.

Alternative 4: District solar assisted heat pump with boreholes seasonal storage

- District heat pump
- District solar collectors
- District storage with boreholes.

JUSTIFICATION

TECHNICAL CONSIDERATIONS

Alternative 1: Individual solar assisted ground source heat pump with water tank seasonal storage

COP of the proposed system

A normal COP for a Ground source individual heat pump in this area may be 3,3 (Sørensen, 2012).

The integration in the system of solar collectors and seasonal storage is under development and there is no much data available. One recent study achieved a 30% of reduction of the length of the boreholes for the same efficiency and 20% of cost reduction (Cauret & Kummert, 2011). So a reasonable assumption may be a 20 % of improvement of the efficiency.

Taking into account these two assumptions, it is logical to assume an average COP of **4**.

Individual storage water tank

The annual heating period considered would be of 9 months (between September to March). As it is shown in the Appendix 7.8, many studies have been conducted in order to get the suitable amount of storage that it is needed for a domestic householder.

Considering Denmark as much colder than mid- European countries a normal size for individual water tank could be **24 m^3.**
An average dimensions for our water tank that could be feasible in Føns householder's plots would be a water tank of 4*3*2 meters.

Individual solar collectors.

Taking into account all the solar radiation information that have been gathered on Middelfart region (Appendix 7.5) and according the technical characteristics of the solar collectors used, a relation between m^3 of storage in a water tank and m^2 of solar collector is going to be used. (Appendix 7.8)

Assuming a water tank storage of 24 m^3 and a relation around;

$$1,5\ {}^{m^3 storage\ volume}\!/_{m^2\ solar\ collector}$$

It is needed a surface of 16 m^2 of solar thermal collector in each household.
According to some legal restrictions in the area, in some householders in which could be possible putting the solar thermal collectors in the plot area would be considered as well as the usual solar collectors in the roof. It is considered that those houses which a roof made by straw cannot install solar collector in their roof.

Alternative 2: Individual solar assisted ground source heat pump with borehole seasonal storage

COP of the proposed system

In this system is going to be considered a COP of **4** due to the same consideration explained behind in the alternative 1.

Individual boreholes

The boreholes dimension would be 100 m long. A closed loop vertical should be considered as a possible solution for storage system in the individual ground source heating.

The amount of heat that can be extracted per borehole could be different depending on the different type of rock. Looking into the geological maps gathered in the Appendix 7.8, it is considered that the main geological formation in the area is clay. In the first instance, it can be observed that the first layers of the soil is usually compound by saturated sand, but considering boreholes of 100 meters depth should be considered the geological formation below as the main type of rock for the following calculations.

According to the German standard (VDI 4660), the thermal conductivity and heat capacity of the soil can be obtained as:

Thermal conductivity W/mK → 1,5 W/Mk
Heat capacity → 2,000 10 6 J/m^3 K.

With reference to the Energy extraction per year in W/m borehole considering 1800 hours of production and considering clay soil, the value considered should be 35-50 W/m borehole. (Bjørn, 2012).

As the boreholes will have higher losses owing to the lower amount of boreholes put in a household plot the energy extraction per year will be considered as 30 W/m borehole.
The annual heat demand by a household is considered as 174 KWh/m^2/year, in other words, as it is considered a household average of 157, 15 m^2, the annual heat demand of each householder is 174 KWh/m^2/year * 157,15 m^2 = 27,34 MWh/year,

1. **Calculate energy extracted per borehole**

$E_{borehole}$= 30 w/m *100 m* 1800 $^{hours}/_{year}$ = 6300000 $^{W}/_{year}$ = 6, 3 $^{Mw}/_{year}$

2. **Energy extracted for an individual house** (adopting a COP for an individual heat pump of 4)

$COP = 4 = \frac{Output}{Input} = \frac{27{,}34 Mwh}{I}$

I= 6,835 Mwh

ET = Output – Input = 27, 34 – 6,835 = 20,505 Mwh

3. **<u>Number of boreholes</u>**

We can calculate the number of boreholes that we need to put in the district lot through this expression

N° = $\frac{Demand*I}{Eb}$ = $\frac{20{,}505\ Mwh}{6{,}3\ Mw/year}$ = **4 boreholes**.

Individual solar collectors

As well as in the alternative 1 the assumption taken lead us to a total amount of solar thermal collectors needed of **16 m²** for each individual house.

Alternative 3: Individual ground source heat pump with borehole.

COP of the proposed system

This alternative is not assisted by solar. The COP considered for this system will be 3.3 (Sørensen, 2012).

Individual boreholes

The boreholes dimension would be 100 m long. A closed loop vertical should be considered as a possible solution for storage system as in the alternative 2. As in the other alternatives, clay soil is considered as the type of soil in the area.

Considering the annual heat demand as 27,34 MWh/year, as it was calculated in the alternative 2, the number of boreholes that we will needed should be:

1. **<u>Calculate energy extracted per borehole</u>**

$E_{borehole}$= 35 w/m *100 m* 1800 $^{hours}/_{year}$ = 6300000 $^{W}/_{year}$ = 6, 3 $^{Mw}/_{year}$

2. **<u>Energy extracted from an individual house</u>** (adopting a COP for an individual heat pump of 3.3)

COP =3,3 = $\frac{Output}{Input}$= $\frac{27{,}34Mwh}{I}$

I= 8.29 Mwh

E_T = Output – Input = 27,34 – 8,55 = 19,06 Mwh

3. **<u>Number of boreholes</u>**

We can calculate the number of boreholes that we need to put in the district lot through this expression

N° = $\frac{Demand*I}{Eb}$ = $\frac{19.06\ Mwh}{6{,}3\ Mw/year}$ = **4 boreholes.**

Alternative 4: Collective solar assisted ground source heat pump with inclined boreholes seasonal storage

COP of the proposed system

A normal COP for a Ground source District heat pump in this area may be 4 (Plan energy, 2012).

The integration in the system of solar collectors and seasonal storage is under development and there is no much data available. One recent study achieved a 30% of reduction of the length of the boreholes for the same efficiency and 20% of cost reduction (Cauret & Kummert, 2011). So a reasonable assumption may be a 20 % of improvement of the efficiency.

Taking into account these two assumptions, it is logical to assume an average COP of **4,5.**

Collective boreholes

The district is compound by 71 households as it was said in the general district assumptions.

A closed loop vertical boreholes should be considered as a possible solution for storage system in the ground source district heating.
The boreholes dimension would be 150 m long. The amount of heat that can be extracted per borehole could be different depending on the different type of rock. As we are considered clay according to the German standard (VDI 4660) we can get that the thermal conductivity and heat capacity of the soil as;

Thermal conductivity W/mK → 1,5 W/Mk
Heat capacity → 2,000 10 ^{6} J/m^{3}K.

Energy extraction per year in W/m borehole considering 1800 hours of production will be 35-50 W/m borehole. (Bjørn, 2012).
The annual heat demand is considered as 1,941,492 Kwh/year, in other words, the heat demand is 1942 Mwh/year,

1. **Calculate energy extracted per borehole**

$E_{borehole}$= 35 w/m *150 m* 1800 $^{hours}/_{year}$ = 9.450.000 $^{W}/_{year}$= 9, 45 $^{Mw}/_{year}$

2. **Energy extracted from the district** (adopting a COP for the district heat pump of 4.5)

COP =4,5 $\frac{Output}{Input}$= $\frac{1942Mwh}{I}$

I= 431.5 Mwh

E_T = Output – Input = 1942 – 431.5 = 1510.5 Mwh

3. **Number of boreholes**

We can calculate the number of boreholes that we need to put in the district lot through this expression

N° = $\frac{Demand*I}{Eb} = \frac{1510.5\ Mwh}{9{,}45\ Mw/year}$ = **160 boreholes.**

District solar collectors

Assuming 71 households in the entire community and a minimum surface of solar collectors in each house of 16 m^2 (explain in detail in alternative 1, individual system), the total amount of solar collector that it is needed for the district heating will be 1136 m^2.
It is supposed that a district heating results in an improvement in the efficiency of the systems, that is to say, it is considered a reduction of a 20% of the solar collector' surface.

The central solar heating plant needs **950 m^2** of solar collectors

SOCIAL ASPECTS

The main social aspect is the acceptance of the people who considered that solar panel does not fit with the surrounding. Indeed the visual impact concerns as much the individual alternative with panel on the roof or in the plot as the collective one.
Nevertheless, ground source heating and heat pump does not have any rejection from people to implement them, although the government does not provide any grant.

ENVIRONMENTAL ASPECTS

The disadvantage of a ground source heating with boreholes, water tank or any other storage system is the modification of the soil proprieties and a pollution of the underground water. Indeed, by remove the ground and creating a pipe scheme, animal species can be affected. Moreover the worst is in case of storage (boreholes, water tank…).
Depending on the soil and the aquifer, the ground will keep more or less the collected heat; an increasing of temperature in the soil can have different repercussions on flora and fauna. The composition of the soil and the aquifer are unknown, so the temperature lost between summer and winter cannot be determined. So to be aware of the real consequences of such installation, a survey, drillers and tests in laboratory of Føns soil has to be done to have an idea of the environmental impact of such increase of temperature. Moreover the design of the loops is important in order to avoid leaking in case of earth movement: a total knowledge of the field has to be planned.

Concerning the solar panels which only collect heat in water pipe, the environmental impact of that system is negligible; except the fact of creating a pipe system to link them with the borehole in the ground and the material needed for the production (plastics). The particular point can be the land, especially concerning the collective solution.

Concerning the environmental impact of a heat pump, the heat waste in the heat sink has to be mentioned because it affects organisms and plants around the device by thermal contamination. Moreover this impact increases with the size of the heat pump; therefore this parameter has to be taken into account for the collective measure. Besides, the main pollutant of heat pump device is the refrigerant which circulates inside the heat pump. Indeed, the common one HCFC-22 (R-22) is very harmful for the ozone layer. To avoid that impact, it is advised to use one of its substitutes, even if the efficiency is a bit lower. Finally, Føns area in Denmark is known for negative temperature, the implementation of a heat pump will require antifreeze during the heating operation to work in optimal conditions. Nevertheless it has to be mentioned that most of these products are toxic, corrosive and flammable, reason for what the priority is given to ethanol and propylene-though that one is a bit less efficient- because of their low environmental impact.

Nevertheless, this renewable alternative is one with less impact on environment especially with a few amount of CO_2 emission. Indeed, the heat pump requires only less than one third of the energy that it provides and the CO_2 emissions is calculated as follows:

Energy (kWh) x Carbon Factor ($kgCO_2/kWh$) = CO2 Emissions ($kgCO_2$)

With the CO_2 Emissions per kWh Electricity Sold in Denmark kWh: 0.478 kg/kWh. (Danish Energy Agency, 2010) and the electrical consumption of the heat pump per alternative, the CO_2 emission with each system is calculated as it is shown in the table below.

SCENARIOS	ELECTRICAL CONSUMPTION (KWh/year)	CO2 EMISSIONS (ton/year)		CO2 REDUCTION
		Old system	New system	
IH. TANK STORAG	6.910	523	234,51	55%
IH. B.STORAGE	6.910	523	234,51	55%
IH. B.NO STORAGE	8.375	523	284,23	46%
DH. B.STORAGE	6.142	523	208,45	60%

Figure 4.2.2_1: CO_2 Emissions in Føns

ECONOMIC ANALYSIS

First of all each alternative should be evaluated in terms of cost of the system. After that it is gathered all the cost evaluation considering a payback period of each one of the different system considered.

SOLUTION ANALYSIS

Alternative 1: Individual solar assisted ground source heat pump with water tank seasonal storage

- Initial Investment – 198.278 DKK

DESCRIPTION	COST (DKK)
Heat pump and installations	74.604 DKK
Solar collectors	20.720 DKK
Water tank	35.810 DKK
Earth movements	67.144 DKK
TOTAL	**198.278 DKK**

Figure 4.2.2_2: Installation cost (alternative 1)

- Annual consumption – 6.910 KWh/year
- Annual maintenance cost – 1.120 DKK
- Annual energy cost – 15.202 DKK
    - Yearly energy inflation - +3,00%

Alternative 2: Individual solar assisted ground source heat pump with borehole seasonal storage

- Initial Investment – 267.864 DKK

DESCRIPTION	COST (DKK)
Heat pump and installations	67.144 DKK
Solar collectors	20.720 DKK
Boreholes	180.000 DKK
TOTAL	**267.864 DKK**

Figure 4.2.2_3: Installation cost (alternative 2)

- Annual consumption – 6.910 KWh/year
- Annual maintenance cost – 1.120 DKK
- Annual energy cost – 15.202 DKK
    - Yearly energy inflation - +3,00%

Alternative 3: Individual ground source heat pump with borehole

- Initial Investment – 224.762 DKK

DESCRIPTION	COST (DKK)
Heat pump and installations	44.762 DKK
Boreholes	180.000 DKK
TOTAL	**224.762 DKK**

Figure 4.2.2_4: Installation cost (alternative 3)

- Annual consumption – 8.375 KWh/year
- Annual maintenance cost – 1.120 DKK
- Annual energy cost – 18.426 DKK
  - Yearly energy inflation - +3,00 %

Alternative 4: Collective solar assisted ground source heat pump with inclined boreholes seasonal storage

DESCRIPTION	COST (DKK)
Heat pump	23.116 DKK
Tank and installations	3.152 DKK
Pumper and water treatment	1.050 DKK
Oil boiler and tank	5.253 DKK
Electrical installation	1.050 DKK
Solar collectors	20.070 DKK
Boreholes	152.112 DKK
Pipes	39.402 DKK
Building	3.152 DKK
TOTAL	**248.362 DKK**

Figure 4.2.2_5: Installation cost (alternative 4)

- Annual consumption – 6.142KWh/year
- Annual maintenance cost – 1.120 DKK
  - Annual maintenance cost installation – 395 DKK
  - Annual maintenance cost district heating – 725 DKK
- Initial Investment – 248.362 DKK
  - Initial Investment system but distribution – 245.210 DKK
  - Initial Investment district heating – 39.403 DKK
- Annual energy cost – 13.512 DKK
  - Yearly energy inflation - +3,00

CONCLUSIONS

INDICATORS

SCENARIOS	INITIAL INVESTMENT (DKK)	LOAN PERIOD (YEARS)	BREAK-EVEN POINT (YEAR n)	PROFIT 10Yr (DKK)	PROFIT 20Yr (DKK)
IH.TANK STORAG	198.278	10	14	-71.012	+135.435
IH. B.STORAGE	267.864	14	19	-92.214	+ 41.319
IH. B.NO STORAG	224.763	11	20	-123.200	+15.201
DH. B.STORAGE	248.362	13	16	-66.603	112.248

Figure 4.2.2_6: Cash-flow indicators of the four alternatives evaluated

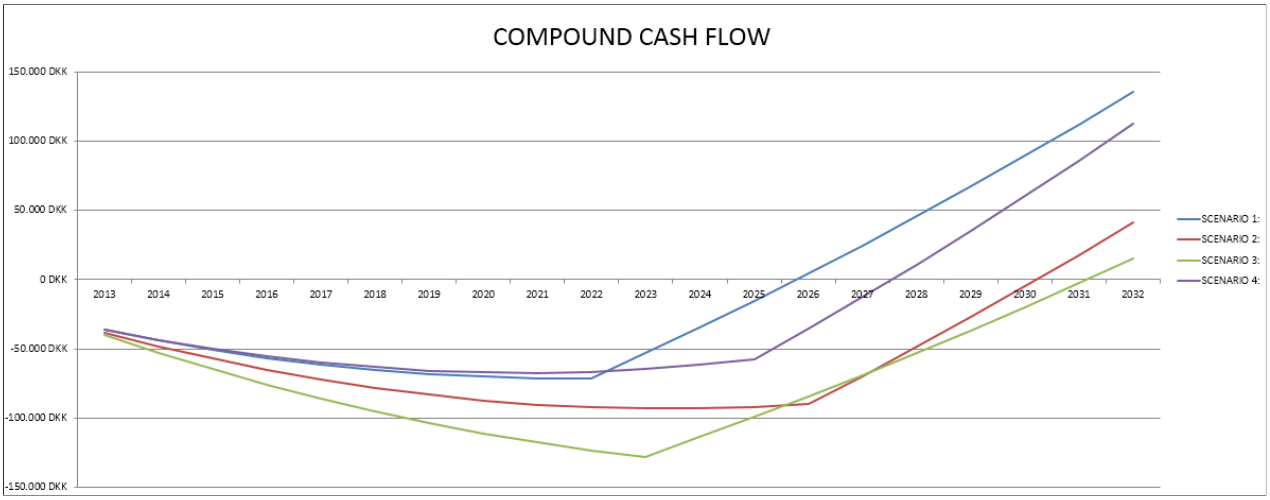


Figure 4.2.2_7: Compound Cash-flow

The tables of the cash flow can be seen in the Appendix 7.12.

INDIVIDUAL SYSTEMS

Three individual variations of the system have been proposed. As it can be seen in the economic study the variation of the values are up to 25% between extreme values.
The Break- even point is quite high in all alternatives (14 years the lower case) due to the high initial costs caused. These big initial costs are caused by the complexity of the system: storage energy from summer to winter in an effective way, and achieve good efficiencies in so hard climate require big investments. Besides, despite the fact that the energy consumption is reduced drastically (75% of reduction in average), heat pumps consumes electricity, with is rather expensive compared with other types of energy sources.

The SAGSHP with seasonal water tank storage seems to be the best solution. The lower investment and quite good performance let the system be the one with lower break-even point (14 years). Besides, to store heat in a water tank is more certain and reliable than doing it in boreholes.

The high requirements of a reliable SAGSHP with seasonal boreholes storage trigger high initial investment. The clay layer in the ground provides better efficiencies in the storage, but requires more investment as well. These considerations, combined with the similar performance of the system make this system less suitable than the water tank system (16 years to recover the investment).

As for the system with no storage (and therefore without solar collectors), we have the same problem than in the previous system: The cost of the boreholes increase a lot the investment, and in this case the COP is the worst because we do not get benefit of the heat storage capacity of the ground. In this case, and due to the cost of the boreholes, the most simple and common system have the worst performance in the system studied. Innovation therefore is in this case a good opportunity to improve the system.

As a conclusion, it can be said that, on one hand, these types of systems have a really good performance, reduce drastically energy consumption and CO_2 emissions, and the cost of purchase energy is quite low. On the other hand, they require big investments that are not recovered until 14 years at least. Besides, the cost of purchase energy is lower than oil boilers or electricity heaters, but not than solid fuels boilers whose energy purchase is much cheaper.

COLECTIVE HEATING SOLUTIONS

It has been studied a district heating system as well. In this case, the district heating system has quite similar performance than the individual ones. The investment is quite similar, because despite the fact that the cost of the boreholes is lower, the district installation and other elements are more expensive. The operational costs are the lower but not very different from the others.
The conclusion of this system is, therefore, the same than the individual conclusions: Good performance, huge energy saving and CO_2 emissions reduction, but quite big investment and not enough decrease in the operational costs to make it attractive (16 years to recover the investment).

4.3. ELECTRICITY ALTERNATIVES FEASIBILITY STUDY

4.3.1. ALTERNATIVE 1: PHOTOVOLTAIC SOLAR CELLS

INTRODUCTION

Aim, context and consideration

As already mentioned, this part aims to study some possibilities of renewable energy to supply electricity to Føns area, in Denmark. In the next paragraphs, the installation of photovoltaic solar cells will be studied as a possible solution to the electricity needs of this Danish community of 70 houses.

The completion of this feasibility study will permit to determine the most adapted and suitable solution, according to the Report, *"Systems for sustainable energy supply for small villages"*. As mentioned in this report, Photovoltaic solar cells are one of the most trusted, efficient and renewable installations to produce electricity. Apart from that, the main problem is linked to the costs of these systems, which stay quite expensive nowadays.

Nevertheless, the Danish context seems to be favourable to this kind of systems and the environmental policy could bring some answers to the economic barrier mentioned. Indeed, since 2010, a regulation called "net metering" intends to develop the PV market in Denmark through interesting prices to sell extra-electricity produced. Recently modified, this law has significantly participated in the expansion of PV systems and still proposes attractive economic benefits. Based on those statements, this part aims to determine which one, between common and individual installations, is the most suitable for this legal context, taking into account different parameters as explained below.

Steps of the analysis

The following analysis will be organized following a structure divided into Technical, Environmental, Social and Economical considerations.

Regarding Technical conditions, a brief extract from *"Systems for sustainable energy supply for small villages"* will be shown in order to take into account technical aspects of both solutions. Indeed, those aspects would directly influence the management and procurement phases during the possible implementation of the project.

In the Environmental field, the focus of the analysis will be settled in the environmental impact of the options mentioned before. In the case of common systems, land occupation and the possible restrictions applied for protected areas will be main concerns.

The next step will be based on Social considerations, where the current situation of the Danish regulation regarding solar energy and its influence on the willingness of the population to install solar systems will be explained and examined.

Finally, the gross part of the report will consist in an economic analysis in order to determine the feasibility of the options suggested. In this section, the initial investment, possibility of grants, payback period, legal conditions and further factors will outline the conclusions (together with the previous concerns) of this study.

All the conclusions will be summarized in a comparison table in order to be able to notice by a glance the differences, advantages and disadvantages of the possibilities formulated.

Technical considerations

In our study, as mentioned before, we will consider two options regarding the possibilities for photovoltaic systems, individual installation and common installation. The economic benefits regarding the new regulation in Denmark have already been analysed, so the following lines will focus on the technical aspects to be considered, which will be obviously connected to the final profitability of the installation.

Individual installation

There are two aspects that will really determine the final convenience of carrying out an individual photovoltaic installation, space and orientation.

Roofs

This kind of installation is normally placed in the roofs, where there is normally plenty of space (in detached houses) and do not suppose an inconvenient for "land occupation" in backyards. Anyway, there are several points that must be taken into account, such as type of roof (sloped roof or horizontal roof), level of protection of the house, orientation of the slopes (if there are) and shadow level.

In our case, the configuration of this community makes it almost impossible to generalise with a single calculation.

Although this, general assumptions can be made in order to obtain a map with areas in which solar photovoltaic systems could result interesting. These maps can be checked in Appendix 7.13 *Individual Solutions maps.*

Backyard

The other possibility is the installation of the photovoltaic panels in the backyards of the houses. Once again, some limitations will have to be considered, such as space availability, orientation (not that much) and as main limitation, the possible shadows that will be applied to the PV by the house itself, vegetation, etc.

In this part, it is important to mention the legal hitches that involve the protected areas in which are included many houses, because of the proximity of the community to the sea. This situation will need to be studied case by case.

As before, the heterogeneity of the urban distribution will reduce the individual proposal to an average one, regarding assumptions (orientation, availability of land, etc) that will suppose the first step before a deeply individualized analysis.

The general considerations concerning the solar requirements together with the shadows calculation can be found in the Appendix 7.10.1 and 7.10.3.

Common installation

Regarding the common installations, the first and most complex aspect will be finding a proper area to settle the system. This area will have to be wide enough to hold the photovoltaic surface needed (with special attention to the shadow interaction), and also to be close to a connection point to the grid.

In this case, in legal aspects, we find the same situation as before; being so close to the sea will make it difficult to find a common area that will satisfy all the requirements: economically (need to buy, rent, etc.), legally-environmentally (protected area) and technically (shadows, distance to connection point)

The general considerations concerning the solar requirements together with the shadows calculation can be found in the Appendix 7.10.2 and 7.10.3.

Size of the system

An electricity consumption of 4500 kWh per year and house will be the bases to be considered. In order to dimension the size of the installation, software from the website of the National Renewable Energy Laboratory of the United States of America, has been used.

With this tool, several factors have been considered in the different cases to study: locations, power of the installation, derate factor, inclination of the panels and azimuth orientation.

For the first variable, location, the website tool has as the only option in Denmark the data coming from Copenhagen; in our case, the data is similar enough, regarding solar exposition and weather conditions, in order to take it as valid for the estimation.

The other variables will be analysed in the two possible scenarios, individual and common installations, as follows.

Individual estimation:

The power of the installation will depend on the amount of demand that is going to be covered. In this line, according to the preliminary consideration of 4500 kWh/year and house, an installation of 5 kW will produce electricity in an amount close to that value.

An installation of 6,5 kW has also been considered, and will be economically analysed and compared with the 5 kW solution afterwards.

Regarding inclination, this factor will depend on the disposition of the roof (inclination and orientation), availability of space inside the plot, and shadow interaction. As mentioned before, the many different possibilities inside this matter will be faced by generalising in three main cases: 35°, 45° and 60°, accounting for ground disposition (or flat roof), roof of 45° slope and roof of 60° slope; all of them facing south.

The different results can be checked in Appendix 7.10.5 and 7.10.7.

Common estimation:

For this estimation, two options have been considered; and installation of 5 kW of power per house, which means 5 kW x 70 houses ≈ 350 kW, and the same consideration but using 6,5 kW per house, which means approximately 450 kW.

Regarding the inclination, only two options have been considered, as the 60° option has just been considered in order to take into account those houses where there is space only in the roof and it has slopes with this level of inclination (it must be clarified that higher angles will result in higher production in winter, whereas lower angles will result in higher production during summer).

Conclusions and comments about electricity production will be done in the "economic considerations" point.

Solar photovoltaic cells considered

For the analysis of the different options, model "Alex-Solar" 250w monocrystaline from Aktivesol has been used; technical specifications can be checked in Appendix 7.10.4 .

Remaining devices (inverter, wiring, connection, etc.) composing the solar system can be found in the same document. (http://www.aktivsol.dk/)

Environmental considerations

At this point, it must be said that solar photovoltaic systems do not have a direct environmental impact, due to the fact that they do not produce CO_2 emissions in the electricity production.

Apart from that, the only consideration could deal with the possible effects that a large installation could cause to the wildlife of the area. Anyhow, in this case, an installation of approximately 350 kW could suppose a land occupation of 2000 m^2. Analysing the urban distribution of the area, this surface is more or less the average area of a plot in this village.

As final concern, in a deeper study, a Life Cycle Analysis (LCA) of the materials that compose the system should be done in order to have a global idea of the environmental impact of this technology from a global point of view.

Social considerations

The change of law and its importance

In November 2012, the Danish policy concerning energies and renewable development has been modified. Indeed, seven of the eight Danish political parties agreed for a law change to improve the attractiveness of solar panel investment. The intention of the government is "to ensure uniform economic conditions affecting plant that can settle net and common facilities, which can only settle net joint consumption" (Law amending No. L86). To understand this common decision, it's important to remind here that the Danish government expects to reduce greenhouse gas emissions to approximately 0.2 million ton equivalent to 500MW by 2020, in particular with the further development of solar cells.

To enter more into details, this change in the law concerns the prices of electricity to be sold and to be bought. To summarize, the previous system concerning electricity exchanges with the grid was based on an annualized net metering. Basically, at the end of the year, the difference between energy produced and energy consumed was calculated to determine what should be paid. This system used to permit to buy power without fees when the installation was temporally producing less than the energy needed. With this regulation, the settlement price was DKK 0.60 /kWh. (Seenews, Nov 7, 2012)

The new regulation changed from annual calculation to a daily one. Since the 19th November, the consumption and the production of electricity is monitored hour by hour and the difference between energy needed and energy produced is sold or bought with different prices. Indeed, all the PV solar cell systems installed in 2013 will be able to sell exceeded electricity for DKK 1.30 /kWh private installations during 10 years. This high price will decrease constantly each year (DKK 1.16/kWh in 2014) to go back to the previous price DKK 0.6/kWh in 5 years (2018).

This new metering system aims to be more profitable for large solar installation which will be allowed to sell electricity for a higher price of DKK 1.45/kWh for the systems installed in 2013 for 10 years. Such as the individual installations, this price will be decreasing each year (DKK 1.28 in 2014 for 10 years). This difference in the selling prices aims to "create opportunities for businesses such as garden centers and farms". (Danish Ministry of Climate, Energy and Building, Nov 15, 2012). This official article also underline also that "It will also become easier and more attractive for housing associations to install solar panels".

Economical considerations

The impact of the Danish law

According to the actual law (presenting in the social consideration paragraph), the economical analysis of PV solar cells systems must be based on a model which takes into account the variation of production along the days of the years. To be completely precise the analysis should take into account the evolution of production and consumption among the different hours of the day in order to evaluate precisely the amount of energy to be sold and to be bought hour by hour. Indeed, taking into account that the new law fixes different prices to buy or sell electricity and that the balance is made hourly, the economic features are going to vary a lot among the year.

Hypothesis taken

In order to evaluate these economic aspects, all the calculations explained in this report are based in a monthly comparison of production and consumption.
The annual consumption of a Foens typical house has been evaluated to 4500kWh per year. From this value, it was necessary to get curves and tables representing the evolution during the years.

This calculation has been made using a real Danish electricity bill of a house consuming 3308kWh per year. The table below shows the amount of electricity consumed each month (1st column). The percentage of the total consumption each month (2nd column) calculated from the values of the first column permitted us to simulate the evolution of the consumption per month of our Foens house (3rd column).

	Average (kWh)	%	Simulation (kWh)
June	181,445	5,48	246,80
July	179,19	5,42	243,74
August	181,24	5,48	246,53
September	168,745	5,10	229,53
October	240,905	7,28	327,68
November	244,09	7,38	332,01
December	421,605	12,74	573,47
January	421,145	12,73	572,85
February	501,545	15,16	682,21
March	375,32	11,34	510,52
April	232,37	7,02	316,07
May	160,705	4,86	218,59
TOTAL	**3308,305**	**100**	**4500**

Figure 4.3.1_1: Simulation of electricity consumption per month

The following curves show more visually the evolution along the year:

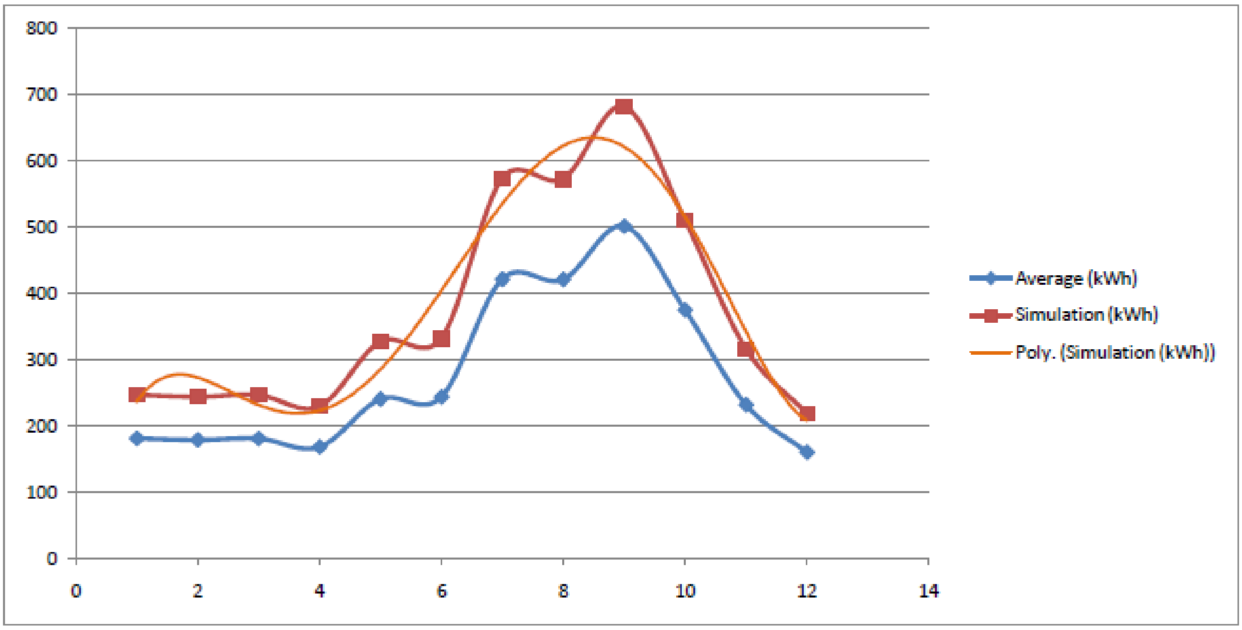


Figure 4.3.1_2: Curve of the evolution of consumption along the year
(Months are represented horizontally with the number from 1(June) to 12 (May))

Logically, the consumption is higher during autumn and *winter*. During those months the PV Solar cells production would be lower and electricity will be bought while in summer and sunny time electricity would be sold.

Individual options

Analysis of the different options

Based on the previous assumptions, the work exposed below tries to define the best solution to be implemented from an economical point of view (Note that the repercussion of the price of the land will be only considered in the different scenarios studied in section 5). Indeed, depending of the orientation and the power installed the efficiency during certain period of the year evolves.

In accordance with the production tables presented in the appendix 7.10.5, the following tables show the difference by month between needs and supply of electricity and the cost linked. The final line shows the amount of money to pay or to be paid per year for one house.

Scenario 1: 5kW 35°

	Consumption	Production 5kWh 35°	Diff. (kWh)	Costs (DKK)
January	572,85	91	-481,85	- 1 060
February	682,21	180	-502,21	- 1 105
March	510,52	360	-150,52	- 331
April	316,07	474	157,93	205
May	218,59	630	411,41	535
June	246,80	645	398,20	518
July	243,74	626	382,26	497
August	246,53	554	307,47	400
September	229,53	347	117,47	153
October	327,68	237	-90,68	- 200
November	332,01	92	-240,01	- 528
December	573,47	72	-501,47	- 1 103
TOTAL	4500,00	4308,00		- 2 020

Scenario 2: 5kW 45°

	Consumption	Production 5kWh 45°	Diff. (kWh)	Costs (DKK)
January	572,85	103	-469,85	- 1 034
February	682,21	192	-490,21	- 1 078
March	510,52	367	-143,52	- 316
April	316,07	468	151,93	198
May	218,59	608	389,41	506
June	246,80	616	369,20	480
July	243,74	599	355,26	462
August	246,53	541	294,47	383
September	229,53	347	117,47	153
October	327,68	246	-81,68	- 180
November	332,01	100	-232,01	- 510
December	573,47	82	-491,47	- 1 081
TOTAL	4500,00	4269,00		- 2 018

Scenario 3:5kW 60°

	Consumption	Production 5kWh 60°	Diff. (kWh)	Costs (DKK)
January	572,85	114	-458,85	- 1 009
February	682,21	200	-482,21	- 1 061
March	510,52	361	-149,52	- 329
April	316,07	438	121,93	159
May	218,59	546	327,41	426
June	246,80	544	297,20	386
July	243,74	534	290,26	377
August	246,53	500	253,47	330
September	229,53	332	102,47	133
October	327,68	249	-78,68	- 173
November	332,01	106	-226,01	- 497
December	573,47	92	-481,47	- 1 059
TOTAL	4500,00	4016,00		- 2 318

Scenario 4: 6.5kW 35°

	Consumption	Production 6,5kWh 35°	Diff. (kWh)	Costs (DKK)
January	572,85	119	-453,85	- 998
February	682,21	233	-449,21	- 988
March	510,52	468	-42,52	- 94
April	316,07	617	300,93	391
May	218,59	819	600,41	781
June	246,80	839	592,20	770
July	243,74	814	570,26	741
August	246,53	720	473,47	616
September	229,53	451	221,47	288
October	327,68	308	-19,68	- 43
November	332,01	119	-213,01	- 469
December	573,47	94	-479,47	- 1 055
TOTAL	4500,00	5601,00		- 61

Scenario 5: 6.5kW 45°

	Consumption	Production 6,5kWh 45°	Diff. (kWh)	Costs (DKK)
January	572,85	134	-438,85	- 965
February	682,21	250	-432,21	- 951
March	510,52	478	-32,52	- 72
April	316,07	608	291,93	380
May	218,59	791	572,41	744
June	246,80	800	553,20	719
July	243,74	779	535,26	696
August	246,53	704	457,47	595
September	229,53	451	221,47	288
October	327,68	320	-7,68	- 17
November	332,01	130	-202,01	- 444
December	573,47	107	-466,47	- 1 026
TOTAL	4500,00	5552,00		- 54

Scenario 6: 6.5kW 60°

	Consumption	Production 6,5kWh 60°	Diff. (kWh)	Costs (DKK)
January	572,85	148	-424,85	- 935
February	682,21	261	-421,21	- 927
March	510,52	469	-41,52	- 91
April	316,07	569	252,93	329
May	218,59	710	491,41	639
June	246,80	707	460,20	598
July	243,74	694	450,26	585
August	246,53	650	403,47	525
September	229,53	431	201,47	262
October	327,68	323	-4,68	- 10
November	332,01	138	-194,01	- 427
December	573,47	120	-453,47	- 998
TOTAL	4500,00	5220,00		- 450

With those tables it's obvious that with a bigger installation the amount of electricity produced (and so the money earned) is higher. It's also interesting here to remark that the inclination as a small influence on the final results excepting that a high angle provides a more "constant" amount of electricity.
Finally it's really important to notice here than even if the installation is providing more electricity after one year (720 kWh more) you will have a negative economic balance due to the Danish regulation and its selling and buying prices (1.3DKK to sell and 2.2DKK to buy).

Feasibility study for individual installation

Evolution of the production cost through the years

From the previous assumptions, the feasibility study which will be lead concerns the scenario one representing an installation of 5kWh with an inclination of 35°.
The economic analysis and the cash-flow will be lead over a 20years period. To realize this analysis, it was necessary to evaluate precisely the evolution of the cost and the change of regulations over the years.

The table presented in appendix 7.10.6 represents the evolution of the money earned and invest each month during 20 years to fulfill the electricity needs of the house. This table takes into consideration several important aspects mentioned below:

- The price of electricity (buying price) increase by 3% each year due to the inflation
- The electricity is bought to the price mentioned in the previous point
- The electricity is sold at 1.3DKK during the first 10years and 0.6DKK after
- The system lose some efficiency after 10 year and only 80% of the initial electricity will be produce

It is finally the last lines which are the most important for us in order to realize the cash flow. This total (in DKK and €) represents the amount of money to pay each year for electricity. This cost starts around 2 000DKK for the first year and reach 7 700DKK after 20years due to the parameters explained in the previous points.

Payback period

In order to define the payback period, the cash flow will be realized using the total (annual) value of the previous table. This Cash flow table (Figure 4.3.1_4) presented in the appendix 7.12., takes into account the following aspects:

- 45 000DKK are directly provided and not lend from the bank
- The loan as a fixed interest rate of 3%
- The annual cost to return the money loaned is considered around 12 500DKK
- The money loaned will be returned after 3 years
- The maintenance costs will raise through the life cycle of the panel (starting at 375DKK per year during the first five years and increasing after as presented in the table)
- The initial investment needed for this installation is 82 350DKK (As presented in the following table 4.3.1_3)

DESCRIPTION	COST (DKK)
20 Panelsmodel "Alex-Solar" 250W Monocristaline	45.001 DKK
1 Inverter model Danfos TLX 6000	7.077 DKK
Installation and connection (10%)	5.207 DKK
Total installation cost	57.286 DKK
GC+IB (9%+6%)	8.593 DKK
Total cost	65.880 DKK
VAT (25%)	16.470 DKK
TOTAL	**82.350 DKK**

Figure 4.3.1_3: Initial investment for an individual installation of 5kW

Comparing now this cash flow with the annual cost of the previous installation we are able to determine the payback period and the amount of money saved after 20 years.
We finally estimated here a 10years payback period and a final saving of 9 706€ after 20years.

Collective options

Analysis of the different options

Based on the same method than the one used for individual installations, the work exposed below aims to define the best option regarding to the economical aspects. Once again considering the orientation and the power installed, this part will try to evaluate the efficiency of the systems along the years.

In accordance with the production tables presented in the Appendix 7.10.7, the following tables show the difference by month between needs and supply of electricity for the all village. The final line shows the amount of money to pay or to be paid per year by the whole community.

It is important here to remind that the community of Foens studied here is composed by 71 houses. Nevertheless only 70 houses will be taken in consideration because one already has its own electricity supply system.

Taking this into consideration the total amount of electricity to be provided is:
70*4 500kWh = **315 000kWh/year**
The monthly consumption has been calculated following the model explained in the previous paragraph as already mentioned.

Scenario 1: 350kW 35°

	Consumption	Production 350kW 35°	Diff. (kWh)	Costs (DKK)
January	40099,29	6404	-33695	- 74 130
February	47754,57	12572	-35183	- 77 402
March	35736,06	25220	-10516	- 23 135
April	22125,09	33205	11080	16 066
May	15301,51	44123	28821	41 791
June	17276,27	45155	27879	40 424
July	17061,56	43820	26758	38 800
August	17256,75	38767	21510	31 190
September	16067,04	24294	8227	11 929
October	22937,75	16559	-6379	- 14 033
November	23241,01	6423	-16818	- 37 000
December	40143,09	5069	-35074	- 77 163
TOTAL	**315000,00**	**301611,00**		**- 122 663 DKK**

Scenario 2: 350kW 45°

	Consumption	Production 350kW 45°	Diff. (kWh)	Costs (DKK)
January	40099,29	7205	-32894	- 72 367
February	47754,57	13444	-34311	- 75 483
March	35736,06	25714	-10022	- 22 049
April	22125,09	32758	10633	15 418
May	15301,51	42576	27274	39 548
June	17276,27	43086	25810	37 424
July	17061,56	41931	24869	36 061
August	17256,75	37900	20643	29 933
September	16067,04	24298	8231	11 935
October	22937,75	17231	-5707	- 12 555
November	23241,01	6984	-16257	- 35 765
December	40143,09	5768	-34375	- 75 625
TOTAL	**315000,00**	**298895,00**		**-123 527 DKK**

Scenario 3: 450kW 35°

	Consumption	Production 450kW 35°	Diff. (kWh)	Costs (DKK)
January	40099,29	8234	-31865	- 70 104
February	47754,57	16164	-31591	- 69 499
March	35736,06	32426	-3310	- 7 282
April	22125,09	42692	20567	29 822
May	15301,51	56729	41427	60 070
June	17276,27	58057	40781	59 132
July	17061,56	56340	39278	56 954
August	17256,75	49844	32587	47 252
September	16067,04	31236	15169	21 995
October	22937,75	21291	-1647	- 3 623
November	23241,01	8258	-14983	- 32 963
December	40143,09	6518	-33625	- 73 975
TOTAL	**315000,00**	**387789,00**		**17 778 DKK**

These tables confirm the conclusions exposed for individual installations. With bigger installations the amount of electricity produced (and so the money earned) is higher while the inclination as a small influence on the final results excepting that a high angle provides a more "constant" amount of electricity.

Here by over-estimating the installation we reach a positive economical balance. And a 450kW system seems (at this stage to be more profitable). To take into consideration the initial investment, it's important to realize a cash flow for both installations in order to get an idea of which one is the best. This point is the aim of the following paragraph.

Collective Feasibility study

Evolution of the production cost through the years

The economic analysis and the cash-flow will be lead over a 20years period for both 350kW and 450kW installations. To realize this analysis, it was necessary to evaluate precisely the evolution of the cost and the change of regulations over the years.

The tables presented in Appendixes 7.10.8 and 7.10.9 represents the evolution of the money earned and invested each month during 20 years to fulfill the electricity needs of the all community. This table takes into consideration several important aspects mentioned below:

- The price of electricity (buying price) increase by 3% each year due to the inflation
- The electricity is bought to the price mentioned in the previous point
- The electricity is sold at 1.45DKK during the first 10years and 0.6DKK after
- The system lose some efficiency after 10 year and only 80% of the initial electricity will be produce

It's finally the last lines which are the most important for us in order to realize the cash flow. Those totals (in DKK and €) represent the amount of money to pay each year for electricity (first by the all community and then by houses).

For the 350kW installation those cost per year start around 1 750DKK for the first year and reach 7 800DKK after 20years due to the parameters explained in the previous points.

For the 450kW installation, the first years show a positive economic balance and permit to earn money. During the year of the installation 792 DKK will be earned while after 20years, around 6 350DKK would be paid.

Payback period

In order to define the payback period, the cash flow will be realized using the total (annual) value of the previous table. These Cash flow tables (Figure 4.3.1_7 and 4.3.1_8) presented in the appendix 7.12., takes into account the following aspects:

- 45 000DKK are directly provided and not lend from the bank
- The loan as a fixed interest rate of 3%
- The annual cost to return the money loaned is considered around 17 000DKK (for the 350kW installation) and 31 000DKK (for the 450kW installation).
- The money loaned will be returned after 2 years for both installations.

- The maintenance costs will raise through the life cycle of the panel (starting at 375DKK per year during the first five years and increasing after as presented in the table)
- The initial investments needed for this installation are presented in the following tables (4.3.1_5 and 4.3.1_6)

DESCRIPTION	COST (DKK)
1400 Panels model "Alex-Solar" 250 Monocristaline	2.322.096 DKK
1 Inverter	195.430 DKK
1 Transform station	182.525 DKK
Installation and connection	270.000 DKK
Total installation cost	2.970.056 DKK
GC+IB (9%+6%)	445.508 DKK
Total cost	3.415.565 DKK
VAT (25%)	853.891 DKK
TOTAL	**4.269.456 DKK**

Figure 4.3.1_4: Initial investment for a common installation of 350kW

DESCRIPTION	COST (DKK)
1800 Panels model "Alex-Solar" 250 Monocristaline	2.985.553 DKK
1 Inverter	195.430 DKK
1 Transform station	182.525 DKK
Installation and connection	336.350 DKK
Total installation cost	3.699.859 DKK
GC+IB (9%+6%)	554.978 DKK
Total cost	4.254.838 DKK
VAT (25%)	1.063.709 DKK
TOTAL	**5.318.548DKK**

Figure 4.3.1_5:Initial investment for a common installation of 450kW

Comparing now this cash flow with the annual cost of the previous installation we are able to determine the payback period and the amount of money saved after 20 years.
We finally estimated here a 7/8 years payback period and a final saving of 13 000€ (350kW installation) and 16 600€ (450kW installation) after 20years.

GENERAL CONCLUSIONS

The following table presents some indicators which will permit to analyse and make decision regarding all the economic calculations lead below. More information and precise analyses can be found in the individual and collective scenarios presented in the following paragraphs.

INDICATOR	Individual 5kW	Collective 350kW	Collective 450kW
Initial investment	82.350 DKK	62.251 DKK	75.919 DKK
Loan period	3 years	2 years	2 years
Break-even point	11 years	8 years	8 years
Profit 10 years	none	21.242 DKK	35.812 DKK
Profit 20 years	72.313 DKK	96.832 DKK	123.892 DKK
Profitability 10 years	-4 %	34 %	47 %
Profitability 20 years	88 %	156 %	163 %

Figure 4.3.1_6: Key indicators of individual and collective solutions

4.3.2. ALTERNATIVE 2: WIND POWER

ALTERNATIVE 2.1 - CONVENTIONAL WIND TURBINES

This alternative considers the execution of a unique wind turbine connected to the grid and located on Føns surroundings in order to supply the needs of energy for the village.

The selection of the turbine is carried out in this feasibility study in order to provide the energy requirements in terms of electricity. The document will try to cover as much as possible in terms of environmental impact and social aspect. This study will take into account not only the animals and vegetables species but also the damage the turbine can cause to humans.

