Aleksandra Li

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OFFSHORE WIND ENERGY IN FINLAND

Simulation of energy consumption of a single-family house

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Aleksandra Li

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Abstract

Energy consumption is increasing worldwide harmfully affecting the environment. Greater deployment of renewable energy sources is a solution to the problem of pollution. Although offshore wind energy is not the most common renewable energy source, development and application of the technology continue to grow. In Europe, offshore wind energy has a great potential, especially in Northern conditions.

The main aim of the bachelor’s thesis is to find out if offshore wind energy can be used for HVAC needs in single-family houses in Finland. This study is done to understand if generated offshore wind energy will be enough to cover the heating demands and what are heating options in the studied case. Besides, environmental consequences and economical aspects are depicted.

In this thesis, one storey single-family house located in west coast of Finland is investigated. The total net heated area is 138 m^2. Simulation of energy consumption of is performed in IDA ICE program. The task is to compare energy consumption, energy prices, and GHGE of studied heating modes. Possible GHGE reduction is evaluated according to obtained results.

Finally, all the examined information is analyzed to make a conclusion about current application of offshore wind energy and future expectations.

Subject headings, (keywords)

Offshore wind energy, Wind energy, Renewable energy, Energy consumption

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APPENDIX

1 INTRODUCTION

1.1 Background

Nowadays, the energy problem is a burning issue. Modern lifestyle and industry keep energy consumption growing worldwide affecting the atmosphere with green house gas emissions (GHGE); consequently, the need for sustainable and clean energy is undeniable. The only possible solution of reducing ecological problems is expanding deployment of renewable energies.

One of the most promising sources of renewable energy is wind energy. In this thesis, offshore wind energy is discussed, as it has become one of the fastest growing renewable energy sources in the world.

In Finland, offshore wind power generation has a small share in energy market. However, the government of Finland is very optimistic about feasibility of offshore wind energy in the country. The construction and commissioning of Tahkoluoto offshore farm near Pori, west-coast of Finland is about to prove that offshore wind energy is a great solution to reducing CO_2 emissions and reaching European 2020 climate and energy targets./1./

1.2 Aims

The main aim of the bachelor's thesis is to find out how offshore wind energy can be used in single-family houses in Pori. The objective is to understand if offshore wind is a good solution of sustainable and feasible source of energy in Pori region. Will available offshore wind energy be enough to cover space heating needs in single-family houses located in the area? How using energy generated by offshore wind turbines influences the environment? Is it profitable source of energy in terms of money saving?

In other words, what are pros and cons of implementing offshore wind power? Eventually, is it reasonable from economical and environmental points of view to invest money in offshore wind development particularly in Finland?

To answer these questions the following tasks are determined. Firstly, the task is to discover general information about offshore wind energy economical aspects including offshore wind farm installation costs, energy prices, and future expectation. Then environmental advantages and disadvantages are depicted, as there are contradictive opinions about offshore wind energy generation.

The next task is to give a profound overview on offshore wind energy deployment in Europe providing with latest statistics and trends. A special emphasis is given to cold climate conditions that are applicable for Finland. So what are Northern climate challenges and solutions?

Next task touches upon a subject of energy consumption in Finland. In this thesis, single-family house is analyzed; hence, IDA ICE simulations are carried out to compare energy consumption of commonly used energy sources in the studied building.

The last tasks are to calculate and compare energy costs per year and GHGE reduction in case of utilizing offshore wind energy for space heating.

1.3 Methods

Research methods used in this thesis include literature study, data analysis, and software simulation.

Firstly, in order to familiarize with the topic of offshore wind energy information from various sources will be collected and studied. Comparison of different literature sources will help to get reliable facts and details. In addition, current reports and statistics will be thoroughly analyzed to investigate latest news and get a clear overview of the subject. The main source of statistical data is Statistics Finland that is the only Finnish public authority providing with the variety of official statistics.

Energy consumption of a typical single-family house located in Pori is evaluated. Energy consumption simulation will be performed by means of IDA ICE software. Simulation part includes comparison of energy demands when different energy sources are used: district heat, ambient energy, and electricity. E-values and energy consumption values will be calculated by the program and then compared.