As the alternative will provide more energy than the necessary for supplying Føns, the average cost of this alternative can be higher than the cost of the other systems. This is way while assessing this solution the amount of energy produced must be taken into account. Moreover the subsidies of the Danish government will be studied on the document as them will reduce the final cost of the project.

The feasibility study for a wind turbine solution is detailed below.

TECHNICAL ASPECT

First of all, the study was focus on the existing wind turbines in Middelfart. All the information gathered in the Appendix 7.9 reflects generally old wind turbines with a low or medium capacity. Some of these types of turbines are already decommissioned what supposed the selection of a modern high capacity wind turbine.

Finally, the wind turbine SWT-2.3-93 from Siemens Wind Turbine is the one selected for developing the project.

This selection has been done taken into account the four wind turbines SWT-2.3-93 settle in Keterminde, more exactly in Mundeko. After compiling all the necessary information of those turbines, which can be found in the Appendix 7.9., this project proposal has selected the same prototype of turbine.

Master data register for wind turbines at the end of December 2012 has provided the necessary information for knowing that the annual output of Mundeko's turbines is approximately 6.500.000 to 7.000.000 kWh what means a vast output in accordance to the energy needed to supply Føns (Danish Energy Agency, 2013). The figure is more than the average output of a new large onshore wind turbine sited where there are good wind conditions, that it is supposed to be around 5.000.000 kWh per year (C. Jensen & Hartvig Jacobsen, 2009). The following map reflect the location of the turbines and the colours the average wind speed in the area. Light blue colour in the zone supposes winds of 7.8 to 8 m/s (SagsGIS)

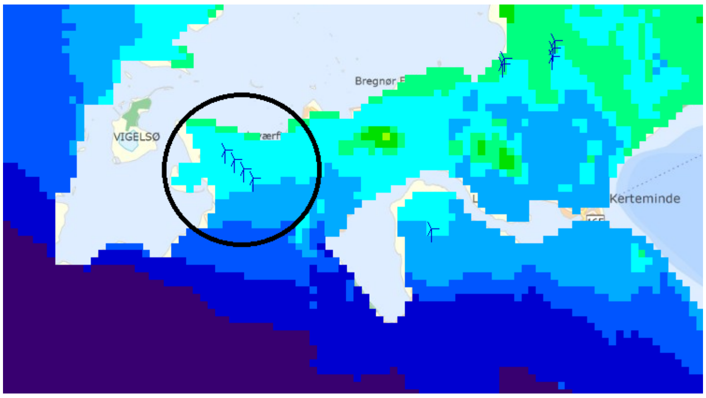


Figure 4.3.2_1: Wind map and location for Kerteminde wind turbines. Source: (SagsGIS, n.d.)

The technical specifications of the turbine needed to develop the different points required for the alternative project are provided (Siemens AG Energy Sector, 2009) (Siemens AG, 2013). For further information see Appendix 7.9.

- Rotor diameter 93 m
- Hub height 63.3 - 80 m → 80 m for this project proposal
- Blades length 45 m
- Annual output at 8 m/s: 9,0 GWh

ENVIRONMENTAL IMPACT

The following information must be studied in order to not to create a vast environmental impact while setting the wind turbine. This information will provide those places that must be discarded for placing the turbine. All the environmental maps studied are collected into the Appendix 7.5.

Figure 4.3.2_2: Environmental Impact map. Source: (SagsGIS, n.d.)

Figure 4.3.2_3: Environmental Impact map Føns area. Source: (SagsGIS, n.d.)

SOCIAL ASPECT

The social section must take into account all the rules and requirements in order to develop the wind turbine project. This supposes a subdivision of the section into different points concerning to regulations, neighbours and subsidies. The following information is developed in detail in the Appendix 7.6. Here it is shown the most relevant data:

- Rules and requirements
  - Distance

Wind turbine SWT-2.3-93 that has a height of 125 m must be placed further than 500 m from houses.

  - Noise

The noise created by a modern wind turbine will vary from 96 to 101 dB. So the wind turbine assuming the worst case will create a noise of 101 dB (Danish Wind Industry Association). As reflect on the Appendix 7.6 the wind turbine cannot create noise above 39 dB in residential areas.

Calculating the noise in accordance to the distance of the wind turbine form a house it is obtained a noise frequency underneath 39 dB for distance between 350 to 500 m far from houses. The following table shows that the wind turbine SWT-2.3-93 if it is set further than 350 m it complies with the noise restriction (Danish Wind Industry Association):

Turbine Source dB(A)	Distance m	Resulting dB(A)
101	500	36,029
101	450	36,944
101	400	37,967
101	350	39,127

Figure 4.3.2_4: Table of noise frequency measured in dB. Source: (Danish Wind Industry Association, n.d.)

- Shadow casting

It is recommended that the neighbours most exposed to the phenomena cannot be displayed more than 10 hours per year.

- Loss of value for neighbours

If after the turbine is set a neighbour lost value on its property by law they can demand for damages.

- Subsidies
  - 25 øre/kWh (0.25 DKK/kWh) for the first 22.000 full-load hours 2.512
  - 2,3 øre/kWh (0.023 DKK/kWh) for the entire lifetime
  - Contribution of 176.000 DKK

LOCATION OF THE TURBINE

Taking into account all the information collected in the environmental and social aspect this section will provide the proper settlement for SWT-2.3-93 wind turbine.
First of all, the following map reflects the best places for setting wind farms in Middelfart provide by Middelfart community discussion paper:

★ Existing wind turbines

Appointed areas for wind turbines

Proposal for potential wind

Figure 4.3.2_5: Proposed zone to establish wind turbines by Middelfart Community. Source: (Middelfart Kommune)

Some of the areas proposed by Middelfart community are closed to Føns. These areas will be of special interest for the scenario development.

Secondly, environmental and social requirements must be fulfilled. The following map will show those placed located further than 500 m from residential areas and the areas that will create a huge environmental impact, in accordance with the different points studied during phase 1:

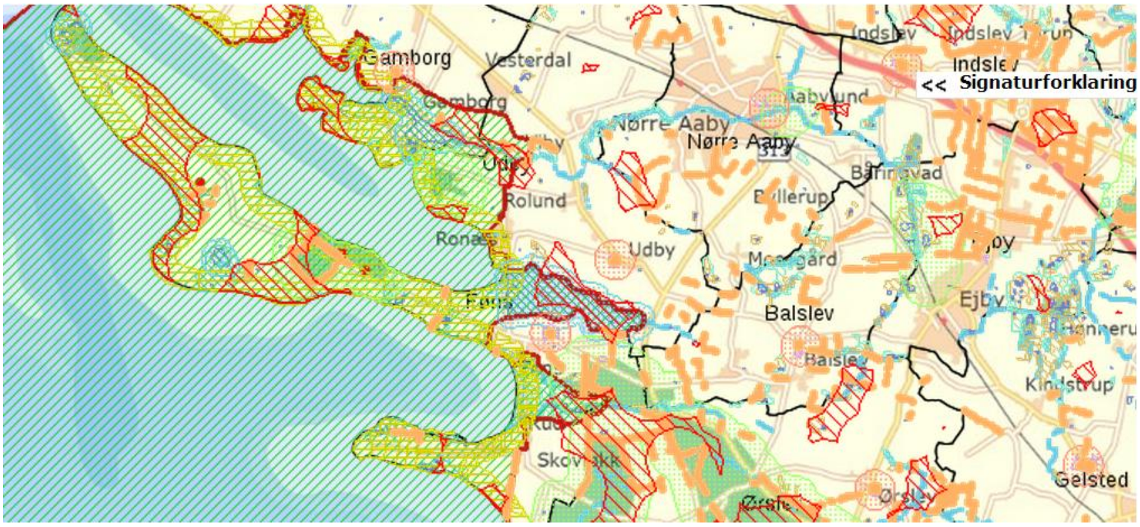


Figure 4.3.2_6: Environmental and social maps merge in one. Source: (SagsGIS)

Then wind speed conditions must ensure the better output for the turbine. The following map reflects the wind average at a height of 100 m and also it merges all the plans already shown to conclude with the final location of the turbine:

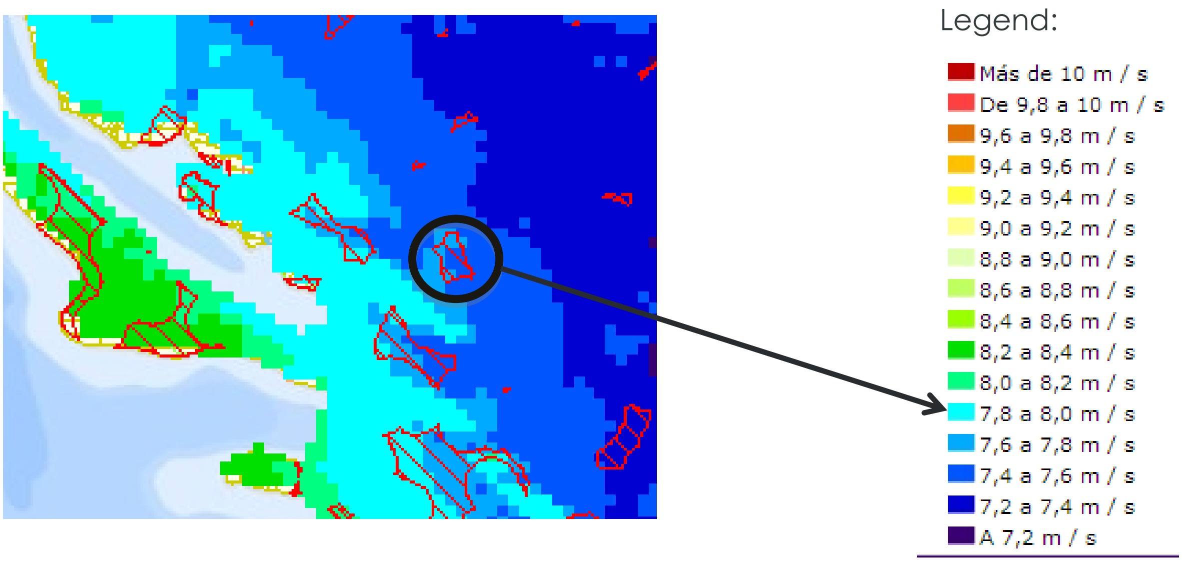


Figure 4.3.2_7: Merge of maps to choose the wind turbine location area. Source: (SagsGIS, n.d.)

WIND TURBINE POSITION

Once the plot to set the wind turbine is found it is necessary to know the correct direction to place it. Thanks to the wind rose we can obtain that information. The following graph shows the wind rose in Bågø Fyr, which is an island, located less than 100 km far from Føns (Cappelen & Jørgensen, 1999).

Analysing the graph it is established that the dominant wind direction is west. The wind turbine must be placed perpendicular to the west, perpendicular to the most favourable direction. Therefore as Figure X reflects the wind turbine faces the wind direction (Molinero Benitez, 2009) (Wind Energy Technology, 2013).

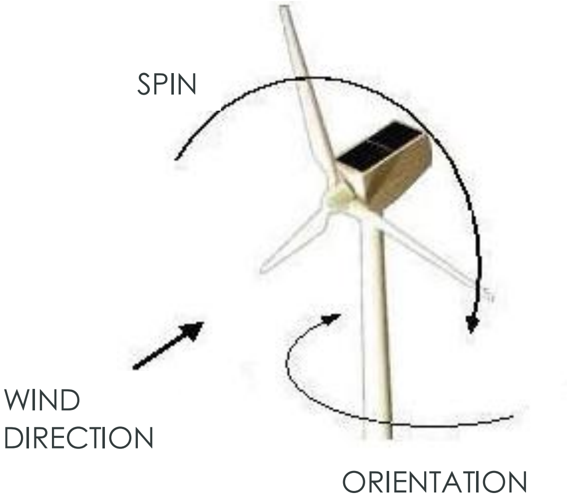


Figure 4.3.2_8: Suitable orientation of the turbine in regard to wind direction. Source: (GEOLICA, n.d.)

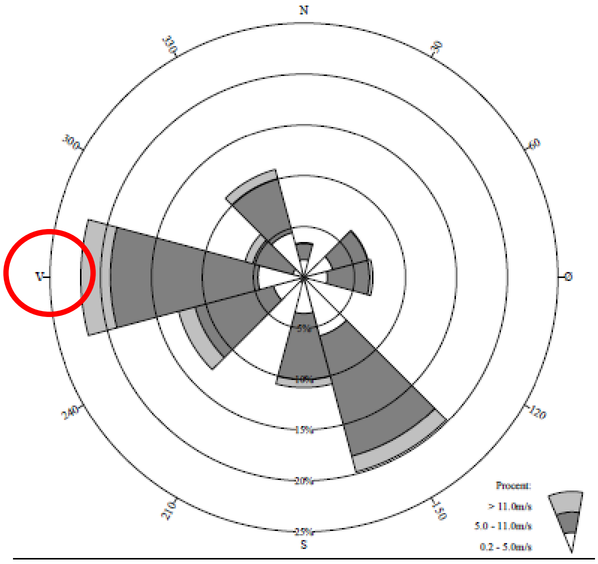


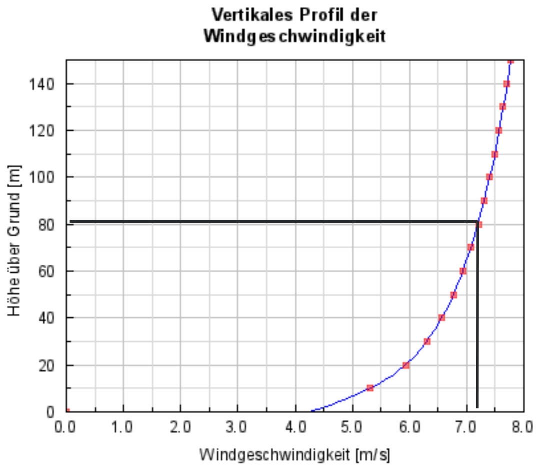
Figure 4.3.2_9: *wind* rose in Bågø Fyr. Source: (Cappelen & Jørgensen, 1999)

WIND TURBINE OUTPUT

Finally the output of the turbine must be calculated. The average wind speed in the area will be as worst 7,4 m/s calculated at 100 m height. The following calculations are done for obtaining the average wind speed at the hub height of wind turbine SWT-2.3-93 (Suisse éole)

Height above ground	100		
Wind speed	7,4		
Roughness	0,03		
Hub height	**80**	**Wind speed**	**7,2**

Figure 4.3.2_10: Calculator of wind speed. Source: (Suisse éole, n.d.)



Now and In accordance with the tables for Siemens wind turbine SWT-2.3-93 the hourly and annual average output is shown (Siemens AG, 2013).

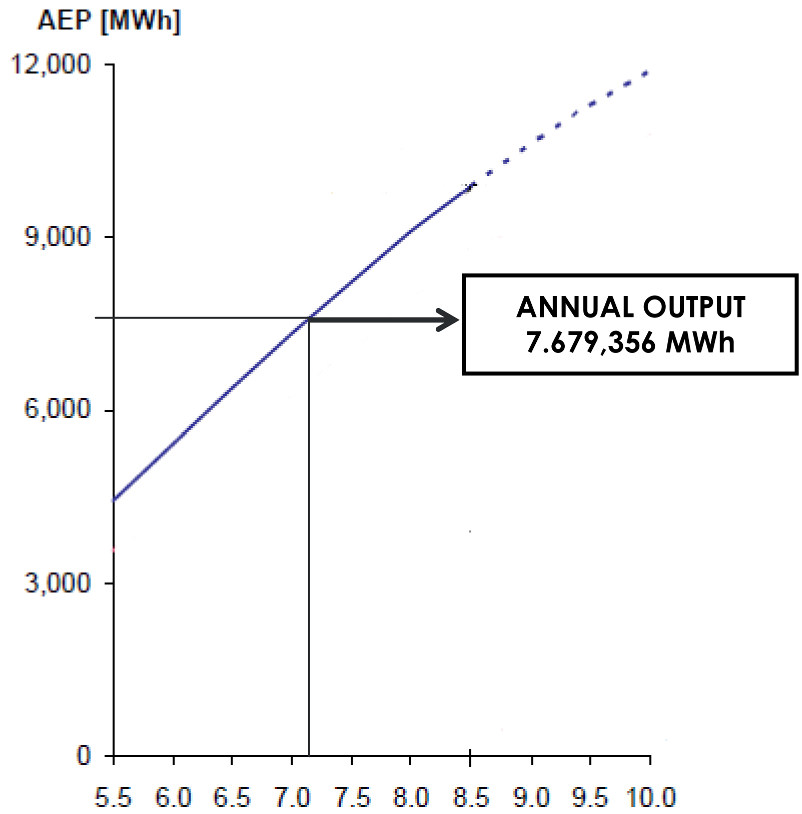


Figure 4.3.2_11: Annual Average wind speed. Source: (Siemens AG, 2013)

ECONOMIC ASPECT

Modern wind turbines are designed to work for some 120.000 hours of operation throughout their design lifetime of 20 years (Danish Wind Industry Association)

Thanks to VINDMOLLER KONOMI (Nielsen & et al, 2010) the average cost of a wind turbine including O&M costs is shown below. This statistics is gathered from more than 250 operating turbines in Denmark.

The document provides prices for different wind turbines depending on their MW. The following table reflects the turbine data:

MW	ROTOR	HUB	W/M2
2,3	93	80	339

Figure 4.3.2_12: Wind turbine technical specification. Source: (Nielsen & et al, 2010)

And the table below shows the cost split into activities:

DESCRIPTION	COST m. DKK
INSTALLATION	18,9
FOUNDATION	1,4
ROAD ACCESS	0,6
INTERNAL NET	0,3
LAND	1
PROJECT DEVELOPMENT	0,9
FINANCING COST	0,6
NEARBY COMPENSATION	0,1
SCRAP	0,8
TOTAL	24,6

Figure 4.3.2_13: Wind turbine cost divided in targets. Source: (Nielsen & et al, 2010)

The final cost according to this method for SWT-2.3-93 turbine is **24.600.000 DKK** VAT included.

This final cost is similar to the figure obtain from Birger T. Madsen (BTM Consultant) and Anders Wiisbye (Siemens Wind Power A/S). They provide a key-figure of 10,82 m. DKK/MW. This supposed a final cost for SWT-2.3-93 turbine of 24.886.000 DKK.

Finally to this figure The O&M costs must be added. For newer machines the estimates range around 1.5 to 2 per cent per year of the original turbine investment (Danish Wind Industry Association). This will means **430.500 DKK** VAT INCLUDED per year.

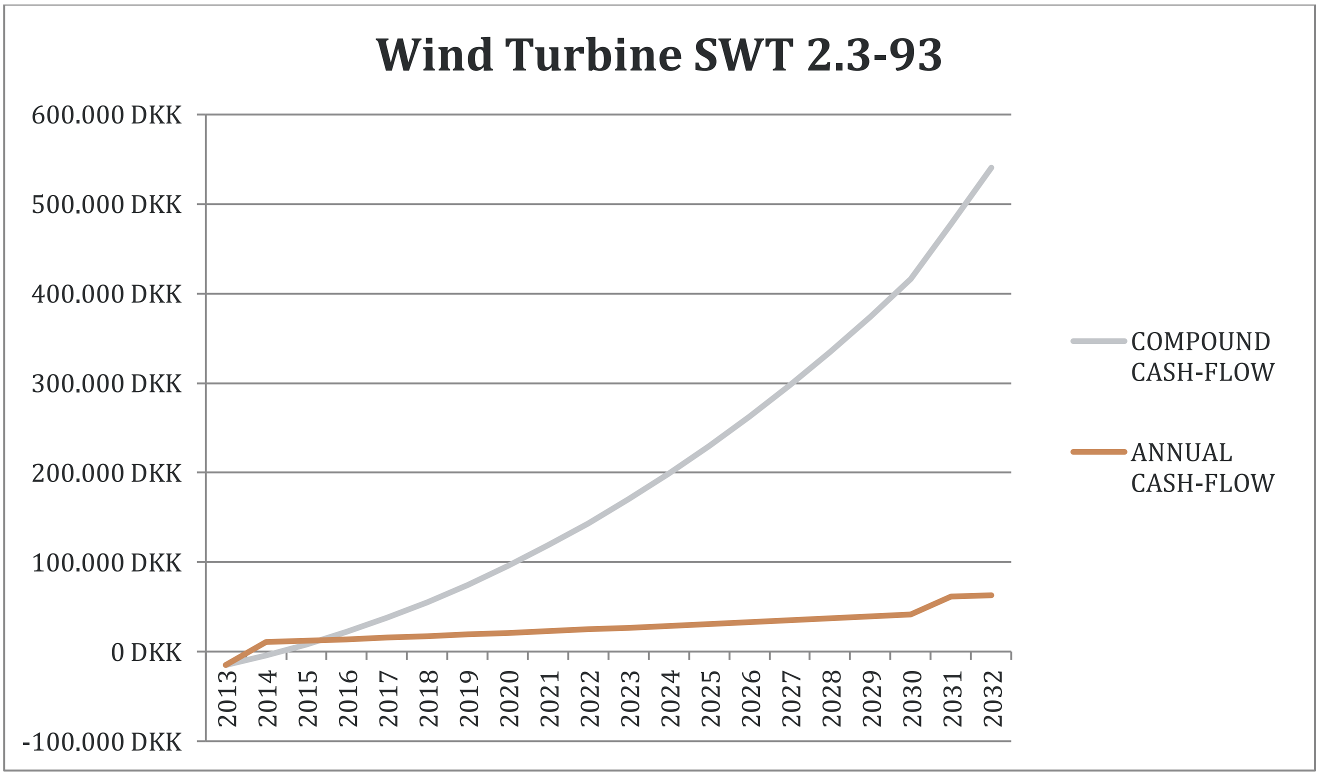
PAYBACK PERIOD

The following table reflects the different points that must be taken into account to calculate the payback period, for further information check cash flow tables in appendix 7.15:

DESCRIPTION	TOTAL COST	PER USER
Investment	24.600.000 DKK	346.478 DKK
O&M	430.500 DKK	6.063 DKK
Sale Of Electricity (*)	2.687.774 DKK	37.855 DKK
Cost Of Electricity (**)	702.900 DKK	9.900 DKK
Initial Investment Grant	176.000 DKK	2.478 DKK
Anual Grant (***)	395.486 DKK	5.570 DKK
Loan Period	--	18 years
Break-event point	--	2 years
Profit 10 years	--	143.461 DKK
Profit 20 years	--	540.676 DKK
Profitability 10 years	--	41,4%
Profitability 20 years	--	156,0%

Figure 4.3.2_14: sum up chart for the different figures and cash-flow indicators

(*)The electricity from the wind turbine is assumed here to be sold to the grid to 0,35 DKK/kWh (PlanEnergi, 2012). It is taken into account an annual output of 7.679.356 kWh.
(**)Electricity cost per user 2.2 DKK/kWh. Annual average consumption per house of 4.500 kWh
(***)Annual grant 0,0515 DKK/kWh. Annual output 7.679.356 kWh



ALTERNATIVE 2.2 - SMALL WIND TURBINES

Another possibility to supply electricity to Føns is installing Small Wind Turbines (SWT). Danish Regulations (Petersen, 2011) consider Domestic Turbines all those turbines with:

- A maximum height of 25 meters
- A maximum power of 25 kW
- A maximum diameter of 13 meters

The regulation 4/6/2010 states that for energy supply installations of no more than 6kW, Net Metering grant system is allowed. This solution can provide real economic benefits, reduce the time for return of investments (ROI) and improve the social acceptance of SWT.

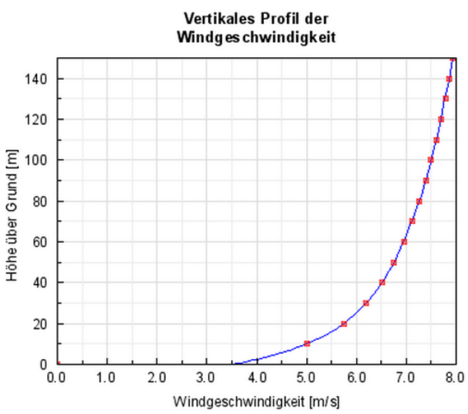
Technical aspects

Some preliminary calculations will be carried out, in order to understand the feasibility of supplying Føns with SWT. First, we need to evaluate the average energy consumptions in the village. As a common assumption, suggest a value of 4500 kWh/year has been

Höhe über Grund	10	m	
Windgeschwindigkeit	5	m/s	
Rauhigkeitslänge z_0 (siehe Tabelle weiter unten)	0.1	m	Aktualisieren

Resultat

Höhe über Grund	Windgeschwindigkeit
150 m	7.94 m/s
140 m	7.87 m/s
130 m	7.78 m/s
120 m	7.70 m/s
110 m	7.60 m/s
100 m	7.50 m/s
90 m	7.39 m/s
80 m	7.26 m/s
70 m	7.11 m/s
60 m	6.95 m/s
50 m	6.75 m/s
40 m	6.51 m/s
30 m	6.19 m/s
20 m	5.75 m/s
10 m	5.00 m/s



Roughness and lengths

Roughness class	Roughness length z_0	Types of terrain surfaces
0	0.0002 m	Of water: sea and lakes
0.5	0.0024 m	Open area with a smooth surface, such as concrete runways in airports, mowed grass, etc.
1	0.03 m	Open agricultural area without fences and hedgerows and very widely scattered buildings and rolling hills
1.5	0.055 m	Agricultural land with some houses and 8 meter high hedges at a distance of more than 1 km
2	0.1 m	Agricultural land with some houses and 8 meter tall sheltering hedgerows with a distance of about 500 m
2.5	0.2 m	Agricultural land with many houses, shrubs and plants, or 8 meter tall sheltering hedgerows with a distance of about 250 m
3	0.4 m	Villages, towns, agricultural land with many or tall hedges, forests and very rough and uneven terrain
3.5	0.6 m	Larger cities with tall buildings
4	1.6 m	Large cities with tall buildings and skyscrapers

Figure 4.3.2_15 Wind profile and terrain roughness calculation; source, http://www.wind-data.ch/tools/profile.php?h=100&v=7.4&z0=0.03&abfrage=Aktualisieren

considered; by multiplying this time's 70 houses involved, a value of 315000 kWh/year is obtained.

The market of domestic wind turbines offers many possibilities; of course, not all turbines are equal; in this phase, their performances will be analyzed taking into account only the power curve, which relates the output to the wind speed. In Føns, the average wind speed at 100 m height is approximately 7,8 m/s (See appendix 7.5). A preliminary approximation of wind speed at 22 m height can be done using the logarithmic wind profile curve, as shown in picture 4.3.2.15.

Concerning the roughness of terrain, a z_0 of 0,3 has been considered, as 0,2 corresponds to a scenario with open land and many households, and 0,4 represent a small urban scenario.
According to this calculation, the wind speed at 20 m height (the average height of a 6 kW SWT) is approximately 6 m/s.
Some wind turbines in the Danish market have been analyzed, and for the preliminary calculation a 6 kW, 4 m diameter Bornay 6000 turbine has been chosen (www.bornay.dk). Here is shown a chart comparing the power curve and the wind speed distribution (with an average speed of 5,8 m/s at 22 m height and a Weibull coefficient approximated to 2 as first instance).

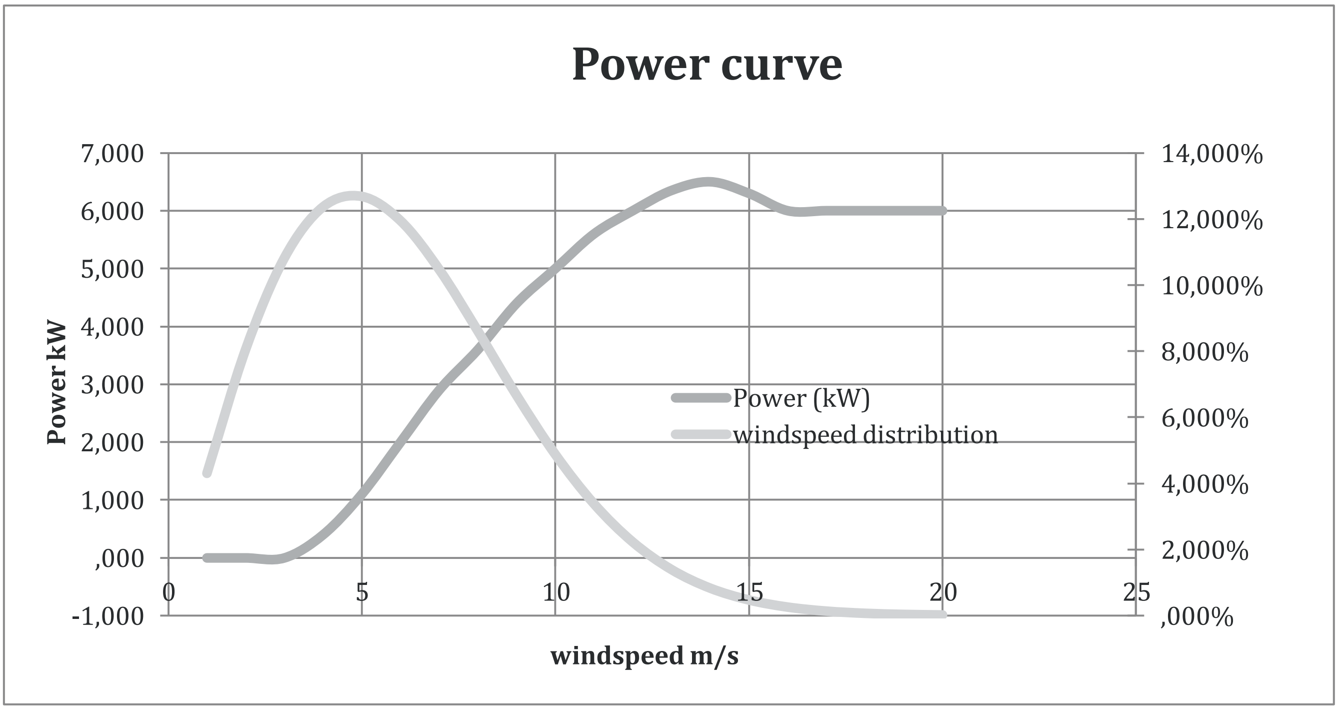


Figure 4.3.2_16 Bornay 6000 power curve; source www.bornay.dk

Inputs:	
Ave. Wind (m/s) =	6
Weibull K =	2
Site Altitude (m) =	0
Wind Shear Exp. =	0,200
Anem. Height (m) =	20
Tower Height (m) =	20
Turbulence Factor =	0,0%

Figure 4.3.2_17 wind power calculation: inputs

Hub Average Wind Speed (m/s) =	**5,80**
Air Density Factor =	0%
Average Output Power (kW) =	1,98
Daily Energy Output (kWh) =	47,5
Annual Energy Output (kWh) =	**17.344**
Monthly Energy Output =	1.445
Percent Operating Time =	75,0%

Figure 4.3.2_18 wind power calculation: outputs

As shown in the table, the yearly production this wind turbine is approximately 17350 kWh, which means, it can cover the electricity needs of 4 households; therefore, 17 turbines have to be placed in order to supply all involved houses. This turbines are approximately 20 m height, and the Danish regulation specify that the maximum distance to the household should be 30 meters without a more detailed urban plan (Petersen, Energinet.dk), but a noise limit of 42 dB at 6 m/s should be respected; therefore, the turbine should be placed at approximately 20 – 25 meters from the household (Cace, Aeolus Power). A 6 kW SWT should supply 4 houses, but it could be quite difficult to place it and respecting at the same time the maximum distance.

This means that in this case, smaller turbines could be considered more indicated; let us consider a 1,5 kW Bornay 1500 SWT, with a yearly power production, at 6 m/s, of circa 4500 kWh, enough to supply one household. Anyway, in Føns, the shape and height of the buildings is approximately the same; therefore, in order to avoid turbulence, the turbine should have a height around 15-18 up to 20 meters, no matter what the power of the device is. That means that, in order to supply Føns, 18 6 kW turbines or 75 1,5 kW micro-turbines could be placed, but the height and dimensions of the devices would not change consistently.

Economic aspects

Investment and payback period

To consider the economical investment of a SWT, many factors have to be known:

- Installation costs
- O&M costs
- Electricity production per year
- Average cost of electricity
- Forecast electricity escalation rate
- Performance derating
- Interest rate (loan)
- Down payment percentage (loan)
- Debt term (loan)
- Expected lifespan of the turbine

In the case studied, some assumptions have been made, where data was missing or not reliable. The following calculations are for a Bornay 6000 turbine, in an environment like Føns.

Summary of assumptions

Financial assumptions

Downpayment	45.000 DKK
Interest Rate (%/year)	**3 %**
Debt Term (years)	**10**

Site properties

Average Wind Speed (m/s)	7,4
Anemometer Ht (m)	100
Wind Shear Exponent	0,143
Weibull k	2
Site Elevation (m)	0

Avoided energy costs

Average Cost of Electricity (DKK/kWh)	**2,2**
Nominal Electricity Escalation Rate (%/year)	**0,03**

System costs

Installation Investment + Distribution net (DKK)	**260.000***
Installation running annual cost + distr net (DKK/kW)	**866,67**

System characteristics

Rated Power (kW)	**6**
Rotor Hub Height (m)	22
Availability (%)	0,98
Performance Margin	0,00%
Performance Derating	10,00%

Hub Height Average Wind Speed (m/s)	5,8
Air Density Factor	1,00
Average Annual Power Output (kWh)	**16.055**
Implied Capacity Factor	31%

Figure 4.3.2_19 Assumptions

* (Energinet.dk, 2012; PureEnergy Centre)

Analyzing the economical estimation of the system the following data can be highlighted in order to take it as a baseline for decision-making. The detailed cash-flow can be found in Appendix 7.12.

INDICATOR	Individual 5kW
Initial investment	260.000 DKK
Loan period	13 Years
Break-even point	5 Years
Profit 10 years	73.187 DKK
Profit 20 years	459.929 DKK
Profitability 10 years	28,14 %
Profitability 20 years	176,89 %

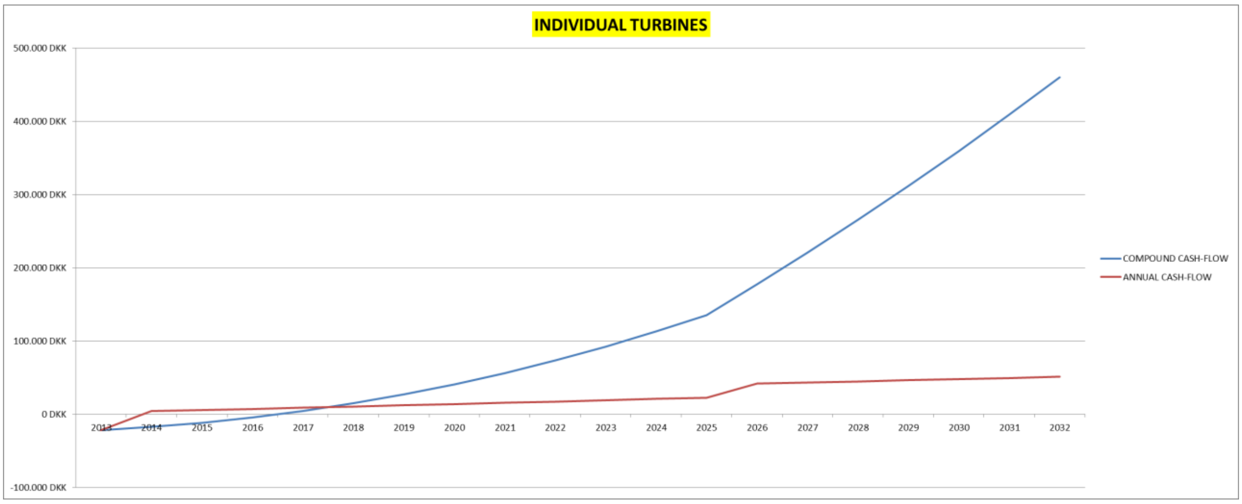


Figure 4.3.2_20 Cash flow

Environmental and social aspects

SWT have less impact than conventional ones, due to their reduced size; nonetheless, noise, shadow casting and land consuming are to be considered; concerning noise and shadows, the regulations are the same considered before for bigger turbines.

Protected sites

In the area there are protected sites, as historic buildings buffer areas, protected rivers, Ramsar protected areas or protected shores. In the appendix 7.5 it can be found a picture showing all the free areas for construction in Føns.

Wildlife

The impact on wildlife of SWT is certainly small, compared to the one of bigger turbines; anyway, in the studied area there are protected zone for birds preservation. The placement of turbines in those areas is not recommended.

Noise

A SWT has a sound emission of approximately 80 dB, which means that to stay under the 39 dB required by the law, the device should be placed at least 24 meters away from the houses. (Danish ministry of Environment)

Shadows

It is recommended that neighbours should not be exposed to this phenomenon for more than 10 hours per year.
Automatic controls can help in this, turning off the turbine when the limit has been reached. Shadow flicker should be calculated before placing a turbine, in order to find the most suitable location.

Potential loss of value in neighbors properties

In some cases wind turbines can reduce the value of a neighbour's property; before placing domestic wind turbines, it is useful to organize discussions with the neighbours, in order to avoid claims.

Possible locations for the turbines

Overlaying all the critical areas, it has been possible to obtain those areas (Red line in the following picture) suitable, in general, for SWT.
Not all areas in Føns are involved in this project; the 68 houses studied are in an area marked with the orange line.
17 possible locations of SWT are indicated in the following picture; the criteria used for the placement are:
Less than 30m from one of the supplied houses

- More than 24 meters from all houses
- 4 houses should be connected to the same turbine

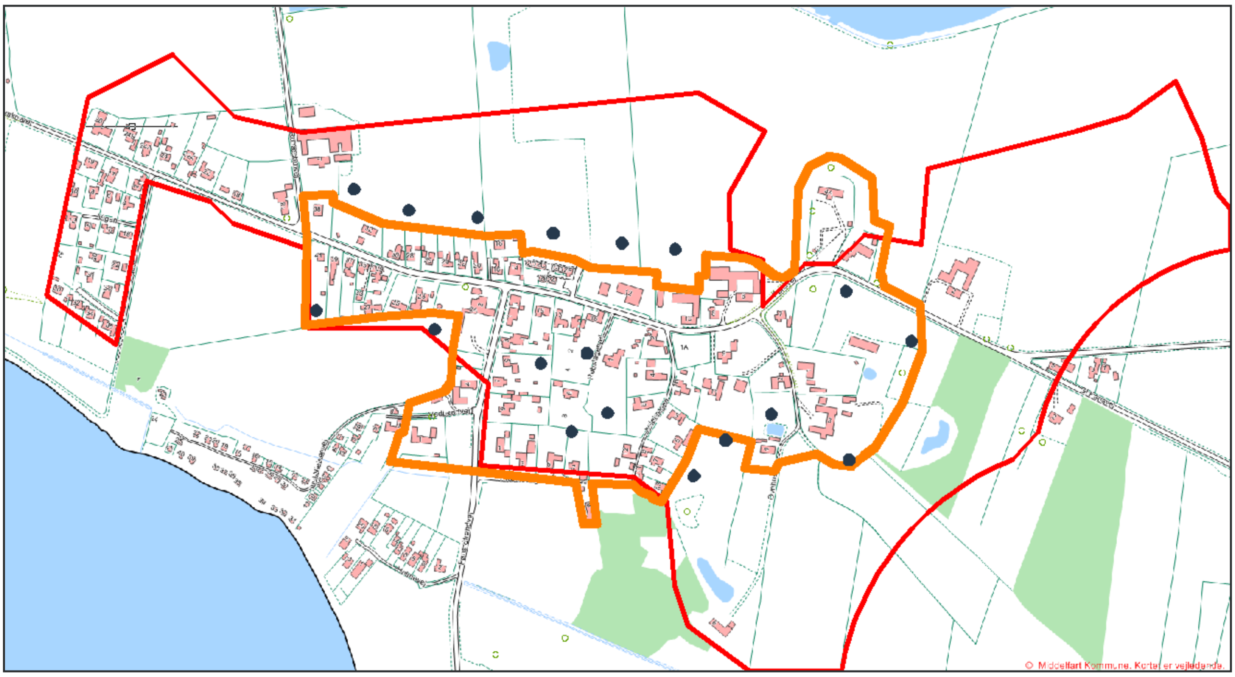


Figure 4.3.2_21 Possible SWT locations

Spaces as open as possible to avoid turbulences

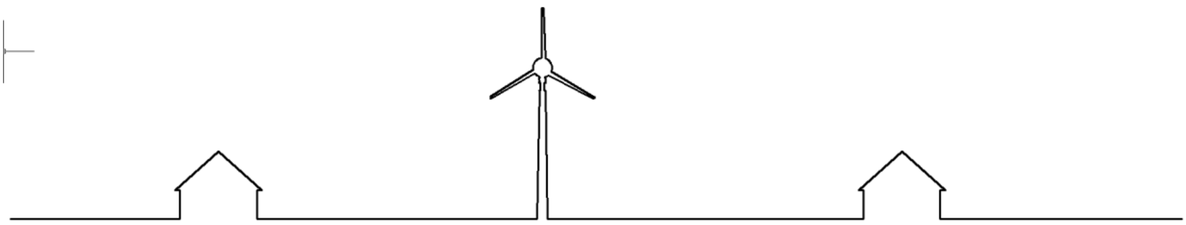


Figure 4.3.2_22 Visual impact of a SWT

This solution, even if technically, environmentally and economically feasible at first glance, has many issues connected with it:

- First, the morphology of the town allows the installation of turbines mainly in the upper area; the mandatory limit of 30m in distance may imply some turbulence phenomena, which would surely affect the performance and the power output.
- To avoid turbulence, the height of the turbines should be remarkable, and this would strongly affect the environmental and social suitability of the installations. (See picture 4.2.3_22)
- Furthermore, the social acceptability of such a solution would be extremely low, and this has been confirmed asking directly of some of the house owners on site.
- SWT have faster rotations, and this implies a more disturbing shadow flickering; due to the location of the turbines, this would probably involve many houses near each turbine.
- The shape of the hills near the town could create a complex wind flow; it would be probably difficult harvesting this flow without higher turbines.

For these reasons, a solution based only on SWT is not considered suitable for the analysed area, at current conditions; further solutions that integrate SWT with other energy supply will be considered, in order to reduce the number of turbines to be placed and improve their suitability.

5. PHASE 2 SCENARIOS

5.1. INTRODUCTION

This phase deals with different solutions combining heating and electricity alternatives developed on phase 1. The same assumptions reflected in the introduction of the phase 1 are taken into account. The solutions have been divided in individual and collective trying to cover all possible opportunities for Føns.

INDIVIDUAL SOLUTIONS

This section provides different individual solutions to supply energy to Føns. These options will be useful in case some houses are isolated and it is not feasible to apply a collective solution. The report will provide the guidelines, for choosing the best option.

HEATING

With regards to the heating needs, this section analyses the different individual solutions to provide heat and hot domestic water for each house in Føns. Inside each analysis, technical and economic considerations will be found in order to determine the feasibility of the heating system proposed.

ELECTRICITY

The supply of electricity will be also analysed from an individual point of view, both for small wind turbines and solar photovoltaic systems. In the Appendix 7.13, two maps can be found in order to check the best areas to make these installations, depending on the different factors studied in the feasibility study of each solution.

COLLECTIVE SOLUTIONS

This section provides five different scenarios that will supply energy to Føns. The scenarios have been developed fixing first a heating solution and then the best electricity choice for that heating solution.

In all the cases, the heating solution will have a common installation for the distribution, a district heating system. The considerations about the distribution net and general aspects will be analysed in section 5.3.

SCENARIO 1

In order to supply the village with a district heating system and electricity, this case will study the implementation of a **ground source heating** systems aid by **solar thermal panels**, all of that connected to a heat pump. For the electricity solution, a **single wind turbine** with high electricity production will provide energy to the village.

SCENARIO 2

In the second scenario, the heating and electricity demand will be solved by a **straw boiler** in the first case, and a combination of **small wind turbines** and **solar photovoltaic cells** in the second.

SCENARIO 3

For the third case of study, the supply of both heating and electricity needs will be provided by a single system. The scenario shows the technical and economical considerations of a **Stirling CHP wood chips cogeneration** installation.

SCENARIO 4

Similarly to the first scenario, in relation with heat supply, the fourth scenario will deal with a **ground source heat pump** installation, integrated in this case with a **biogas boiler**. For the electricity supply, a combined system of **solar photovoltaic cells** and **small wind turbines** will be optimized to produce electricity for the whole village. The difference with scenario 2 in the electricity solution will be determined by the existence of a single building; fact that will limit the amount of small wind turbines allowed and thus, the conditions of the scenario.

SCENARIO 5

The last scenario proposes a trendy solution for district heating in Denmark, **solar thermal plant** assisted by a **biogas boiler**. In this case **small wind turbines** will provide the electricity demand. It must be taken into account, that in this particular case, the conditions of this scenario limit the electricity production to a 47% of the whole demand, as it is explained in this section.

5.2. INDIVIDUAL SOLUTIONS

The following chart represents the plots studied in the zone of Føns, according to the maps and charts developed on the appendix 7.13.

The columns refer to the individual solutions proposed on this section are plotted:

- Pellet Boiler – [5.2.1.1 Heating solution 1] – Individual pellet boiler.
- SA GSH – [5.2.1.2 Heating solution 2] – Solar assisted ground source heat pump with water tank seasonal storage.
- GSH – [5.2.1.3 Heating solution 3] – Ground source heat pump.
- Wind turbines – [5.2.2.1 Electricity solution 1] – Small wind turbines
- Solar (roof) – [5.2.2.1 Electricity solution 2] – Photovoltaic solar panels installed on the roof.
- Solar (plot) – [5.2.2.1 Electricity solution 2] – Photovoltaic solar panels installed on the plot.

The different rows represent the studied plots of the studied houses in Føns, the relation between the code and the number and location of the plot is shown in the section 3.1 of this report.

The rows are marked as YES if the solution can be applied and NO if not. Further information about these solutions can be found on the section of each individual solution.

PLOT CODE	PELET OILER	SA GSH	GSH	WIND TURBINES	SOLAR (ROOF)	SOLAR (PLOT)
27	YES	YES	YES	YES	YES	YES
31	YES	YES	YES	YES	NO	YES
34	YES	YES	YES	NO	NO	YES
39	YES	YES	YES	NO	YES	YES
10b	YES	NO	YES	NO	NO	NO
11a	YES	NO	YES	YES	NO	NO
11f	YES	YES	YES	NO	YES	NO
11g	YES	NO	YES	NO	NO	NO
11l	YES	YES	YES	NO	YES	YES
1a	YES	YES	YES	YES	YES	YES
1æ	YES	YES	YES	NO	YES	YES
1f	YES	YES	YES	NO	YES	YES
1h	YES	YES	YES	NO	YES	YES
1i	YES	YES	YES	YES	YES	YES
1l	YES	YES	YES	NO	YES	YES
1ø	YES	YES	YES	YES	NO	YES
1q	YES	YES	YES	YES	YES	YES
1r	YES	YES	YES	YES	NO	YES
1s	YES	YES	YES	YES	YES	NO
1t	YES	YES	YES	YES	YES	NO
1u	YES	YES	YES	NO	YES	YES

1y	YES	YES	YES	YES	YES	NO
21a	YES	YES	YES	NO	YES	YES
1z	YES	NO	YES	NO	NO	NO
23a	YES	YES	YES	NO	YES	YES
23b	YES	YES	YES	YES	YES	NO
23d	YES	NO	YES	YES	NO	NO
23e	YES	NO	YES	YES	NO	NO
23f	YES	NO	YES	NO	NO	NO
23k	YES	NO	YES	YES	NO	NO
24a	YES	NO	YES	NO	NO	NO
24c	YES	YES	YES	NO	YES	NO
24e	YES	YES	YES	NO	YES	NO
26a	YES	YES	YES	YES	YES	NO
26d	YES	YES	YES	NO	YES	NO
28a	YES	YES	YES	YES	NO	YES
29b	YES	NO	YES	YES	NO	NO
2a	YES	YES	YES	YES	YES	NO
2aa	YES	YES	YES	NO	YES	YES
2ac	YES	YES	YES	NO	NO	YES
2ae	YES	YES	YES	YES	YES	YES
2æ	YES	NO	YES	NO	NO	NO
2af	YES	YES	YES	NO	NO	YES
2b	YES	NO	YES	NO	NO	NO
2bp	YES	NO	YES	NO	NO	NO
2c	YES	NO	YES	NO	NO	NO
2e	YES	NO	YES	NO	NO	NO
2f	YES	NO	YES	NO	NO	NO
2o	YES	YES	YES	NO	NO	YES
2z	YES	YES	YES	NO	YES	YES
32b	YES	NO	YES	NO	NO	NO
32c	YES	YES	YES	NO	NO	YES
32d	YES	YES	YES	NO	YES	YES
32e	YES	YES	YES	NO	NO	YES
38a	YES	YES	YES	NO	YES	YES
38c	YES	NO	YES	NO	NO	NO
38d	YES	YES	YES	NO	YES	YES
3a	YES	NO	YES	NO	NO	NO
3c	YES	NO	YES	NO	NO	NO
43a	YES	NO	YES	NO	YES	NO
43b	YES	YES	YES	NO	NO	YES
4a	YES	YES	YES	NO	YES	YES
5a	YES	NO	YES	YES	NO	NO
5e	YES	NO	YES	NO	NO	NO
5g	YES	YES	YES	NO	YES	NO

5h	YES	YES	YES	NO	YES	NO
5i	YES	YES	YES	NO	YES	NO
5k	YES	YES	YES	NO	NO	YES
5l	YES	YES	YES	NO	NO	YES
5m	YES	NO	YES	NO	NO	NO
5o	YES	YES	YES	YES	NO	YES
6a	YES	YES	YES	NO	NO	YES
7a	YES	YES	YES	YES	NO	YES
7e	YES	NO	YES	NO	NO	NO
8c	YES	YES	YES	YES	NO	YES
9d	YES	YES	YES	NO	YES	YES

Figure 5.2_1: Individual solutions chart

5.2.1. HEATING SOLUTIONS

5.2.1.1. HEATING SOLUTION 1: PELLET BOILER

INTRODUCTION

The solution proposed in this scenario, consists on an individual heating supplying system based on a pellet boiler.
In this analysis, the feasibility of this system will be studied in order to determine its suitability in the case of study for Føns. As a baseline the previous analysis developed in the alternative study section 4.2.1, will be followed.

JUSTIFICATION

TECHNICAL CONSIDERATIONS

The proposed system will be a HPK-RA 12,5 "CLIBER-GILLES or similar. It is an environmental friendly and economical effective alternative to oil or gas boilers, being the boiler run by means of burning wood pellets. The boiler has a store and a hopper to load the boiler.

The installation is formed by:

- Pellet boiler
- Integrated feeding system with manual loading
- Pellet container of 150- 200 l.
- Sanitary Hot Water tank of 75 l. (Logalux ER 75 "BUDERUS", or similar), designed to accumulate the necessary hot water for one day.
- Extraction system (COAXIS W "NEGARRA", or similar)

The technical features of the boiler are: (Gilles, 2012) (Burdeus, 2012) (Negarra, 2012)

- Power – 12.5Kw
- Temperature range:
  - Impulsion: 70°C
  - Return: 50 °C
- Performance: 85%
- Self-regulation from 30% to 100%
- Annual consumption: 30.382 KWh/year
- Automatic turn-on, ashes extraction, and cleaning of the exchanger.

The main advantages of the pellets boiler are that there is no need of being connected to the grid in order to have heat supply; it has low running costs, a long use life and it is easy to switch and regulate. Despite the main disadvantages are the need of a space to store the combustible and the cost of itself.

SOCIAL ASPECTS

Dealing with the installation of individual heating systems, there are no legal restrictions; it is just required to obtain a work permit emitted by the local authorities.
Concerning grants award, heating installations are not given neither Danish nor European ones.

ENVIRONMENTAL ASPECTS

As it is well known, biomass systems are considered legally zero balance carbon emissions energies. However, the environmental impact of this heating system is reduced to the limitation of the gaseous emissions on protected areas and living areas; the real emissions of a pellet boiler are 25 kg CO2/ MWh (WPS, 2012).

SCHEME

HEATING SCHEME

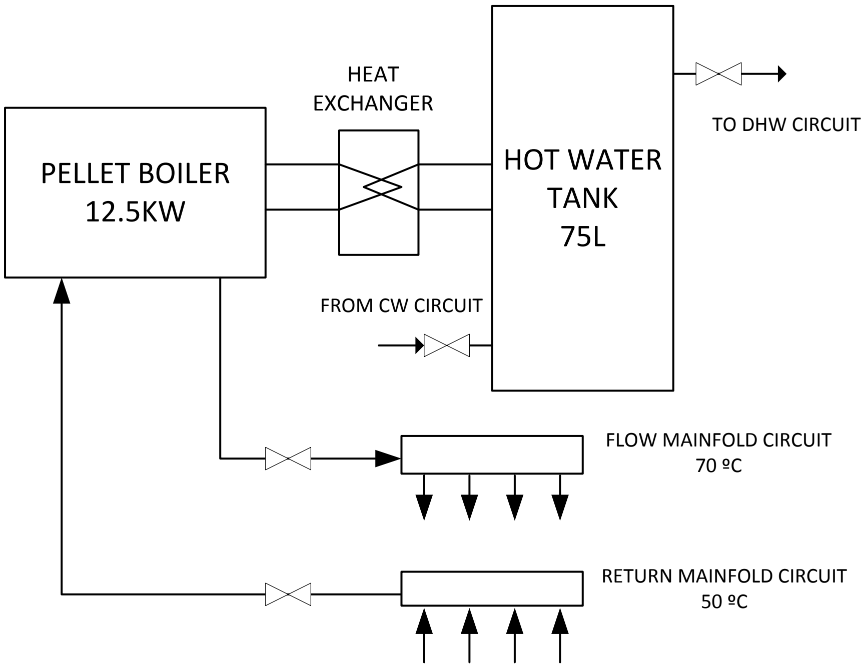


Figure 5.2.1.1_1: Heating scheme

ECONOMIC ANALYSIS

SOLUTION ANALYSIS

The data used on this economic analysis has been justified previously on the report. See alternative study section 4.2.1 of the report.

- Annual consumption costs –**8.373 DKK/year (+1.00% annual variation)**
  - Annual consumption – 32.574KWh/year
  - Fuel costs – 257,04 DKK/MWh (estimated yearly variation +1.00%)
- Annual maintenance cost – **1.250 DKK/year**
- Installation cost –**176.669DKK**

DESCRIPTION	COST (DKK)
Pellet boiler *(HPK-RA 12,5 "CLIBER-GILLES")*	*105.500 DKK*
SHW- tank 75l *(Logalux ER 75 "BUDERUS")*	*4.700 DKK*
Extraction system *(COAXIS W "NEGARRA")*	*1.200 DKK*
Installation and connection (10%)	11.500 DKK
TOTAL INSTALLATION COST	**122.900 DKK**
GC+IB (9%+6%)	18.435 DKK
TOTAL COST	**141.335 DKK**
VAT (25%)	35.334 DKK
TOTAL	**176.669 DKK**

Figure 5.2.1.1_2: Installation cost

* This costs refer to the estimated costs for the implementation of the solution into a house heated by a combustion based method. The internal installations concerning emitters will not be included.
After calculating the initial investment of the installation, as it is has been shown, an economic analysis of the system has been developed.

CONCLUSION

Thanks to the system versatility it can be implemented in every single house of the village.
Analyzing the economical estimation of the system the following data can be highlighted in order to take it as a baseline for decision-making.

Initial investment	**176,669 DKK**
Annual fuel costs	8,873 DKK + 1% each year
First year with a positive cash flow	Year 2
First year with a positive cash flow	Year 6
First year without loan	Year 10
Profit in 10 years	60,269 DKK
Profit in 20 years	415895,441 DKK

Figure 5.2.1.1_3: Cash-flow indicators

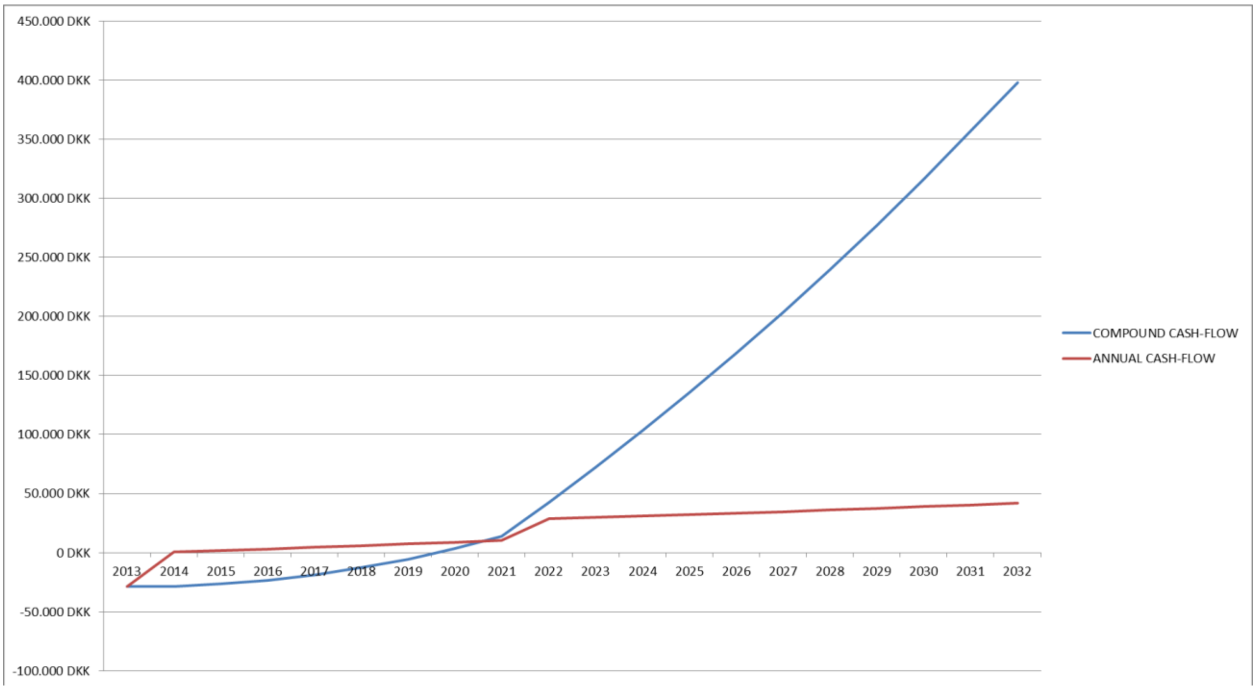


Figure 5.2.1.1_4: Cash-Flow Chart

5.2.1.2. HEATING SOLUTION 2: SOLAR ASSISTED GROUND SOURCE HEAT PUMP WITH WATER TANK SEASONAL STORAGE

INTRODUCTION

The solution proposed in this scenario consists on an ***individual heating supply system based on an individual solar assisted heat pump with water tank seasonal storage***.

In the following sections of this document the feasibility of this system will be studied owing to its implantation as a suitable individual supply system for the small community of Føns.

As a baseline the previous analysis developed in Feasibility Study, will be followed (section 4.2.2.)

JUSTIFICATION

TECHNICAL CONSIDERATIONS

It is known the benefits and the better efficiencies reached by ground source heat pump systems. Introducing new elements such as solar collectors and heating storage, the efficiencies achieved are good enough to make this system feasible even to individual purposes.

The fact of using solar collectors and seasonal storage systems implies an increasing of the heat pump input temperature which means a higher coefficient of performance of the heat pump.

This combined system is formed by:

- A Heat pump with an average COP of 4.
- A buried individual water tank of a volume around 24 m^3.
- Individual solar collectors of a total surface around 16 m^2. The solar collector would be situated on the householder's roof. In those houses which have straw roofs the solution of locating the solar thermal collector in the plot should be considered as well.

The heat pump will work with a Coefficient of performance of 4. The output temperature will be around 65-70 degrees and the annual consumption 6900 KW/year on average.

The technical features of the solar thermal panel are:

- Flat solar collectors are used (www.Arcon.dk)
- The optimal inclination angle will be 38 degree (appendix, section n)
- Life time around 25 – 30 years. Little maintenance is required.
- The irradiation on optimally inclined plane is around 3050 Wh/m^2/day in a sunny day.

The technical features of the water tank thermal energy storage:

- Reinforced concrete tank fully buried in the ground.
- Thermally insulated in the roof and in the vertical walls.
- High density concrete materials.
- Heat capacity around 60 KWh/m^3.
- Charge and discharge processes are available.

Main advantages of the system:

- Improve the efficiency of a GSHP system getting benefit of the summer solar energy achieving really good performances (COP of 4 is expected).
- Less uncertainty than the boreholes storage system
- Easier to design the appropriate system for each case than the boreholes storage system

Main disadvantages

- Less developed than other GSHP systems, so the real behavior is slightly uncertain
- It is a complex system with a lot of different elements
- Expensive system compared with other type of installations
- Possible problems to emplace the solar collectors
- Plot necessary to allocate the water tank

SOCIAL ASPECTS

The possible social impacts and benefits for the installation of this individual heating supply system have been explained in section 4.2.2.

ENVIRONMENTAL ASPECTS

Concerning the environmental impact for the implantation of this individual system in the small community of Fons, have to be considered either negative or positive aspects.

While this heating supply system is one with less CO_2 emissions, remove the ground of the household plot could affect the natural environment, which includes fauna and flora.
For further information, see section 4.2.2.

SCHEME

HEATING SCHEME

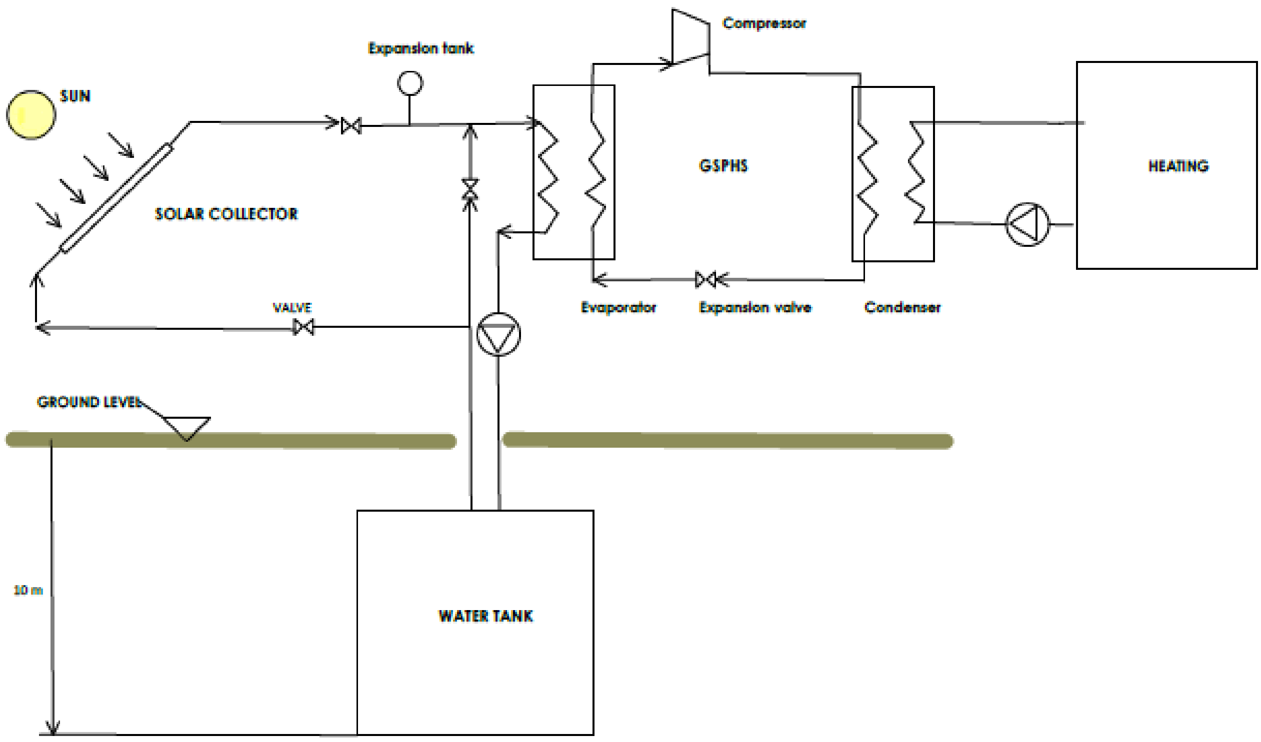


Figure 5.2.1.2_1. Heating scheme

SOLUTION ANALYSIS

- Initial Investment – 198.278 DKK

DESCRIPTION	COST (DKK)
Heat pump and installations	74.604 DKK
Solar collectors	20.720 DKK
Water tank	35.810 DKK
Earth movements	67.144 DKK
TOTAL	**198.278 DKK**

Figure 5.2.1.2_2. Installation cost

- Annual consumption – 6.910 KWh/year
- Annual maintenance cost – 1.120 DKK
- Annual energy cost – 15.202 DKK
    - Yearly inflation - +3,00%

CONCLUSION

This system has some advantages compared with the other GSHP system studied: the economic data is the best, with lower investment, and the storage system is simpler and with less uncertainty than the boreholes storage system.

Despite the fact that this system seems to be the best among the SAGSHP systems studied, it is still little attractive because of its high initial costs and long payback period (14 years). The system performs really well (COP of 4 is expected) and the energy consumption is up to 4 times less than the current energy needs, triggering about 60% of CO2 emissions reduction, but it is expensive and despite being the reduction of consumption drastically reduced, the energy consumed is electricity, whose price is much more expensive than solid fuels (biomass), so finally the investment is not recovered so fast.
The economic indicators are the following:

INDICATOR	VALUE
Initial investment	198.278 DKK
Loan period	10 Years
Break-even point	14 Years
Profit 10 years	-71.012 DKK
Profit 20 years	135.435 DKK
Profitability 10 years	-35.8 %
Profitability 10 years	68,3 %

Figure 5.2.1.2_3. Cash-flow indicators

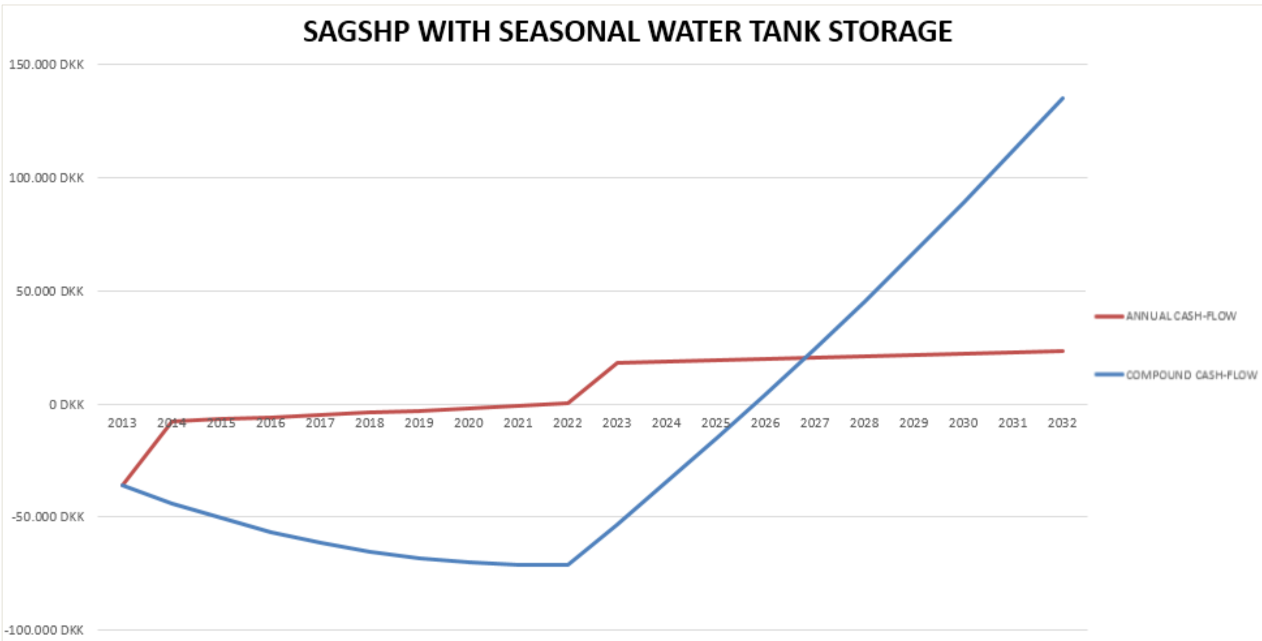


Figure 5.2.1.2_4. Cash- Flow graph

5.2.1.3. HEATING SOLUTION 3: GROUND SOURCE HEAT PUMP

INTRODUCTION

The solution proposed in this scenario consists on an ***individual heating supply system based on an individual ground source heat pump with boreholes***.

In the following sections of this document the feasibility of this system will be studied owing to its implantation as a suitable individual supply system for the small community of Føns.
As a baseline the previous analysis developed in Feasibility Study, will be followed (section 4.2.2.)

JUSTIFICATION

TECHNICAL CONSIDERATIONS

The proposed system will be compound by a ground source heating system without being assisted by solar thermal energy. The heat pump will heat from boreholes which act as heat sources.

This alternative takes advantage of the moderate temperatures in the ground that are considered around 9 degrees.

This installation is formed by:
- A Heat pump with an average COP of 3,3 (Sørensen, 2012).
- 4 Closed loop vertical boreholes of a dimension around 100 m long.

The Coefficient of performance (COP) of the heat pump expected is 3,3, with an energy consumption of 8.375 KWh per year and house. The output temperature is from 65 to 70 degrees.

The technical features of the boreholes are:
- The type of soil considered in Føns area is mainly clay, taking into account that there is a small superficial layer of saturated sand which is not significant in the study.
- Energy extracted per boreholes about 6,3 Mw/year.
- Distance between boreholes around 3 meters.
- The boreholes will be filled with groundwater.
- High durability and less maintenance.

Advantages
- The system is simpler than the storage systems, and predictable
- The system is cheaper than the SAGSHP with boreholes storage
- No solar collectors are needed, so it is no problem of emplacement of them

Disadvantages

- The boreholes are very expensive, due partly to the high heating demand, and the soil characteristics.
- The performance is worse than with storage systems and the difference in price is not so much because the main costs are the boreholes construction.
- As there is no heat replacing, the temperature of the ground may decrease yearly reducing therefore the efficiency

SOCIAL ASPECTS

Regarding to the acceptance of the implementation of this alternative there is any rejection. Even without any grant provided by the government, people are willing to put this system in their houses. For more information, see section 4.2.2.

ENVIRONMENTAL ASPECTS

Most of the possible environmental impacts caused by the implementation of this alternative are related to the boreholes installation. The properties of the soil could be changed, as well as the underground water could be contaminated. Further information, see section 4.2.2.

SCHEME

HEATING SCHEME

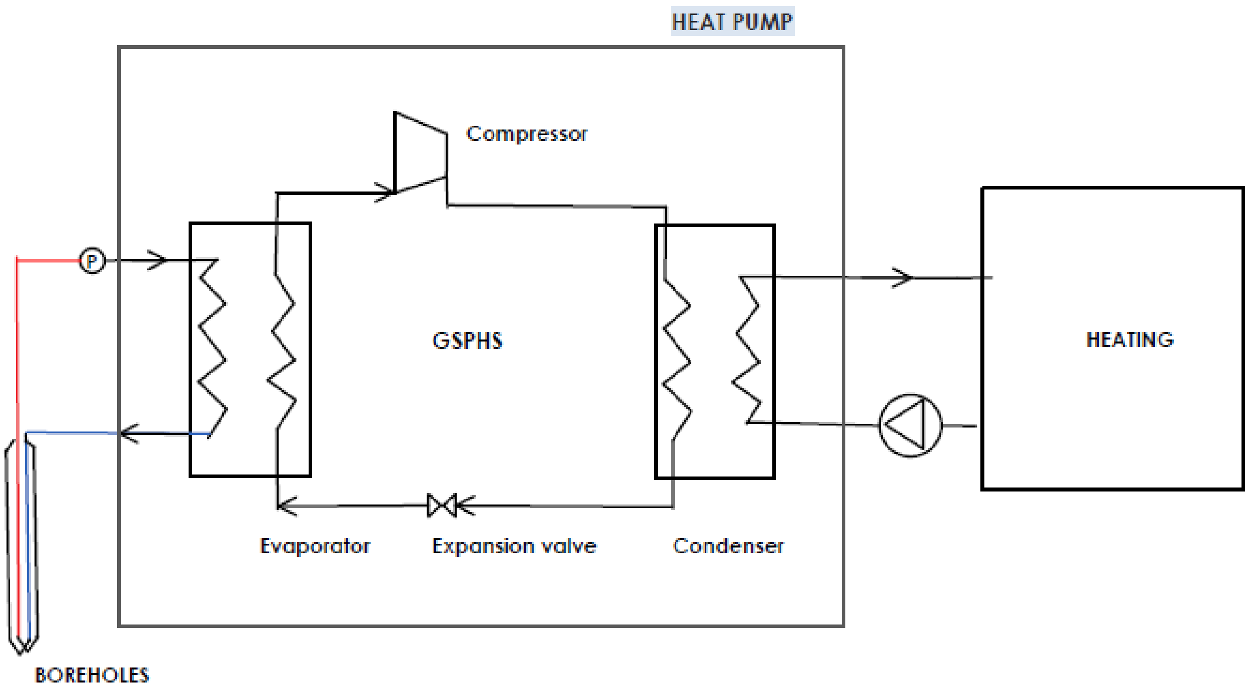


Figure 5.2.1.3_1. Heating scheme.

ECONOMIC ANALYSIS

- Initial Investment – 224.762 DKK

DESCRIPTION	COST (DKK)
Heat pump and installations	44.762 DKK
Boreholes	180.000 DKK
TOTAL	**224.762 DKK**

Figure 5.2.1.3_2. Installation costs

- Annual consumption – 8.375 KWh/year
- Annual maintenance cost – 1.120 DKK
- Annual energy cost – 18.426 DKK
    - Yearly energy inflation - +3,00 %

CONCLUSION

This system is the most common among the GSHP systems studied, and even in Føns some are already installed. However, the analysis shows that actually this system, more developed, simpler and easier have worse economic data than the others studied. This is due to the high costs of the boreholes. Integrating in the system solar collectors and extra installation to storage the heat is not so expensive compared with the cost of the boreholes (is estimated in about 20% of the total costs), and the improvement of efficiency let the system recover the investment earlier and have better results, as it can be seen in the feasibility study (alternative 2 vs. alternative 3).
Compared with other types of individual systems, the investment is high and the payback period is quite long (about 20 years), and despite being the reduction of consumption drastically reduced, the energy consumed is electricity, whose price is much more expensive than solid fuels (biomass), so finally the investment is not recovered so fast.

INDICATOR	VALUE
Initial investment	224.762 DKK
Loan period	11 Years
Break-even point	20 Years
Profit 10 years	- 127.880 DKK
Profit 20 years	15.207 DKK
Profitability 10 years	-56,89 %
Profitability 20 years	6,7 %

Figure 5.2.1.3_3. Cash-flow indicators

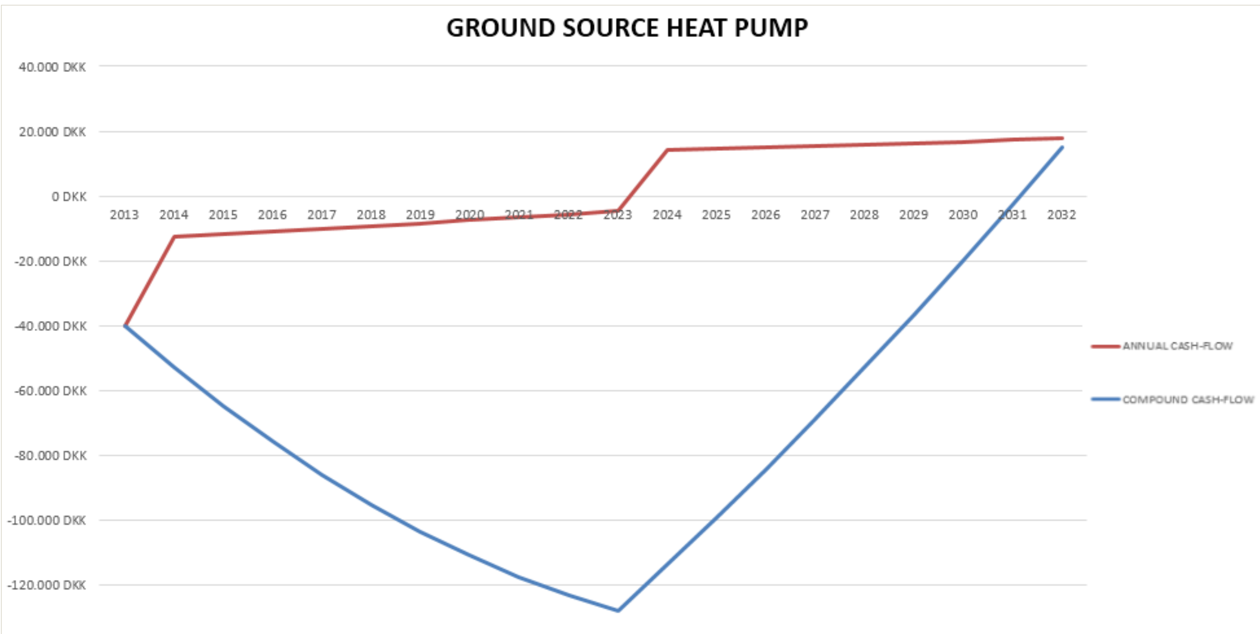


Figure 5.2.1.3_4. Cash-Flow Graph

5.2.2. ELECTRICITY SOLUTIONS

5.2.2.1. ELECTRICITY SOLUTION 1: SMALL WIND TURBINE

INTRODUCTION

One of the possible solutions to supply a single household with electricity is a Small Wind Turbine. This can be a good solution thanks to the subsidy regime in Denmark, which allows net-metering regulation for turbines under 6 kW, as explained in the section 4.3.2.

JUSTIFICATION

TECHNICAL CONSIDERATIONS

From the technical point of view, the installation of a domestic turbine would be almost exactly the same as explained in section 4.3.2. The only one difference is that, in order to supply the electricity needs of only one household, one 1,5 kW turbine.
The chosen turbine will be a Bornay 1500 turbine, coupled with a BornayAeocon inverter, which integrates all functions necessary for wind home production (Inverter, peak limiter, rectifier, overload safety system, filter).
Considering an average wind speed of 5,3 m/s, the power output of this turbine would be 4570 kWh/year.

SOCIAL ASPECTS

As explained in section 4.3.2, wind turbines can reduce the value of a neighbour's property; before placing domestic wind turbines, it is useful to organize discussions with the neighbours, in order to avoid claims.

ENVIRONMENTAL ASPECTS

All environmental aspects connected with such an installation have been treated in section 4.3.2.

SCHEME

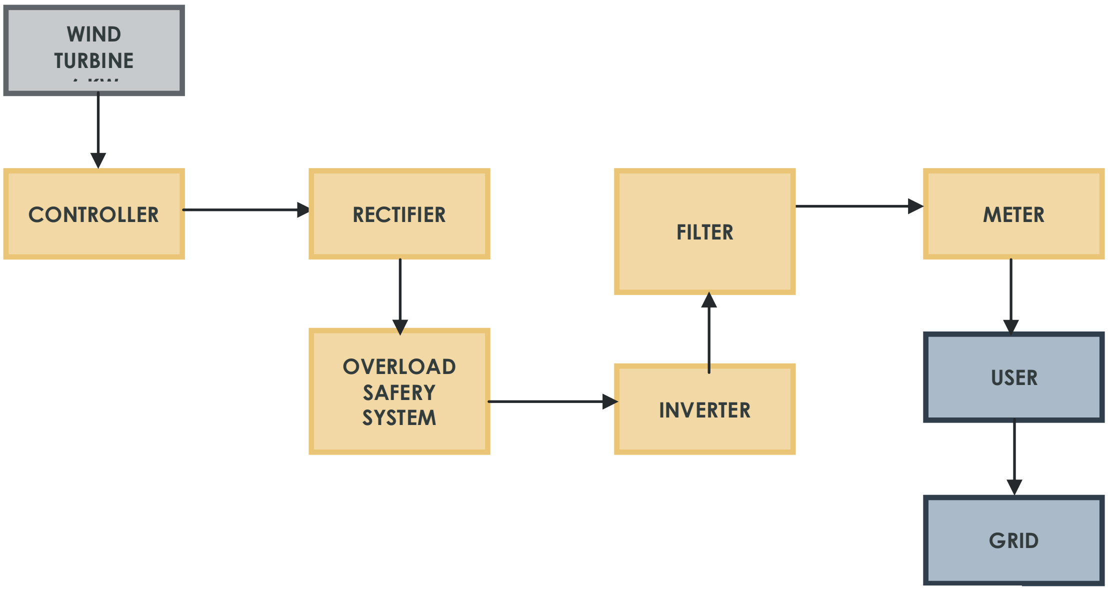


Figure 5.2.2.1_1 Electricity scheme

ECONOMIC ANALYSIS

SOLUTION ANALYSIS

To consider the economical investment of a SWT, many factors have to be known:

- Installation costs
- O&M costs
- Electricity production per year
- Average cost of electricity
- Forecast electricity escalation rate
- Performance derating
- Interest rate (loan)
- Downpayment percentage (loan)
- Debt term (loan)
- Expected lifespan of the turbine

In the case studied, some assumptions have been made, where data was missing or not reliable. The following calculations are for a Bornay 1500 turbine, in an environment like Føns.

Summary of assumptions

Financial assumptions

Downpayment	45000 DKK
Interest Rate (%/year)	**3 %**
DebtTerm (years)	**10**

Site properties

Average Wind Speed (m/s)	7,2
AnemometerHt (m)	100
Wind ShearExponent	0,143
Weibull k	2
Site Elevation (m)	0

Avoided energy costs

Average Cost of Electricity (DKK/kWh)	**2,2**
Nominal Electricity Escalation Rate (%/year)	**0,03**

System costs

Installation Investment + Distribution net (DKK)	**120000**
Installation running annual cost + distr net (DKK/kW)	**400**

System characteristics

RatedPower (kW)	**1,5**
RotorHubHeight (m)	18
Availability (%)	0,98
Performance Margin	0,00%
Performance Derating	10,00%

Hub Height Average Wind Speed (m/s)	5,3
Air DensityFactor	1,00
Average Annual Power Output (kWh)	**4570**
ImpliedCapacityFactor	31%

Figure 5.2.2.2_2 Assumptions

INDIVIDUAL TURBINES			Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
HEATING	Total	Annual cost	2013	2014	2015	2016	2017	2018	2019	2020	2021
Installation Investment	110.000 DKK	5.254 DKK	-46.950 DKK	-7.146 DKK	-6.988 DKK	-6.830 DKK	-6.673 DKK	-6.515 DKK	-6.358 DKK	-6.200 DKK	-6.042 DKK
Annual running + maintenance costs	600 DKK		-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK
Annual electricity revenue	10.357 DKK	+3,00% per year	10.668 DKK	10.988 DKK	11.317 DKK	11.657 DKK	12.007 DKK	12.367 DKK	12.738 DKK	13.120 DKK	13.514 DKK
Initial investment grant	3.000 DKK		3.000 DKK								
Annual grant	0 DKK		0 DKK	0 DKK	0 DKK	0 DKK	0 DKK	0 DKK	0 DKK	0 DKK	0 DKK
ANNUAL CASH-FLOW			-33.882 DKK	3.242 DKK	3.729 DKK	4.226 DKK	4.734 DKK	5.252 DKK	5.780 DKK	6.320 DKK	6.871 DKK
COMPOUND CASH-FLOW			-33.882 DKK	-30.640 DKK	-26.911 DKK	-22.684 DKK	-17.951 DKK	-12.699 DKK	-6.919 DKK	-599 DKK	6.273 DKK

Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
-5.885 DKK	-5.727 DKK	-5.569 DKK	-5.412 DKK							
-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK	-600 DKK
13.919 DKK	14.337 DKK	14.767 DKK	15.210 DKK	15.666 DKK	16.136 DKK	16.620 DKK	17.119 DKK	17.632 DKK	18.161 DKK	18.706 DKK
0 DKK	0 DKK	0 DKK	0 DKK	0 DKK	0 DKK	0 DKK	0 DKK	0 DKK	0 DKK	0 DKK
7.434 DKK	8.009 DKK	8.597 DKK	9.198 DKK	15.066 DKK	15.536 DKK	16.020 DKK	16.519 DKK	17.032 DKK	17.561 DKK	18.106 DKK
13.707 DKK	21.716 DKK	30.313 DKK	39.511 DKK	54.577 DKK	70.113 DKK	86.133 DKK	102.652 DKK	119.684 DKK	137.245 DKK	155.351 DKK

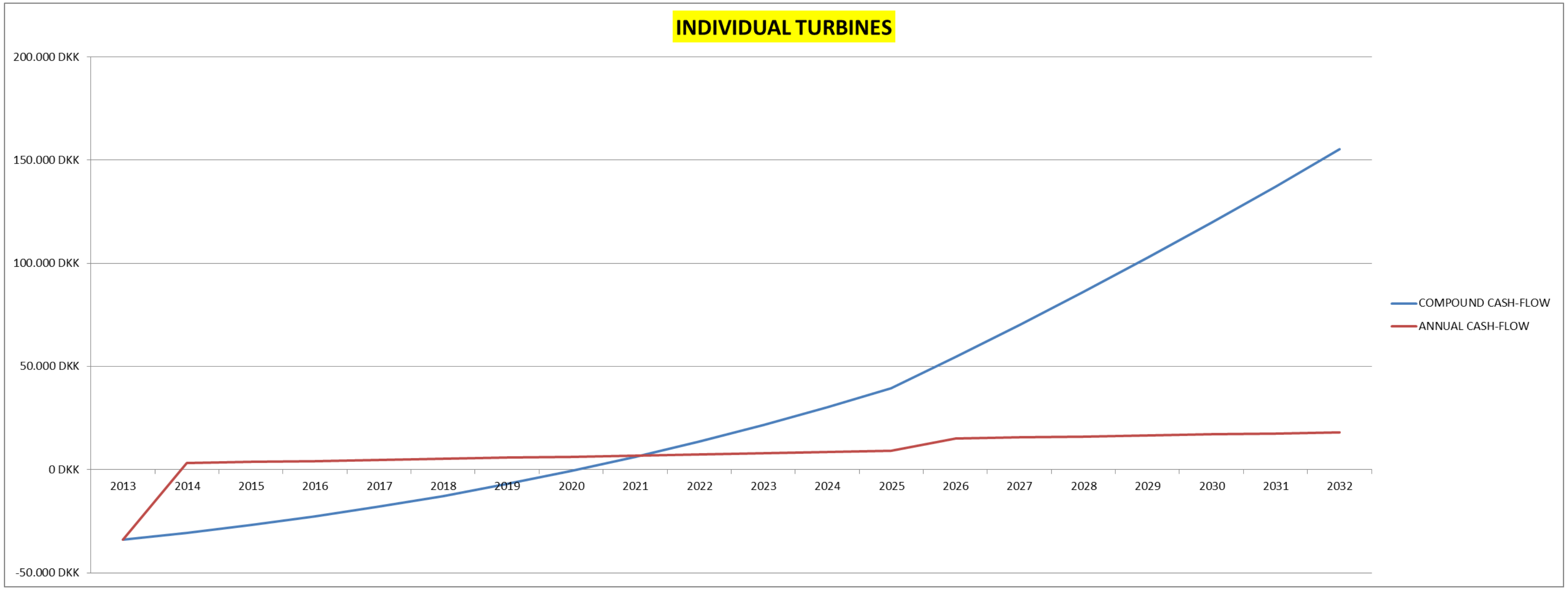


Figure 5.2.2.2_3 Cash-flow

CONCLUSION

Analyzing the economical estimation of the system the following data can be highlighted in order to take it as a baseline for decision-making.

INDICATOR	Small turbine 1,5kW
Initial investment	120.000 DKK
Loan period	13 years
Break-even point	9 years
Profit 10 years	13.843 DKK
Profit 20 years	154.970 DKK
Profitability 10 years	11,5%
Profitability 20 years	129,14%

Figure 5.2.2.2_4 Cash-flow indicators

OPTIMAL PLACEMENT OF SWT

The criteria for an optimal placement of SWT are shown below:

- The distance from the household hasn't to be greater than 30m
- The distance from each house in the neighborhood should be more than 24m, in order to keep the noise emissions under 39 dB
- The turbine should face the prevailing wind (from West) without higher obstacles; if there are obstacles, a good distance should be ensured in order to avoid turbulent regimes. In the map in appendix 7.13 it is possible to see the lines representing the best wind flows, i.e. the ones coming from west and not encountering relevant obstacles.
- The power output is increased if the turbine is placed in higher places; in appendix 7.13 an elevation map has been presented;
- All these maps can be overlaid in order to have a general overview of the optimal location to install SWT.

5.2.2.2. SOLUTION 2: PHOTOVOLTAIC SOLAR CELLS

INTRODUCTION

One of the possible solutions to supply a single household with electricity is a photovoltaic solar cells installation. As explained in the feasibility study, the Danish regulation offers special conditions for the installation of this systems, with special prices for selling and buying electricity; situation that makes this alternative an attractive one.

JUSTIFICATION

TECHNICAL CONSIDERATIONS

The basic installation for an individual solution will be based on solar photovoltaic systems of around 5 kW installed. That means 20 solar panels with a total area of 32,6 m^2. With this technology, and depending on the place where the solar cells are located, almost the whole average consumption of electricity per year could be covered (4.309 kWh/year from 4.500 kWh/year as average needs).

Regarding the location, the roof represents the best place to install them since is the less exposed to shadows and avoids land occupation. As studied in the feasibility phase, the inclination of the panels together with the orientation will determine the final energy output of the system. In this line, after different simulations, the best option is to install the panels at 35° with South orientation. It must be taken into account that in case the panels are installed in the ground, a shadow study should be carried out in order to know how to get as much benefit as possible from the space available.

SOCIAL ASPECTS

For the solar panels, as mentioned in the feasibility study, the energy regulation from 2010 in Denmark (although recently changed to worse economic conditions) made from solar panels an attractive investment, situation corroborated with the rise in the number of photovoltaic installation since 2010.

ENVIRONMENTAL ASPECTS

At this point, it must be said that solar photovoltaic systems do not have a direct environmental impact, due to the fact that they do not produce CO2 emissions in the electricity production.

SCHEME

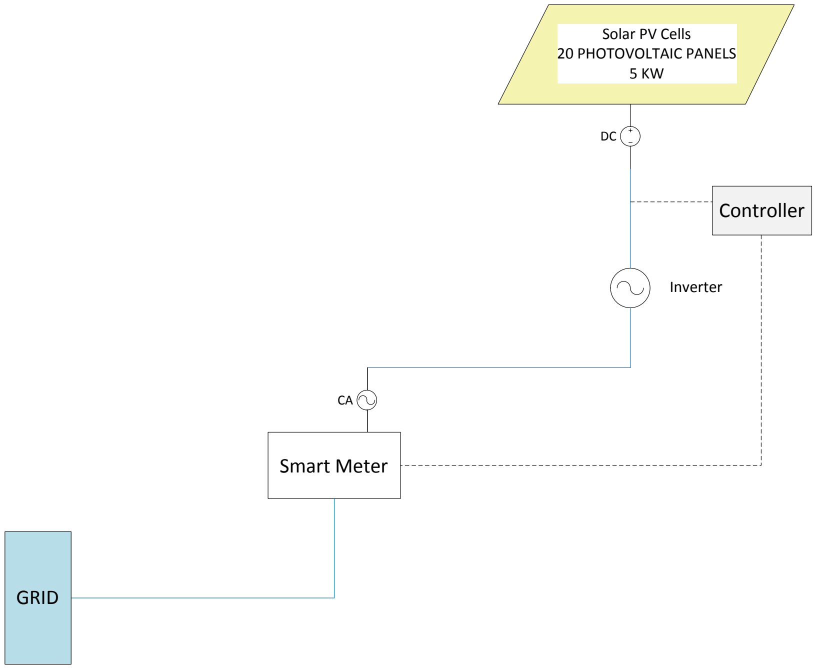


Figure 5.2.2.2_1 Electricity scheme for 5kW individual installation

ECONOMIC ANALYSIS

SOLUTION ANALYSIS

The following results and calculations are basically based on the feasibility study presented previously in the report (section 4.3.1).
As already mentioned in this part all the estimation are dependant from the recent Danish regulation which aims to compare daily the production and the consumption to estimated if electricity should be bought or sold.

In that context, the annual costs of the system (balance between energy to be sold and energy to be bought) have been estimated and are presented in the Appendix 7.10.6.

With the solar installation the costs per year are reduced from 9900DKK to 2020DKK. Due to the inflation of the electricity costs (3.00% each year) and the change of selling prices after 10 years (0.6DKK per kWh instead of 1.3DKK) the costs per year reach 7712DKK after 20 years while without the installation 17360DKK would be spend to provide electricity to a house.
The annual maintenance costs are considered increasing through their lifetime, starting at 375DKK per year, then 750DKK/year after 5 years to finally reach 1000DKK/year after 10years.

The initial investment is, once again, based on the assumptions made in the section 4.3.1 and are presented in the table below.

DESCRIPTION	COST (DKK)
20 Panelsmodel "Alex-Solar" 250W Monocristaline	45.001 DKK
1 Inverter model Danfos TLX 6000	7.077 DKK
Installation and connection (10%)	5.207 DKK
Total installation cost	57.286 DKK
GC+IB (9%+6%)	8.593 DKK
Total cost	65.880 DKK
VAT (25%)	16.470 DKK
TOTAL	**82.350 DKK**

Figure 5.2.2.2_2– Initial investment for an individual installation of 5kW

Thanks to all the data mentioned before it's now possible to evaluate the pay-back period and benefits from this installation. The cash flow of this solution is presented in Appendix 7.10.10.