The next step involves annual energy costs calculations based on simulation’s results. Prices of heating energy are provided by Statistics Finland and reflect average energy prices in 2015. This calculation will allow comparing operational costs of studied heating options.

Then annual green house gas emissions using conventional energy sources will be calculated. When Tahkoluoto offshore wind farm is brought to operation electricity generated by wind will be available in Pori region. Estimation of possible CO_2 reduction if offshore wind energy is used will be performed.

Finally, all the studied material and obtained data will be properly analyzed to made a conclusion and answer the research questions.

2 OFFSHORE WIND ENERGY

Offshore wind energy is a new and still developing technology. Consequently, when offshore wind energy farm project is discussed, it is likely to happen that available information about offshore wind energy is not enough to give very precise and detailed project description.

Nowadays, the interest in application of offshore wind energy is growing; therefore, more specific researches and studies, especially the ones concerning environmental impact, wind resources estimation, efficiency estimation, and reduction of capital costsare needed. The fundamental aspects of offshore wind energy remain the same, as onshore, yet there are differences that make offshore wind energy installations more challenging.

The first point is offshore wind energy projects sizes are typically greater than onshore, which leads to higher capital costs and greater economical risks. Moreover, capital costs of offshore wind farms are generally higher than similar onshore installations. However, there are economical benefits that are usually disregarded when energy costs are estimated. Chapter 3 provides with more precise information about real offshore wind energy costs.

Secondly, offshore wind speeds are higher and more consistent than on land. Reports from Danish Tunø Knob offshore wind farm indicate 20–30% higher output and better availability than estimated with mean speed prediction models./2./

Since wind energy is heavily dependent on location, estimation of wind resources is crucial for both onshore and offshore developments. Yet operation of offshore wind energy turbines depends on other factors. One of the most important parameters that affect wind power is surface roughness. It can be defined as deviation of the actual surface of the ground from the ideal smooth surface.

Generally, topographic effects do not matter much for offshore wind installations. The surface roughness is low, and it is dependent on sea state and wave conditions that are complicated to estimate, as the sea does not remain fixed as trees, buildings, and other city elements. Low surface roughness result in low turbines' intensity and increased energy demand in the end./3./

Stable flow conditions are also possible to occur offshore. It happens when air flow mixing is slow due to different airflow temperatures or airflow origins. In some uncommon and particular circumstances, wind speed even reduces with height./3./

Moreover, coastal zone conditions have an impact on wind speed, turbulence and boundary layers profiles across wind farms. Another important parameter that affects mean wind speed is tide level. In high tidal areas, rise and fall of the sea heavily influence on location of a turbine./3./

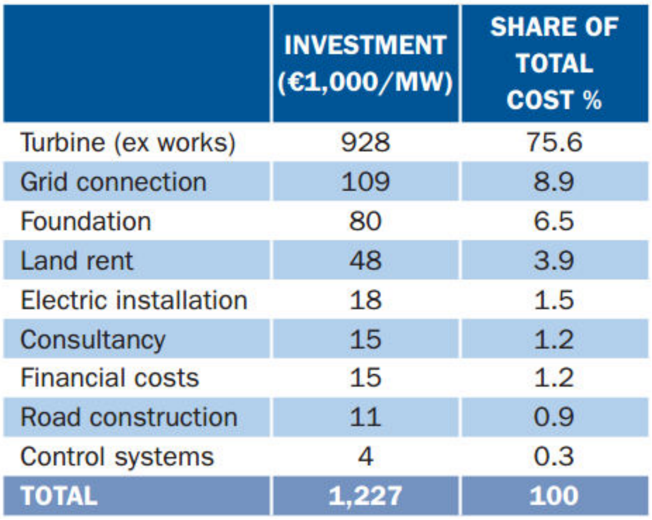
3 OFFHORE WIND ENERGY ECONOMICS

In spite of active development and growing range of application, offshore wind energy relates only to 1% of total installed wind power capacity in the world./3./ Due to small share and limited data most of the information given in this chapter refers to economics of wind energy in general, and only several facts are given regarding offshore wind power generation.

3.1 Basic costs

Compared to conventional energy sources wind energy is a capital-intensive source of energy. Approximately 75% of the total costs of wind energy relate to the construction and installation of a wind turbine while fuel costs equal to zero. The costs structure of a typical wind turbine is given in the Table 1 (2006 prices)./4./

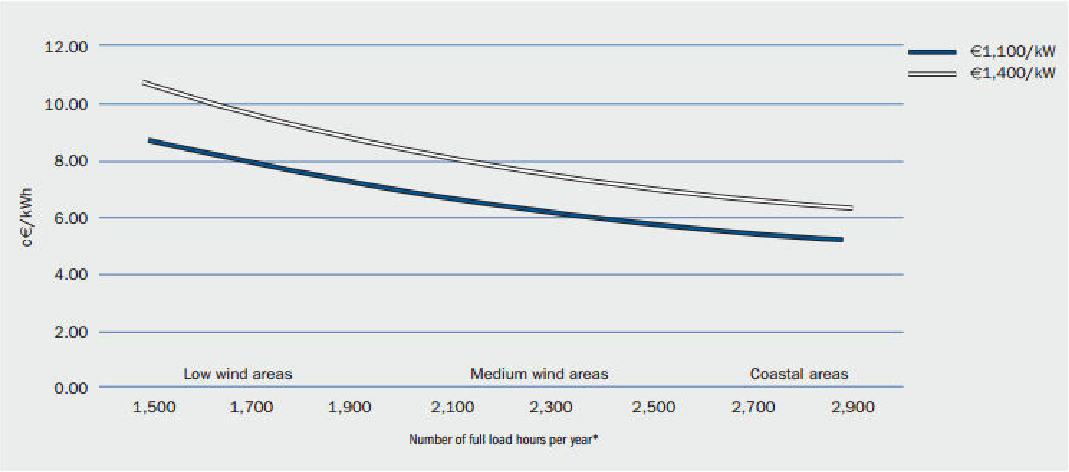
TABLE 1. Cost structure of a typical 2MW wind turbine installed in Europe /4/



	INVESTMENT (€1,000/MW)	SHARE OF TOTAL COST %
Turbine (ex works)	928	75.6
Grid connection	109	8.9
Foundation	80	6.5
Land rent	48	3.9
Electric installation	18	1.5
Consultancy	15	1.2
Financial costs	15	1.2
Road construction	11	0.9
Control systems	4	0.3
TOTAL	**1,227**	**100**

According to Spanish data about 60% of operational and maintenance (O&M) costs are spent directly for operation and maintenance needs including labor costs and spare parts. Another 40% cover the costs of insurance, land rental, and overheads. For onshore wind turbine O&M costs amount approximately 1.2-1.5c€ per kWh of total generated electricity over a lifetime of a turbine./4./

The cost per kWh of energy generated by a wind turbine is shown in Figure 1. The costs were calculated depending on the wind regime of the chosen site. As shown in Figure 2 the costs of wind energy fall down with higher mean wind speeds./4./



* Full load hours are the number of hours during one year during which the turbine would have to run at full power in order to produce the energy delivered throughout a year (i.e. the capacity factor multiplied by 8,760).

Source: Risø DTU

FIGURE 1. Calculated costs per kWh of wind generated power as a function of the wind regime at the chosen site (number of full load hours) /4/

Owing to intensive development all over the world and introduction of new technology, wind energy costs have a tendency to go down. Besides, wind farms and wind turbines became larger improving cost-effectiveness. For example, two times bigger wind farm leads up to 9-17% decrease of costs per kWh produced energy for a new turbine./4./

3.2 Offshore wind energy economics

Offshore wind costs remain 50% higher than for similar onshore installations. The main points are reasonably higher investment costs: foundations, cables, installation, and grid connection are more expensive. O&M costs are also greater because of more complicated service and conditions.