CONCLUSION

Analyzing the economical estimation of the system the following data can be highlighted in order to take it as a baseline for decision-making.

INDICATOR	PV individual 5kW
Initial investment	82.350 DKK
Loan period	3 years
Break-even point	Year 4
Profit 10 years	0 DKK
Profit 20 years	72.313 DKK
Profitability 10 years	0%
Profitability 20 years	87,81%

Figure 5.2.2.2_3: Cash-flow indicators

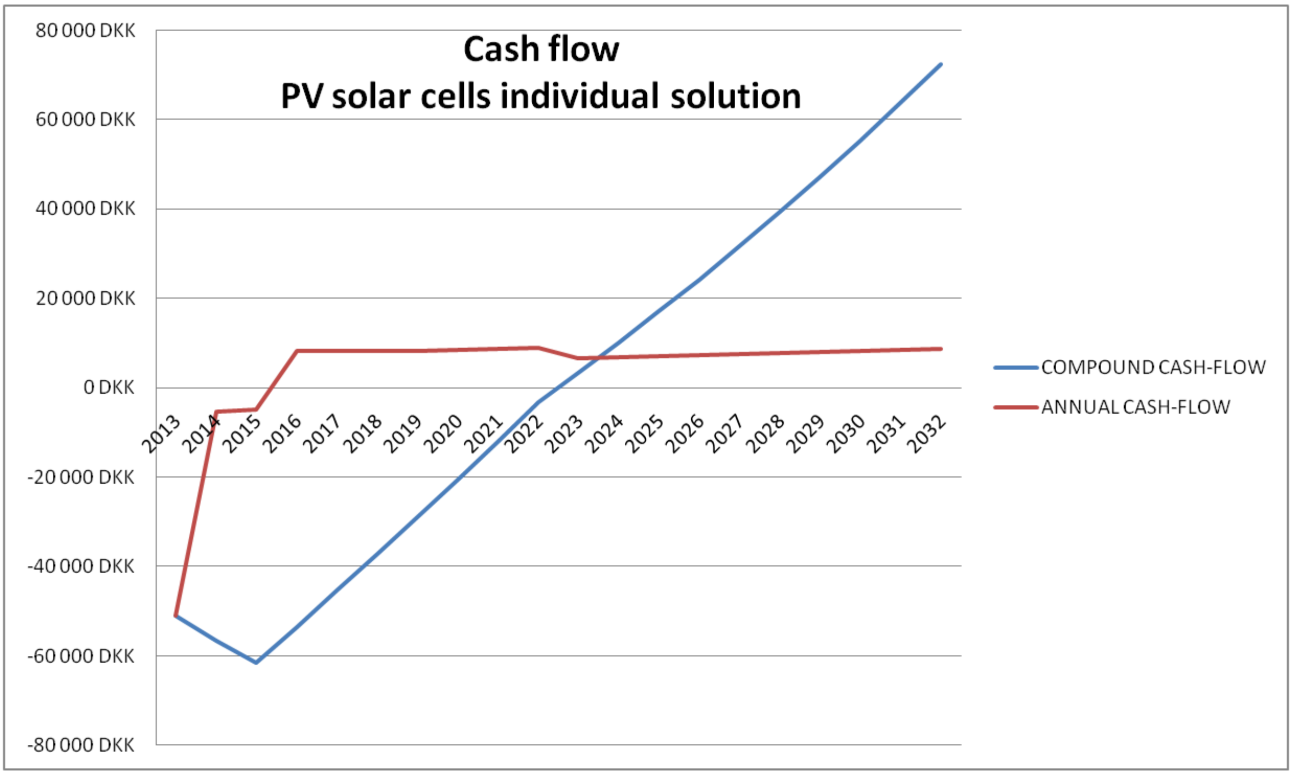


Figure 5.2.2.2_4: Cash-Flow Chart

Those data and the information exposed before highlight some interesting point about the installation of PV solar cells in an individual context.
First of all, it's important to realize that the initial investment is not huge and the money loaned can be return after 3 years paying only around 13000DKK per year (considering 45000DKK available). This amount of money represent around 140€ per month during 3 years meaning a low impact on the economical balance of a family.

From the 4th year, the cash flow starts to be positive meanwhile the cost per year per house reaches 2.413DKK (201DKK per month).

It is here important to realize that the savings after 20 years are not huge (only 72313DKK) but the installation permits to reduce considerably the annual (and so monthly) costs.
After 3 years, this stability permits to keep an annual bill of electricity below 8000DKK representing less than 90€ per month even after 20 years of inflation.

From an economical point of view, this solution appears as a good compromise for all budgets. Indeed, with a low initial investment, it is possible to reduce the annual electricity bill during the 20 years of lifetime of the product. The money saved is not here the main objective and the main advantage of the solution but it's its stability through the time that can be more interesting.

5.3. DISTRICT HEATING NETWORK

INTRODUCTION

In this part of the report, a feasibility study for the District Heating Network (DHN) will be performed. The DHN will go from the plant to each of the potential consumers. The sustainable planning of a heating plant does not make sense nowadays without the conception of a DHN. The design and the economic analysis will involve the connection to the grid of each of the consumers as well as the grid dimensioning regarding the output of the designed plants studied in each of the scenarios that will be developed later on. However, before starting, some assumptions must be done:

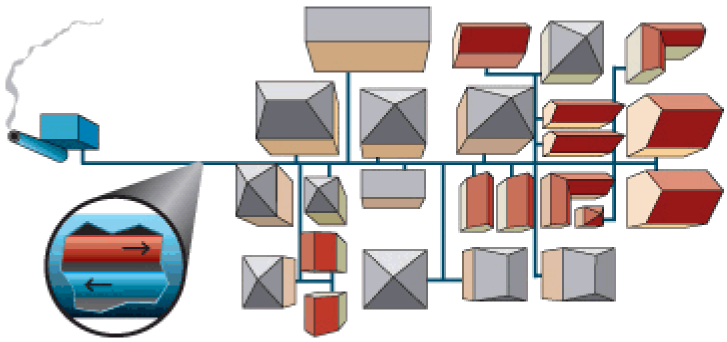


Figure 5.3_1: District Heating Scheme (Swedish Energy Agency, 2011).

ASSUMPTIONS

- The grid will be common for the corresponding scenarios that require common District Heating (DH).
- The proposed DH will full cover all the heating and hot water demand for the 71 dwellings studied.
- The location of the plant is the one shown in the map provided at the end of this part and it respects all the environmental and Urban Planning restrictions considered in the Urban Planning. See Appendix 7.1.
- The Price of the land for the plot where the plant will be located has been considered 9,75 DKK/m^2 (Universidad de Santiago de Compostela, 2008). The surface of the plot has been considered in each scenario since the land needed is different from one to other. So in this chapter the price is not considered.
- The location of the plant will be common for all the scenarios that require DHN:
  - Ground source heating
  - Straw without Cogeneration
  - Cogeneration + Wood Chips / Biomass
  - Ground source + Biomass (CHP)
  - Solar thermal + Biomass
- The plot will house the electricity generation system in case the scenario requires it. So, it will be needed in the following scenarios:
  - Scenario 2 (Biomass + Solar Energy + Wind Energy)

    - Scenario 3 (Biomass + Cogeneration + Solar Energy + Wind Energy)
    - Scenario 4 (Ground Source Heating + Biomass CHP + Solar Energy + Wind Energy)
    - Scenario 5 (Solar thermal + Biomass + Solar Energy + Wind Energy)

  This makes bigger the area required for the location of the plant. It is assumed that the selected area is big enough to house all the required installations.
- As 4 scenarios with different types of System Heat Generation (Fuel) must be considered, it has been assumed that this factor has not conditioned the choice nor the design of the DHN. The output that comes from the plant has been established to 639 kW (see appendix 7.4) and this will be the starting point.
- In this chapter one District Heating Net will be designed:
    - The implementation of a collective heating system is the aim.
    - The study includes a simple design and the economic study of the collective District Heating and the individual connection to each potential consumer.
    - The individual connection for each consumer has been considered as 4 m length and applicable to all the cases so as to simplify the study.
- While designing the grid and the cross section the following restrictions and conditionings have been taken into account:
    - Water quality assumptions: it is assumed that the water in Føns fulfills the required parameters (Danfoss, 1995):
        - Conductivity max 10 µS/m
        - pH-value 9-10
        - Hardness 0,1 tH°
        - Appearance: clear and sediment free
        - O2: 0,02 mg/liter
    - Water pipes assumptions:

      The DHN should follow in all the length the rainwater and the sewage pipes, because these two types of pipes should be taken into account for the design. As just a site plan of the current status is available with no information about the cross section and the depth, the designed grid does not have taken into account this conditioning.
    - Regarding the water supplying pipes, necessary for the connection assumptions for the plant and for the design, no information is available, but it is noted that as the previous point, it should be taken into account. The same happens with the next services supplying:
        - Electricity grid and transformation centers and public lighting.
        - Gas grid, although in Føns there is not a gas grid located.
        - Telecommunication grid and pipes.
- To make an idea about the cross section of the design, a picture is given:

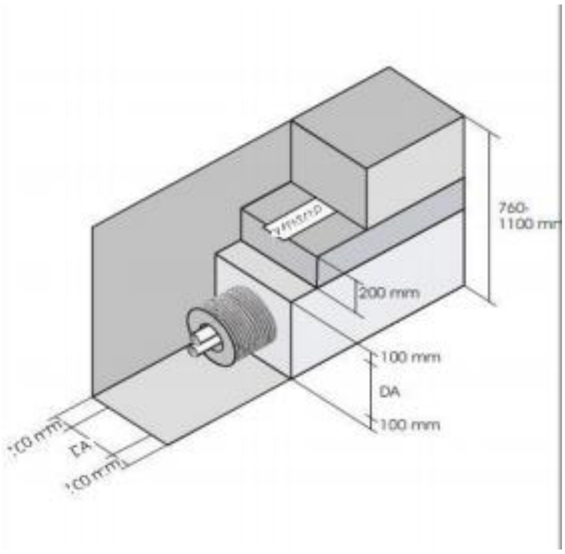


Figure 5.3_2: District Heating pre-insulated pipes cross section (Flexenergy, 2011).

- For the proposed design, the technical aspects, the economic aspects, the regulations and social aspects and the environmental considerations will be studied.
- The installation costs involve the labor hours.

OPTIONS CONSIDERED

- As it is studied in the Appendix 7.14 about District Heating, exists the possibility for retrofitting and implementation of Low temperature District Heating in the future, however the proposed system is designed on the traditional district heating systems. The reason for this is that the houses where the LTDH system would be implemented need to meet Denmark's low-energy house Class 1 rating. The houses in Føns are older and would require a certain level of retrofitting to meet the minimum efficiency levels required for the implementation of LTDH system.

- In each dwelling will be located a small sub-station that will involve together the heating installation and the domestic hot water. A very simple connection has been considered since there are not big houses.

JUSTIFICATION

DESIGN AND TECHNICAL CONSIDERATIONS

The designed grid is a very small one, taking into account that the design guidelines state that the DH lines lie between 40 to 60 MW (Danfoss, 1995). Besides, the local heating plant should be connected either to a bigger CHP plant or to a supporting electric standby boiler that would be used only at peak demands and at operational break downs and maintenance moments of the existing plant. However, it has been considered that in case the plant stops working when maintenance works are needed or damage of the system occurs a provisional supplying system will be contracted.

- The following DH Distribution Net system has been proposed. The corresponding plan is given at the end of this chapter but now a scheme is provided. Later on, the working conditions of the grid are given:

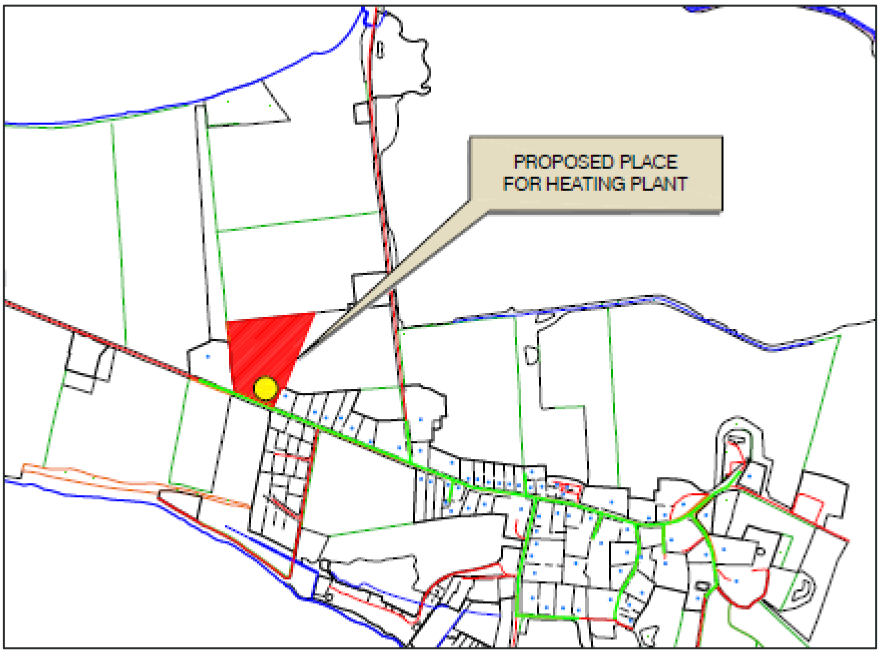


Figure 5.3_3: Proposed District Heating floor plan. In green it is highlighted the network

  - Total length – 2.435,4 m. Considering the following estimated distances:
    - Main branch – 1.130,5 m
    - Sub-branches – 83,1 m; 41,9 m; 45,4 m; 353,1 m; 54,1 m; 194,5 m; 56,8 m; 182 m.
    - Individual connections – 71 dwellings * 4 m = 284 m
    - Plant connection – 10 m
  - The flow/supply temperature has been considered 80°C (PlanEnergi, 2012). Being the operating minimum temperature level required of 70°C for Denmark (IEA, 1999).
  - The return temperature has been considered 40°C (PlanEnergi, 2012) Being the minimum operating temperature level required of 40°C for Denmark (IEA, 1999).
  - The proposed grid establishes a heat loss in the network of about 15-16% on an annual basis (PlanEnergi, 2012).
  - The considerations about the static pressure and the dynamic one that must be at least 150 kPa have been assumed to be achieved with the selected type of circulating pump (Danfoss, 1995).

The DHN as a whole has three main parts: the heat generation plant, the distribution network and the individual connection to the consumers. At this point, the projected systems and equipment for each of those parts will be provided together with the technical aspects and costs considered:

- Central Source/Production Plant
    - Power output – 639 kW (Appendix 7.4)
    - Heat exchangers (have already been considered in the study of alternatives).
    - Accumulator/Buffer tanks (have already been considered in the study of alternatives).
    - Boiler (has already been considered in the study of each of the alternatives).
    - Peak and standby boilers
      In case the plant stops working due to maintenance or damage of the system a provisional supplying system will be contracted. Anyway, an exhaustive maintenance system will be performed continuously in the plant so as to avoid break downs.
    - One circulation pump is needed to ensure the required flow and pressure in the whole circuit. The main technical features are described in the District Heating Appendix 7.14:
        - Annual maintenance cost – 284 DKK (Cype, 2012)
        - Installation cost – 111.907 DKK

- Principal Distribution Network
  The specifications are the ones described in Appendix 7.14 about District Heating in the part of design guidelines and prices. Summarizing tables are provided below:
  The prices are estimated according to the Danish price level in 2013, which have included Danish labor cost, Danish installation methods and Danish materials (Price book 2013).

HEAT DISTRIBUTION NETWORK COST				
MATERIALS				4.161.060 DKK
District heating pipes ø60,3/140 mm	2151	1780	3.828.780 DKK	
District heating pipes ø60,3/140 mm	284	1170	332.280 DKK	
INSTALLATION COST				743,070 DKK
District heating pipes ø60,3/140 mm	2151	290	623.790 DKK	
District heating pipes ø60,3/140 mm	284	420	119.280 DKK	
TOTAL COST				**4,904,130 DKK**
Annual maintenance cost	1%		4,904,130 DKK	**49.041 DKK**

Figure 5.3_4: Cost estimation for heat distribution network.

- Individual System/Consumer system. In-building equipment:
  The estimated cost for individual mix arrangement system with double shunts has taken into account all the equipment, in relation to operation with district heating and hot water supply.

The prices are estimated according to the Danish price level in 2013, which have included Danish labor cost, the Danish installation methods and Danish materials (Price book 2013).

INDIVIDUAL SYSTEMS					
EQUIPMENT / MATERIALS COST					986.900 DKK
Hot water tank 200 liter incl. Valves, pipes etc.		71	13.900	986.900 DKK	
INSTALLATION COST					663.850 DKK
Hot water tank 200 liter incl. Valves, pipes etc.		71	3.800	269.800 DKK	
Electric installation	71*10	710	555	394.050 DKK	
TOTAL COST					**1.650.750 DKK**
Annual maintenance cost		1%			**16.507 DKK**

Figure 5.3_5: Cost estimation for individual systems.

After studied all the elements of the DHN, an economic study is done:

ECONOMIC ASPECTS

For this analysis, it will be taken into account the technical feasibility of installing and running the system, considering the previous proposals. An estimated budget for the installation cost and the annual maintenance will be added. Gathering all the costs exposed before, the following table is provided:

DESCRIPTION	COST (DKK)
Circulation Pump (SE 500-70-16)	111.907
Distribution Network	4.904.100
Individual Systems	1.650.800
Total Installation Cost	6.666.807
GC+IB (9%+6%)	1.000.021
Total cost	7.666.828
VAT (25%)	1.916.707
TOTAL	**9.583.535**

*Some values have been round up since it is a rough analysis.

Figure 5.3_6: Investment costs.

DESCRIPTION	ANNUAL MAINTENANCE COSTS (DKK)
Circulation Pump (SE 500-70-16)	284
Distribution Network	49.000
Individual Systems	16.500
Total Installation Cost	65.784
GC+IB (9%+6%)	9.868
Total cost	75.652
VAT (25%)	18.913
TOTAL	**94.565**

**Electricity consumption considered in annual maintenance costs.*

Figure 5.3_7: Annual maintenance costs.

Apart from those previous tables, now are provided the costs for each consumer:

DESCRIPTION	COST (DKK)
Total Initial Investment per House Installation	**33.423**

*The data per consumer only considers the individual installation per house, taxes included.

Figure 5.3_8: Individual Investment costs.

DESCRIPTION	ANNUAL MAINTENANCE COSTS (DKK)
Maintenance per Consumer	**334**

*The data per consumer only considers the individual installation per house, taxes included.

Figure 5.3_9: Individual annual maintenance costs.

The economic considerations have basically taken into account the cost of the initial investment and the maintenance costs yearly. The annual electricity consumption will be included in the maintenance costs. This cost includes the electricity consumption to run the circulation pumps, the individual electric systems and the accumulator.

It must be bear in mind that this solution is common to all the scenarios involving common heating that will be developed in the following chapters of the report.
Other economic consideration could be the marginal cost for District Heating production (DKK/MWh) which varies between seasons. This might make a change in the tariffs with seasonal difference that some municipalities in Sweden apply. There can appear three typical season levels (Sköldberg, 2009).

- Winter: 160 % of yearly average
- Autumn/spring: 75 % of yearly average
- Summer: 30% of yearly average

However, having a low marginal cost can have some negative consequences (Sköldberg, 2009):

- Loss of economic optimization due to excessive energy savings.
- The price for the district heating could be increased so as to cover costs.

SOCIAL ASPECTS

Before following, some barriers to DHN deployment will be mentioned (Pöyry, 2009):

- Economic barriers due to Project risks and costs.
- General Institution issues.
- Carbon price that is not taken into account in the traditional heating systems.

On this section, all the actual regulations will be taken into account in order to evaluate if it is legally feasible to execute the project. Furthermore, the existence of grants and governmental support will be studied, providing a more favourable scenario so as to carry on the investment.
The main problem appears with the restrictions because of the closeness to the coast and because the project is developed on a rural area. However, it has been considered that as the service will improve the well-being of the area and it enhances sustainability since final environmental consequences are positive for the town, the project is feasible.
Besides, taking notice of other similar projects, this feasibility is more justified. This could be the next case studied:

<u>Similarities with DH in Onsbjerg (Samsø)</u>

Taking as a close example the case of the District Heating station in Onsbjerg in the island of Samsø that was executed for about 80 houses, there is the possibility to extrapolate and apply the results to the present project. It was executed with biomass plant of straw heating. The initial costs were about 8,5 million DKK and the Danish Energy Authority gave a grant of 3 million DKK (Jørgensen, 2007).
Administratively, the plant is run of by a group of 8 people gathering members of the company in charge of the plant, city council and consumers. Moreover, changes in the heating price must be checked and approved by the city council (Jørgensen, 2007).
Regarding connection fee, the model introduced by NRGi was used. This model makes inexpensive to sign up for the district heating before the plant is constructed, paying just 80 DKK as a registration fee. It is different to the traditional Danish model which applies high registration fees. Nevertheless, a negative consequence of this model is the higher heating price, although the payment is favourable in comparison to the elevate costs of heating by oil or electricity (Jørgensen, 2007).

ENVIRONMENTAL ASPECTS

The District Heating deployment has several advantages for the different agents involved in the process such as promoters, consumers and society in general, not only regarding environmental aspects, but also economic and social, what makes a more sustainable use of the heating resources (Esen, 2008).

- Execution time and costs are reduced since the trenches for the water supplying pipes are used for the DHN and also because of the substitution of boilers in each dwelling with one common plant.
- The access to grants is possible.
- Operative and maintenance costs of the installations are reduced.
- The installed capacity and the fuel consumption is reduced in each dwelling.

- It is not necessary storing fuel in the buildings.
- It reduces noise pollution in buildings.
- It improves global energetic efficiency.
- It reduces the emission of CO_2 and GHG.
- It allows the use of Renewable Energies for the heating production at the same time that allows the cogeneration, what improves the energetic efficiency of the system.

CONCLUSION

Finally, it can be said that the execution of the District Heating Network is feasible after having studied the previous points. Indeed, this values and studies are not exact, but they are very close to reality.

The economic data values are summarized to end this part:

Summarizing the previous calculations, here are provided the initial investment costs (in total and per consumer) and the maintenance costs (in total and per consumer):

DESCRIPTION	COST (DKK)
Total Initial Investment (without land)	**9.583.535**

*This value has just included the installation costs and the taxes. Not land cost included.

Figure 5.3_10: Investment costs.

DESCRIPTION	ANNUAL MAINTENANCE COSTS (DKK)
Total Initial Investment (without land)	**94.565**

*This value has just included the installation costs and the taxes. Not land cost included.

Figure 5.3_11: Annual maintenance costs.

DESCRIPTION	COST (DKK)
Total Initial Investment per House Installation	**33.423**

*The data per consumer just considers the individual installation per house, taxes included.

Figure 5.3_12: Total Initial Investment per House Installation.

DESCRIPTION	ANNUAL MAINTENANCE COSTS (DKK)
Maintenance per Consumer	**334**

*The data per consumer just considers the individual installation per house, taxes included.

Figure 5.3_13: Annual maintenance costs per House Installation.

5.4. COLLECTIVE SCENARIOS

5.4.1. SCENARIO 1: GROUND SOURCE HEATING AND WIND TURBINE

INTRODUCTION

This scenario based on collective measures, will provide Føns with heat and electricity exclusively from natural inputs.

Concerning heat demand a collective ground source heating system has been selected. To be able to work the heat pump of the system needs electricity and heat. The heat is provided thanks to solar panels and deep boreholes and the electricity necessary for the heat pump to run is supplied by the collective wind turbine. Finally, the need of electricity for the whole village is provided by the wind turbine.

JUSTIFICATION

TECHNICAL CONSIDERATIONS

HEATING INSTALLATIONS

That scenario requires a heat pump with a COP of 4,5, 160 boreholes deep of 100 meters with a distance of 3 meters between each, in order to limit loss in the soil during the storage, according the following scheme. Moreover the borehole will be supplied by the heat collected by 20 solar collectors of 48m² each, oriented in south with an inclination of 35°. For more details see section 4.2.2.
The total area of plot required is around 2800 m²; the cost per square meter has been calculated on section 5.3 of this report.

ELECTRICITY INSTALLATTIONS

The wind turbine SWT-2.3-93, 2.3 MW and 93 m of rotor diameter, is the one selected to supply electricity for Scenario 1. The bases of the technical considerations are reflected in section 4.3.2. and for further information Appendix 7.9.

The output of the turbine was established in 7.679,356 MWh for an average wind speed of 7.2 m/s.

SOCIAL ASPECTS

HEATING INSTALLATION

The main problem with that scenario is the huge plot which concentrates many square meters of solar panels and another one with the collective wind turbine. The natural landscape can lose beauty, especially in touristic place as Føns.

Moreover, the collective measures propose by that scenario can be rejected by people which prefer manage their own installations in order to control it. The point is a collective solution is always cheaper, especially for a ground source heating and a collective heat pump, referred to the different alternatives: "Group Project 1, Ground Source Heat Pump, Economic analysis".

ELECTRICITY INSTALLATION

Social aspects have been considered during the entire study. From the report done in Group Project I to the section 4.3.2 developed on phase 1. It must be highlighted the distances, noise and subsidies consideration, all the information is gathered in the section 4.3.2. already mentioned and more in detail in Appendix 7.6.

ENVIRONMENTAL ASPECTS

HEATING INSTALLATION

Concerning the collective heating installation, the main environmental aspect is the amount of land occupied. Indeed, 160 boreholes spaced of 3 meters between each, and 960m² of panel solar require a field of at least 2800m², without counting the building to place the collective heat pump which should be about 100 meters.

Moreover, the soil removed is so important (100 meters of depth on 1500m²) that the propriety of the land will be affected as much on the flora as on the fauna.

Nevertheless, for this collective measure, the different protective areas around Føns have been taken into account to implement the borehole, and the solar collectors. Moreover, that scenario is by far the one which consumes less energy compared to others. Also it has to be said that scenario is the one which requires the less energy, especially when it is combined with wind turbine, the amount of energy collected is even more important than the needs.

PLANT DESIGN

For the design of the site, some factors have been taken into account:

- The building of the heating plant which needs to be near the road and to the district network.
- The solar thermal collectors which use at least 960 m² of the total plot.
- Enough plot surface to drill 160 boreholes. The boreholes, as it was explained before, will be 3 meters spaced among them and they will be disposed generating a compact grid in order to achieve less heating losses.

The figure below shows the plant design for the plot.

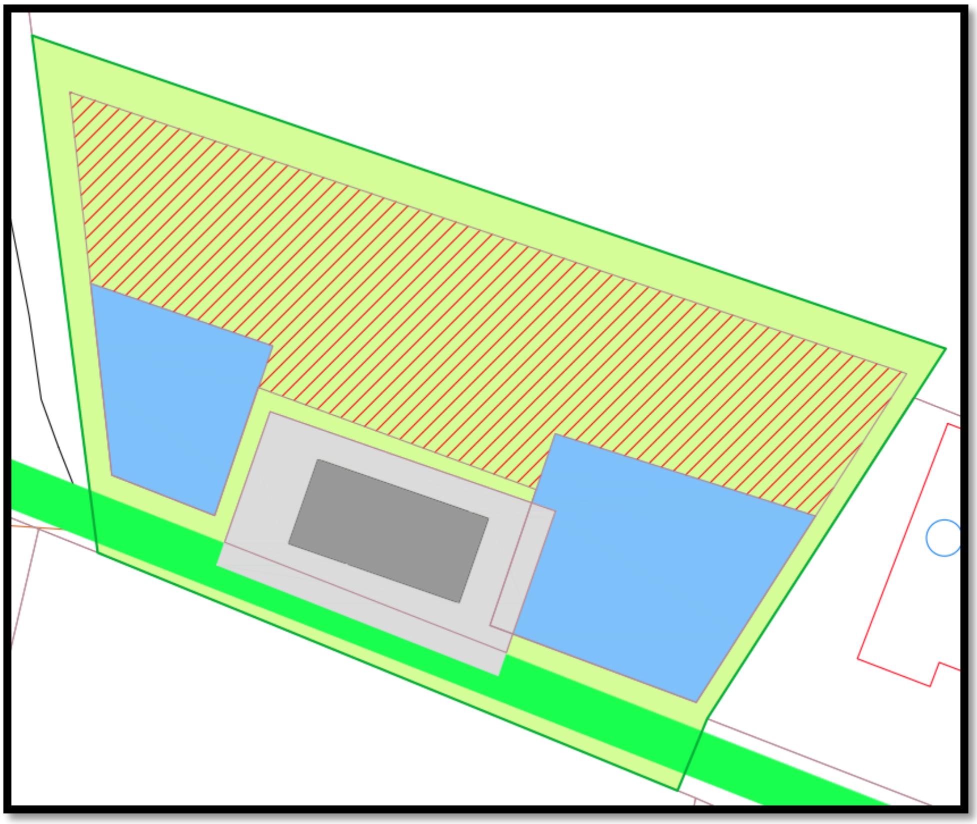


Figure 5.4.1_1: Plant design Scenario 1

Boreholes

Building

Communication road

Solar thermal collectors

ELECTRICITY INSTALLATION

As for the social considerations, the environmental aspects have been considered for the development of the wind turbine project. The location of the turbine developed in section 4.3.2. takes into account all possible natural variables. For further information see Appendix 7.5.

SCHEME

HEATING SCHEME

Concerning the heating scheme, all the collective devices have to be on the same plot, in order to avoid the distance between the different connections which lead to loss of heat and an increasing of price. The plot is at least 2800m², without the collective wind turbine which will be out of Føns area. To implement the boreholes spaced of 3 meters between each, a square of 17 boreholes per 17 boreholes has been considered to optimize the space; nevertheless, this parameter can be modified depending on the shape of the field.

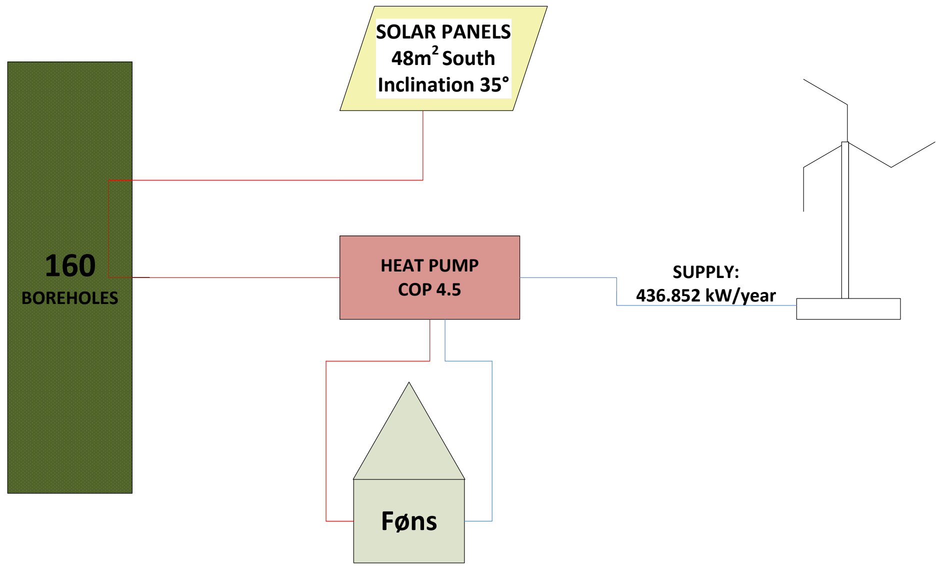


Figure 5.4.1_2: Scheme proposal for the ground source heating of the scenario 1.

ELECTRICITY SCHEME

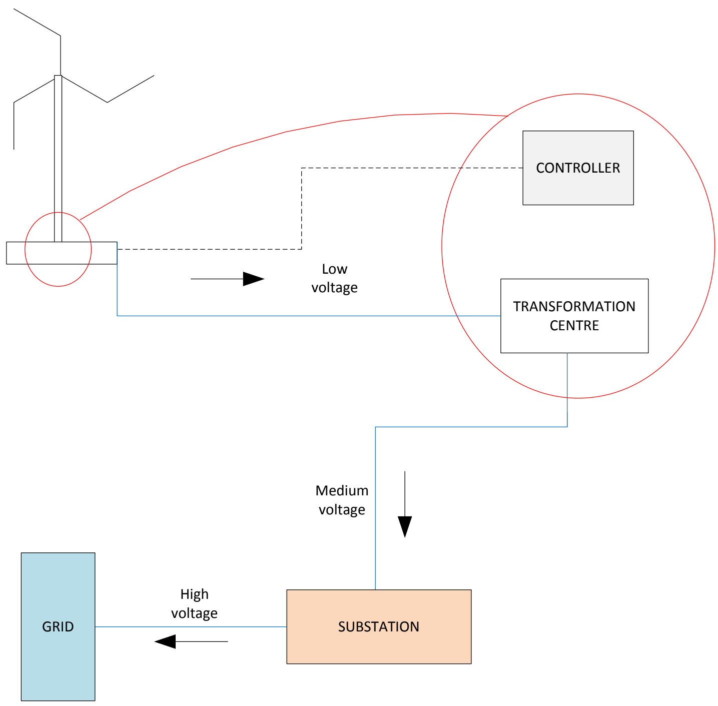


Figure 5.4.1_3 Scheme of the electricity flow from the wind turbine to the grid.

Wind energy has the characteristic of not being able to store in big quantities. This is way the energy generated must be consume and so wind turbines have to be connected to the net/grid. It depends on the way taken to connect the turbine to the grid, design and route change. However, every wind farm actually is composed by the following installations (Ayuntamiento de durcal, n.d.):

- **Transformation centre**: the low voltage wiring is the internal installation of the turbine to elevate the voltage from low to medium, from 690 V to 20 kV.
- **Substation:** It transforms the medium voltage power generated in the wind farm to high voltage power needed for the grid connection, from 20 kV to 132 kV
  The most common typology of substation is a prefabricated mix structure that will need the refurbishment of the placed selected to locate it.
- **Underground network of medium voltage**: it connects wind turbine among them and with the substation. As the project only is design for one wind turbine the underground medium voltage network connects the wind turbine with the substation. This section must be taken into account in case of enlargement of the project.
  The trench designed to contain the wiring has an average width of 60 cm and an average deep of 100 cm.
- **Grounding:** each wind turbine must be provided of a specific trench for the grounding. It measures 100 cm deep and 40 cm wide.

ECONOMIC ANALYSIS

COMMON INSTALLATION: DISTRICT HEATING AND BUILDING

The district heating installation has been studied in the Appendix 7.14 of this report; the following data represents a summary of the initial investment and total annual costs.

Annual land rent – **44.850 DKK/year**

Land requirements – 4.600 m^2.

Land rent price – 97.500 DKK/Ha per year

Annual running costs – **94.565 DKK/year**

Total investment – 9.583.535 DKK

DESCRIPTION	COST (DKK)
District heating investment	9.583.535 DKK
TOTAL	**9.583.535 DKK**

Figure 5.4.1_4: Initial investment for the common district heating installation

HEATING INSTALLATION

The district heating installation has been studied in the previous sections (section 5.13 and section 7.8) of this report; the following data represents a summary of the initial investment and total annual costs.

Annual consumption costs – **959.415 DKK/year**

Annual consumption – **2.231.600KWh/year**

Fuel cost – **489 DKK/MWh** (estimated yearly variation 3%)

Annual maintenance cost – **10.000DKK**

Installation cost – **14.836.161,00 DKK**

DESCRIPTION	COST DKK
Heat pump	1.641.301DKK
Tank and installations (200 m^3)	223.813 DKK
Pumper and water treatment	74.604 DKK
Oil boiler and tank	373.023 DKK
Electrical installation	74.604 DKK
Solar collectors	1.425.000 DKK
Boreholes (storage and heat pump source)	10.800.000 DKK
Building (100 m2 * 400 euro/m2)	223.813 DKK
TOTAL	**14.836.161 DKK**

Figure 5.4.1_5: Heating installation cost for GSHP

ELECTRICITY ANALYSIS

The following chart reflects the investment needed for developing the wind turbine project:

Annual energy production – **2.687.774 DKK**

Annual maintenance cost – **430.500 DKK/year**

Installation cost – **24.600.000 DKK**

DESCRIPTION	COST DKK
Installation	18.900.000 DKK
Foundation	1.400.000 DKK
Road Access	600.000 DKK
Internal Net	300.000 DKK
Land	1.000.000 DKK
Project Development	900.000 DKK
Financing Cost	600.000 DKK
Nearby Compensation	100.000 DKK
Scrap	800.000 DKK
TOTAL	**24.600.000 DKK**

Figure 5.4.1_6: Electricity installation cost

COMMON SOLUTION ANALYSIS

Initial investment

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
District heating	9.583.535 DKK	134.979 DKK
Heating installation	14.836.161 DKK	208.960 DKK
Electricity installation	24.600.000 DKK	346.478,87 DKK
TOTAL	**49.019.696 DKK**	**690.418 DKK**

Figure 5.4.1_7: Initial investment for the common solution

Annual running costs

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
HEATING INSTALLATION		
Land renting	44.850 DKK	632 DKK
HEATING INSTALLATION		
Annual consumption heat pump	961.074 DKK	13.536 DKK
Maintenance costs	79.453 DKK	1.120 DKK
ELECTRICITY INSTALLATION		
Annual consumption Føns	702.900 DKK	9.900 DKK
Maintenance costs	430.500 DKK	6.063 DKK
TOTAL	**2.201.227 DKK**	**31.003 DKK**

* A yearly variation for the cost of the electricity of +3% until 2020 is considered.

Figure 5.4.1_8: Annual running cost for the common solution

Annual production benefits

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
ELECTRICITY INSTALLATION		
Annual production	2.687.774 DKK	37.855 DKK
TOTAL	**2.687.774 DKK**	**37.855 DKK**

* A yearly variation for the heating costs with traditional fuels of +3.00% is considered.

Figure 5.4.1_9: Annual production benefits for the common solution

CONCLUSION

INDICATORS

The following economic indicators referred to the investment have been selected in order to compare all the scenarios proposed on the conclusion section of this report (see section 6.1).

INDICATOR	VALUE
Initial investment	690.418 DKK
Loan period	20 Years
Break-even point	12 Years
Profit 10 years	-21.847 DKK
Profit 20 years	276.996 DKK
Profitability 10 years	-3.2%
Profitability 20 years	40.1%

Figure 5.4.1_10: Cash-Flow indicators

GRAPHICS

The following graphics represent the evolution of the investment during the life period of the system.

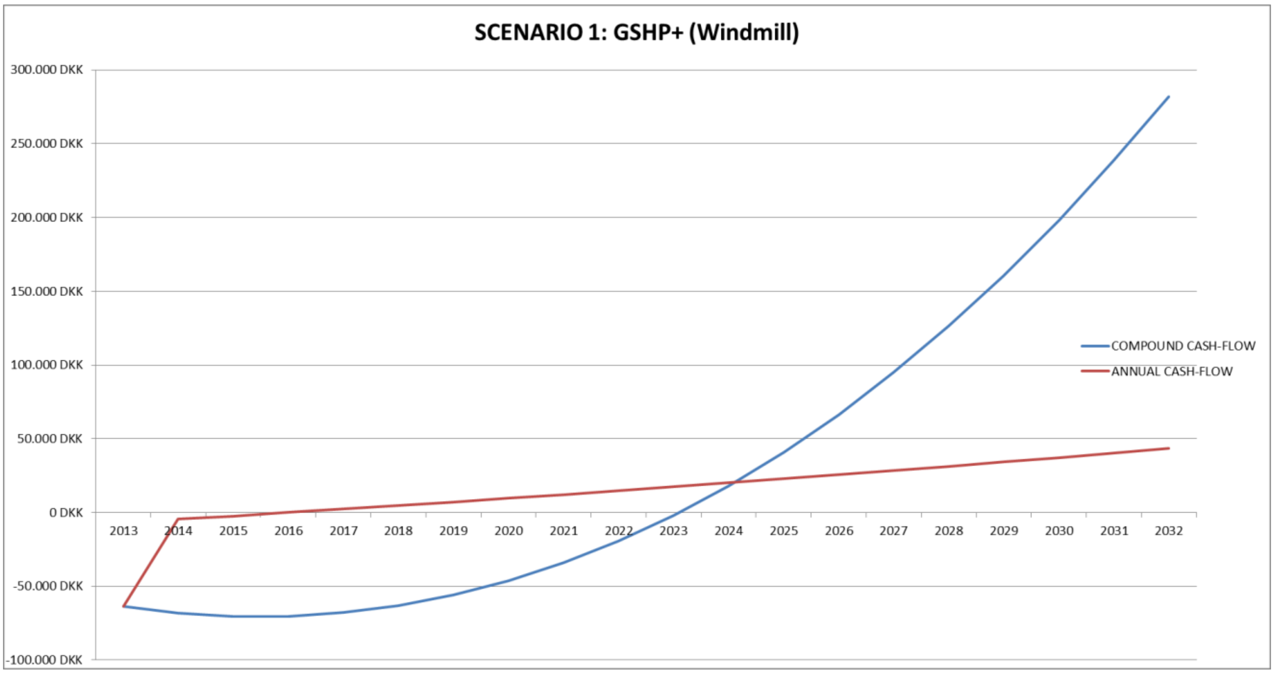


Figure 5.4.1_11: Cash-Flow

5.4.2. SCENARIO 2: STRAW BOILER WITH SOLAR PV AND SWT

INTRODUCTION

On this scenario the feasibility of the implementation of a district heating solution combined with a mixed electricity generation system will be studied. This solution will consist on the following installations:

- A district heating installation for the 71 houses proposed, this installation has been studied in the section 4.2.1 of this report.
- The heat production will be supplied by a straw boiler installation, which will produce the 100% of the heat requirements.
- The electricity production will be supplied by a mixed system combining solar photovoltaic cells and Small Wind Turbines; this combination will provide the 100% of electricity requirements.

JUSTIFICATION

TECHNICAL CONSIDERATIONS

COMMON INSTALLATION

The main considerations taken on the whole installation refer to the district heating distribution net, all these considerations have been explained previously on this report in section 5.3.
The considerations taken respecting the design of the plant are concerning the main volumes of building needed. As on this case the heating installation will require a covered storage area, there will be considered two industrial constructions:

- A closed construction of 200m2 where the heating plant, district heating pumps and communications will be installed. This area will count with a small storage area in order to leave the necessary straw bales for a week of use.
- An opened construction of 200m2 with lower qualities, which will be used to store the required straw bales for a period of a year of use. By having this storage, the straw bales would be bought at a lower price as the producer does not charge storage costs on the price.

The distribution and location of the building on the plot is explained graphically on the following section of this scenario. The total area of plot required is 17.600m2, the cost per square meter has been calculated on section 5.3 of this report.
All the requirements for the electricity production installation have been considered on the design, but a further detailed study will be needed if choosing the solution.

HEATING INSTALLATION

The heating installation has been dimensioned to reach a peak power of 600KW, by the use of a straw boiler, considering the model *HTHW HHF600 "DANSTOKER"*, similar models from other suppliers can be adapted to the solution. The installation will consist on the following elements:

- A conveyor belt with capacity for 7 straw bales, this system has enough capacity to ensure the feeding requirements of one day, considering the most exigent periods of working. The loading of this system will be done daily by the operator of the plant, by using a minilader included in the installation investment.

- An adapted straw boiler, including the multifuel burning system. This installation will have enough capacity for one straw bale, which will be loaded automatically by the conveyor belt feeding system.
  All the electronics and telematics of the system are included in the price. The main computer will operate this boiler automatically.
  The overall performance of the boiler has been estimated as 87%, in the section 4.2.1 of this report.
- An auxiliary gas-oil boiler with a peak power of 125KW will be installed, considering the model *Logano SK 645 "BUDERUS"*. This boiler will be fed by a gas-oil tank of 3 cubic meters. The purpose of this installation is to give support to the main boiler on moments of peak demand, and during the maintenance of the main boiler. The gas-oil tank has been sized to provide enough fuel for the operation of the boiler in one year.
- A heat storage system composed by 4 buffer tanks of 800l, considering the model *PSM 800 "CLIBER-AUSTRIA". The mission of these elements is* to provide enough thermal lag to the system to ensure that the straw boiler works on continuous periods, reducing the starts and stops of the boiler and improving the efficiency.

  The connection of the tanks will be done on parallel permitting the modularity of the storage, so it will adapt easily to de demand of the different seasons (eg. During winter all the buffer tanks will work, while during summer three of them will be closed to reduce loses).
- A central computer will control all the installation; this device will receive data from all the thermal sensors installed on the elements of the internal installation, the measures of the flow in the system and the external temperature. Using this data the software will control the boiler and pumps in order to optimize the performance of the system.
  This system has been considered into the cost of the installation of the boiler.
- All the piping system, including the valves, electro-valves, pumps and connections is considered as a part of the installation, which has been estimated as a percentage of the total costs.

*A performance of 87% will be considered when estimating the total consumption of the boiler. (Plan Energi, 2012)
*The solution has been studied considering the approach of a feasibility study, further calculations and design shall be done to reach more accurate data.

ELECTRICITY INSTALLATION

To supply the electricity needed to the town, a combination of Photovoltaic Panels and Small Wind Turbines has been considered.
As explained in section 7.6, Danish regulation allows net metering policies for turbines under 6kW. The chosen model is a Bornay 6kW SWT, which technical features can be found in detail in section 7.11.
Considering the contribution of the PV panels to the total energy needed, 18 turbines have to be placed.
The prevailing wind direction is West (see section 7.9).

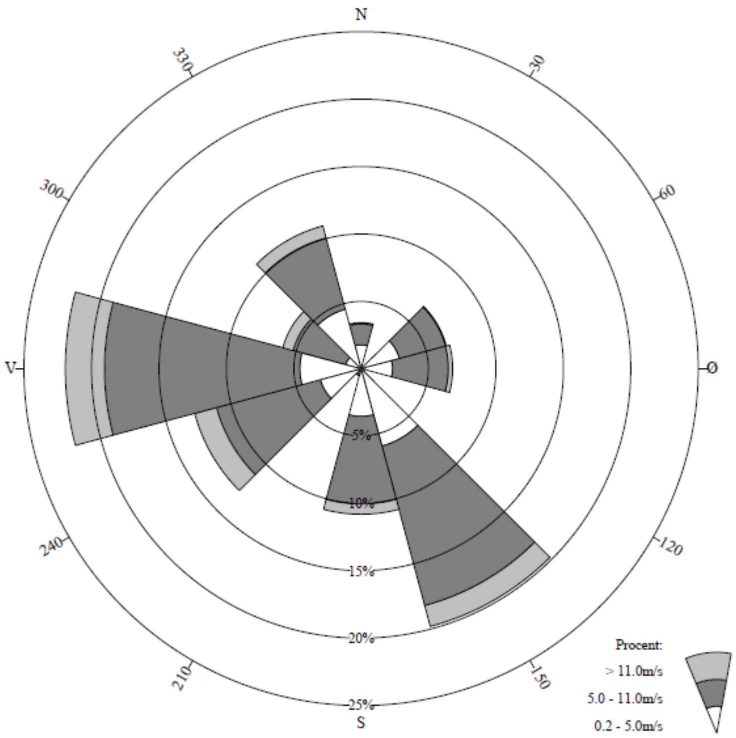


Figure 5.4.2_1: Prevailing wind speeds

For the calculations, monthly average wind speeds have been taken into account. In these conditions (the same reported in section 4.3.2), the power output of a single turbine is 14730 kWh/year.
To connect the turbines to the grid, Aurora 6ke Inverter will be used.
The minimum distance of two consecutive turbines in an array should be 5 times the rotor diameter (in this case 4m) in the direction of the prevailing wind and 3 in the perpendicular direction; the minimum distances will therefore be 20m and 12m.
One important factor is the distance of the turbines from the two buildings; in fact, being those buildings constructed by an association, they are part of the list of "non-commercial buildings" mentioned by the Danish Regulation; that way, it is possible to take profit of the net metering regulation to supply all other houses.