Nevertheless, offshore wind generation is potentially beneficial. Firstly, because of higher mean speeds over sites. Investment costs are expected to be offset by higher total electricity production. If the energy generation indicators are compared, onshore sites have normally around 2,000-2,500 full load hours per year when offshore wind installations reaches up to 4,000 full load hours per year, depending on the location of the farm./4./

European Wind Energy Association developed a positive scenario for offshore wind power market. Based on 2015 report cost-competiveness can be met by 2023 by introducing higher capacity turbines, improving supply chain optimisation and logistics, and achieving continuous production with better pipelines./5./ Figure 2 represents the estimated costs dynamics if offshore wind technology continues to improve and expand its share in the market.

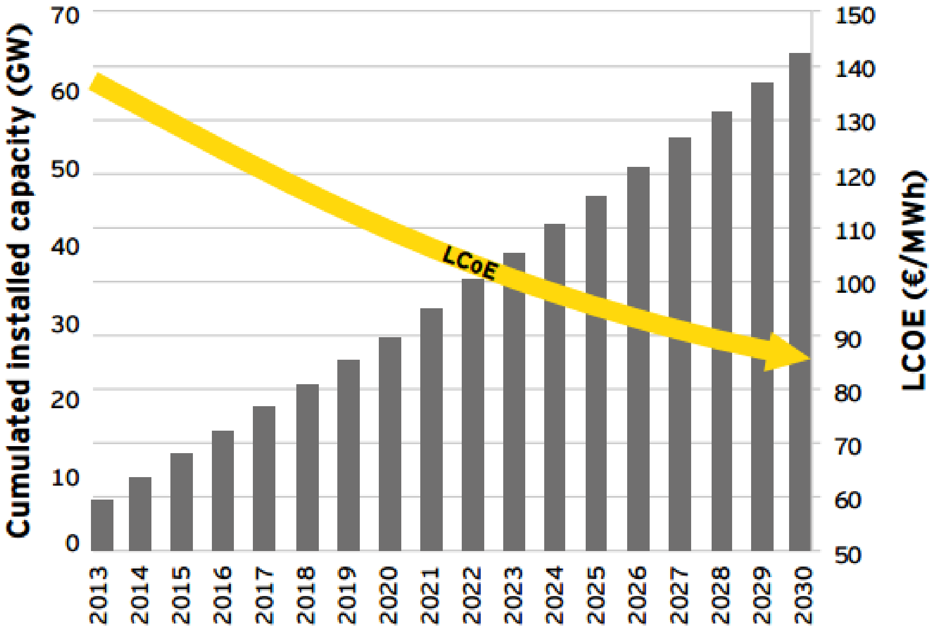


FIGURE 2. Evolution of the levelized cost of electricity (LCoE) according to the cumulated offshore wind capacity installed /5/

3.3 The cost of offshore wind generated energy

When energy costs are calculated the following issues are taken into account:

- the annual energy production from the wind turbine installation,
- the capital costs of the offshore wind farm project,
- the applied discount rate to the capital costs of the project,
- the terms of contract between an electricity supplier and consumer,
- payback period or time of recovery of the project,

- O& M costs, including maintenance of the wind turbines, insurance, land leasing, offshore leasing etc.

The present methods of calculation energy costs do not take into consideration many important factors, so economical benefits remain unclear. In fact, the main benefit of wind power is reduction of economics' reliance on fuel price volatility./4./ Although the risk reduction from wind energy is crucial for cost calculation, it is missing in standard methods.

Other things are cost and benefit to society that are different from consumers or sellers points of view. Using fossil fuels and dumping combustion wastes might be cheaper for power generation companies than using expensive renewable technologies, but it affects society in a negative way creating extra costs for people in the form of health problems or nature damage.