With regards to the solar photovoltaic system, the size of the installation has been determined in order to get profit from the roofs of the two buildings needed. The combined area of the two building is 400 m^2; taking into account this area, and an inclination of the roofs of 30° (technical justification of this inclination is exposed in the feasibility study), the total area covered by the panels will be around 300m2. With these conditions, and using panels of 250w, the total power installed in the roofs is 45kw (each panel has an area of around 1,65 m^2, which will suppose a total amount of 180 panels; for further information about the solar cells see Appendix 7.10.

This power installed will produce an output of 38.600 kwh per year. The distribution of energy output by months, together with the calculations can be checked in the Appendix 7.10.11.

The strength of this solution is based on the fact that selling price for surplus electricity produced by solar cells (1,45 DKK) is higher than the one produced with wind (0,60 DKK). From the legal point of view, buying and selling electricity is a complex procedure, as both systems are not covered by the same regulation. For wind turbines smaller than 6kw, as mentioned before, the net-metering systems is of application, whereas for solar photovoltaic systems, net-metering is based on an hourly-consumption-production scheme; further information will be found in the solar feasibility study.

SOCIAL ASPECTS

COMMON INSTALLATION

The plant location will generate people disagreements due to the proximity of the plant to their house.
The plant construction will affect the surroundings and some services during the execution phase.

HEATING INSTALLATION

The implementation of the straw boiler requires the permission of the local legal authorities in order to integrate the district heating net.

ELECTRICITY INSTALLATION

The installation of 18 SWT of 20m height can certainly imply social non-acceptance; the distance of the devices from the nearest households ensures a good protection from noise, but still the visual impact of the turbines may be an issue to the neighbors. Even if technically and economically feasible, this solution could be strongly affected by the opinion of the inhabitants, which is very difficult to predict in this early stage.

For the solar panels, as mentioned in the feasibility study, the energy regulation from 2010 in Denmark (although recently changed to worse economic conditions) made from solar panels an attractive investment, situation corroborated with the rise in the number of photovoltaic installation since 2010.

ENVIRONMENTAL ASPECTS

COMMON INSTALLATION

The construction and integration of a district heating plant will imply a visual impact on the area, considering that an industrial building would represent a strange element on a zone dominated by traditional architecture. The placement of a storage area will require a plant of bigger dimensions, which will increase this effect.
For this reasons, during the design phase of the plant, the integration with the environment shall represent a critical point.
All the environmental restrictions have been followed, and are explained in depth on the appendix 7.5 of this report.

HEATING INSTALLATION

Despite biomass systems are legally considered zero balance carbon emission, emissions really exists during the heat generation process. Moreover different particles and dust are emitted during straw combustion. It is recommended to include a fabric filter in order to remove them (Midleton, CO. Cork, 210).

ELECTRICITY INSTALLATION

This scenario does not present any specific situation that may change the considerations made in the solar cells feasibility study regarding environmental issues.

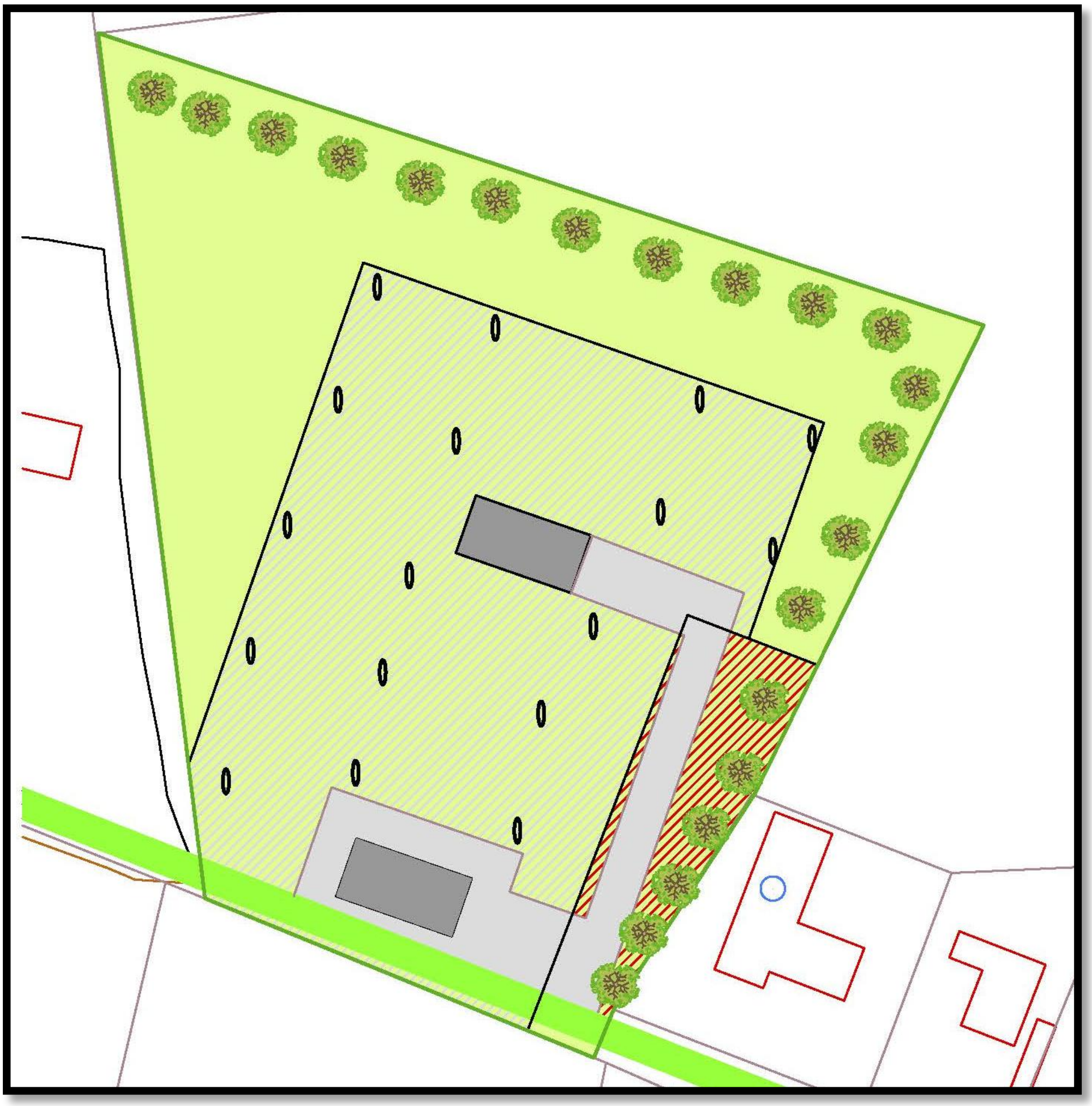
WIND

All environmental issues have been analyzed in section X; the area chosen for the installation of the turbines does not overlay with protected areas, either for flora or for wildlife. The only one impact could be the noise, but a minimum distance of 25m from the nearest houses has been respected, in order to keep the emissions under 39 dB.
The visual impact may be a strong issue, in terms of modification of the landscape but, thanks to the limited height of the devices, this can be limited thanks to tree planting in the area.

PLANT DESIGN

For the design of the site, many factors have been taken into account:

- The two buildings of the biomass plant need to be near
- The building containing the heating plant needs to be near the road and to the district heating network
- The Small Wind Turbines have been placed according to the distance criteria explained before:
    - A distance of 25m from the nearest house (South-West) has been respected
    - A maximum distance of 30m from the two buildings has been respected, in order to take profit of the "net-metering"
- The turbines are west-oriented, to take profit of the prevailing wind direction
- The turbines have been placed in order to try to avoid turbulent wind regimes as much as possible
- The visual impact of the turbines has been limited by planting trees. This has been done in all sides except west, the prevailing wind direction; anyway, even the wind of other directions can be harvested without turbulences, thanks to the great distance between the trees and the turbines.



Distance of 30 meters (to be considered domestic)

Distance of 25 meters from neighbors (for noise impact)

Buildings

Communication road

Figure 5.4.2_2: Plant distribution of both buildings and wind turbines.

HEATING SCHEME

Working scheme of the heating system during autumn to spring season.
The buffer tanks will be used progressively, with all of the being used on the winter period and two of them during spring and autumn.
The backup boiler would be used during maintenance or peak demand periods.

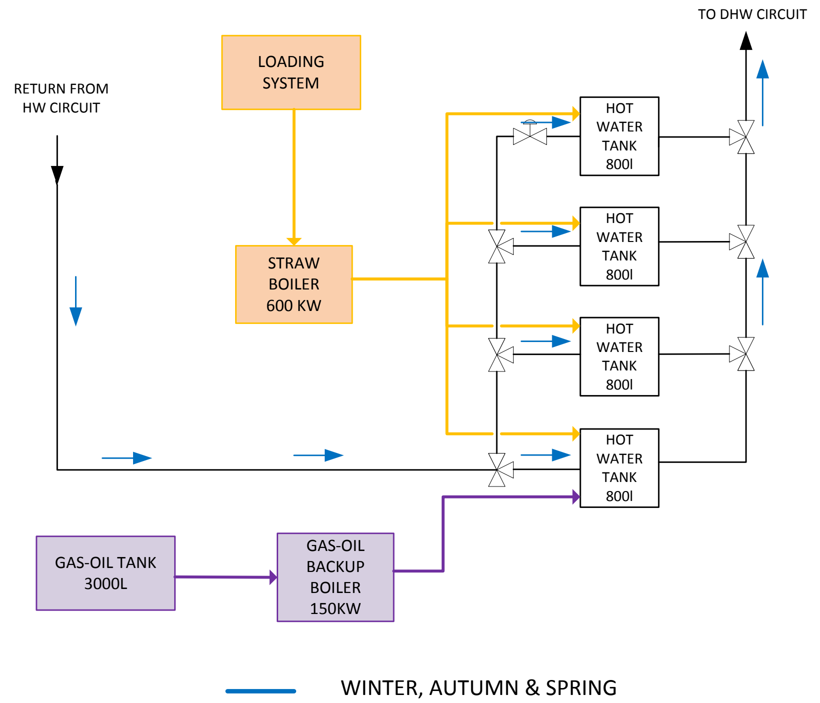


Figure 5.4.2_3: Heating scheme working in Winter, Autumn and Spring

Working scheme of the heating system during summer season.
Just one buffer tank will be used, the back-up boiler would be used in case of maintenance.

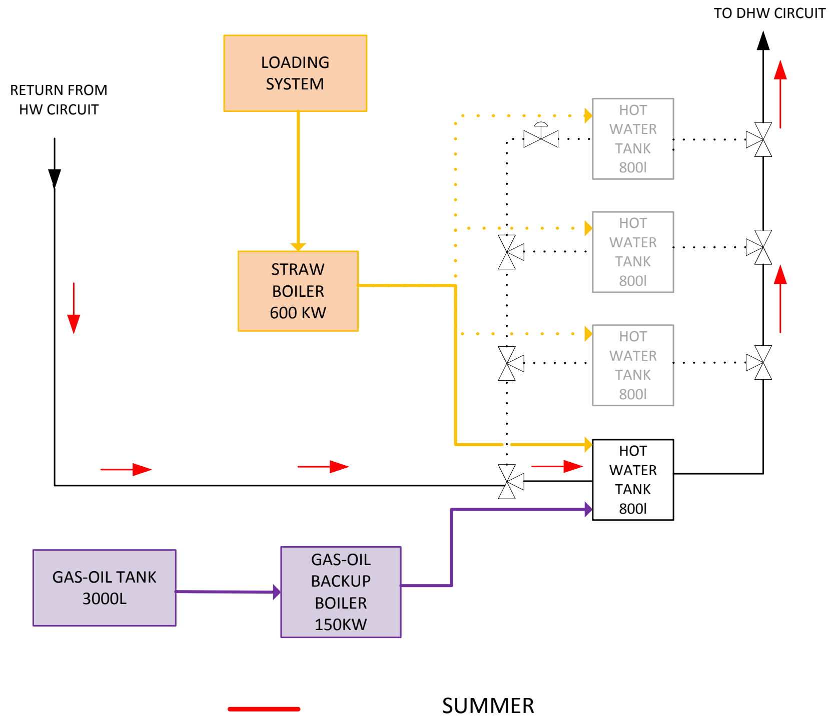


Figure 5.4.2_4: Heating scheme working in Summer

ELECTRICITY SCHEME

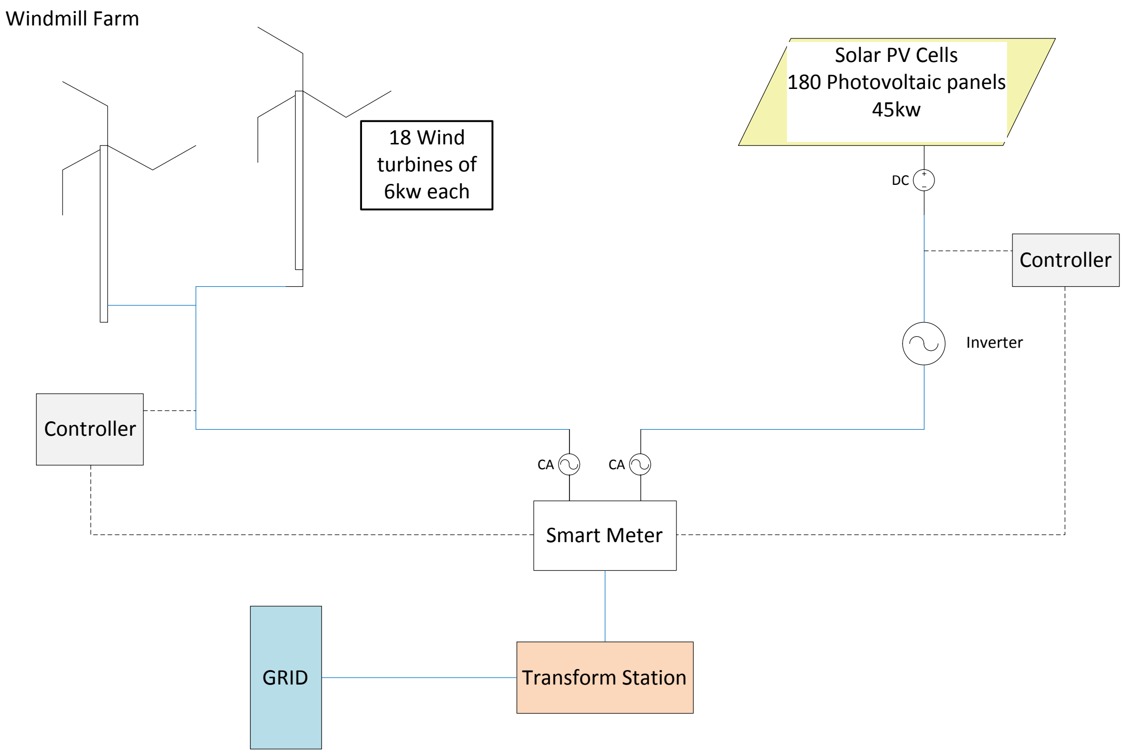


Figure 5.4.2_5: Electricity scheme

ECONOMIC ANALYSIS

COMMON INSTALLATION: DISTRICT HEATING AND BUILDING

The district heating installation has been studied in the previous sections (see section 5.3) of this report; the following data represents a summary of the initial investment and total annual costs.

- Annual land rent – **171.600 DKK/year**
  - Land requirements – 17.600 m2
  - Land rent price – 97.500 DKK/Ha per year
- Annual running costs – **94.565 DKK/year**
- Total investment - **11.113.577 DKK**

DESCRIPTION	COST (DKK)
Site building	**1.530.042DKK**
Closed building (200m2, industrial)	985.634DKK
Opened building (200m2, industrial)	238.400 DKK
VAT (25%)	306.008 DKK
District heating investment	**9.583.535 DKK**
TOTAL	**11.113.577 DKK**

Figure 5.4.2_6: Initial investment for the district heating installation

HEATING INSTALLATION: STRAW BOILER

The data used on this economic analysis has been justified previously on the report. See appendix 7.11, and section 4.2.1 of the report.

- Annual consumption costs –**313.808 DKK/year (+1.67% annual variation)**
  - Annual needs – 2.231.600KWh/year
  - Fuel cost – 140,62 DKK/MWh (estimated yearly variation +1.67%)
- Annual maintenance cost – **106.425 DKK/year**
- Installation cost –**4.123.170 DKK**

DESCRIPTION	COST (DKK)
Straw boiler *(HTHW HHF600 "DANSTOKER")*	2.300.000 DKK
BACKUP SYSTEM	
Gas-oil boiler *(Logano SK 645 "BUDERUS")*	56.200 DKK
Gas-oil tank (3000l)	11.250 DKK
Loading system *("DANSTOKER")*	32.000 DKK
Charging machinery *(CAT "216B")(2nd hand)*	90.000 DKK
Buffer-tank 800l X4 *(PSM 800 "CLIBER-AUSTRIA")*	25.200 DKK
Extraction system *(GC-25 ALU PLUS "NEGARRA")*	41.980 DKK
Installation and connection (10%)	311.663 DKK
TOTAL INSTALLATION COST	**2.868.293 DKK**
GC+IB (9%+6%)	430.243 DKK
TOTAL COST	**3.298.536 DKK**
VAT (25%)	824.634 DKK
TOTAL	**4.123.170 DKK**

Figure 5.4.2_7: Initial investment for the heating installation

ELECTRICITY INSTALLATION

DESCRIPTION	COST (DKK)
180 Solar panels model "Alex-Solar" monocristaline 250w	298.558 DKK
Inverter	19.543 DKK
Transform station (50%)	18.252 DKK
Installation and connection	33.635 DKK
18 wind turbines	2.627.106 DKK
Inverter	171.966 DKK
Controller	160.610 DKK
Installation and connection	295.968 DKK
TOTAL INSTALLATION COST	**2.868.293 DKK**
GC+IB (9%+6%)	543.846 DKK
TOTAL COST	**4.169.488 DKK**
VAT (25%)	1.042.372 DKK
TOTAL	**5.211.860 DKK**

Figure 5.4.2_8: Initial investment for the electricity installation

COMMON SOLUTION: SUMMARY

Initial investment

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
District heating	11.113.577 DKK	156.529 DKK
Heating installation	4.123.170 DKK	58.073 DKK
Electricity installation		
Solar PV system	531.860 DKK	7.598 DKK
Windmills	4.680.000 DKK	66.857 DKK
TOTAL	**20.448.607 DKK**	**289.057 DKK**

Figure 5.4.2_9: Initial investment for the common solution

Annual running costs

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
COMMON INSTALLATION		
Land renting	171.600 DKK	2.417 DKK
DISTRICT HEATING		
Annual costs	2.300.000 DKK	32.857 DKK
HEATING INSTALLATION		
Annual consumption	*313.808 DKK	*4.420 DKK
Maintenance costs	106.425 DKK	1.499 DKK
ELECTRICITY INSTALLATION		
Solar panels		
Maintenance costs	22.350 DKK	320 DKK
Windmills		
Maintenance costs	93.000 DKK	1.337 DKK
TOTAL	**3.007.183 DKK**	**42.850 DKK**

* A yearly variation for the cost of the straw of +1.76% until 2020 is considered.

Figure 5.4.2_10: Annual running costs for the common solution

Annual production incomes

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
HEATING INSTALLATION		
Potential savings	*2.110.191 DKK	*29.721 DKK
ELECTRICITY INSTALLATION		
Potential savings	**693.000 DKK	**9.900 DKK
TOTAL	**2.803.191 DKK**	**39.621 DKK**

* A yearly variation for the heating costs with traditional fuels of +3.00% is considered.
** A yearly variation for the electricity costs of +3.00% is considered.

Figure 5.4.2_11: Annual production incomes for the common solution

CONCLUSION

INDICATORS

The following economic indicators referred to the investment have been selected in order to compare all the scenarios proposed on the conclusion section of this report (see section 6.1).

INDICATOR	VALUE
Initial investment	289.057 DKK
Loan period	10 Years
Break-even point	9 Years
Profit 10 years	28.980 DKK
Profit 20 years	485.986 DKK
Profitability 10 years	10%
Profitability 20 years	168%

Figure 5.4.2_12: Cash-Flow indicators

GRAPHICS

The following graphics represent the evolution of the investment during the life period of the system.

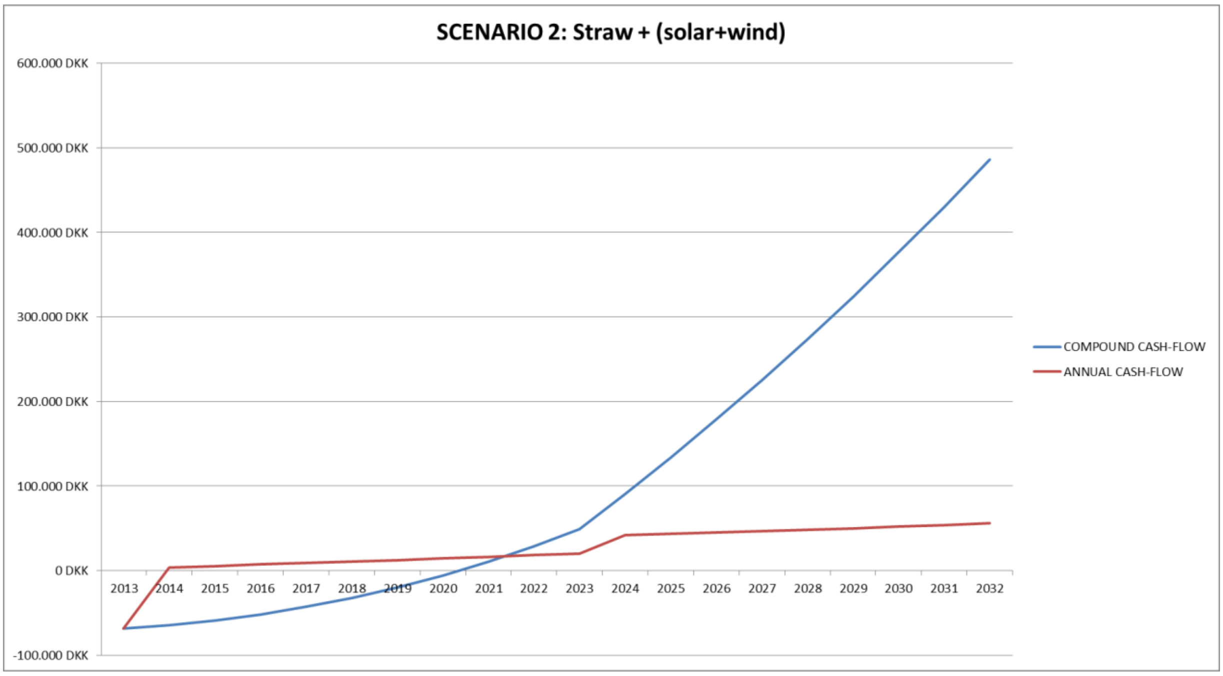


Figure 5.4.2_13: Cash-Flow graphic

5.4.3. SCENARIO 3: CHP GASIFICATION STIRLING ENGINE

INTRODUCTION

On this scenario the feasibility of the implementation of a district heating solution combined with a mixed electricity generation system will be studied. This solution will consist on the following installations:

- A district heating installation for the 71 houses proposed, this installation has been studied in the (section 5.3.) of this report.
- The heat and electricity production will be supplied by a Stirling CHP wood chips cogeneration installation, which will produce the 100% of the heat requirements and 100% of electricity as well.

JUSTIFICATION

TECHNICAL CONSIDERATIONS

COMMON INSTALLATION

The main considerations taken on the whole installation refer to the district heating distribution net, all these considerations have been explained previously on this report (see section 5.3.).
The considerations taken respecting the design of the plant are concerning the main volumes of building needed. As on this case the heating installation will require a covered storage area, there will be considered industrial constructions:

- A closed construction of 200m2 where the CHP plant, district heating pumps and communications will be installed.

The distribution and location of the building on the plot is explained graphically on the following section of this scenario. The total area of plot required is 4.100m2, the cost per square meter has been calculated on section 5.3 of this report.

HEATING & ELECTRICITY INSTALLATION

The heating installation has been dimensioned to reach a peak power of 685KW, by the use of 4 Stirling engines feed by woodchips gasification. The installation will consist on the following elements:

- Feeding installation:
  - Outdoor storage silo for woodchips connected to a
  - Loading system which feeds the updraft gasifier.
- Updraft gasifier: 1 Updraft gasification where the fresh woodchips are slowly combusted releasing gas which is then led into the 4 combustion chambers (one for each engine)
- 4 modules of cogeneration system from “Stirling DK installed in parallel.
  - 4 Combustion chambers
  - 4 Biogas boilers boiler

- 4 Stirling engines: with electrical power of 35 kw and 140Kw of heating each one. Produces electricity at the same time that water is heated.
- Electricity transformation center
- An auxiliary gas-oil boiler with a peak power of 125KW will be installed, considering the model *Logano SK 645 "BUDERUS"*. This boiler will be fed by a gas-oil tank of 3 cubic meters. The purpose of this installation is to give support to the main boiler on moments of peak demand, and during the maintenance of the main boiler. The gas-oil tank has been sized to provide enough fuel for the operation of the boiler in one year.
- A heat storage system composed by 4 buffer tanks of 800l, considering the model *PSM 800 "CLIBER-AUSTRIA". The mission of these elements is* to provide enough thermal lag to the system to ensure that the straw boiler works on continuous periods, reducing the starts and stops of the boiler and improving the efficiency.
  The connection of the tanks will be done on parallel permitting the modularity of the storage, so it will adapt easily to de demand of the different seasons (eg. During winter all the buffer tanks will work, while during summer three of them will be closed to reduce loses).
- All the installation will be controlled by a central computer; this device will receive data from all the thermal sensors installed on the elements of the internal installation, the measures of the flow in the system and the external temperature. Using this data the software will control the engines and pumps in order to optimize the performance of the system.
  This system has been considered into the cost of the installation of the CHP system.
- All the piping system, including the valves, electro-valves, pumps and connections is considered as a part of the installation.

*A performance of 69% will be considered when estimating the total consumption of the Stirling engine system. (Stirling DK, 2011)

*The solution has been studied considering the approach of a feasibility study, further calculations and design shall be done to reach more accurate data.

SOCIAL ASPECTS

COMMON INSTALLATION

The plant location will generate people disagreements due to the proximity of the plant to their house.
The plant construction will affect the surroundings and some services during the execution phase.

HEATING & ELECTRICITY INSTALLATION

The implementation of the Stirling CHP biomass boiler requires the permission of the local legal authorities in order to integrate the district heating net.

Stirling CHP systems offer interesting performances, high efficiency and are economically profitable. The drawbacks might be that Stirling CHP technology is rather too innovative and only few companies are in order to dispose these kinds of systems in which time durability has not been certainly proved. Wood chips gasifier is an option being now these small scale solutions the first of its generation to be commercialized.

ENVIRONMENTAL ASPECTS

COMMON INSTALLATION

The construction and integration of a district heating plant will imply a visual impact on the area, considering that an industrial building would represent a strange element on a zone dominated by traditional architecture. The placement of a storage area will require a plant of bigger dimensions, which will increase this effect.
For this reasons, during the design phase of the plant, the integration with the environment shall represent a critical point.
All the environmental restrictions have been followed, and are explained in depth on the appendix 7.5 of this report.

HEATINGAND ELECTRICITY INSTALLATION

Despite biomass systems are legally considered zero balance carbon emission, emissions really exists during the heat generation process. Moreover different particles and dust are emitted during woodchips combustion. It is recommended to include a fabric filter in order to remove them (Midleton, CO. Cork, 210).

HEATING AND ELECTRICITY SCHEME

HEATINGAND ELECTRICITY INSTALLATION

Working scheme of the heating system during autumn to spring season.
The buffer tanks will be used progressively, with all of the being used on the winter period and two of them during spring and autumn.
The backup boiler would be used during maintenance or peak demand periods.

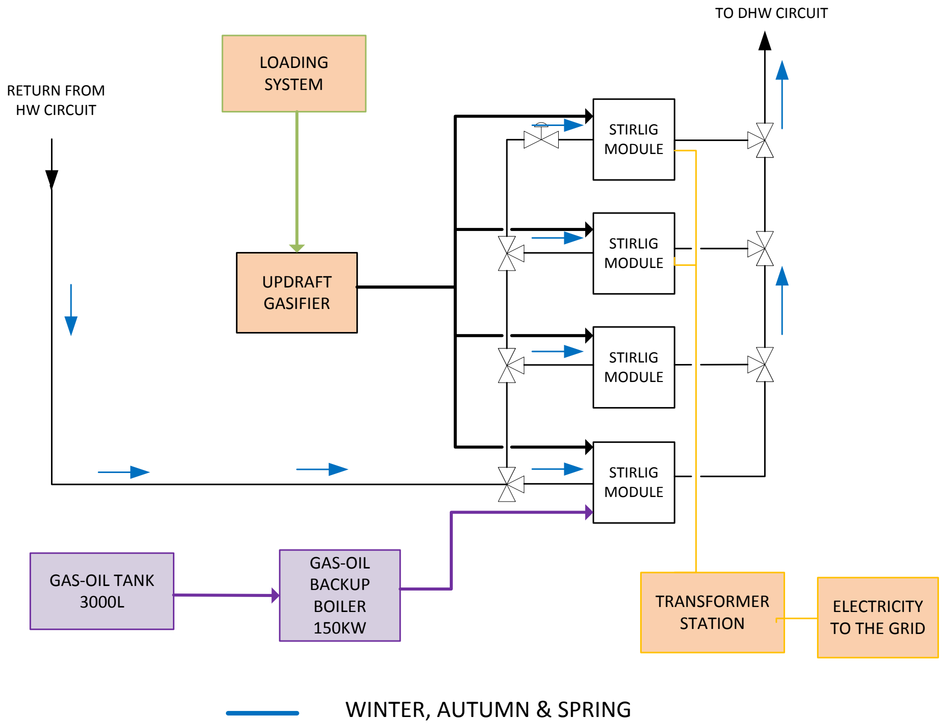


Figure 5.4.3_1 CHP scheme operating in winter, autumn & spring

Working scheme of the heating system during summer season.
Just one buffer tank will be used, the back-up boiler would be used in case of maintenance.

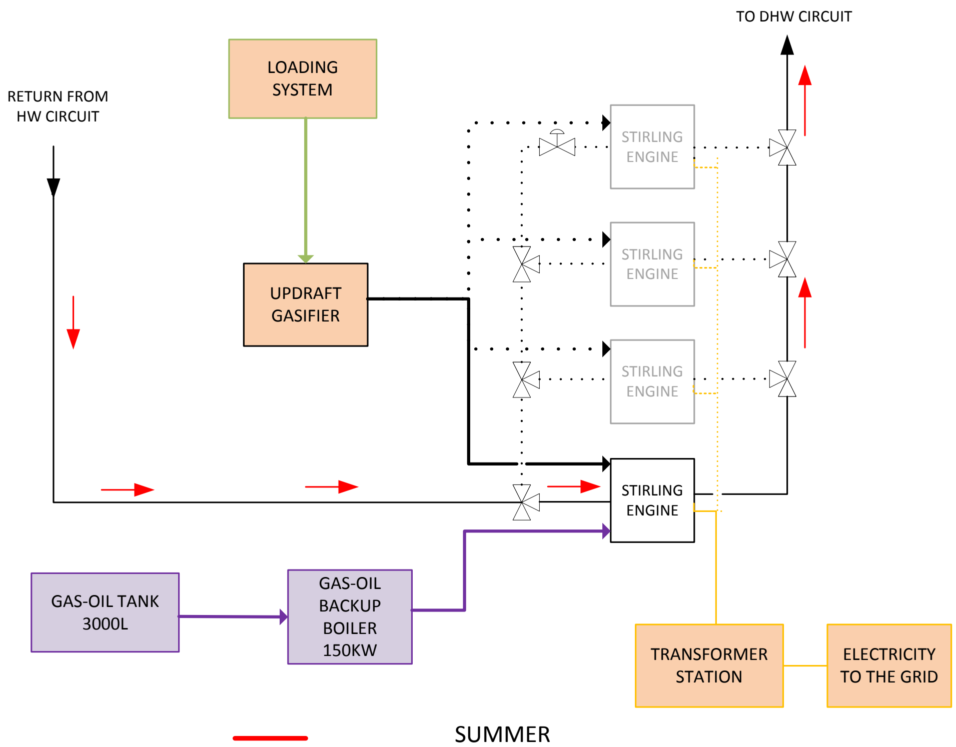


Figure 5.4.3_2 CHP scheme operating in summer

ECONOMIC ANALYSIS

COMMON INSTALLATION: DISTRICT HEATING AND BUILDING

The district heating installation has been studied in the previous sections (section 4.2.1) of this report; the following data represents a summary of the initial investment and total annual costs.

Annual land rent – **39.975 DKK/year**

Land requirements – 4.100 m2

Land rent price – 97.500 DKK/Ha per year

Annual running costs – **171.182 DKK/year**

Total investment - **10.815.577 DKK**

DESCRIPTION	COST (DKK)
District heating investment	**9.583.535 DKK**
Site building	**1.232.042 DKK**
Closed building (200m2, industrial)	985.634 DKK
VAT (25%)	246.408 DKK
TOTAL	**10.815.577 DKK**

Figure 5.4.3_3 Initial investment for the common district heating installation

HEATING & ELECTRICITY INSTALLATION: WOOD CHIPS STIRLING ENGINE

The data used on this economic analysis has been justified previously on the report. See (appendix 7.11.), (section 4.2.1.) of the report.

Annual consumption costs – **348.795,3 DKK/year (+3% annual variation)**

Annual consumption – 2.808.335,7KWh/year

Fuel cost – 0,1242DKK/KWh (estimated yearly variation +3%)

Annual maintenance cost –**102.138DKK/year**

Installation cost – **8.505.156 DKK**

DESCRIPTION	COST (DKK)
4x35 kw Stirling engine wood chips system (STIRLING DK)	*5.222.000 DKK*
Storage silo	
Loading system	
Updraft gasification and combustion system	
Biogas boiler	
Buffer-tank 800l X4 *(PSM 800 "CLIBER-AUSTRIA")*	*25.200 DKK*
Extraction system *(GC-25 ALU PLUS "NEGARRA")*	*41.980 DKK*
BACKUP SYSTEM	
Gas-oil boiler *(Logano SK 645 "BUDERUS")*	56.200 DKK
Gas-oil tank (3000l)	11.250 DKK
Site building (200m2, industrial)	560.000 DKK
TOTAL INSTALLATION COST	**5.916.630 DKK**
GC+IB (9%+6%)	887.495 DKK
TOTAL COST	**6.804.125 DKK**
VAT (25%)	1.701.031 DKK
TOTAL	**8.505.156 DKK**

Figure 5.4.3_4 CHP installation cost

COMMON SOLUTION: SUMMARY

Initial investment

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
District heating	11.113.577 DKK	156.529 DKK
CHP installation	8.505.156 DKK	119.791DKK
TOTAL	**19.618.733 DKK**	**276.320 DKK**

Figure 5.4.3_5 Initial investment for the common solution

Annual running cost

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
COMMON INSTALLATION		
Land renting	39.975 DKK	563 DKK
DISTRICT HEATING		
Annual costs	94.565 DKK	1.332 DKK
CHP INSTALLATION		
Annual consumption	*348.795 DKK	*4.912 DKK
Maintenance costs	102.138DKK	1.438 DKK
TOTAL	**585.473 DKK**	**8.245 DKK**

Figure 5.4.3_6 Annual running cost for the common solution

* A yearly variation for the cost of the woodchips of +3% until 2020 is considered.

Annual production income

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
HEATING INSTALLATION		
Potential savings	*2.110.191 DKK	*29.721 DKK
ELECTRICITY INSTALLATION		
Electricity benefits	1.157.385,4 DKK	16.301,2 DKK
TOTAL	**3.267.576,4DKK**	**46.022,2DKK**

Figure 5.4.3_7 Annual production benefits for the common solution

* A yearly variation for the heating costs with traditional fuels of +3.00% is considered.

CONCLUSION

INDICATORS

The following economic indicators referred to the investment have been selected in order to compare all the scenarios proposed on the conclusion section of this report (see section 6.1).

INDICATOR	VALUE
Initial investment	276.320 DKK
Loan period	12 Years
Break-even point	3 Years
Profit 10 years	107.817 DKK
Profit 20 years	586.884DKK
Profitability 10 years	39%
Profitability 20 years	212,4%

Figure 5.4.3_8 Cash-flow indicators

GRAPHICS

The following graphics represent the evolution of the investment during the life period of the system.

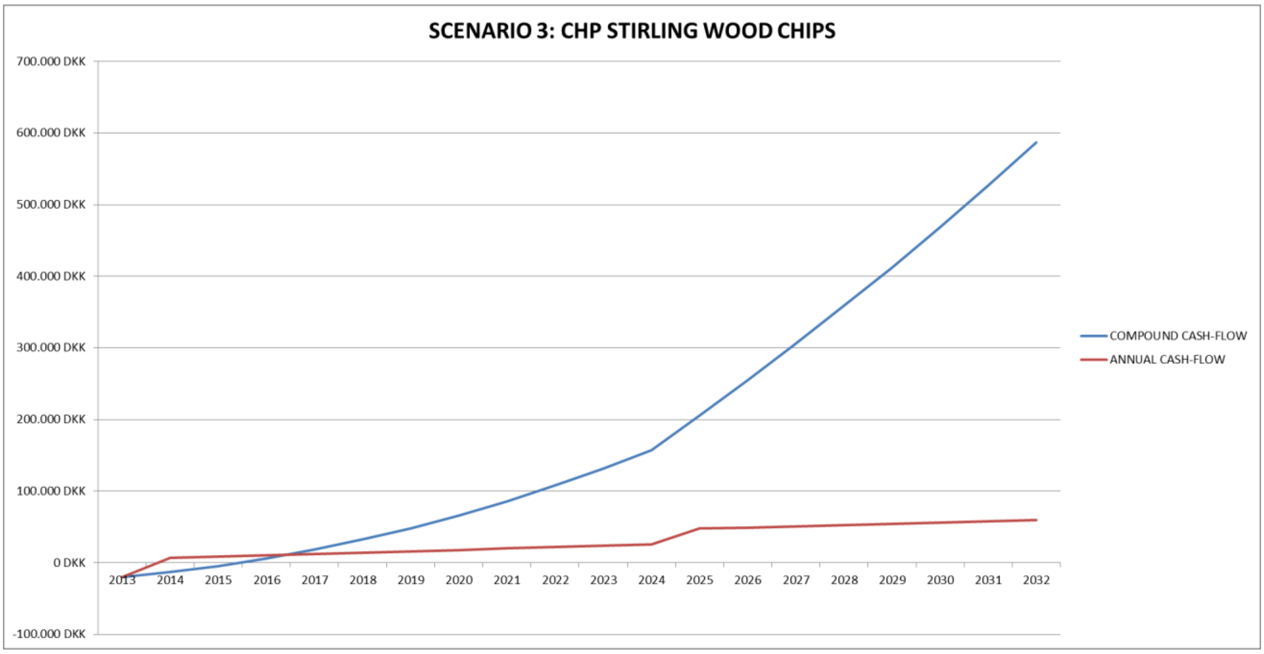


Figure 5.4.3_9 CHP cash flow graph

5.4.4. SCENARIO 4: BIOGAS BOILER AND GROUND SOURCE WITH SOLAR PV AND SWT

INTRODUCTION

On this scenario the feasibility of the implementation of a district heating solution combined with a mixed electricity generation system will be studied. This solution will consist on the following installations:

- A district heating installation for the 71 houses proposed, this installation has been studied in the (section 5.3) of this report.
- The heat production will be supplied by an integrated system between a biogas boiler and a ground source heat pump installation. The geothermal installation is designed to supply the required demand during summer; while during the winter the biogas boiler will act as a support system.
  The GSHP system will supply heat during all the year, up to a maximum output temperature of 73ºC, during the periods from January to April and October to December the biogas boiler will support the system to rise up the temperatures up to 90ºC.
- The electricity production will be supplied by a combination of small wind turbines, providing a 23% and solar photovoltaic cells providing 77% of the total demand.

JUSTIFICATION

TECHNICAL CONSIDERATIONS

COMMON INSTALLATION

The main considerations taken on the whole installation refer to the district heating distribution net, all these considerations have been explained previously on this report (section 5.3).
The considerations taken respecting the design of the plant are concerning the main volumes of building needed. As on this case the heating installation will require:

- A closed construction of 200m2 where the heating plant, district heating pumps and communications will be installed.
- The installation and placement of the biogas tank, this tank will be placed horizontally on the exterior as a precaution against gas leaks. It has been located close to the building in order to reduce the gas pipe length.

The GSHP system requires a plot of 1125 m2 in which drill the boreholes. The rest of the installation will be placed in the common building.
The distribution and location of the building on the plot is explained graphically on the following section of this scenario. The total area of plot required is 20.600 m^2, the cost per m^2 has been calculated in section 5.3 of this report.

HEATING INSTALLATION

The heating installation has been dimensioned taking into account the combination of a biogas boiler system and a geothermal system designed to work as the main system.
The following chart represents the monthly repercussion of each technology, according to the flow temperature of the district heating net, for further information see Appendix 7.16.

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Maximum temperature (ºC)	9,0	9,0	11,0	17,0	18,0	25,0	23,0	24,0	20,0	15,0	12,0	11,0
Minimum temperature (ºC)	-12,0	-8,0	-8,0	0,0	5,0	8,0	11,0	11,0	7,0	-3,0	-3,0	-11,0
Average temperature (ºC)	1,0	1,4	3,2	7,0	11,7	14,7	17,3	17,5	13,8	9,7	4,6	2,0
Max. Flow temperature (ºC)	73,4	73,4	73,2	73,0	72,9	73,0	73,0	72,9	72,7	72,4	73,2	73,2
Min. Flow temperature (ºC)	99,4	89,1	89,1	77,5	73,6	73,3	73,2	73,2	73,4	81,6	81,6	94,7
Aver. Flow temperature (ºC)	76,3	75,2	74,1	73,4	73,2	72,7	72,9	72,9	73,1	73,3	73,7	74,9
Max. Return temperature (ºC)	43,2	43,2	43,4	44,8	44,6	45,4	46,6	45,7	44,9	44,5	43,6	43,4
Min. Return temperature (ºC)	56,1	52,1	52,1	46,6	43,9	43,2	43,4	43,4	43,4	48,5	48,5	55,1
Avg. Return temperature (ºC)	46,1	46,3	44,7	43,4	43,5	44,4	44,7	44,7	44,2	43,0	44,2	45,5
% Annual heating repercusion	18,77%	17,78%	8,33%	7,75%	2,90%	1,52%	1,44%	1,46%	4,10%	8,28%	11,22%	16,44%
MONTHLY REPERCUSION												
Biogas	30%	25%	25%	15%	0%	0%	0%	0%	0%	20%	20%	30%
Geothermal	70%	75%	75%	85%	100%	100%	100%	100%	100%	80%	80%	70%
ANNUAL REPERCUSION												
Biogas	5,63%	4,45%	2,08%	1,16%	0,00%	0,00%	0,00%	0,00%	0,00%	1,66%	2,24%	4,93%
Geothermal	13,14%	13,34%	6,25%	6,59%	2,90%	1,52%	1,44%	1,46%	4,10%	6,62%	8,98%	11,51%

Figure 5.4.4_1: Monthly distribution of the production between Biogas and Geothermal systems.

The final repercussion of each system on the overall production is represented on the following chart, considering the annual estimated needs are 1.965.835Kwh/year (section 3.1) of this report:

SYSTEM	ANNUAL PRODUCTION %	ANNUAL PRODUCTION (KWH)
Geothermal heat pump	77.84%	1.530.206 KWh
Biogas boilers	22.5 %	442.313 KWh

Figure 5.4.4_2: Distribution of the overall production between the systems.

The biogas installation is composed by the following elements:

- A pressurized biogas tank of 16m3 which will be installed outdoors. The tank will be filled by a regional supplier according to a long term contract which has to be determined. The capacity has been pre-dimensioned in order to ensure 1 month of supply on the most demanding period.
- One biogas boiler of 310KW of peak power, considering the model *Logano Plus SB 615 "BUDERUS", the boiler will integrate a pressurized biogas burner which has been included in the estimated cost of the boiler. All the electronics and valves have been included on the costs of the boiler.*
  The overall performance of the boiler has been estimated as 99%,(Appendix 7.11), (section 4.2.1) of this report.

The ground source heat pump installation is composed by the following elements:

- A large scale heat pump. This heat pump will provide 1.530.206 KWh of heat yearly (450 KW of peak power), so the needs of electricity will be 340.046 KWh yearly (peak of 100 KW).
- 120 boreholes of 150 m length, calculated for 1800 hours of production a year.
- Pumper and water treatment device, necessary in order not to damage the heat pump

The common installation is composed by the following elements:

- A heat storage system composed by 4 buffer tanks of 800l, considering the model *PSM 800 "CLIBER-AUSTRIA"*.
  The mission of these elements in this solution is to provide enough thermal lag to the system in order to reduce start-stops on the installation improving the efficiency.
  The connection of the tanks will be done on parallel permitting the modularity of the storage, so it will adapt easily to de demand of the different seasons (eg. During winter all the buffer tanks will work, during summer just one of the tanks will be working in order to reduce loses, during transition periods two of the tanks will be closed to adjust the thermal inertia to the needs).
- All the installation will be controlled by a central computer; this device will receive data from all the thermal sensors installed on the elements of the internal installation, the measures of the flow in the system and the external temperature. Using this data the software will control the boiler, pumps and valves in order to optimize the performance of the system.
  This system has been considered into the cost of the installation of the boiler.
- All the piping system, including the valves, electro-valves, pumps and connections is considered as a part of the installation, which has been estimated as a percentage of the total costs.

ELECTRICITY INSTALLATION

The technical aspect of the electricity installation can be found in the Scenario 2, in the section "Technical consideration-Electricity installation". Also in this case, the electricity will be supplied thanks to a combination between photovoltaic panels and wind turbines.
The maximum number of turbines that can be placed in the area without a detailed urban planning approved by the authorities is 10. Installing further turbines would require great efforts in terms of policies, agreements and, furthermore, would be economically less profitable, because it would be impossible to take profit of the "net-metering policy".
Whit this number of turbines, it is only possible to supply the 23% circa (147300 kWh/year) of the total electricity needs.

To achieve the 100% of the electricity needs of the village a solar photovoltaic farm will be disposed in the plot, in order to cover the 77% of the remaining electricity needs. This means a total of 508.959 kwh per year. To cover this needs, and considering the technical features of the installation studied in the feasibility study, a total installation of 600kw of power installed will be considered. With this, and taking into account the use of solar cells of 250w and 1,65 m^2, as the ones used in scenario 2, a total of 2400 solar panels will be needed. Calculations can be checked in Appendix 7.10.13.

In this point, a shadows study has been developed in order to take into account the influence of the inclination of the solar rays in the worst months of the year (specially the 21^{st} of December). With the data collected and the calculations made (can be checked in Appendix 7.10.3), it can be observed that a total surface of approximately 15.000 m2 will be needed if we do not want to lose electricity production. It must be taken into account that this area could be optimized by disposing the solar cells in a more compact layout in which some loses could appear, although in an insignificant number.

This power installed will produce an output of 517.052 kwh per year. The distribution of energy output by months, together with the calculations can be checked in the Appendix 7.10.

The economic considerations regarding price for selling and buying electricity, especially according to the current Danish regulation, can be checked in scenario 2.

SOCIAL ASPECTS

COMMON INSTALLATION

The plant location will generate people disagreements due to the proximity of the plant to their house.
The plant construction will affect the surroundings and some services during the execution phase.
All the security measures shall be taken, in order to prevent any explosions from the biogas tank (pressurized tank).

HEATING INSTALLATION

The implementation of the district heating plant requires the permission of the local legal authorities in order to be integrated.
The grants considered for the biogas consumption are included on the price subvention from the Danish government, this grant ensures a steady price for the biogas on the first 10 years of the installation (see Appendix 7.6).
As far as GSHP installation is concerned, its implementation is positively accepted by the society although without receiving any grant by the government. (see Appendix 7.6 and Appendix 7.8)

ELECTRICITY INSTALLATION

The electricity installation regarding wind is very similar to the one in Scenario 2; all information about social aspects can be found in that section.

For the solar panels, as mentioned in the feasibility study, the energy regulation from 2010 in Denmark (although recently changed to worse economic conditions) made from solar panels an attractive investment, situation corroborated with the rise in the number of photovoltaic installation since 2010.

ENVIRONMENTAL ASPECTS

COMMON INSTALLATION

The construction and integration of a district heating plant will imply a visual impact on the area, considering that an industrial building would represent a strange element on a zone dominated by traditional architecture.
For this reason, during the design phase of the plant, the integration with the environment shall represent a critical point.
The placement of the biogas tank will require a specific study, in order to prevent leaks and affection to nearby dwellings, this installation will require a specific project and study.

All the environmental restrictions have been followed, and are explained in depth on the (Appendix 7.5) of this report.

HEATING INSTALLATION

As explained in previous section of this report (see Appendix 7.11) and previous reports (Alberdi Pagola, et al., 2012), the consumption of biofuels as biogas is considered a neutral balance reaction.
Regarding to GSHP system, it is known that is one of the renewable alternative with less impact on environment, generating a few amount of CO_2 emissions. For further information see (section 4.2.2)

ELECTRICITY INSTALLATION

The electricity installation regarding wind is very similar to the one in Scenario 2; all information about environmental aspects can be found in that section.

This scenario does not present any specific situation that may change the considerations made in the solar cells feasibility study regarding environmental issues.

PLANT DESIGN

For the design of the site, many factors have been taken into account:

- The building containing the heating plant needs to be near the road and to the district heating network
- The Small Wind Turbines have been placed according to the distance criteria explained before:
    - A distance of 25m from the nearest house (South-West) has been respected
    - A maximum distance of 30m from the building has been respected, in order to take profit of the "net-metering"
- The turbines are west-oriented, to take profit of the prevailing wind direction
- The turbines have been placed in order to try to avoid turbulent wind regimes as much as possible
- The visual impact of the turbines has been limited by planting trees. This has been done in all sides except west, the prevailing wind direction; anyway, even the wind of other directions can be harvested without turbulences, thanks to the great distance between the trees and the turbines.

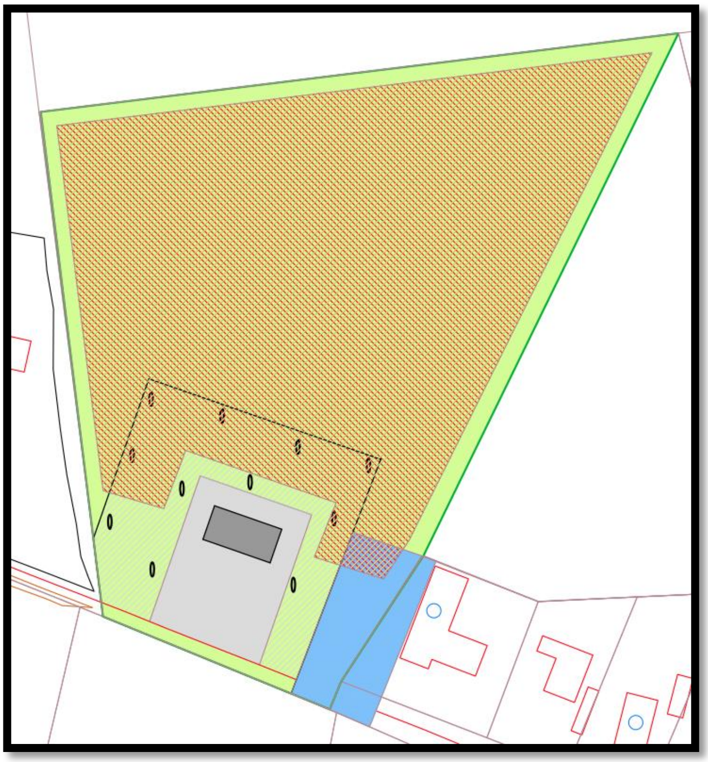


Figure 5.4.4_3: Plant design.

Distance of 30 meters from the building to the turbines (to be considered domestic)

Solar photovoltaic panels

Building

Communication road

Distance of 25 meters from wind turbines to neighbours (for noise impact)

HEATING SCHEME

Working scheme of the heating system during winter season

The buffer tanks will be used, the geothermal installation will preheat the water from the return of the district heating, and the biogas boiler will rise up the temperature up to the 90ºC required.

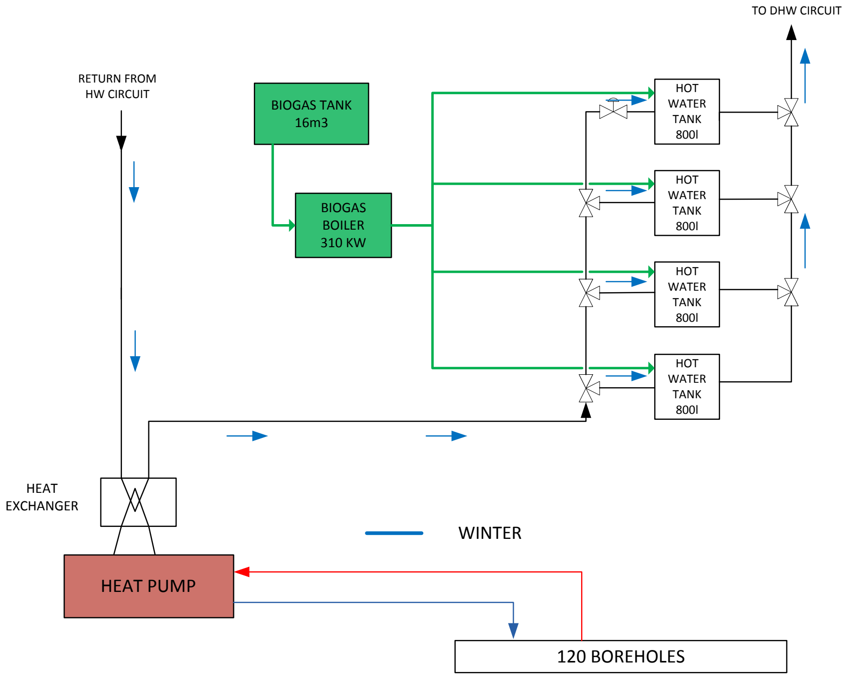


Figure 5.4.4_4: Heating scheme working during winter season.

Working scheme of the heating system during summer season

Two of the buffer tanks will be used, the geothermal system will heat the return water up to the required temperature. The biogas boiler will work during maintenance.

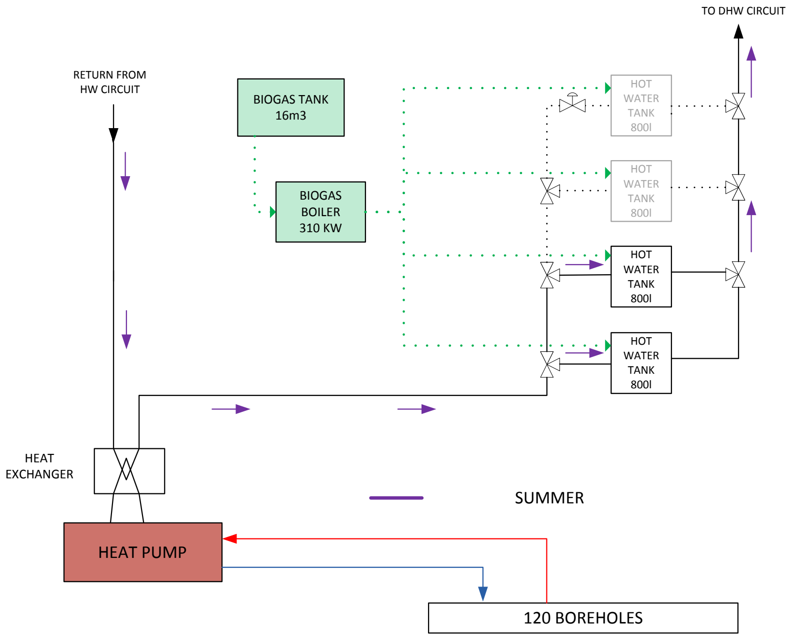


Figure 5.4.4_5: Heating scheme working during summer season.

Working scheme of the heating system during spring and autumn season
Two of the buffer tanks will be used, the geothermal system will heat the return water up to the required temperature. The biogas boiler will work during maintenance and peak demand periods.

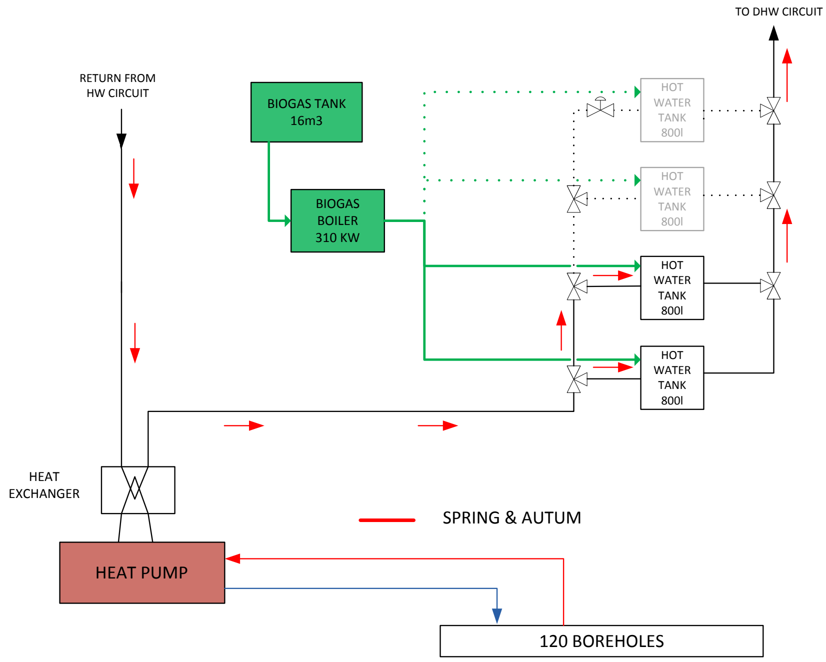


Figure 5.4.4_6: Heating scheme working during spring and autumn season.

ELECTRICITY SCHEME

As can be seen, both systems will be connected with their correspondent controllers and a smart meter, that will determine the amount of electricity bought and sold for both solar and wind electricity.

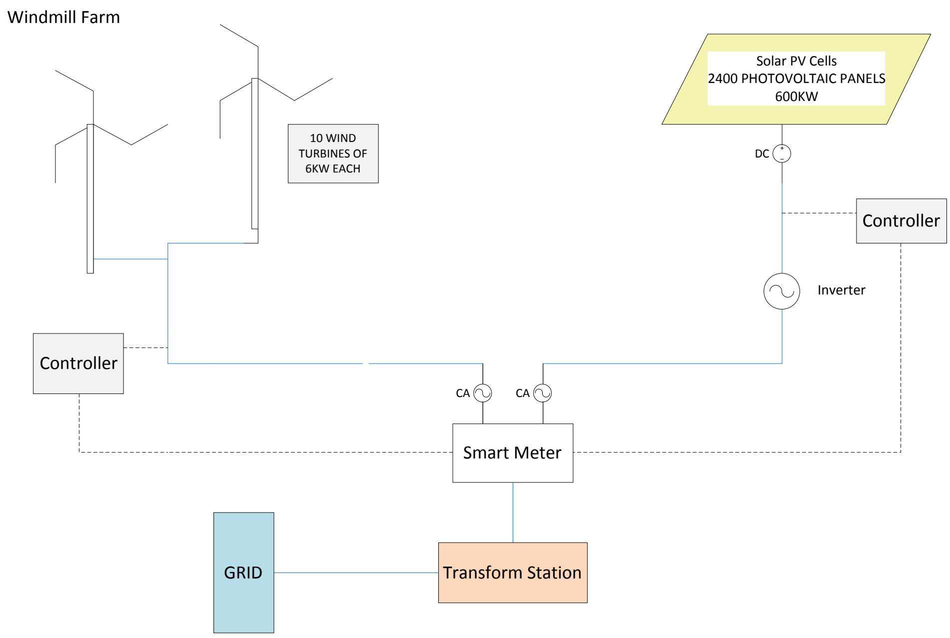


Figure 5.4.4_7: Electric scheme.

ECONOMIC ANALYSIS

COMMON INSTALLATION: DISTRICT HEATING

The district heating installation has been studied in the previous sections (section 5.3) of this report; the following data represents a summary of the initial investment and total annual costs.

- Annual land rent – **200.850 DKK/year**
  - Land requirements – 20.600 m2
  - Land rent price – 97.500 DKK/Ha per year
- Annual running costs – **94.565 DKK/year**
- Total investment - **11.113.577 DKK**

DESCRIPTION	COST (DKK)
Site building	**1.232.042DKK**
Closed building (200m2, industrial)	985.634DKK
VAT (25%)	246.408 DKK
District heating investment	**9.583.535 DKK**
TOTAL	**10.815.577 DKK**

Figure 5.4.4_8: Initial investment for the district heating installation.

HEATING INSTALLATION: BIOGAS BOILERS + GENERAL INSTALATION

The data used on this economic analysis has been justified previously on the report. See (appendix 7.11), (section 4.2.1) of the report.

- Annual consumption costs – **184.967 DKK/year**
- Annual consumption – 446.781 KWh/year
  - Annual consumption – 442.313KWh/year
  - Boiler performance – 99%
- Fuel cost – 414 DKK/MWh
- Annual maintenance cost – **12.500 DKK/year**
- Installation cost – **509.605 DKK**

DESCRIPTION	COST (DKK)
Biogas boiler *(Logano Plus SB 615 "BUDERUS")*	180.100 DKK
Pressurized Biogas tank 16m3 (superficial)	75.000 DKK
Buffer-tank 800l X4 *(PSM 800 "CLIBER-AUSTRIA")*	25.200 DKK
Extraction system *(GC-25 ALU PLUS "NEGARRA")*	41.980 DKK
Installation and connection (10%)	32.228 DKK
TOTAL INSTALLATION COST	**354.508 DKK**
GC+IB (9%+6%)	53.176 DKK
TOTAL COST	**407.684 DKK**
VAT (25%)	101.921 DKK
TOTAL	**509.605 DKK**

Figure 5.4.4_9: Initial investment for the heating installation (biogas boiler)

HEATING INSTALLATION: GEOTHERMAL

DESCRIPTION	COST (DKK)
Heat pump	1.500.000 DKK
Boreholes (160)	8.437.500 DKK
Pump and water treatment	74.600 DKK
TOTAL	**10.012.100DKK**

Figure 5.4.4_10: Initial investment for the heating installation (Geothermal)

ELECTRICITY INSTALLATION

DESCRIPTION	COST (DKK)
2400 Solar panels model "Alex-Solar" monocristlaline 250w	3.980.750 DKK
Inverter	260.574 DKK
Transform station	243.367 DKK
Installation and connection	448.469 DKK
10 Bornay 6000 Turbines (6kW)	1.266.087 DKK
Aurora 6kW inverter	180.869 DKK
Installation and connection	361.739 DKK
TOTAL INSTALLATION COST	**2.868.293 DKK**
GC+IB (9%+6%)	543.846 DKK
TOTAL COST	**4.169.488 DKK**
VAT (25%)	1.042.372 DKK
TOTAL	**9.691.420 DKK**

Figure 5.4.4_11: Initial investment for the electricity installation.

COMMON SOLUTION SUMMARY

Initial investment

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
DISTRICT HEATING	10.815.577 DKK	152.332 DKK
HEATING INSTALLATION		
Biogas boilers + main inst.	509.605 DKK	7.178 DKK
GSHP system	10.012.100 DKK	141.015 DKK
ELECTRICITY INSTALLATION		
Solar panels	7.091.420 DKK	101.306 DKK
Windmills	2.600.000 DKK	37.143 DKK
TOTAL	**31.028.702 DKK**	**438.974 DKK**

Figure 5.4.4_12: Initial investment for the common solution

Annual running costs

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
COMMON INSTALLATION		
Land renting	200.850 DKK	2.829 DKK
DISTRICT HEATING		
Annual costs	94.565 DKK	1.331 DKK
HEATING INSTALLATION		
Biogas boilers + main inst.		
Annual consumption	184.967 DKK	2.605 DKK

Maintenance costs	12.500 DKK	176 DKK
Geothermal installation		
Annual consumption	21.531 DKK	10.526 DKK
Maintenance costs	10.000 DKK	4.420 DKK
ELECTRICITY INSTALLATION		
Solar panels		
Annual costs	372.500 DKK	5.321 DKK
Windmills		
Annual costs	52.000 DKK	743 DKK
TOTAL	**748.063 DKK**	**10.536 DKK**

Figure 5.4.4_13: Annual running costs for the common solution.

Annual production benefits

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
HEATING INSTALLATION		
Potential savings	*2.110.191 DKK	*29.721 DKK
ELECTRICITY INSTALLATION		
Potential savings	**693.000 DKK	**9.900 DKK
TOTAL	**2.803.191 DKK**	**39.621 DKK**

* A yearly variation for the heating costs with traditional fuels of +3.00% is considered.
** A yearly variation for the electricity costs of +3.00% is considered.

Figure 5.4.4_14: Annual production incomes to the common solution.

CONCLUSION

INDICATORS

The following economic indicators referred to the investment have been selected in order to compare all the scenarios proposed on the conclusion section of this report (see section 6.1).

INDICATOR	VALUE
Initial investment	438.974 DKK
Loan period	16 Years
Break-even point	- Years
Profit 10 years	-205.114 DKK
Profit 20 years	-160.418 DKK
Profitability 10 years	-47.6 %
Profitability 10 years	-36.5 %

Figure 5.4.4_15: Cash-Flow indicators.

GRAPHICS

The following graphics represent the evolution of the investment during the life period of the system.

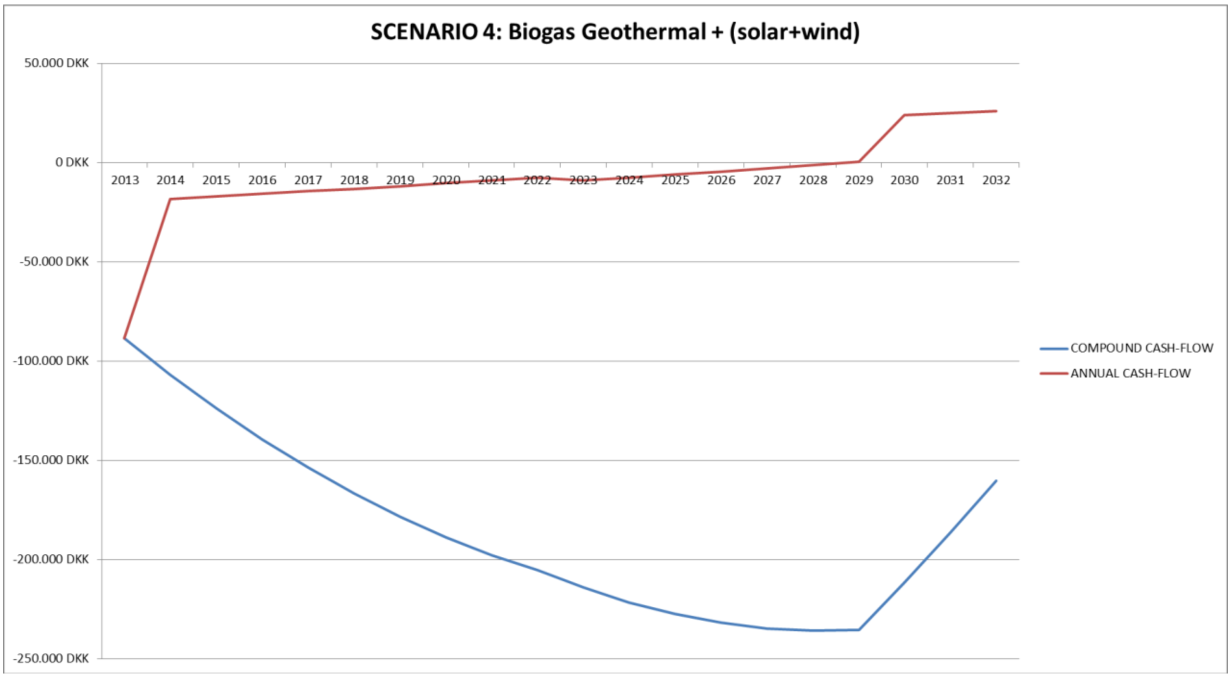


Figure 5.4.4_16: Cash-Flow graph

5.4.5. SCENARIO 5: BIOGAS BOILER WITH SOLAR THERMAL AND SWT

INTRODUCTION

On this scenario the feasibility of the implementation of a district heating solution combined with a mixed electricity generation system will be studied. This solution will consist on the following installations:

- A district heating installation for the 71 houses proposed, this installation has been studied in the section 5.3 of this report.
- The heat production will be supplied by an integrated system between a biogas boiler and a solar thermal installation. The solar system is designed to provide enough heat for the summer period, while during the winter the biogas boiler will provide the energy to the system. During the transition periods both systems will work together, the solar system will preheat the return flux from the district heating and the biogas boiler will provide the rest.
  The solar thermal installation will work from February to October, supplying all the energetic requirements from April to September; the biogas boilers will backup the system if necessary.
- The electricity production will be supplied by Small Wind Turbines; this solution will provide the 47% circa of electricity requirements.

JUSTIFICATION

TECHNICAL CONSIDERATIONS

COMMON INSTALLATION

The main considerations taken on the whole installation refer to the district heating distribution net, all these considerations have been explained previously on this report section 5.3, section 4.1.
The considerations taken respecting the design of the plant are concerning the main volumes of building needed. As on this case the heating installation will require:

- A closed construction of 200m2 where the heating plant, district heating pumps and communications will be installed.
- The installation and placement of the biogas tank, this tank will be placed horizontally on the exterior as a precaution against gas leaks. It has been located close to the building in order to reduce the gas pipe length.

The requirements concerning the solar thermal installation are related to the area where the thermal panels will be installed. The best place for this installation is the roof of the building, as it will suppose the shortest path for the piping and thus, the least losses in heat. Anyway, as our building has 200 m^2, the installation will be divided between roof and ground. With these conditions we will have:

- A surface of approximately 260 m^2 is needed according to the calculation that has been done. Consequently, half of it will be placed in the roof and the other half on the ground (approximately).
- The accumulation tank for water will be placed inside the building.

Details of calculations and further considerations can be checked in (Appendix 7.10).

The requirements for the electricity production installation are mainly concerning the wind disturbances produced by the building to the windmills installed.
The distribution and location of the building on the plot is explained graphically on the following section of this scenario.

With all this, it results a total area of plot required of 7200 m^2, the cost per m^2 has been calculated in section 5.3 of this report.

HEATING INSTALLATION

The heating installation has been dimensioned taking into account the combination of a biogas boiler system and a solar thermal system composed by 21 modules of 5 solar collectors per module. This combination has been designed in order to provide a 100% of the heat needs during summer by the solar panels, while during winter the biogas boilers will supply all the heat power needed.
The working scheme of the central will be the following estimated; further information in Appendix 7.10. The following table expresses the percentage of monthly production of each system in one year.

SYSTEM	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOT.
Solar	0	1,74	6,80	7.75	2.90	1.52	1.44	1.46	4,10	5,58	0	0	**32,29**
Bioen.	18.77	16.04	1.53	0	0	0	0	0	0	3.70	11.22	16.44	**67,71**
Total	18.77	17.78	8.33	7.75	2.90	1.52	1.44	1.46	4.10	8.28	11.22	16.44	**100 %**

Figure 5.4.5_1: Percentage of monthly production of solar and bioenergy in one year

The two heating systems will provide the system with the following amount of energy, considering the annual estimated needs are 1.965.835Kwh/year (section 3.1):

SYSTEM	ANNUAL PRODUCTION %	ANNUAL PRODUCTION (KWH)
Solar thermal colectors	32.29 %	634.698 KWh
Biogas boilers	67.71 %	1.331.136 KWh

Figure 5.4.5_2: Solar and biogas annual production

The biogas installation is composed by the following elements:

- A pressurized biogas tank of 25m3 which will be installed outdoors. The tank will be filled by a regional supplier according to a long term contract which has to be determined. The capacity has been pre-dimensioned in order to ensure 1 month of supply on the most demanding period.
- A group of two biogas boilers of 310KW of peak power each, considering the model *Logano Plus SB 615 "BUDERUS", these boilers will integrate a pressurized biogas burner which has been included in the estimated cost of the boiler. All the electronics and valves have been included on the costs of the boiler.*
  The overall performance of the boilers has been estimated as 99%,(Appendix 7.11), (section 4.2.1) of this report.

The solar thermal installation is composed by the following elements.

- 21 Modules of 5 solar collectors per module, according to the specifications of model HT 28/8 from ANCOR, or similar (see specification in Appendix 7.10)

- A storage tank of 800l, considering the model *PSM 800 "CLIBER-AUSTRIA" that* will perform the heat exchange between the solar circuit and the district heating circuit. It will be displayed as shown in the working scheme.
- Control systems, piping, pumps, etc.

The common installation is composed by the following elements:

- A heat storage system composed by 4 buffer tanks of 800l, considering the model *PSM 800 "CLIBER-AUSTRIA"*.
  The mission of these elements in this solution is to provide enough thermal lag to the system in order to reduce start-stops on the boilers improving the efficiency. Also, during the summer period will help to store enough heat to compensate cloudy periods of 1-3 days without solar production preventing the starting of the boilers.
  The connection of the tanks will be done on parallel permitting the modularity of the storage, so it will adapt easily to the demand of the different seasons (eg. During winter all the buffer tanks will work, also during summer all of them will be opened to store the maximum amount of "free" energy, during transition periods two of the tanks will be closed as just one of the boilers will be operating).
- All the installation will be controlled by a central computer; this device will receive data from all the thermal sensors installed on the elements of the internal installation, the measures of the flow in the system and the external temperature. Using this data the software will control the boiler, pumps and valves in order to optimize the performance of the system.
  This system has been considered into the cost of the installation of the boiler.
- All the piping system, including the valves, electro-valves, pumps and connections is considered as a part of the installation, which has been estimated as a percentage of the total costs.

ELECTRICITY INSTALLATION

The technical aspect of the electricity installation can be found in the Scenario 2, in the section "Technical consideration-Electricity installation". In this case, the electricity will be only supplied thanks to the wind turbines.
The maximum number of turbines that can be placed in the area without a detailed urban planning approved by the authorities is 10. Installing further turbines would require great efforts in terms of policies, agreements and, furthermore, would be economically less profitable, because it would be impossible to take profit of the "net-metering policy".
Whit this number of turbines, it is only possible to supply the 47% circa (147300 kWh/year) of the total electricity needs.

SOCIAL ASPECTS

COMMON INSTALLATION

The plant location will generate people disagreements due to the proximity of the plant to their house.
The plant construction will affect the surroundings and some services during the execution phase.
All the security measures shall be taken, in order to prevent any explosions from the biogas tank (pressurized tank).

HEATING INSTALLATION

The implementation of the straw boiler requires the permission of the local legal authorities in order to integrate the district heating net.
The grants considered for the biogas consumption are included on the price subvention from the Danish government, this grant ensures a steady price for the biogas on the first 10 years of the installation (see Appendix 7.6).
Regarding solar energy, there are no grants coming from the Danish government, although there is the possibility of applying for European funds.

ELECTRICITY INSTALLATION

The electricity installation is very similar to the one in Scenario 2; all information about social aspects can be found in that section.

ENVIRONMENTAL ASPECTS

COMMON INSTALLATION

The construction and integration of a district heating plant will imply a visual impact on the area, considering that an industrial building would represent a strange element on a zone dominated by traditional architecture.
For this reason, during the design phase of the plant, the integration with the environment shall represent a critical point.
The placement of the biogas tank will require a specific study, in order to prevent leaks and affection to nearby dwellings; this installation will require an specific project and study.
All the environmental restrictions have been followed, and are explained in depth on the (Appendix 7.5) of this report.

HEATING INSTALLATION

As explained in previous section of this report (see Appendix 7.11) and the first term report (Alberdi, et al., 2012), the consumption of biofuels as biogas is considered a neutral balance reaction.
Similar considerations can be made to solar thermal systems, as explained in the same report (Alberdi, et al., 2012).

ELECTRICITY INSTALLATION

The electricity installation is very similar to the one in Scenario 2; all information about environmental aspects can be found in that section.

PLANT DESIGN

For the design of the site, many factors have been taken into account:

- The building containing the heating plant needs to be near the road and to the district heating network
- The Small Wind Turbines have been placed according to the distance criteria explained before:
    - A distance of 25m from the nearest house (South-West) has been respected
    - A maximum distance of 30m from the building has been respected, in order to take profit of the "net-metering"
- The turbines are west-oriented, to take profit of the prevailing wind direction
- The turbines have been placed in order to try to avoid turbulent wind regimes as much as possible
- The visual impact of the turbines has been limited by planting trees. This has been done in all sides except west, the prevailing wind direction; anyway, even the wind of other directions can be harvested without turbulences, thanks to the great distance between the trees and the turbines.

Figure 5.4.5_3: Plant design

Distance of 30 meters from the building to the turbines (to be considered domestic)

Distance of 25 meters from wind turbines to neighbours (for noise impact)

Building

Communication road

Solar thermal collectors

HEATING SCHEME

Working scheme of the heating system during winter season

The buffer tanks will be used powered by the two biogas boilers, considering the estimations studied the solar thermal system will not work as the temperature generated will hardly reach the 60°C needed by the system.

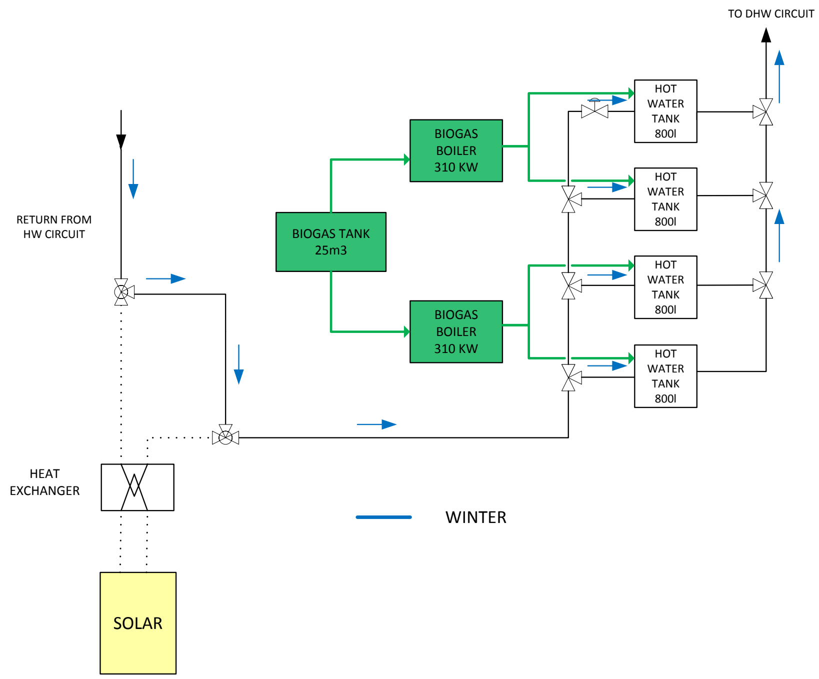


Figure 5.4.5_4: Heating scheme operating in winter

Working scheme of the heating system during spring and autumn seasons

Two of the buffer tanks will be used, supplied by one of the biogas boilers, the solar heating installation will preheat the return water from the circuit when the temperature of the solar circuit reaches the necessary level. The system is studied considering the possibility of having the boilers working, the solar installation or both together, depending on the conditions.

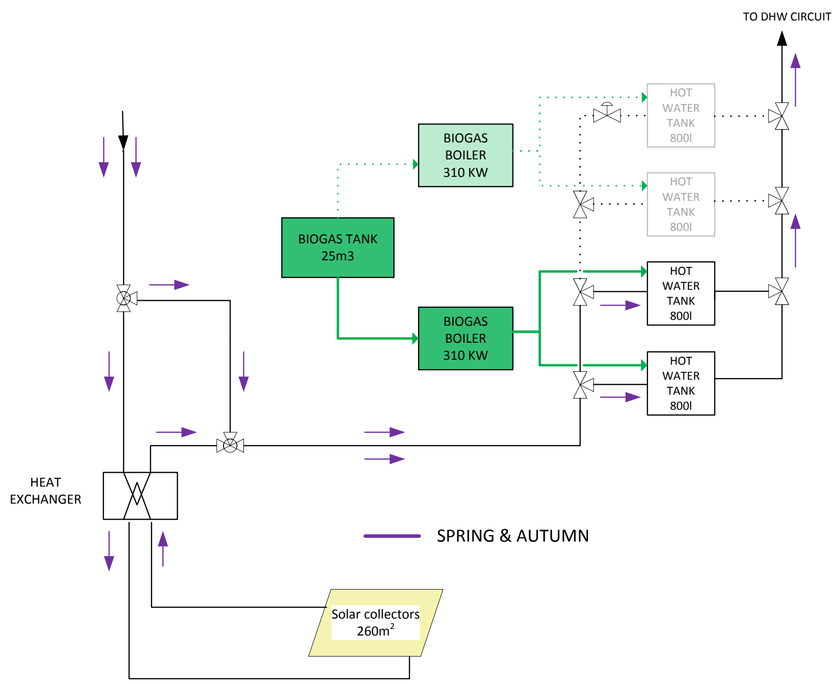


Figure 5.4.5_5: Heating scheme operating in spring and autumn

Working scheme of the heating system during summer season

The four buffer tanks will operate simultaneously, powered by the solar panels. During this season is estimated that considering the thermal lag gained by the buffer tanks the installation would be able to work just using solar energy.

The biogas boilers would be used as a backup system when maintenance or if needed.

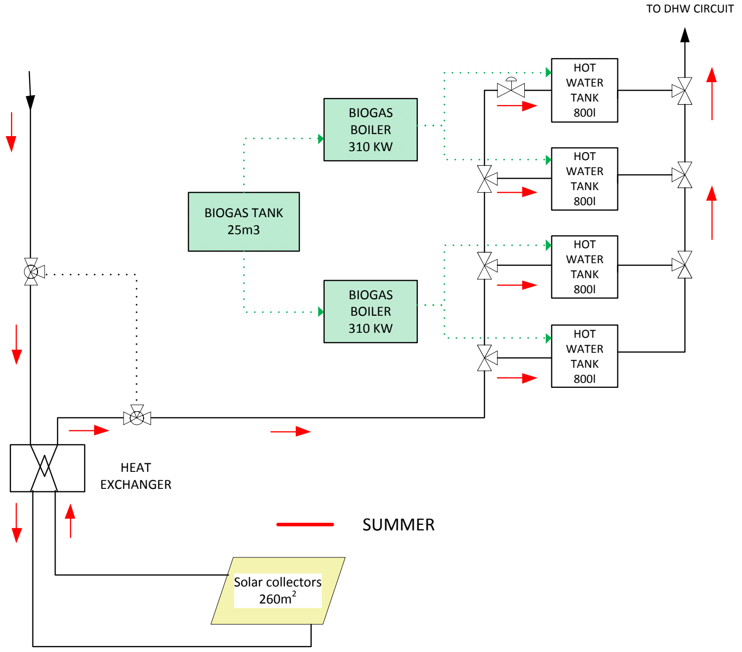


Figure 5.4.5_6: Heating scheme operating in summer

ELECTRICITY SCHEME

The following scheme represents the basic elements which are part of the electricity generation installation.

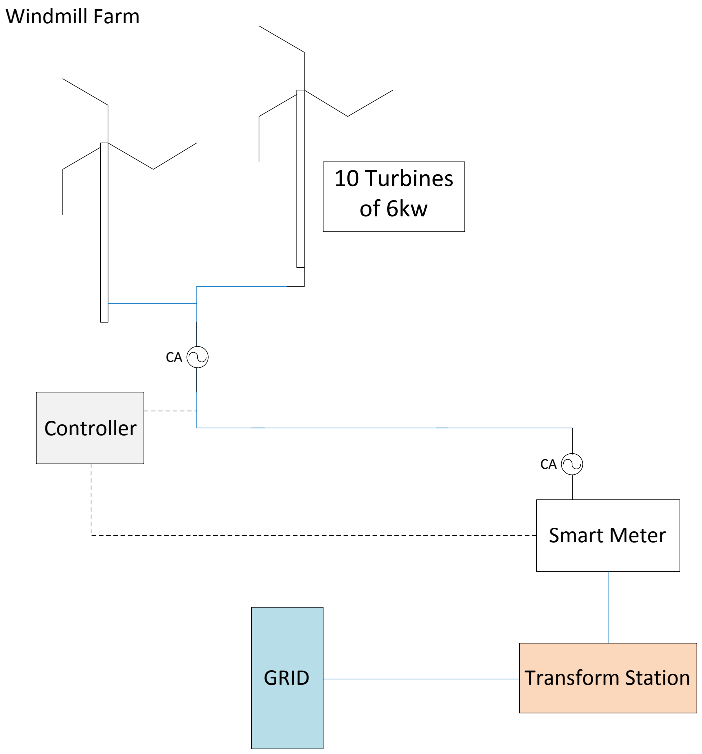


Figure 5.4.5_7: Electricity scheme

ECONOMIC ANALYSIS

COMMON INSTALLATION: DISTRICT HEATING

The district heating installation has been studied in the previous sections (section 5.3) of this report; the following data represents a summary of the initial investment and total annual costs.

- Annual land rent – **70.200 DKK/year**
  - Land requirements – 7.200 m2
  - Land rent price – 97.500 DKK/Ha per year
- Annual running costs – **94.565 DKK/year**
- Total investment - **10.815.577 DKK**
-

DESCRIPTION	COST (DKK)
Site building	**1.232.042DKK**
Closed building (200m2, industrial)	985.634DKK
VAT (25%)	246.408 DKK
District heating investment	**9.583.535 DKK**
TOTAL	**10.815.577 DKK**

Figure 5.4.5_8: Initial investment for the common district heating installation

HEATING INSTALLATION: BIOGAS BOILERS + GENERAL INSTALATION

The data used on this economic analysis has been justified previously on the report. See (appendix 7.11), (section 4.2.1) of the report.

- Annual consumption costs – **556.657 DKK/year** (0.00% annual variation)
- Annual consumption – 1.344.582 KWh/year
  - Annual needs – 1.331.136 KWh/year
  - Boiler performance – 99%
- Fuel cost – 414 DKK/MWh
- Annual maintenance cost – **12.500 DKK/year**
- Installation cost – **912.981 DKK**

DESCRIPTION	COST (DKK)
Biogas boiler X2 *(Logano Plus SB 615 "BUDERUS")*	360.200 DKK
Pressurized Biogas tank 25m3 (superficial)	150.000 DKK
Buffer-tank 800l X4 *(PSM 800 "CLIBER-AUSTRIA")*	25.200 DKK
Extraction system *(GC-25 ALU PLUS "NEGARRA")*	41.980 DKK
Installation and connection (10%)	57.738 DKK
TOTAL INSTALLATION COST	**635.118 DKK**
GC+IB (9%+6%)	95.267 DKK
TOTAL COST	**730.385 DKK**
VAT (25%)	182.596 DKK
TOTAL	**912.981 DKK**

Figure 5.4.5_9: Heating installation cost for the biogas boiler

HEATING INSTALLATION: SOLAR

DESCRIPTION	COST (DKK)
21 modules of solar colectors "ARCON" HT 28/8	625.800 DKK
Buffer-tank 800l *(PSM 800 "CLIBER-AUSTRIA")*	6.300 DKK
Installation, control system and connection (25%)	158.025 DKK
TOTAL INSTALLATION COST	**790.125 DKK**
GC+IB (9%+6%)	118.518 DKK
TOTAL COST	**908.643 DKK**
VAT (25%)	227.160 DKK
TOTAL	**1.135.803 DKK**

Figure 5.4.5_10: Heating installation cost for the solar thermal

ELECTRICITY INSTALLATION

DESCRIPTION	COST (DKK)
10 Bornay 6000 Turbines (6 kW)	1.266.087 DKK
Aurora 6 kW inverters	180.869 DKK
Installation and connection (20%)	361.739 DKK
TOTAL INSTALLATION COST	**1.808.695 DKK**
GC+IB (9%+6%)	271.305 DKK
TOTAL COST	**2.080.000 DKK**
VAT (25%)	520.000 DKK
TOTAL	**2.600.000 DKK**

Figure 5.4.5_11: Electricity installation cost

COMMON SOLUTION SUMMARY

Initial investment

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
DISTRICT HEATING	10.815.577_DKK	152.332 DKK
HEATING INSTALLATION		
Biogas boilers + main inst.	912.981 DKK	12.859 DKK
Solar thermal panels	1.135.803 DKK	15.997 DKK
ELECTRICITY INSTALLATION		
Windmills	2.600.000 DKK	36.620 DKK
TOTAL	**15.464.361 DKK**	**217.808 DKK**

Figure 5.4.5_12: Initial investment for the common solution

Annual running cost

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
COMMON INSTALLATION		
Land renting	70.200 DKK	988 DKK
DISTRICT HEATING		
Annual costs	94.565 DKK	1.332 DKK
HEATING INSTALLATION		
Biogas boilers + main inst.		
Annual consumption	556.657 DKK	7.840 DKK
Maintenance costs	12.500 DKK	176 DKK
Solar thermal panels		
Maintenance costs	22.350 DKK	315 DKK
ELECTRICITY INSTALLATION		
Windmills		
Annual costs	52.000 DKK	743 DKK
TOTAL	**808.272 DKK**	**11.394 DKK**

Figure 5.4.5_13: Annual running cost for the common solution

Annual production benefits

DESCRIPTION	COST (DKK)	COST PER USER(DKK)
HEATING INSTALLATION		
Potential savings	*2.110.191 DKK	*29.721 DKK
ELECTRICITY INSTALLATION		
Windmills		
Electricity production	**693.000 DKK	**9.900 DKK
TOTAL	**2.803.190 DKK**	**39.621 DKK**

* A yearly variation for the heating costs with traditional fuels of +3.00% is considered.
** A yearly variation for the electricity costs of +3.00% is considered.

Figure 5.4.5_14: Annual production benefits for the common solution

CONCLUSION

INDICATORS

The following economic indicators referred to the investment have been selected in order to compare all the scenarios proposed on the conclusion section of this report (see section 6.1).

INDICATOR	VALUE
Initial investment	217.808 DKK
Loan period	7 Years
Break-even point	9 Years
Profit 10 years	48.916 DKK
Profit 20 years	471.598 DKK
Profitability 10 years	22.4 %
Profitability 10 years	216.5 %

Figure 5.4.5_15: Cash-flow indicators

GRAPHICS

The following graphics represent the evolution of the investment during the life period of the system.