Siemens Wind Power elaborated "Society's Cost of Electricity" (SCoE) concept that allows to estimate real costs of wind energy demonstrating actual benefits. The additional factors that were taken into consideration include:

1. Employment effect:

Offshore wind energy market is capable of creating more job opportunities and employing more people than any other source of energy./5./

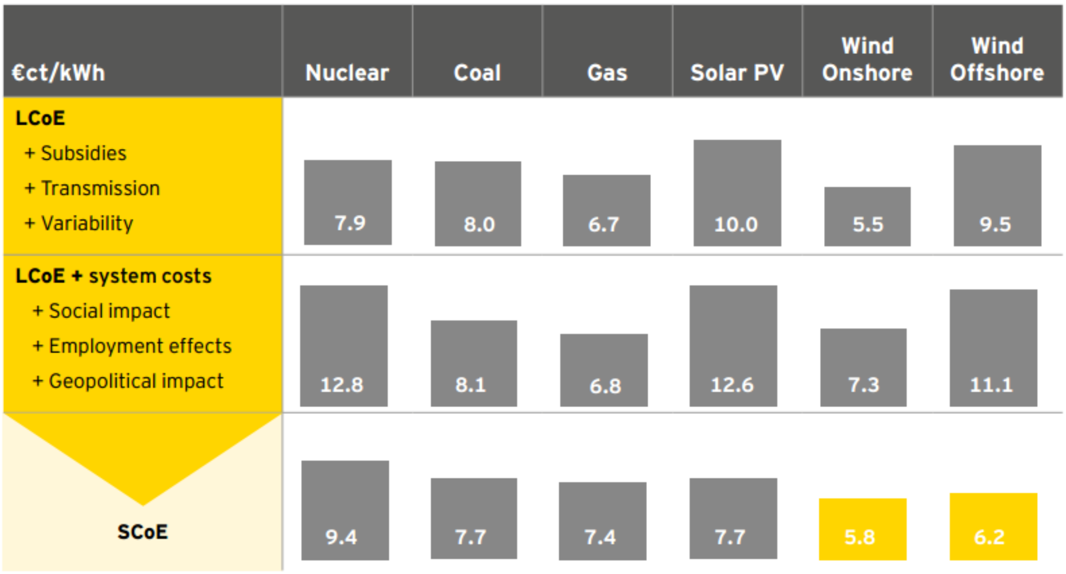
2. Geopolitical impact:

Unlike fossil fuel prices, wind energy is not volatile; it is not dependent on political situation. Wind energy prices stay more stable and predictable or can even remain fixed./5./

3. Subsidies:

Government's investment aid is essential for offshore wind projects. Markets themselves cannot value long-term external effects of wind power generation, so it is under government's responsibility to support offshore wind energy sector. With government's contribution offshore projects' costs can be lowered and more investment is attracted./5./

The analysis of Germany’s offshore wind market conducted by Siemens reveals that wind energy can become the most competitive electricity source in the country by 2025. Applying the same SCoE approach Siemens carried out analysis for the UK as well. The achieved results were similar. Germany’s SCoE by 2025 shows offshore wind competiveness in Figure 3./5./



€ct/kWh	Nuclear	Coal	Gas	Solar PV	Wind Onshore	Wind Offshore
LCoE + Subsidies + Transmission + Variability	7.9	8.0	6.7	10.0	5.5	9.5
LCoE + system costs + Social impact + Employment effects + Geopolitical impact	12.8	8.1	6.8	12.6	7.3	11.1
SCoE	9.4	7.7	7.4	7.7	5.8	6.2

FIGURE 3. Germany’s SCoE by 2025 /5/

4 ENVIRONMENTAL IMPACT

Generation of energy by wind turbines has many environmental benefits comparing to conventional energy sources. Wind is clean and inexhaustible source of energy. In other words, generation of energy by wind turbines does not involve:

- pollutants that cause acid rain or smog;
- radioactivity;
- contamination of land, sea or water courses;
- the consumption of water – unlike many conventional and some renewable energy sources.

The main advantage is production of zero CO_2 emissions while operation of wind turbines. Due to this fact, producing wind energy allows to diminish effects of fossil fuels combustion. The problems of climate change and air pollution can be only solved if the share of total energy produced by renewable sources dramatically increase.

In 2014, Europe set 2030 goals that include up to 40% emissions reduction compared to 1990 levels and achieving 27% use of renewable energy sources for total European energy./5./ Offshore wind generation makes possible reaching these goals as offshore wind seems to be the most stable and sustainable solution in Europe.