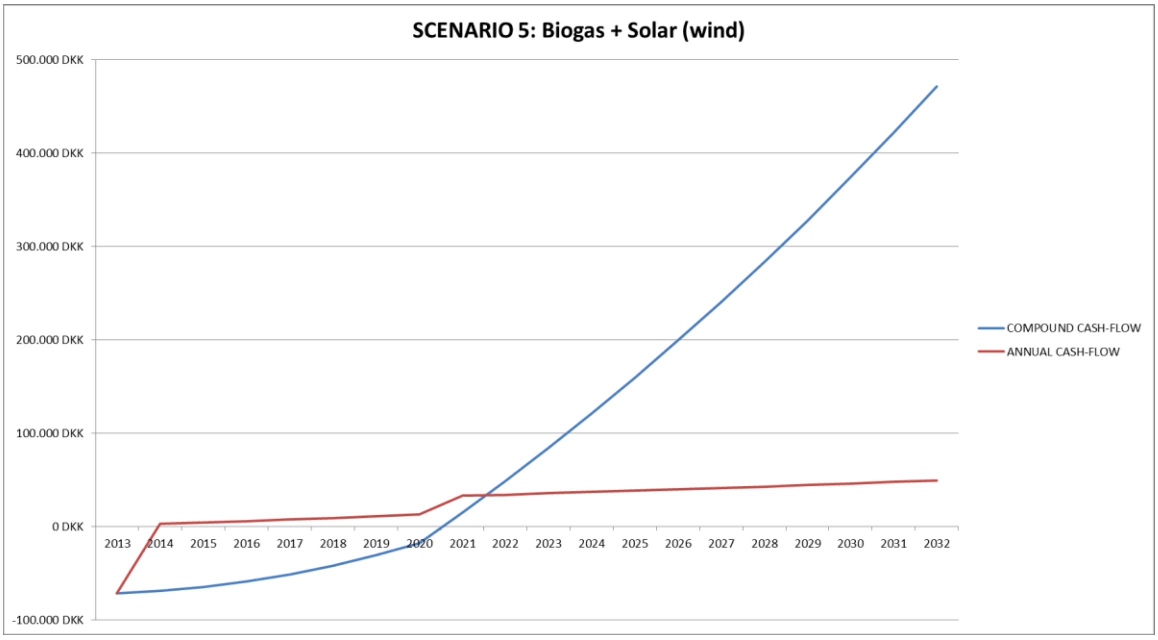


Figure 5.4.5_16: Cash-flow graph

5.4.6. SCENARIOS CONCLUSIONS

The following chart represents the indicators analyzed as a conclusion for the study if the five scenarios proposed

INDICATOR	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5
Initial investment	690.418 DKK	289.057 DKK	276.320 DKK	438.974 DKK	217.808 DKK
Loan period	20 Years	10 Years	12 Years	16 Years	7 Years
Break-even point	12 Years	9 Years	3,5 Years	- Years	9 Years
Profit 10 years	-21.847 DKK	28.980 DKK	107.817 DKK	-205.114 DKK	48.916 DKK
Profit 20 years	276.996 DKK	485.986 DKK	586.884DKK	-160.418 DKK	471.598 DKK
Profitability 10 years	-3.2%	10%	39%	-47.6 %	22.4 %
Profitability 10 years	40.1%	168%	212,4%	-36.5 %	216.5 %

Figure 5.4.6_1: Indicators summary from scenarios cash-flow

The following graphic represents the curves of the compound cash-flow of all the investments:

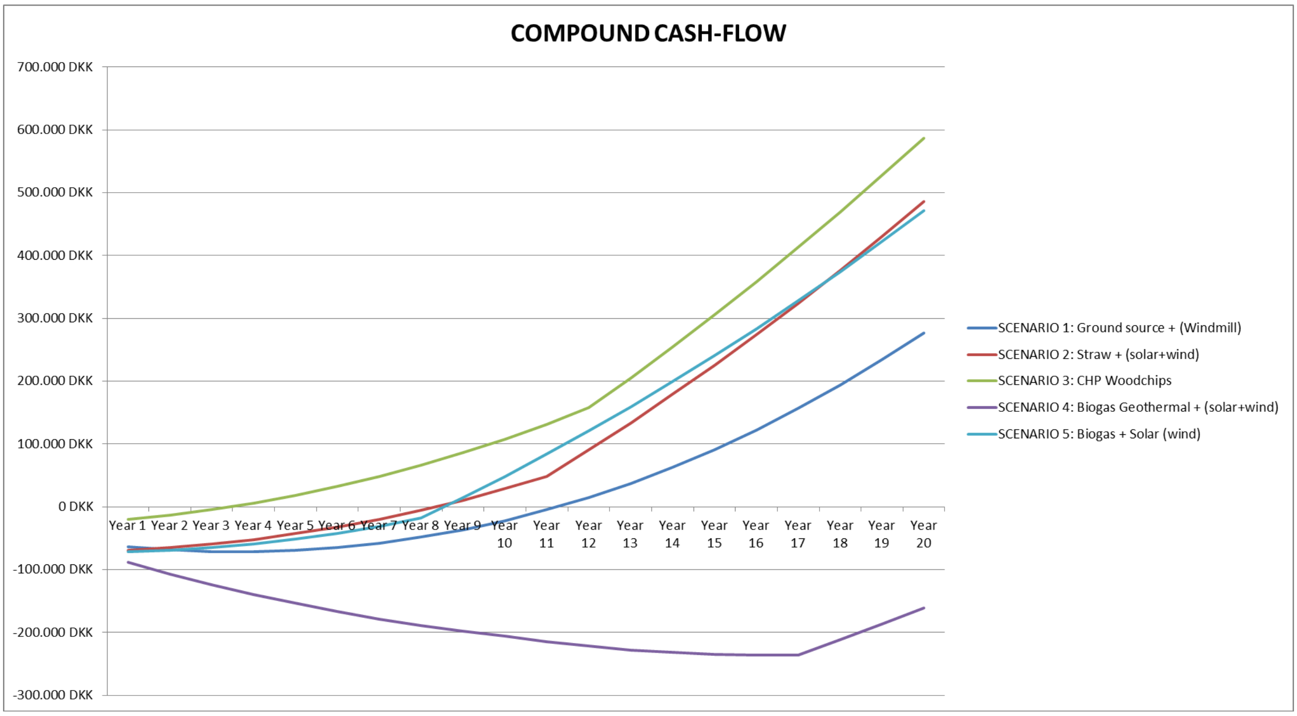


Figure 5.4.6_2: Compound cash-flow for all the scenarios

6. CONCLUSION

6.1 CONCLUSION

INTRODUCTION

The analysis has been done comparing on the one hand heating solutions and on the other hand electricity solutions (taking into account individual and collective ones, and making a brief analysis of the different solutions). Besides, the studied scenarios have been compared between them, in order to find the most profitable option for supplying heating and electricity for Føns commune. Moreover, a comparison between all the studied solutions has been done. Finally, an analysis of insulation solutions has been done, and final recommendations have been given based on the project authors' criteria.

For the analysis the benchmarking method has been used, giving punctuation from 100% to 0%, being 100% the one with better marks in each indicator and 0% the worst one.
The indicators used for this purpose are: initial investment (DKK), loan period (years), break-even point (years), profit 10 years (DKK), profit 20 years (DKK), profitability 10 years (%), profitability 20 years (%).

HEATING SOLUTIONS

In the feasibility study of the present project different heating solutions have been studied, considering collective and individual solutions. The analyzed solutions are: district heating woodchips, district heating straw, district biogas and district borehole storage as collective solutions; and pellet boiler, tank storage, borehole storage and borehole no storage as individual solutions.

INDICATORS AND BENCHMARKING

On the following chart, the summary of the indicators and benchmark of the heating solutions studied are shown:

SOLUTION	COLLECTIVE SOLUTIONS				INDIVIDUAL SOLUTIONS			
	D.H. Woodchips	D.H. Straw	DH. Biogas	DH. Borehole Storage	Pellet boiler	Tank storage	Borehole storage	Borehole no storage
Initial investment (DKK)	124562	102662	57931	248362	176669	198278	267864	224763
Benchmark	68%	79%	100%	9%	43%	33%	0%	21%
Loan period (years)	6	5	2	13	9	10	14	11
Benchmark	67%	75%	100%	8%	42%	33%	0%	25%
Break-even point (years)	4	4	4	16	8	14	19	20
Benchmark	100%	100%	100%	25%	75%	38%	6%	0%

Profit 10 years (DKK)	150415	157008	157221	-66603	42494	-71012	-92214	-123200
Benchmark	98%	100%	100%	20%	59%	19%	11%	0%
Profit 20 years (DKK)	550891	537674	490328	112248	398120	135435	41319	15201
Benchmark	100%	98%	89%	18%	71%	22%	5%	0%
Profitability 10 years (%)	120	153	271	-27	20	-36	-34	-55
Benchmark	54%	64%	100%	9%	23%	6%	6%	0%
Profitability 20 years (%)	442	524	846	45	225	68	15	7
Benchmark	52%	62%	100%	5%	26%	7%	1%	0%

Figure 6.1_1: Heating solutions indicators and benchmark

BENCHMARK GRAPHICS

The following graphics represent the graphical comparison of the benchmark grades obtained from the indicators analysis, considering heating solutions including collective and individual ones.

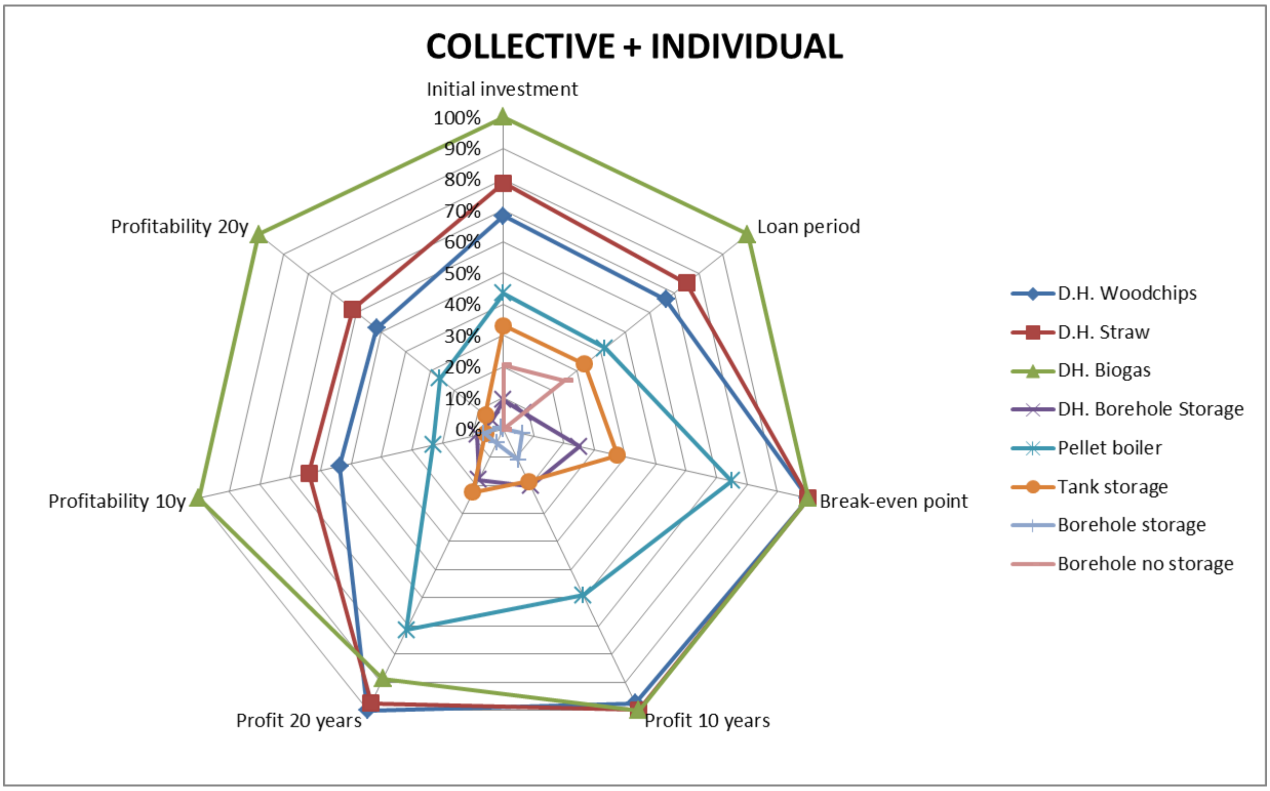


Figure 6.1_2: Collective + Individual heating solutions benchmark radar chart

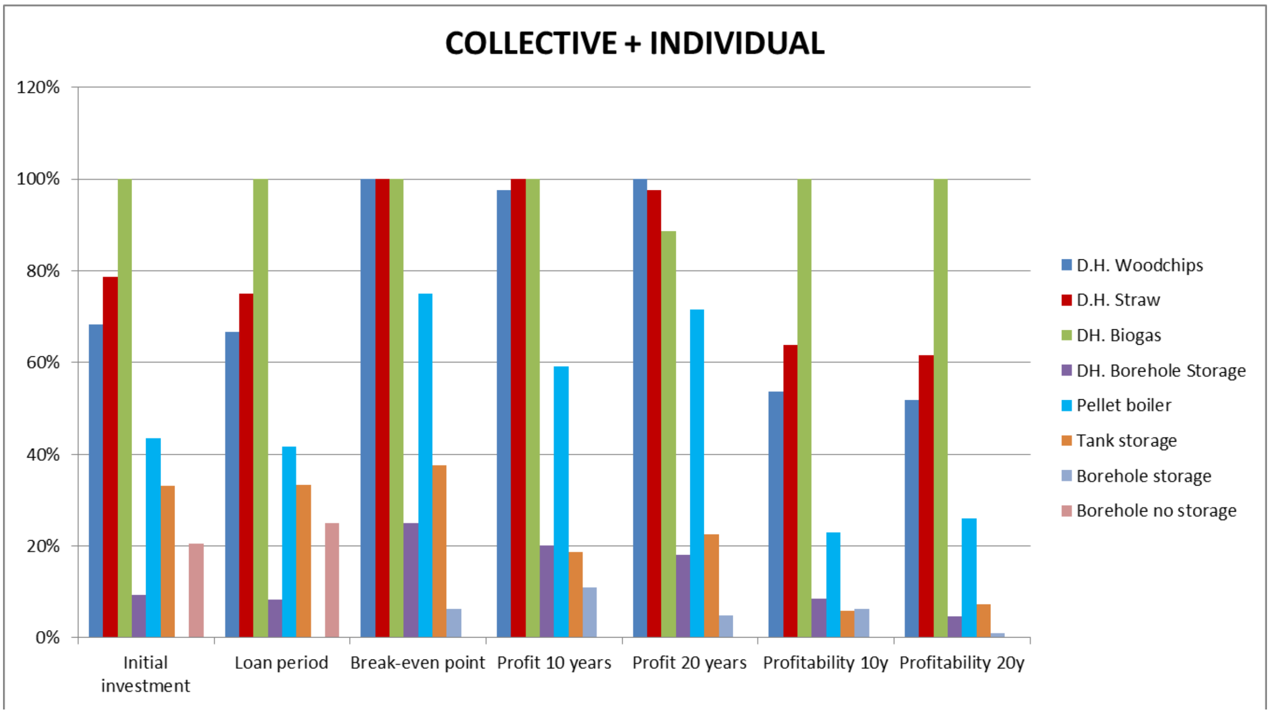


Figure 6.1_3: Collective + Individual heating solutions benchmark bar chart

Moreover, in the following graphics, the previous representation has been divided among individual and collective solutions.

COLLECTIVE SOLUTIONS

In the following graphics the collective solutions have been detailed, in order to see them more clearly.

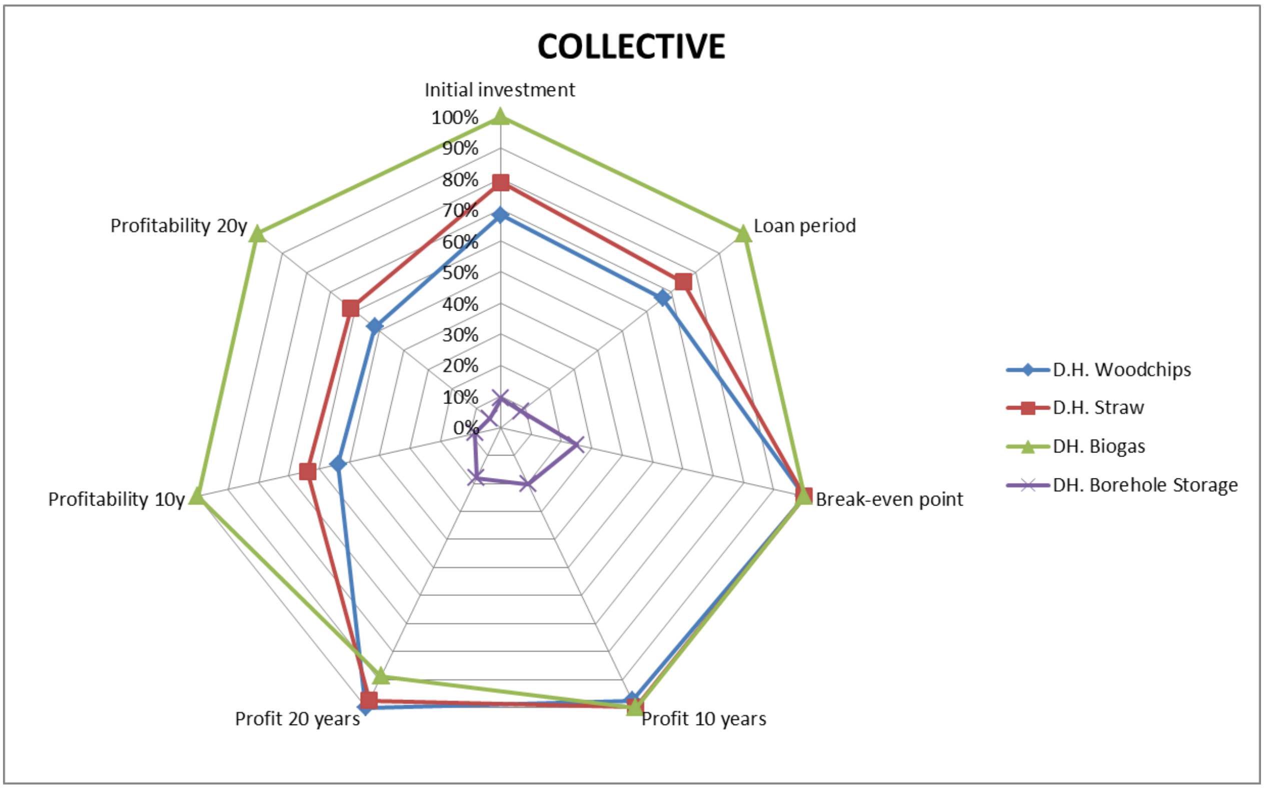


Figure 6.1_4: Collective heating solutions benchmark radar chart

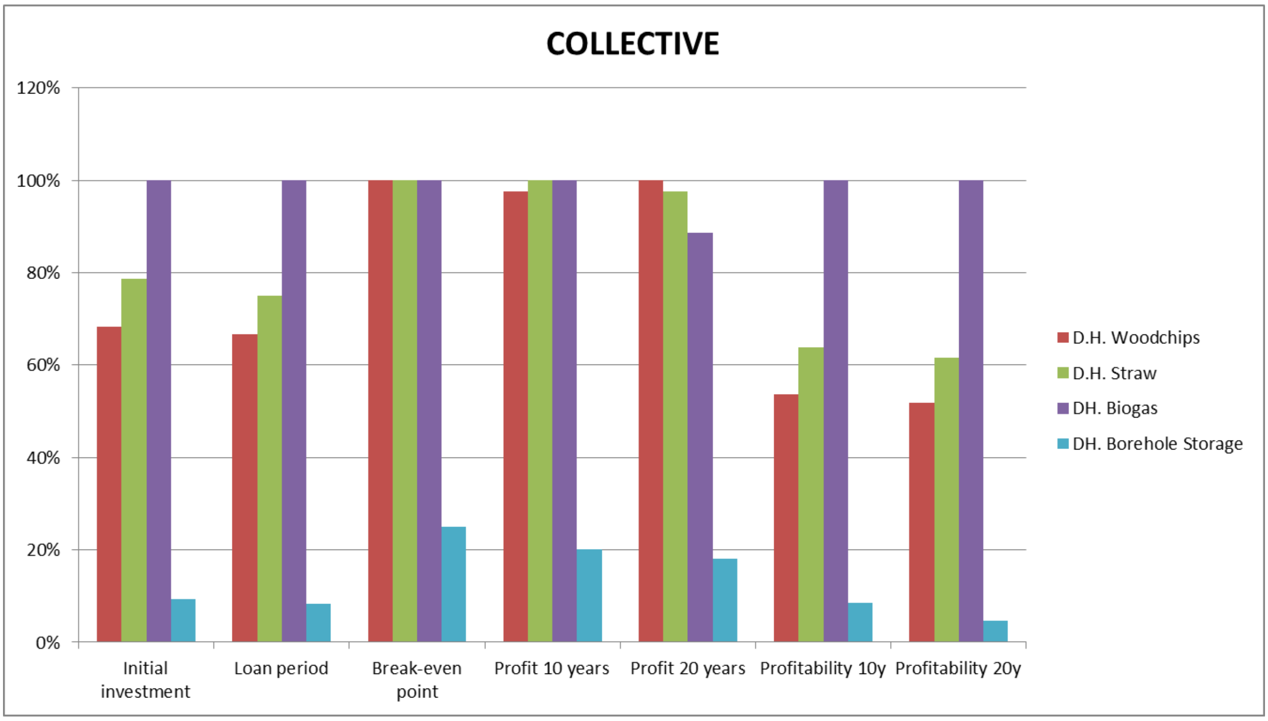


Figure 6.1_5: Collective heating solutions benchmark bar chart

INDIVIDUAL SOLUTIONS

In the following graphics the individual solutions have been isolated to appreciate in more detail the differences between them.

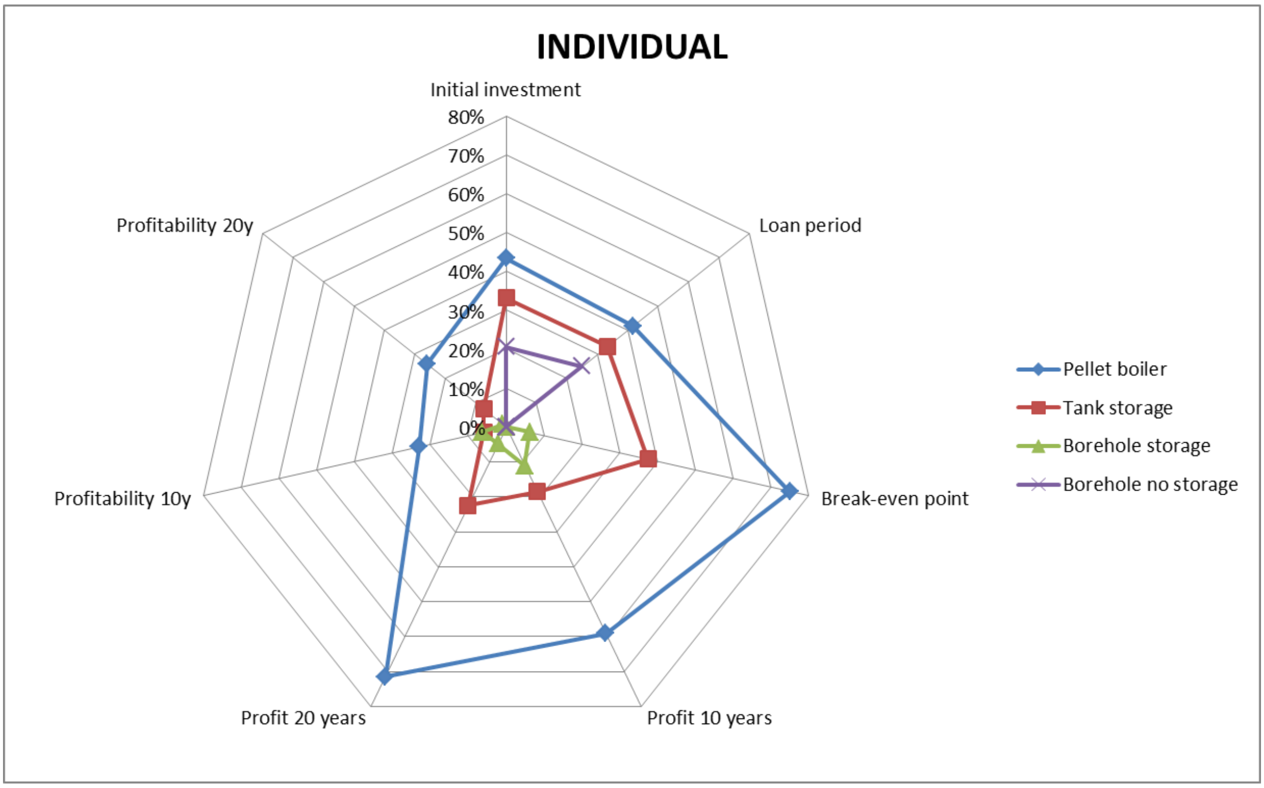


Figure 6.1_6: Individual heating solutions benchmark radar chart

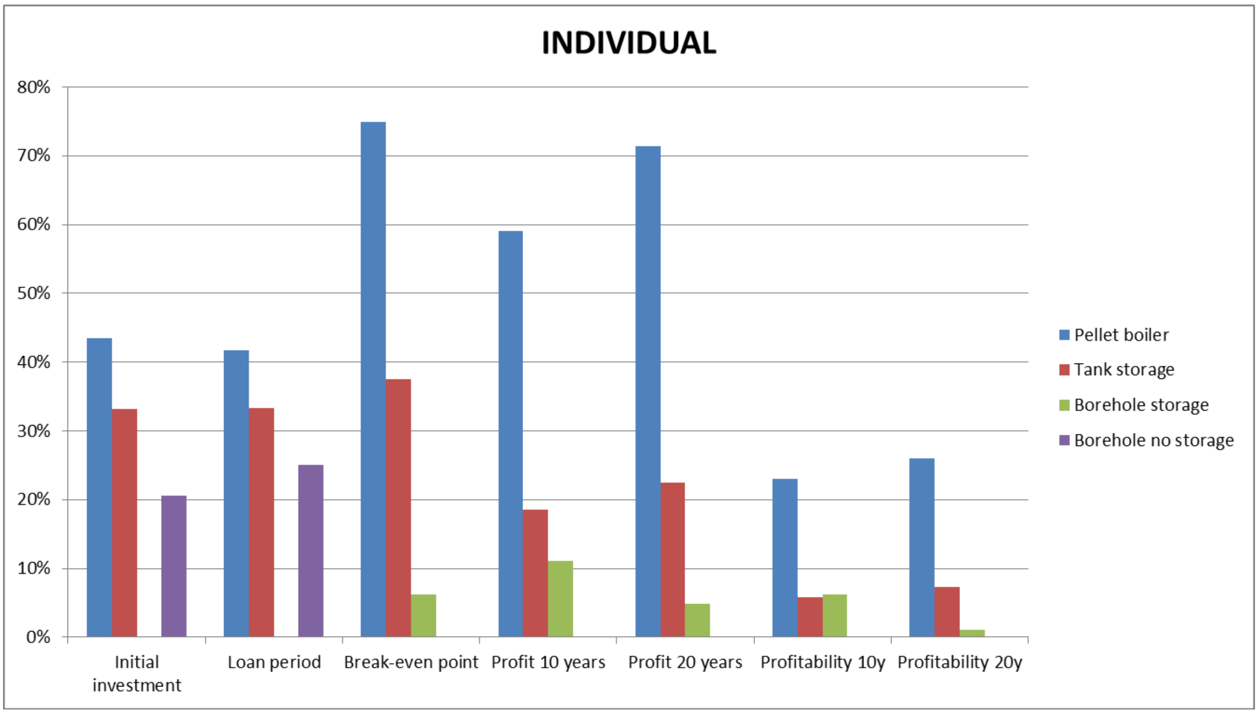


Figure 6.1_7: Individual heating solutions benchmark bar chart

ANALYSIS

GENERAL ANALYSIS

As it can be seen in the graphics, most of the collective solutions raise better marks than the individual ones.
It could be said that the most feasible and profitable option is the collective district heating by using biogas, followed by collective district heating using straw and woodchips which have close values. Then the most suitable individual solution is the pellet boiler followed by the tank storage.
Finally, it could be said that the less suitable solutions are collective district heating by using borehole storage and individual borehole without storage.

CONCLUSION

As the main conclusions achieved from the study of the heating solutions it could be asserted that:

- Collective solutions represent a better option than individual solutions. Implying a lower initial investment per user, and providing a higher overall profitability.
- Solutions based on ground source heating reach lower marks on the overall analysis. The main factors responsible for these results are the high initial investment required and the high running costs of the system.
- The biogas district heating solution represents the most interesting option, reaching the highest benchmarks in all the parameters except the profit at 20 years.
- The straw district heating option could be considered the second best solution, followed by the woodchips plant. These two solutions gather an average initial investment per user.

ELECTRICITY PRODUCTION SOLUTIONS

In the feasibility study of the present project, different solutions for supplying electricity have been studied, considering collective and individual solutions. The analyzed solutions are: two options of solar collective and a wind turbine as collective solutions; and solar and small wind turbine as individual solutions.

INDICATORS AND BENCHMARKING

On the following chart, the summary of the indicators and benchmark of the heating solutions studied are shown:

SOLUTION	COLLECTIVE SOLUTIONS			INDIVIDUAL SOLUTIONS	
	Solar Collective 350kW	Solar Collective 450kW	Wind Turbine	Solar Individual 5kW	Small Wind turbines
Initial investment (DKK)	62251	75919	346478	82.350	260000
Benchmark	100%	95%	0%	93%	30%
Loan period (years)	2	2	18	3	13
Benchmark	100%	100%	0%	94%	31%
Break-even point (years)	8	8	2	11	4
Benchmark	33%	33%	100%	0%	78%
Profit 10 years (DKK)	21242	35812	143461	-3272	73187
Benchmark	17%	27%	100%	0%	52%
Profit 20 years (DKK)	96832	123892	540676	72313	459929
Benchmark	5%	11%	100%	0%	83%
Profitability 10 years (%)	34	47	41	-4	28
Benchmark	75%	100%	88%	0%	63%
Profitability 20 years (%)	156	163	156	88	177
Benchmark	76%	84%	76%	0%	100%

Figure 6.1_8: Electricity solutions indicators and benchmark

BENCHMARK GRAPHICS

The following graphics represent the graphical comparison of the benchmark grades obtained from the indicators analysis.
The graphic representation has been divided among individual and collective solutions, for electricity supply.

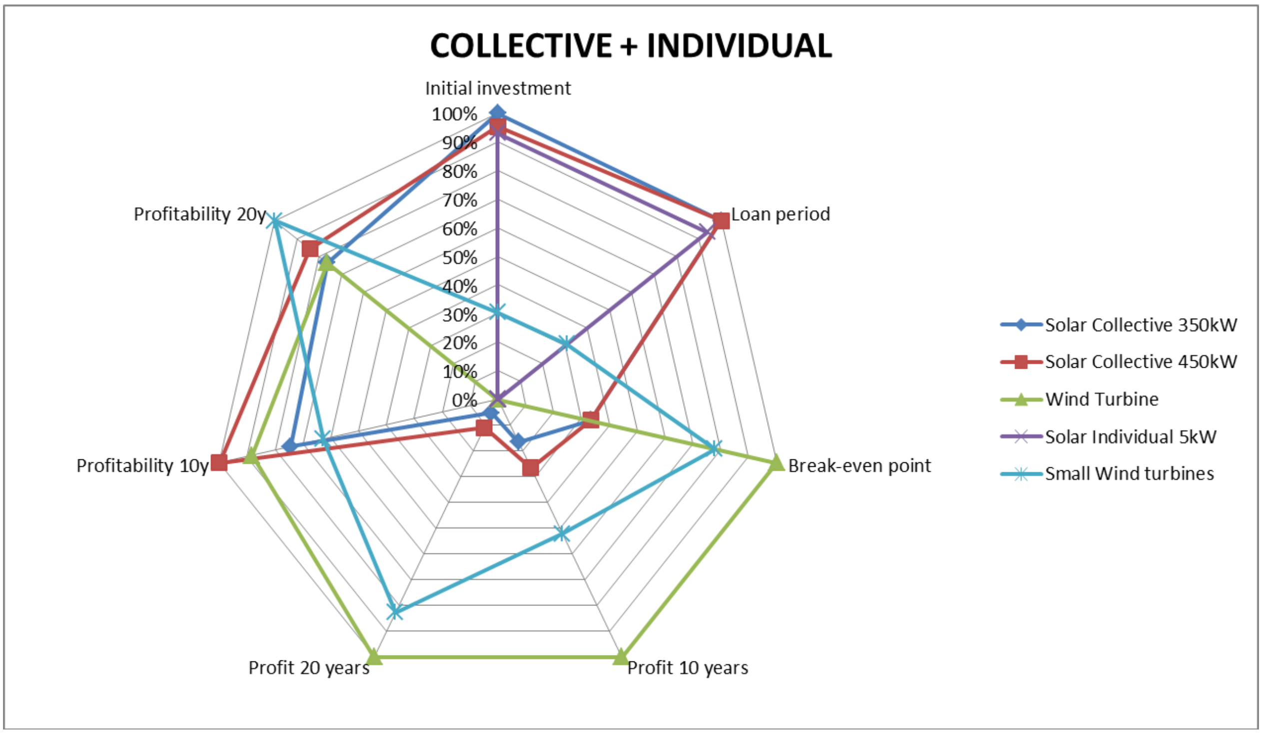


Figure 6.1_9: Collective + Individual electricity solutions benchmark radar chart

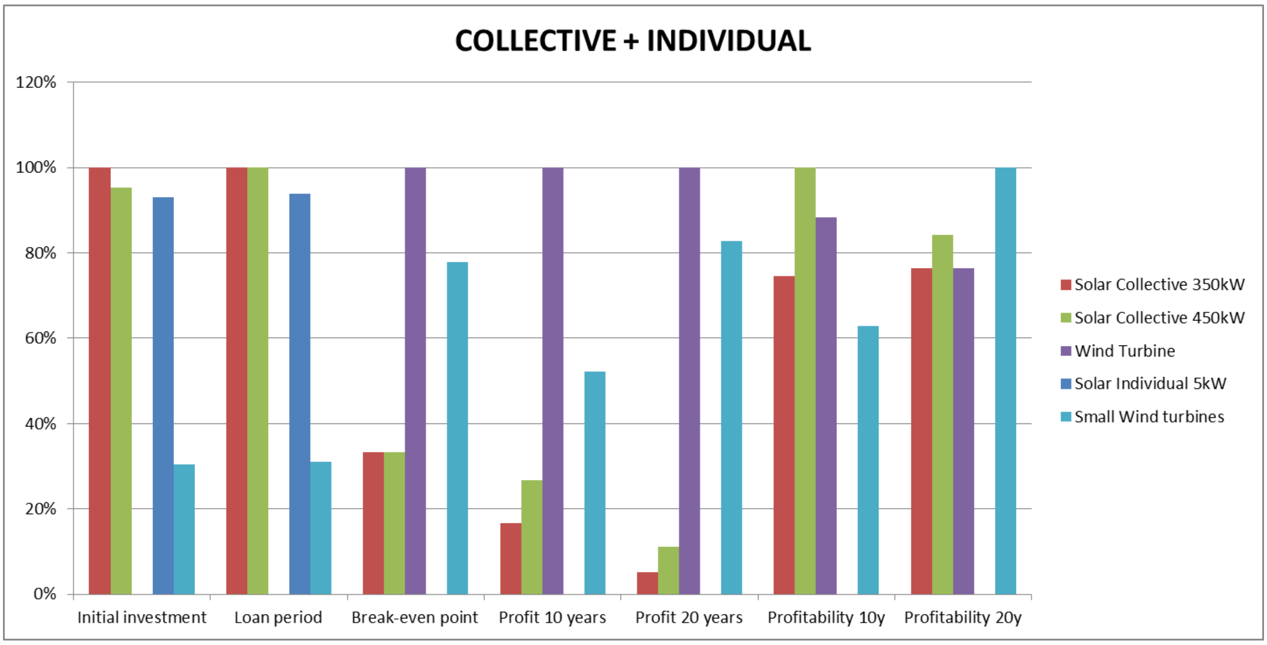


Figure 6.1_10: Collective + Individual electricity solutions benchmark bar chart

COLLECTIVE SOLUTIONS

In the following graphics the collective solutions have been detailed, in order to see them more clearly.

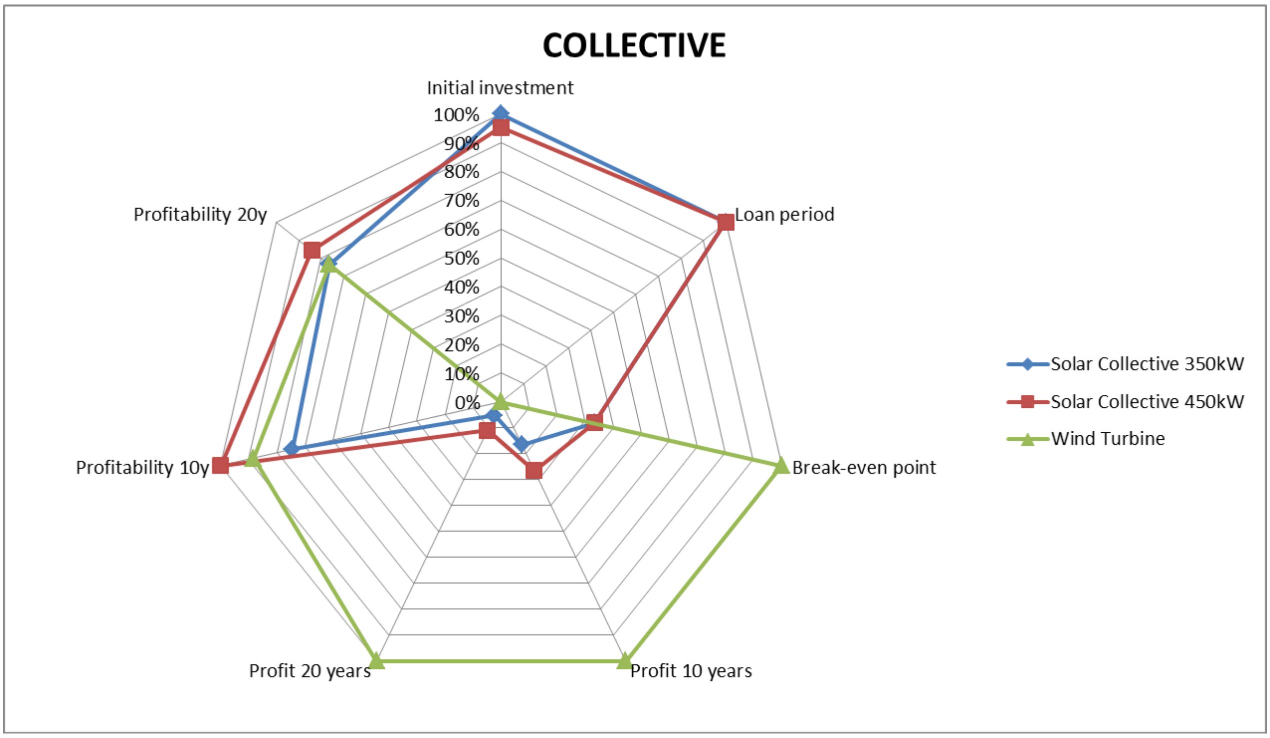


Figure 6.1_11: Collective electricity solutions benchmark radar chart

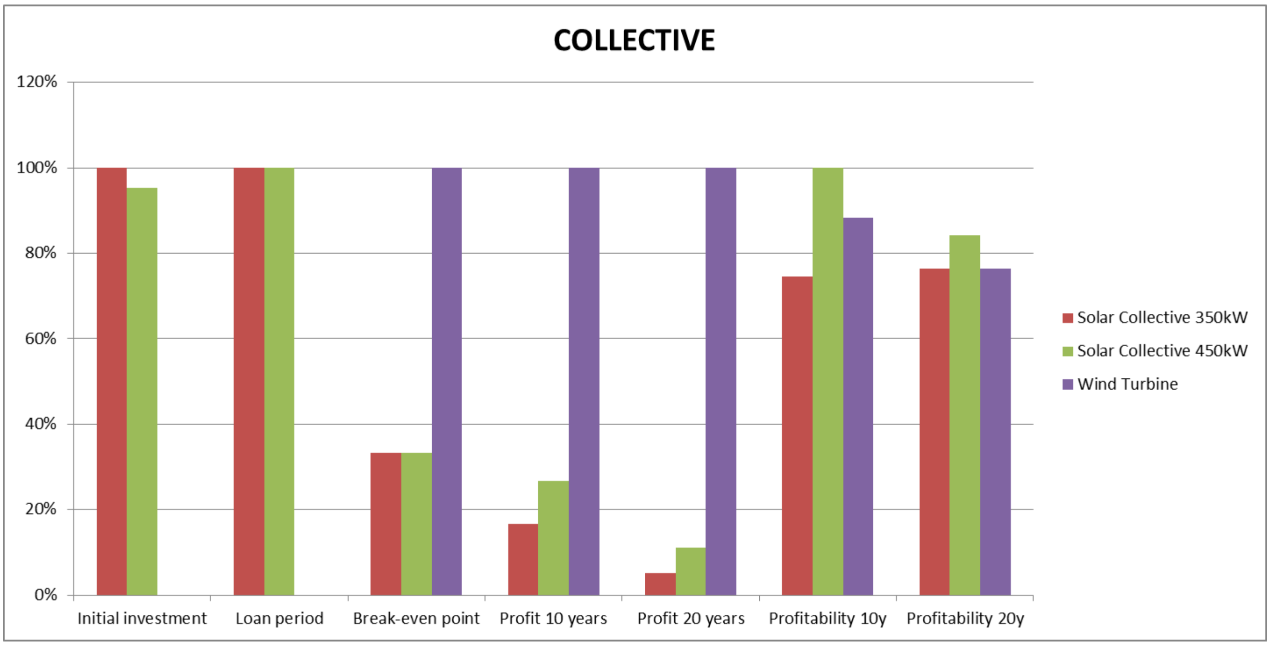


Figure 6.1_12: Collective electricity solutions benchmark bar chart

INDIVIDUAL SOLUTIONS

In the following graphics the individual solutions have been isolated to appreciate in more detail the differences between them.

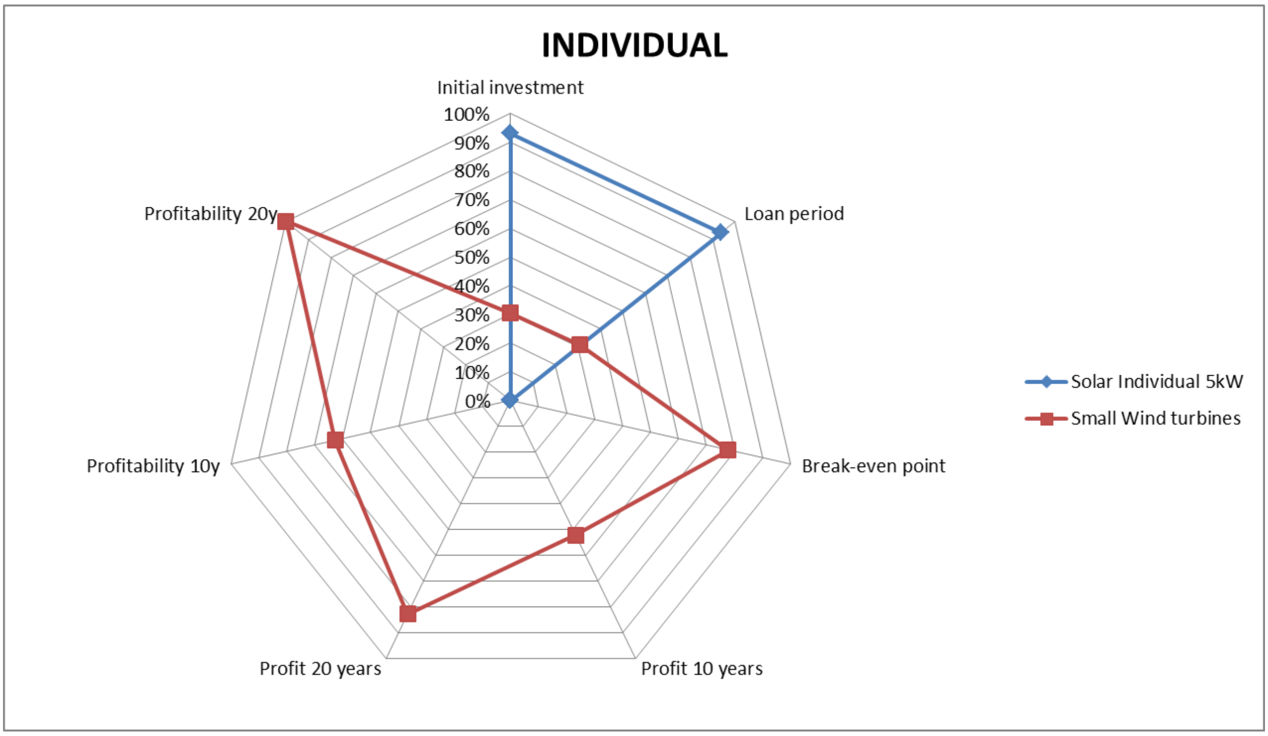


Figure 6.1_13: Individual electricity solutions benchmark radar chart

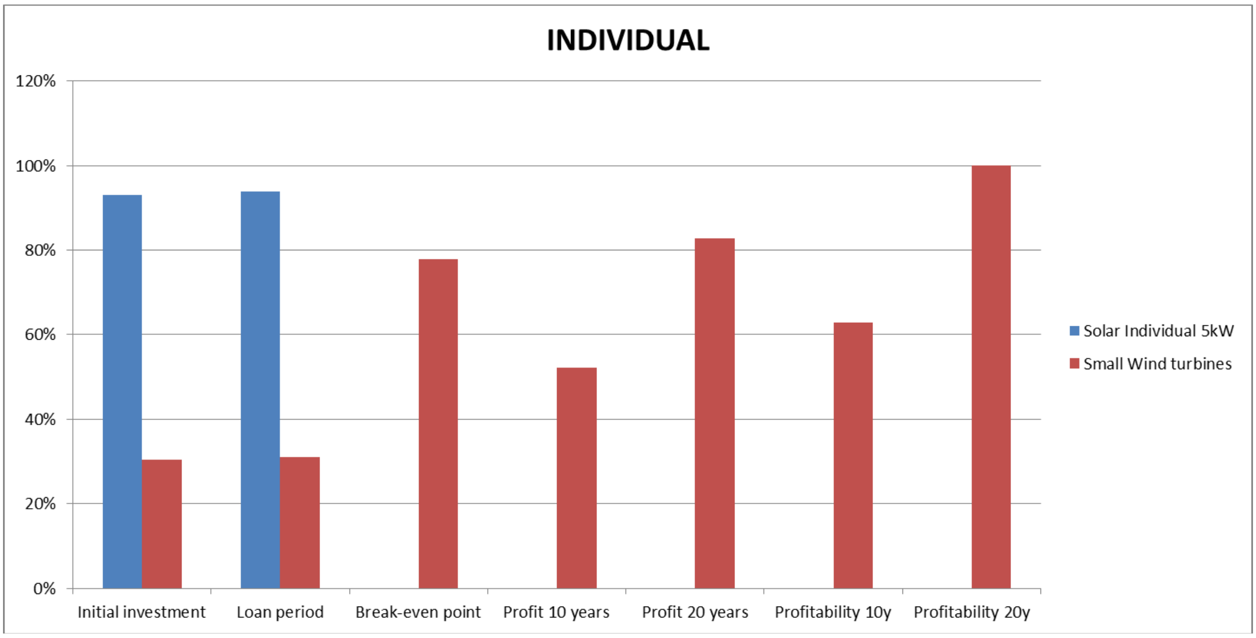


Figure 6.1_14: Individual electricity solutions benchmark bar chart

ANALYSIS

GENERAL ANALYSIS

In contrast to the heating solutions analysis, in the case of the electricity analysis there are no solutions which clear reach the best marks in all the indicators. In this case, there are some solutions with high initial investments and longer loan period such as the solutions of the wind turbines but with good break-even point, and good profit.
Whereas the solar solutions have lower initial investment and shorter loan period but their break-even point and profit is lower than the wind ones.
On the other hand, the profitability values are more homogeneous between solar and wind solutions because they depend on the initial investment and the profit.

CONCLUSION

- Wind turbine solution is the one with highest profit, and an acceptable profitability (but not the best)
- The solar collective 450 kW, is the investment with the greatest long term and medium term profitability, being also one of the ones with lowest initial investment, and shorter loan period. So it could be said that is one of the most safeties electricity solutions.
- The small wind turbine, which is the one with highest long term profitability and with average medium term profitability. It could be considered the best option if only individual solutions were considered, but not the best if collective solutions are taken into account.

COMBINED SOLUTIONS

Based on the results of the feasibility study developed on this project, some solutions were selected to be applied in combined scenarios. The aim of these scenarios was to highlight the most profitable energetic solution for Føns commune.
The considered scenarios are the following:

- Scenario 1 – Ground source district heating + high capacity windmill.
- Scenario 2 – Straw boiler district heating + Photovoltaic and small wind turbines.
- Scenario 3 – CHP woodchips district heating and electric plant.
- Scenario 4 – Ground source district heating with biogas backing + Small wind turbines and photovoltaic panels.
- Scenario 5- Biogas boiler district heating with solar thermal backing + Small wind turbines.

INDICATORS AND BENCHMARKING

On the following chart, the summary of the indicators and benchmark of the heating solutions studied are shown:

SOLUTION	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Initial investment (DKK)	690418	289057	276320	438974	217808
Benchmark	0%	85%	88%	53%	100%
Loan period (years)	20	10	12	16	7

Benchmark	0%	77%	62%	31%	100%
Break-even point (years)	12	9	3	20	9
Benchmark	47%	65%	100%	0%	65%
Profit 10 years (DKK)	-21847	28980	107817	-205114	48916
Benchmark	59%	75%	100%	0%	81%
Profit 20 years (DKK)	276996	485986	586884	-160418	471598
Benchmark	59%	86%	100%	0%	85%
Profitability 10 years (%)	-3,2	10	39	-47,6	22,4
Benchmark	51%	67%	100%	0%	81%
Profitability 20 years (%)	40,1	168	212,4	-36,5	216,5
Benchmark	30%	81%	98%	0%	100%

Figure 6.1_15: Scenarios' indicators and benchmark

BENCHMARK GRAPHICS

The following graphics represent the graphical comparison of the benchmark grades obtained from the indicators analysis.

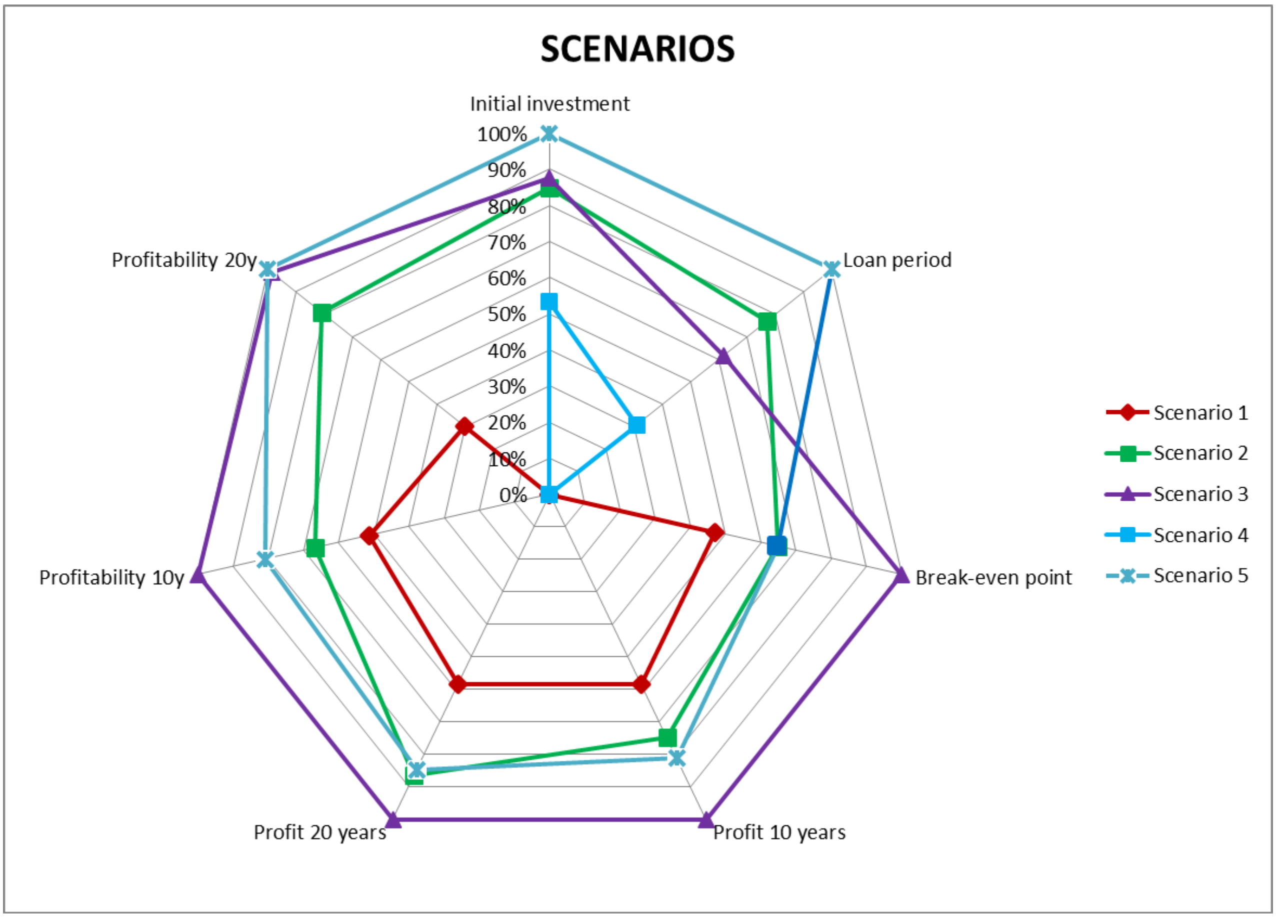


Figure 6.1_16: Scenarios' benchmark radar chart

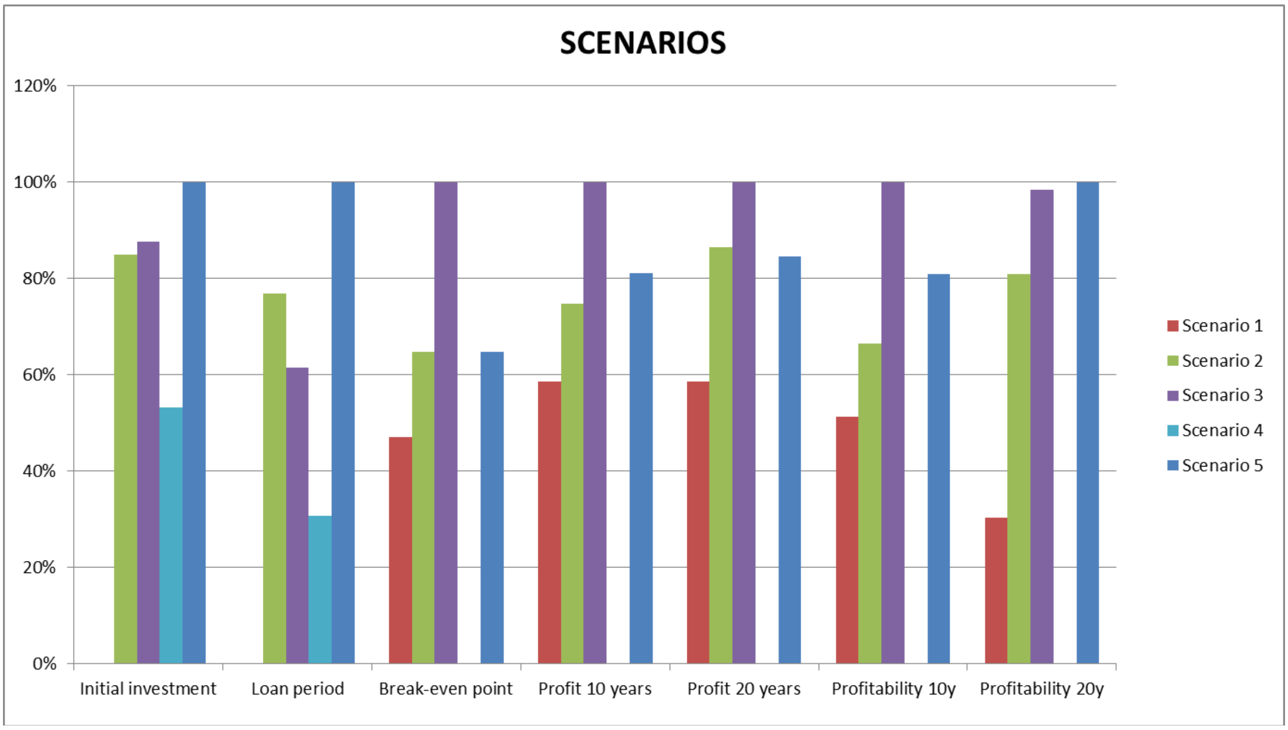


Figure 6.1_17: Scenarios' benchmark bar chart

ANALYSIS

GENERAL ANALYSIS

As it can be seen in the graphics, the scenarios with a heating system based on a biomass solution reach a better overall performance compared with the ones based on a ground source heating solution.
The solution proposed on scenario 4 (Ground source heating with biogas boiler and electricity generation based on photovoltaic solar panels), reaches the lowest marks regarding profit and profitability, even though the solution does not have the highest initial investment.
The scenario 1 (Ground source heating with high capacity windmill) reaches an average profitability mark considering that is the solution with the highest initial investment.
Considering the indicators studied, scenarios 3 and 5 are the solutions with the best benchmark grades, being scenario 3 the one with the greatest profitability grades and 5 the one with the lowest initial investment grades.

CONCLUSION

As the main conclusions achieved from the study of the heating solutions it could be asserted that:

- Solutions based on ground source heating reach the lowest benchmark grades, so it can be considered as a solution to discard when studying the implementation of a combined heating and electricity system.
- The implementation of a high capacity windmill implies the greatest initial investment, but compensates with moderate long term profitability.
- The implementation of a cogeneration solution (scenario 3) represents the option with the greatest middle-term and long-term profitability, implying a moderate initial investment. This solution can be considered the best option when profitability is the main concern.

- The combination proposed on scenario 5 (biogas + solar thermal + windmills), can be considered the safest investment, reaching also the greatest long-term profitability. This solution can be considered the safest combined investment.

INSULATION IMPROVEMENT

In the section 3.2 of this report (insulation study) a rough analysis of the annual heat losses considering the current level of insulation of the houses studied, has been performed. From this study the following summary chart has been created in order to compare the main sources of heat loses on the studied houses.

HEAT LOSS SOURCE	TOTAL LOSS (MWh/year)	PERCENTAGE
Ceiling loss	154,65	8%
Wall loss	110,78	6%
Windows loss	383,86	20%
Slabs loss	169,16	9%
Infiltrations	1.131,57	58%

Figure 6.1_18: Annual heat losses by components

From this study it can be assumed that the main sources of heat losses are the air infiltrations (58%) and the losses on windows (20%).
Comparing these losses with the average cost of the heating solutions calculated from the scenarios proposed (section 5):

SCENARIOS	HEATING CONSUMPTION COSTS (DKK/year)	COST PER MWh/year
SCENARIO 1	13.536	6,89
SCENARIO 2	4.420	2,25
SCENARIO 3	4.912	2,50
SCENARIO 4	13.131	6,68
SCENARIO 5	7.840	3,99
AVERAGE	**8.767**	**4,46**

Figure 6.1_19: Average heating cost per MWh

Comparing these values, it can be seen that the possible savings by improving the windows quality and reducing the air infiltrations can result in an interesting option compared to the increase of production required for satisfying the needs.

	AIR INFILTRATIONS LOSSES		WINDOWS LOSSES	
REDUCTION	**Total loss (MWh)**	**Savings (DKK)**	**Total loss (MWh)**	**Savings (DKK)**
0%	1.131,57	**0 DKK**	383,86	**0 DKK**
10%	1.018,41	**505 DKK**	345,47	**171 DKK**
20%	814,73	**1.413 DKK**	276,38	**479 DKK**
30%	570,31	**2.503 DKK**	193,47	**849 DKK**
40%	342,19	**3.521 DKK**	116,08	**1.194 DKK**
50%	171,09	**4.284 DKK**	58,04	**1.453 DKK**

Figure 6.1_20: Loss reduction savings for the main sources

As it can be seen from the table, a reduction of losses up to a 30% on these two specific heat losses sources can result into important annual fuel savings, considering also the

reduction on the maximum power needed from the heating solution that would end up into the reduction of the initial investment required.
Moreover, the study of the possibility of reducing the annual consumption instead of increasing the efficiency of the heating system has to be a matter for a further specific report getting into detailed cost analysis of both options.

FINAL RECOMMENDATION

In order to conclude this report, some recommendations are given based on the analysis developed previously and the technical criteria of the developers of this report.
The aim is to highlight the most profitable energy supplying solutions for Føns community based on the studied technical criteria and also the community preferences.

INDIVIDUAL VS COLLECTIVE

Comparing collective solutions versus individual ones, it can be said that collective solutions have better performance and economical features than the individual ones.
In the case of heating solutions, the benefits of implementing a common district heating or an individual heating solution are quite different; being the economical features of the collective solutions much better than the individual ones. Moreover, in the case of the heating solutions, collective solutions have less environmental impact in terms of emissions and energy efficiency, but they reach a greater visual impact and land occupation impact.
When comparing electricity generation alternatives, the same patterns as the ones detected on the heating solutions can be identified, i.e. the overall performance of the investment is better the collective solutions than in the individual ones. Also the environmental impacts in terms of energy efficiency are greater on collective solutions, but these common options imply greater visual impacts and land occupation impacts.

HEATING VS ELECTRICITY

The following graphics represent the graphical comparison of the benchmark grades obtained from the indicators analysis, considering the three best heating options and electricity options.
The aim of this analysis is to determine which of the group of investments can be considered a better solution and see the strong and weak points of each of these groups.

SOLUTION	D.H. Woodchips	D.H. Straw	DH. Biogas	E. Wind Turbine	E. Solar Collective 450kW	E. Small Wind turbines
Initial investment (DKK)	124562	102662	57931	346478	75919	260000
Benchmark	77%	84%	100%	0%	94%	30%
Loan period (years)	6	5	2	18	2	12
Benchmark	75%	81%	100%	0%	100%	38%
Break-even point (years)	4	4	4	2	8	4
Benchmark	33%	33%	33%	0%	100%	33%

Profit 10 years (DKK)	150415	157008	157221	143461	35812	73187
Benchmark	94%	100%	100%	89%	0%	31%
Profit 20 years (DKK)	550891	537674	490328	540676	123892	459929
Benchmark	100%	97%	86%	98%	0%	79%
Profitability 10 years (%)	120	153	271	41	47	28
Benchmark	38%	51%	100%	5%	8%	0%
Profitability 20 years (%)	442	524	846	156	163	177
Benchmark	41%	53%	100%	0%	1%	3%

Figure 6.1_21: Heating vs Electricity indicators and benchmark

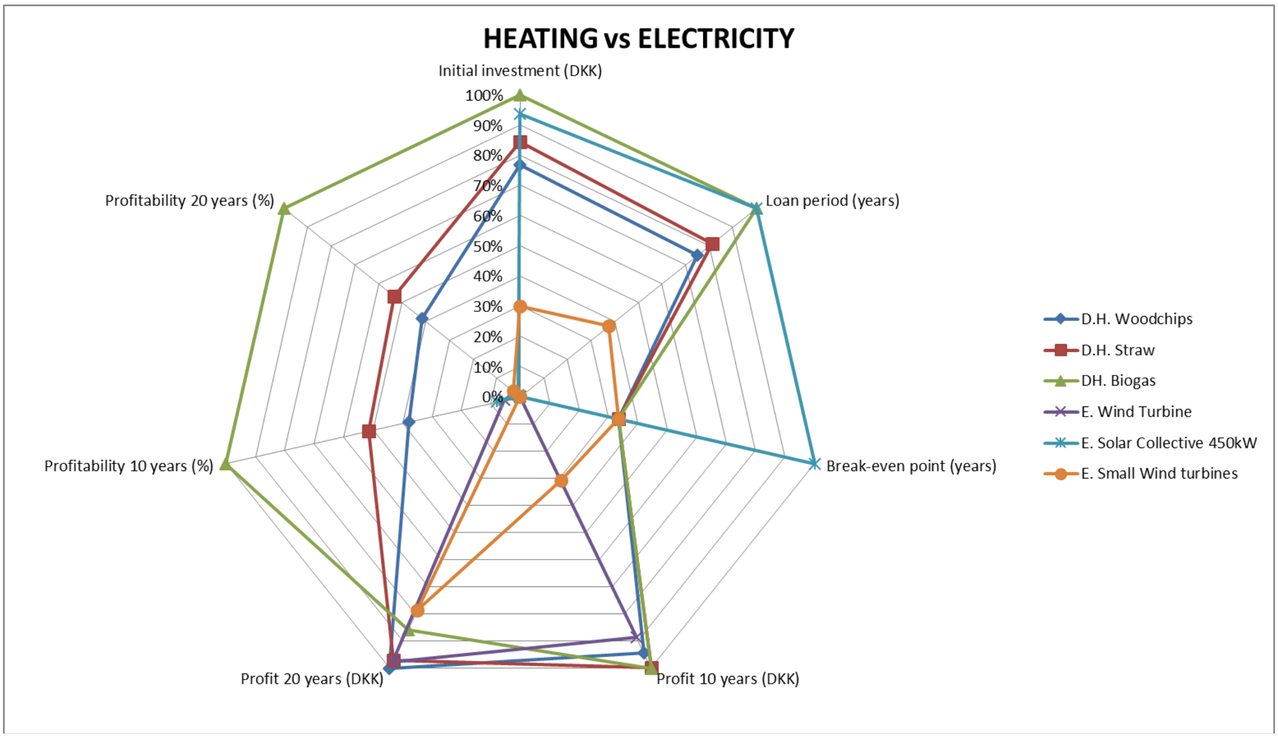


Figure 6.1_22: Heating vs Electricity benchmark radar chart

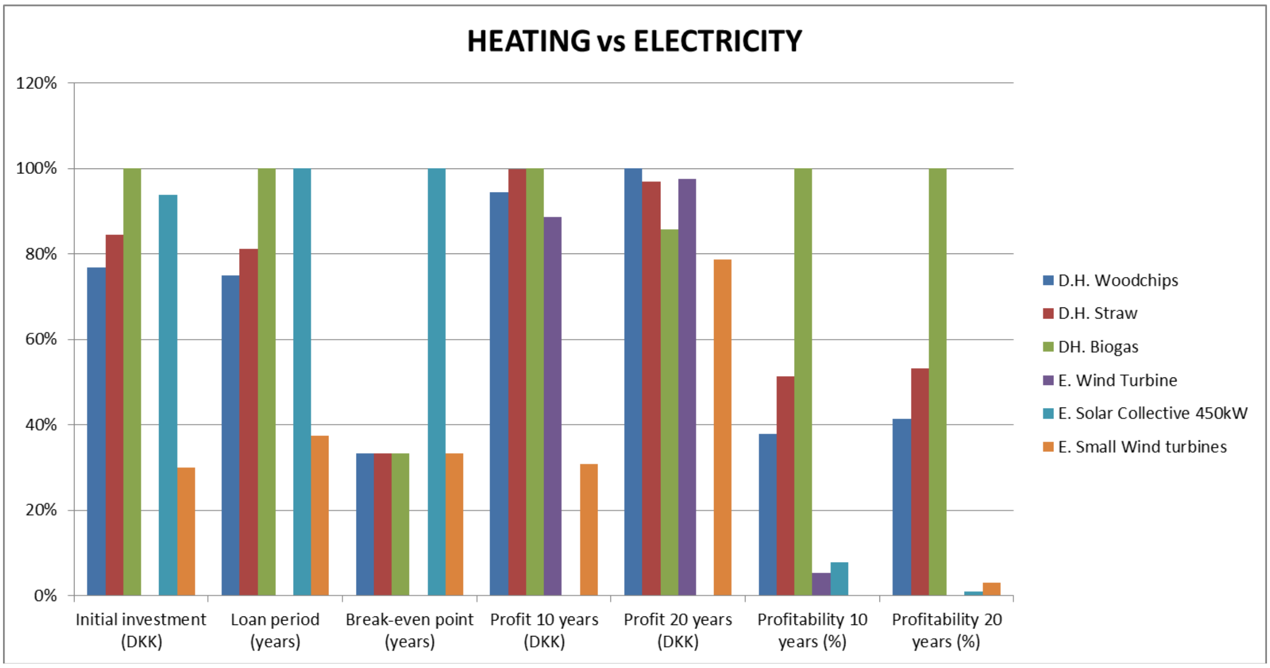


Figure 6.1_23: Heating vs Electricity benchmark bar chart

Once studied the graphics it can be appreciated that the heating solutions get higher benchmarks, especially in terms of profitability, profits, and initial investments required. While electricity production solutions compete on terms of break-even point (Solar collective 450KW) and profits (Wind turbine).

This conclusion just considers the economic aspects of the investment, and the specific needs of the village have to be taken into account when making a decision.

SINGLE VS COMBINED

The following graphics represent the comparison of the benchmark grades obtained from the indicators analysis, considering the two best options from each of the groups studied: heating solutions, electricity production solutions, and combined solutions.

The aim of this analysis is to determine which of the group of investments can be considered a better solution and see the strong and weak points of each of these groups.

SOLUTION	DH. Biogas	D.H. Straw	E. Solar Collective 450kW	E. Wind Turbine	Scenario 3	Scenario 5
Initial investment (DKK)	57931	102662	75919	346478	276320	217808
Benchmark	100%	84%	94%	0%	24%	45%
Loan period (years)	2	5	2	18	12	7
Benchmark	100%	81%	100%	0%	38%	69%
Break-even point (years)	4	4	8	2	3	9
Benchmark	71%	71%	14%	100%	86%	0%
Profit 10 years (DKK)	157221	157008	35812	143461	107817	48916

Benchmark	100%	100%	0%	89%	59%	11%
Profit 20 years (DKK)	490328	537674	123892	540676	586884	471598
Benchmark	79%	89%	0%	90%	100%	75%
Profitability 10 years (%)	271	153	47	41	39	22,4
Benchmark	100%	53%	10%	7%	7%	0%
Profitability 20 years (%)	846	524	163	156	212,4	216,5
Benchmark	100%	53%	1%	0%	8%	9%

Figure 6.1_24: Single vs Combined indicators and benchmark

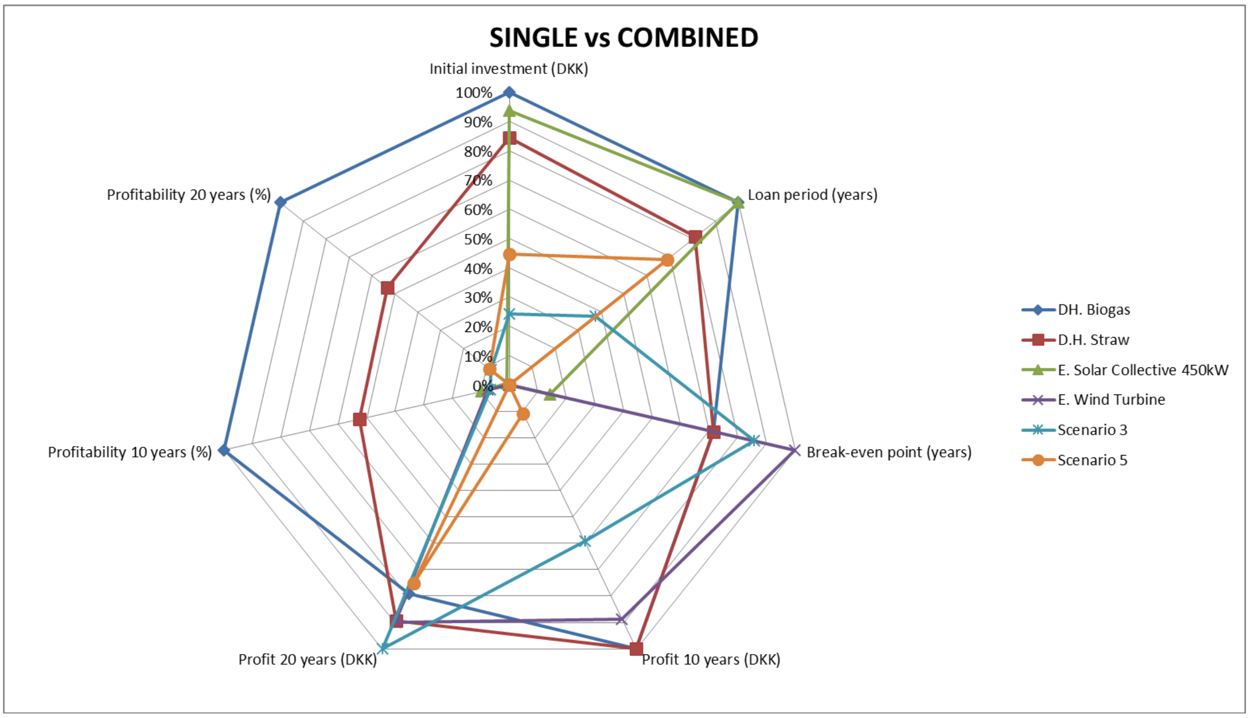


Figure 6.1_25: Single vs Combined benchmark radar chart

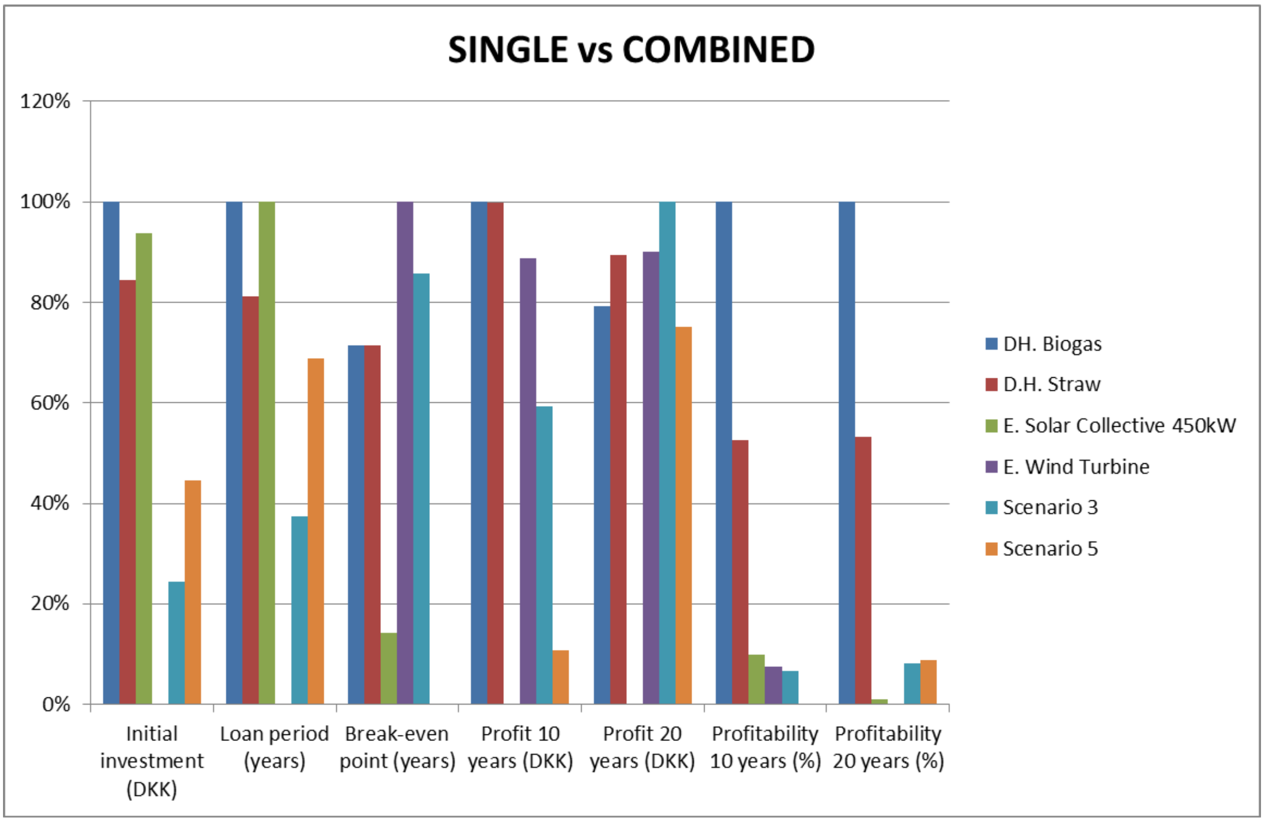


Figure 6.1_26: Single vs Combined benchmark bar chart

As it can be appreciated on the graphics, the implementation of a combined solution represents a less interesting investment, reaching lower benchmarks than the other alternatives in all the indicators considered.
Nevertheless, it has to be remarked that the implementation of a combined alternative will satisfy both demands simultaneously, so considering a scenario where the association requires both productions, the CHP alternative can fulfil both with a reasonable economic performance.

OTHER CONSIDERATIONS

Other considerations, such as technical complexity of the solution and adaptability cannot be taken into account when performing a simple economic analysis. But has to be remarked that some individual solutions proposed in this report can be considered if these factors are the main preferences for the users.

- When considering heating solutions, the installation of an individual pellet boiler in each house of the village can represent a reasonable solution, as this kind of boilers can easily replace a traditional gas-oil boiler without requiring great changes on the existing installation.
- When studying an electricity generation solution, the installation of individual solar panels in the roof has to be remarked as a low maintenance and simple installation solution, which also can be enlarged due to its modularity. The electricity selling and buying process is also easier and requires less administrative process to be installed.
- When considering mixed solutions, any of the choices implies an important technical complexity as these alternatives are studied for a common installation. But a combination of the previous alternatives can be applied individually.

MULTICRITERIA ANALYSIS

The election of one of the proposals provided in this report could be constrained by different aspects. Of course the economic point of view is vital, but a choice could be influenced by other important aspects, indeed, at the end the decision is totally subjective.

So as to make another comparison between the different options, three matrixes have been executed. In each of these matrixes five aspects there have been considered: initial investment, break-even point, profitability in 20 years, environmental impact and social acceptance.

The analysis of environmental and social aspects is very important from the sustainable point of view. It is true that the analysis by giving marks is not easy in such a rough way and, of course, a deeper analysis should be made (Environmental Impact Study) in order to obtain more accurate results. However, the next method has been followed:

Each of the aspects has a weight assigned and a mark has been given to each of them. For the first three criteria the previously done benchmark analysis has been used. For the last two, the issues treated along the studies and the conclusions have been considered.

In order to make the assessment about social and environmental issues, the following points have been taken into account:

- Land use
- Soil pollution
- Benefit for the town
- Aesthetic impact
- Noise pollution
- Distance to houses
- Impact in wildlife

In the following tables the matrixes are provided and the study has been developed dividing heating, electricity and combined solutions as it is shown:

HEATING SOLUTIONS	**DH Wc ***	**DH Straw**	**DH Biogas**	**DH Borehole Storage**	**Pellet boiler**	**Tank storage**	**Borehole storage**	**Borehole no storage**
Initial investment	1,6	1,8	2	0,8	1,4	1,2	0,6	1
Weighted	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Break-even point	2,7	2,7	2,7	1,8	2,4	2,1	1,5	1,2
Weighted	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
Profitability in 20 years	1	0,9	0,8	0,5	0,7	0,6	0,4	0,3
Weighted	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
Environmental impact	1,4	1,4	1,4	2	1,2	1,6	1,8	1,4
Weighted	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Social acceptance	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4

Weighted	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Total	8,1	8,2	**8,3**	6,5	7,1	6,9	5,7	5,3

Figure 6.1_27: Multicriteria matrix for heating solutions

*Wc: woodchips

ELECTRICITY SOLUTIONS	Solar Collective 350kW	Solar Collective 450kW	Wind Turbine	Solar Individual 5kW	Small Wind turbines
Initial investment	2	1,8	1,2	1,6	1,4
Weighted	0,2	0,2	0,2	0,2	0,2
Break even point	2,4	2,4	3	2,1	2,7
Weighted	0,3	0,3	0,3	0,3	0,3
Profitability in 20 years	0,7	0,8	1	0,6	0,9
Weighted	0,1	0,1	0,1	0,1	0,1
Environmental impact	1,4	1,4	1,6	2	1,8
Weighted	0,2	0,2	0,2	0,2	0,2
Social acceptance	1,8	1,8	2	1,6	1,4
Weighted	0,2	0,2	0,2	0,2	0,2
Total	8,3	8,2	**8,8**	7,9	8,2

Figure 6.1_28: Multicriteria matrix for electricity supplying solutions

SCENARIOS	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Initial investment	1,2	1,6	1,8	1,4	2
Weighted	0,2	0,2	0,2	0,2	0,2
Break-even point	2,4	2,7	3	2,1	2,7
Weighted	0,3	0,3	0,3	0,3	0,3
Profitability in 20 years	0,7	0,9	1	0,6	0,8
Weighted	0,1	0,1	0,1	0,1	0,1
Environmental impact	2	1,6	1,8	1,4	1,6
Weighted	0,2	0,2	0,2	0,2	0,2
Social acceptance	1,8	1,4	2	1,2	1
Weighted	0,2	0,2	0,2	0,2	0,2
Total	6,3	6,8	**7,6**	5,5	7,1

Figure 6.1_29: Multicriteria matrix for combined solutions

As it is shown, the most suitable options are:

- For heating supply: biogas plant and district heating network installation
- For electricity supply: wind turbine installation
- Combined solution: Scenario 3 CHP woodchips district heating and electricity plant.

Regarding the heating solutions, the collective solution consisting in Biogas plant with district heating network is the most suitable one, coinciding with the economic criteria. The same happens with the individual solutions, being the most adequate one the pellet boiler. Moreover, the problem with the other individual solution could be the land use and the modification of the soil that the geothermal solutions require.

Not in all the cases the best ones from the economic point of view are the best from the environmental and social point of view. For instance, regarding electricity solutions, although the initial investment for the wind turbine is very high, the other aspects compensate it ant it becomes one of the most suitable options.

Finally, when it comes to the comparison between the scenarios the best option seems to be the scenario 3 about CHP woodchips district heating and electric plant by cogeneration.

In fact, after this study, the bioenergy might be the most suitable way of getting energy to supply the requirements for this specific case in Føns.

However, many data have been provided to inform the final user and give them reliable and clear advices in order to make a supported choice of the heating and electricity supplying systems. Now, it is time for the inhabitants of Føns to make up their minds.

REFERENCES

3. DATA COLLECTION ABOUT HOUSES

Build it Solar, 2013. [Online] Available at: http://www.builditsolar.com/index.htm
All Wall System, 2012, Wall Assembly R-Value. [Online] Available at: http://www.allwallsystem.com/design/RValueTable.html

Danske Bygnings Modeller, 2013, Danske Bygnings Modeller 2.0. [Online] Available at: http://www.danskebygningsmodeller.dk/default.aspx#/home

Danmarks Miljøportal, 2013, Arealinformation. [Online] Available at: http://www.miljoeportal.dk/Arealinformation/

Energigruppen Føns og omegns lokaludvalg, 2012, Føns nærvarme. [Online] Available at: http://miljoe.foens.dk

Energistyrelsen, april 2012, Vejledning i kortlægningsmetoder og datafangst til brug for kommunal strategisk energiplanlægning – Kortlægning og nøgletal

Europe's Energy Portal, 2013. [Online] Available at: http://www.energy.eu/

Føns lokalplan, nº 13, May 1981, Nørre aaby commune

Geodatastyrelsen matrikelinfo, 2013, Miljoministeriet Geodatastyrelsen. [Online] Available at: http://www.mingrund.dk

Ministeriet for By, Bolig og Landdistrikter, 2013, Ejendomsdata. [Online] Available at: http://www.boligejer.dk/

Middelfart kommune, 2013, Kortet er kun vejledende. [Online] Available at: http://drift.kortinfo.net/Map.aspx?Site=Middelfart&Page=Borgerside

Offentlige Informationsserver, 2013. [Online] Available at: www.OIS.dk

SKAT, 2013, Ejendomsvurdering. [Online] Available at: http://www.vurdering.toldskat.dk

Vaarby, E., Sjølin, R., Cappelen, J., 1999. Observed Air Temperature, Humidity, Pressure, Cloud Cover and Weather in Denmark - with Climatological Standard Normals 1961-90, Danish Meteorological Institute, Ministry of Transport, Copenhaguen, [Online edition] Available at: http://www.dmi.dk/dmi/print/tr99-5.pdf

Vedvarende Energy, 2010, Føns by med opland svarende til den gamle sognegraense, Middelfart Kommune

4.1. INTRODUCTION PHASE 1

Ahler, K. (2005). Bygningsdele: Overslag Og Dimensionering. Erhvervsskolernes Forlag.
Alberdi Pagola, M., Alvarez Anton, L., Andersen, L., Awugya, L. K., & De Vivo, V. (2012). Systems for sustainable energy supply for small villages. Santander: Univesity of Cantabria.

Ea Energy Analyses. (2010). Analysis of the market for bioenergy locally and internationally. Midtjylland: CMBI.

Energi Styrlesen. (2012). STRATEGISK ENERGIPLANLÆGNING I KOMMUNERNE. Energi Styrlesen.

Gonzalo, A. (2011). El mayor district heating de España se construye en Soria. BIE.

Plan Energi. (2012). Muligheder for kollektive varmeløsninger i Føns. Føns.
Wheeldon, I., Caners, C., & Karan, K. (2002). Anaerobic Digester Produced Biogas and Solid Oxide Fuel Cells: An Alternative Energy Source for Ontario Wastewater Treatment Facilities. Fuel Cell Research Centre.

4.3.1. ALTERNATIVE 1: PHOTOVOLTAIC SOLAR CELLS

Climate, Energy and Building Minister (Martin Lidegaard) - Draft Law amending on the promotion of renewable Energy, Electricity Supply Act, the Act on tax on electricity and Assessment Act (Law amending No. L 86)

20 November 2012

SeeNews - Nov 7, 2012 - Denmark has proposed a reduction of the solar cell subsidy for private home owners, in a draft agreement, published Tuesday on the website of the Ministry of Climate and Energy. [Online]
Available at:
http://renewables.seenews.com/news/denmark-proposes-reduced-subsidy-for-small-solar-power-facilities-314193

Danish Ministry of Climate, Energy and Building - Jan 16, 2013 - Broad majority support new solar power law. [Online]
Available at:
http://www.kemin.dk/en-us/newsandpress/news/2012/sider/broadmajoritysupportnewsolarpowerlaw.aspx

Solar panel Company Website, 2012. Prices of "Alex-Solar" 250w monocristaline PV solar cells. [Online]
Available at: http://www.aktivsol.dk/

4.3.1 ALTERNATIVE 2: WIND POWER

ALTERNATIVE 2.1

C. Jensen, P. & Hartvig Jacobsen, S., 2009. *Danish Energy Agency.* [Online]
Available at: http://www.ens.dk
[Accessed 23 01 2013].

Cappelen, J. & Jørgensen, B., 1999. *Observed Wind Speed and Direction in Denmark with Climatological Standard Normals, 1961-90, Danish Meteorological Institute, Ministry of transport.* [Online]
[Accessed 08 02 2013].

Danish Energy Agency, 2013. *Danish Energy Agency. Energy Statistics. Register of Wind Turbines.* [Online]
Available at: http://www.ens.dk/en-US/Info/FactsAndFigures/Energy_statistics_and_indicators/OverviewOfTheEnergySector/RegisterOfWindTurbines/Sider/Forside.aspx
[Accessed 01 20 2013].

Danish Wind Industry Association, n.d. *Sound Measurement.* [Online]
Available at: http://wiki.windpower.org/index.php/Sound_measurement
[Accessed 23 01 2013].

Danish Wind Industry Association, n.d. *Wind Turbine Operation and Maintenance.* [Online]
Available at: http://wiki.windpower.org/index.php/O_%26_M
[Accessed 23 01 2013].

Danish Wind Industry Association, n.d. *Wind Turbine Sound Calculator.* [Online]
Available at: http://wiki.windpower.org/index.php/Main_Page
[Accessed 23 01 2013].

GEOLICA, n.d. *GEOLICA, Soluciones en generación de energía distribuida.* [Online]
Available at: http://www.geolica.com/faqs/
[Accessed 25 02 2013].

Middelfart Kommune, n.d. *Vindmølleplan Debatoplæg.* [Online]
Available at: www.middelfart.dk/vindmolleplan
[Accessed 05 02 2013].

Molinero Benitez, A., 2009. *Proyecto de un Parque Eólico.* Madrid: s.n.

Nielsen, P. & et al, 2010. *UEDP projekt 33033-0196 Vindmøllers økonomi.* [Online]
Available at: http://www.emd.dk
[Accessed 27 01 2013].

PlanEnergi, 2012. *Muligheder for kollektive,* Føns: s.n.

SagsGIS, n.d. *Miljoministeriet Naturstyrelsen.* [Online]
Available at: http://miljoegis.mim.dk/cbkort?profile=miljoegis-vindmoeller
[Accessed 23 01 2013].

Siemens AG Energy Sector, 2009. *Siemens.* [Online]
Available at: http://wwww.siemens.com/energy
[Accessed 27 01 2013].

Siemens AG, 2013. *Siemens.* [Online]
Available at: http://www.siemens.com/wind
[Accessed 27 01 2013].

Suisse éole, n.d. *Windprofil-Rechner, Allgemeine Windenergie- Informationen.* [Online]
Available at: http://www.wind-data.ch/tools/profile.php?h=100&v=7.4&z0=0.03&abfrage=Aktualisieren
[Accessed 05 02 2013].

Wind Energy Technology, 2013. *Kid Wind Project.* [Online]
Available at: http://learn.kidwind.org/learn/wind_basics_technology
[Accessed 25 02 2013].

ALTERNATIVE 2.2

Aeolus Power, Noise emission report, available at http://www.aeoluspower-windenergy.co.uk/PDF/Noise%20Emission%20Report.pdf

Cace J., ter Horst E. et al., Guidelines for small wind turbines in the built environment, 2007, available at http://www.urban-wind.org/

Danish Ministry of Environment, Regulations of noise from wind turbines, available at http://www.mst.dk/English/Noise/wind_turbine_noise/wind_turbine_regulations/

Domestic scale wind turbines, 1 - 6 kW, available at http://www.greenspec.co.uk/small-wind-turbines.php

EcoWind, Husstandsmøller report, 2011, available to http://www.ecowind.dk/Filer/EcoWindbrochure.pdf

Energinet.dk, VE-anlæg ≤ 6 kW (Årsbaseret nettoafregning, gruppe 6, updated February 2013, available at http://energinet.dk/DA/El/Solceller-og-andre-VE-anlaeg/Erhverv/Sider/VE-anlaeg-6kW-Aarsbaseret-nettoafregning-gruppe-6.aspx

Energinet.dk, Technology Data For Energy Plants, May 2012

Lussu F., Micro e mini eolico: soluzioni tecnologiche e prospettive del comparto impatti e procedure autorizzative di impianti eolici, 2007, available at http://www.ecoappennino.it/2007/pdf/Seminari%2029-09/Micro%20e%20mini-eolico/Presentazione%20Francesca%20Lussu.pdf

Maegaard P., The Road to Commercialization of Small Wind Power in Denmark, 2012, Nordic Folkecenter for Renewable Energy, available at http://www.dena.de/fileadmin/user_upload/Veranstaltungen/2012/Vortraege_Kleinwindkraft_Daenemark/Maegaard_The_Road_to_Commerzialisation_of_Small_Wind_in_Denmark.pdf

Petersen M., Aspects of the SWT situation in Denmark, 2011, Danish Small Wind Turbine Association

Pure Energy Centre, FAQ on Small Wind Turbines, available at http://www.pureenergycentre.com/pureenergycentre/FAQ/FAQ.php

5.3. DISTRIC HEATING

Danfoss, 1995. Instructions for designing District Heating Systems, s.l.: s.n.
Esen, 2008. Redes de Calefacción Centralizada (District Heating), s.l.: Esen. Eficiencia y Servicios Energéticos.

Euroheat, n.d. Euroheat. [Online]
Available at: http://www.euroheat.org/District-heating---cooling-4.aspx#What_is_district_cooling_
[Accessed 5 November 10 2012].

Foresa, 2006. Servicios energéticos con biomasa, Valladolid, Spain: Foresa, Servicios Energéticos.

Gonzalo, A., 2011. El mayor district heating de España se construye en Soria.. s.l., BIE.
IEA, I. E. A., 1999. District Heating and Cooling Connection Handbook, s.l.: IEA.
Jørgensen, P. J., 2007. Samsø, a Renewable Energy Island. 10 years of Development and Evaluation., s.l.: Plan Energi.

Oklahoma State University, 2004. UK Application of Direct Cooling Ground Source Heat Pump Systems. Edinburgh, ASHRAE-CIBSE Conference.

PlanEnergi, 2012. Føns Nærvarme. Opportunities for collective heating solutions., s.l.: Plan Energi.

Pöyry, 2009. The potential and costs of District Heating Networks, Oxford: Pöyry Energy.
Sköldberg, H., 2009. Distric Heating: the importance of cost-corrective price. An analysis based on Swedish data., Oslo: Profu.

Swedish Energy Agency, 2011. *Bo Reinerdahl.* [Online] Available at: http://energimyndigheten.se/en/Sustainability/Household/Heating-your-home/District-heating/ [Accessed 7 November 10 2012].

Task Force Customer Installations, 2008. Guidelines for District Heating Substations, s.l.: Euroheat & Power.

Universidad de Santiago de Compostela, 2008. Valor del suelo rústico para aprovechamientos energéticos en Galicia, Lugo: Escola Politécnoca Superior, Departamento de Economía Aplicada.

V&S prisdata, 2013. Denmark Price Book 2013.

5.4.1. DISTRIC HEATING

Ayuntamiento de durcal, n.d. *Proceso de un parque eolico.* [Online]
Available at: http://www.adurcal.com/mancomunidad/viabilidad/57.htm
[Accessed 20 02 2013].

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ACRONYMS

CHP - Combined Heat and Power
CHP: Combined Heat and Power generation
COP - Coefficient of Performance
dB - decibels
DHN: District Heating Network
DKK - Danish Krones
GB: General Benefits
GHG: Green House Gasses
GSHP - Ground Source Heat Pump
GWh - Gigawatt hour
HTS: High Temperature System
IB: Industrial Benefit
kW - Kilowatt
kWh - Kilowatt hour
kWh/y (or kWh/year) - Kilowatt hour per year
LTDH: Low Temperature District Heating
m - meters
m/s - meters per second
MWh - Megawatt hour
O&M - Operation and Maintenance
PV - Photovoltaic
ROI - Return of investments
SAGSHP - Solar assisted Ground Source Heat Pump
SWT - Small Wind Turbine
SWT 2,3-93 - Siemens Wind Turbine 2,3 Megawatt nominal power 93 rotor diameter
VAT - Value Added Tax
VAT: Value Added Tax

7. APPENDIX

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All appendix will be found in the dedicated volume.

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(Føns lokalplan, 1981)