Most negative aspects and concerns are still uncertain and require more scientific studies to make proper conclusions. The disadvantages and possible environmental impact are depicted in more detail in this chapter.

4.1 Visual impact

Offshore wind energy installations are typically larger than onshore ones: wind farm projects are greater, and sizes of turbines are bigger. Nevertheless, visual impact is usually comparatively low. The reason is greater distances from a coastline and between turbines.

Although visual impact of offshore wind energy installations is not a great subject of concern, it has a disadvantage in some cases. Coastline areas as well as sea area are unique natural surroundings which attractiveness can be spoilt with massive turbines and offshore wind farm elements like grids, platforms, substations and cables. In order to foresee the level of visual impact of new wind energy farm special technology and tools are used. These include ZTV maps, photomontages, and video montages. They are the same as for onshore wind farms./3./

According to the studies, real visibility tends to be lower than worst expected photomontage due to weather conditions, lightning and distance./3./ The level of visual disturbance depends on several factors such as distance, size of wind farm, number of turbines, size, characteristics (material and colour) of turbines, weather conditions, and lightning.

4.2 Noise impact

Noise impact is a subject of ongoing research. In comparison with onshore wind farms, offshore wind farms are located far away from residential area; hence, there is no actual disturbance because of turbines operational noise to people. At the same time, there is controversial information about possible impact on marine fauna.

Estimation of harmful impact on marine organisms is complicated to perform because of the lack of scientific researches. However, it is a matter of fact that high sound levels are responsible for causing changes in the behavior and physiology of marine fauna. The behavior variations range from avoidance of noise source to panic. So far as known fish hearing system is not damaged due to noise emissions, but high acoustic oscillation interfere with communication of some species such as Atlantic salmon and cod./3./

The influence of noise generated during site contraction or decommissioning and operating period depends mostly on species sensibility and vicinity to the sound source. During the construction phase, noise can be very loud, for example, the measured peak noise during the construction of North Hoyle wind farm located in Wales reached 262 dB at 10 m depth./3./ Such a great level of noise can possibly have an impact on marine animals and fish behaviour even several kilometres further from the sound source.

Another environmental concern is the absence of regulations and threshold values for noise levels; therefore, more research is needed in order to present permitted values of noise levels. As for decreasing noise effects during the construction period, there are several solutions, which include:

- Using air-bubble curtain around noise source,
- Gradually increasing sound emission,
- Using of acoustic devices to keep marine animals away during the noisiest construction period,
- Using sound insulation for tools.

These approaches can reduce noise levels from 5 dB to 25 dB depending on the selected method./3./

The current studies about noise impact during turbines operation reveal controversial results: some of them say that the subject is not clear enough, and more data are required. Others consider that operational time noise emissions from the turbines do not cause significant disturbance and can be neglected. During operation the underwater noise level does not exceed ambient noise level if noise frequency range is above 1 kHz, but when it is below 1 kHz, noise level becomes higher than ambient noise level, and thus noise may lead to negative consequences.

4.3 Electromagnetic field impact

Electric current flowing in cables create artificial static magnetic field, which can possibly affect some marine species. Many marine organisms like mollusks, fish, and marine mammals are sensitive to magnetic field, or they use it for orientation. The question of potential negative influence on them is still a matter of ongoing research./3./

According to the experimental studies, permanent magnetic field of 3.7 mT did not show a significant effect on several benthic organisms and mussels./3./ As for fish behavior, there are not enough available data to make certain conclusions and correlations. In such a case, electromagnetic field impact is assumed to be neglected until more data appear.

4.4 Impact on benthos, fish, marine mammals and sea birds

A group of benthos organisms, named epifauna, lives on hard surface to which they attach. It means that, foundation structure of a turbine can possibly become a habitat for animals like oysters, mussels, sponges, starfish, and snails. They tend to occupy it; therefore, a new ecosystem appears. As a result, biodiversity is expanded, and benthos population increases; for this reason, fish and birds are attracted. However, it happens only during operational time. During construction period marine organisms avoid the site and nearby area.

Turbine slab structure can be assumed an artificial reef. In this case, fish population and diversity are expected to increase. Several European studies prove it, but in the example of Horns Rev and Nysted offshore wind farms located in Denmark an impact was barely noticeable./3./ In order to make clear analysis studies that are more specific need to be carried out.

Mammals seem to be more affected by turbines because they rely on hearing organs in many cases, for instance, communication, echolocation, and orientation. Even if high level noise during construction phase or moderate operation noise do not damage mammals hearing systems, any kind of noise may have an influence on animals behavior. When offshore wind farm is constructed, most animals avoid zone of disturbance because constant and high level sounds vibrations cause stress and misinterpreting environmental signals.

Studies, that were taken place in Danish offshore wind farms Horns Rev and Nysted, revealed no significant impact on seals during operation period but different change of porpoises population. In first case porpoises population slightly decreased during construction but recovered afterwards. In Nysted, porpoises’ population decrease was considerably greater, and recovery took a long time. The reasons of the phenomenon remained obscure./3./

Construction of new offshore wind farm has mostly a negative impact on birds. As well as marine animals, birds try to avoid offshore wind farms especially during construction time. At present birds’ avoidance, do not harm to ecosystem. Yet birds’ collisions with turbines may occur. If compared to onshore developments, impact is higher because of larger sizes of turbines and wind farms in general. Collision statistics is 0.1-1.2 birds per turbine./3./ In brief, birds' mortality due to collisions is very complicated subject to analyze, and it does not drastically affect on birds' population; hence, overall impact can be neglected.

4.5 Ship collision

Ship collision with a turbine structure is also possible. If it happens, consequences are dire: ship is obviously destroyed, and oil is spilt in seawaters. The size of ecological catastrophe depends on type of a foundation slab and a ship. Apparently, number of collisions can be minimized with better navigation systems, professional crew training, and monitoring, but it cannot be equaled to zero.

5 APPLICATION OVER THE WORLD

5.1 Statistics and trends

Offshore wind resources in Europe are enormous, and the potential of utilizing wind energy is impressive. With new technologies and constant development offshore wind energy seems to be a great solution to reducing air pollution and green house gases effect. The total share of offshore wind energy remains significantly smaller compared to fossil fuels or other renewable sources of energy. As shown in Figure 4 wind, solar, biomass, and geothermal power correspond to 1.4% of global final energy consumption, and the total share of offshore wind energy is a small part of it./6./

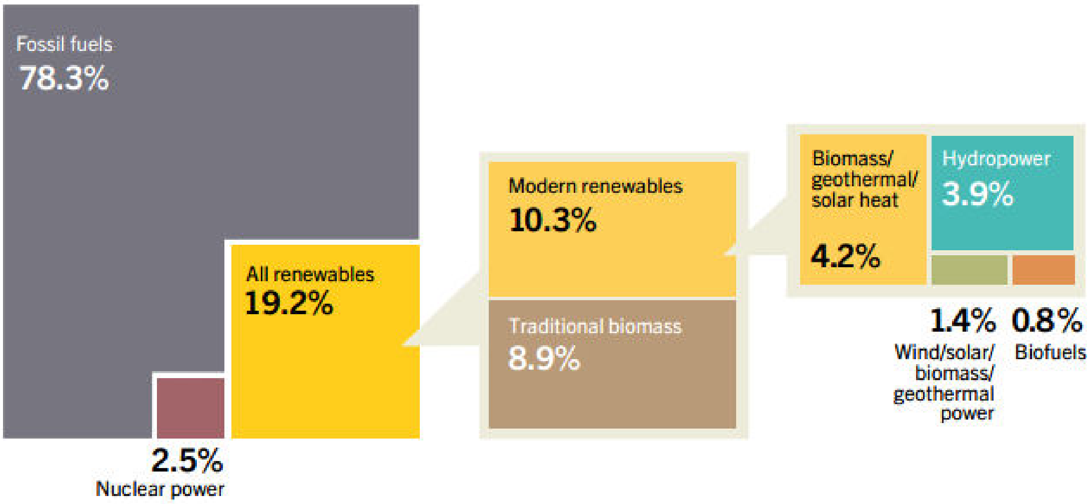


FIGURE 4. Estimated renewable energy share of global final energy consumption in 2014 /6/

In spite of small share, previous year wind energy was the leading growing renewable source of energy in EU and the USA. In Europe, the dynamics of offshore sector development is strong and positive (Figure 5). Despite high capital costs and construction challenges, many European countries have high expectations of expanding offshore wind energy generation. At the end of 2015,cumulative installed capacity reached 11,027.3 MW./7./

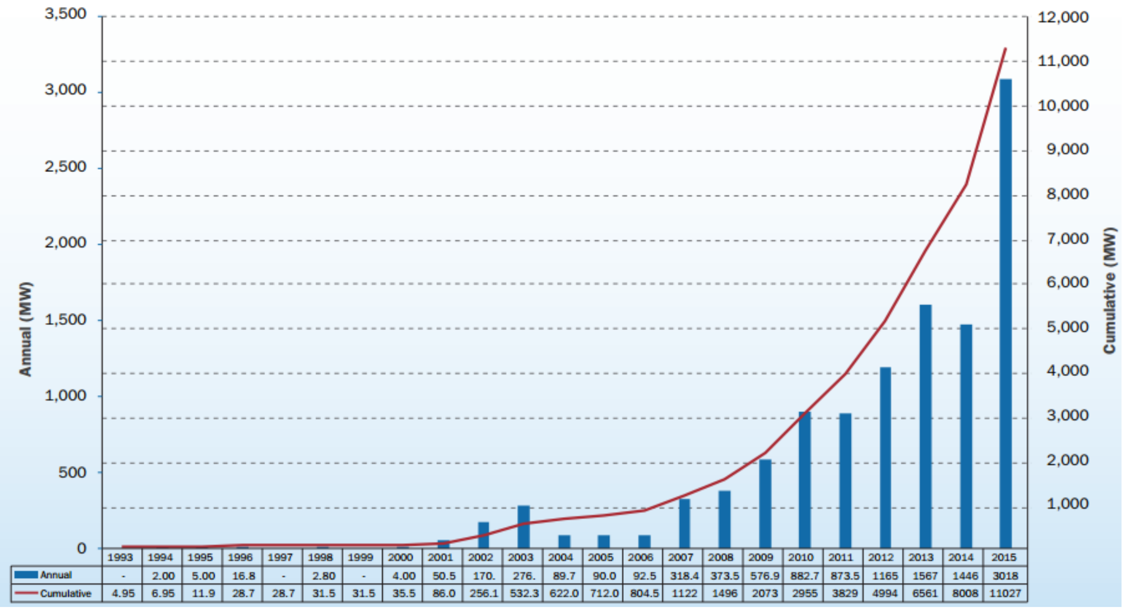


FIGURE 5. Cumulative and annual offshore wind installations by 2015 /7/

The total number of offshore wind farms in Europe including sites under construction is 84. Approximate offshore wind energy generation is about 40.6 TWh in a normal wind year, and this amount of electricity covers 1.5% of Europe's total electricity consumption./7./ As shown in the Table 2 total offshore wind installed capacity is 11,027 MW.

TABLE 2. Offshore wind energy installations at the end of 2015 per country /7/

Country	BE	DE	DK	ES	FI	IE	NL	NO	PT	SE	UK	Total
Number of farms	5	18	13	1	2	1	6	1	1	5	27	80
Number of turbines	182	792	513	1	9	7	184	1	1	86	1454	3230
Capacity installed,MW	712	3295	1271	5	26	25	427	2	2	202	5061	11027

Figure 6 represents cumulative share of total installed capacity per country. The UK has the largest share 45.9% that is almost a half of installed offshore wind capacity in EU. Germany is the second with 29.9% of all installations. Denmark follows with 11.5%. The rest 13% of European installations are located in Belgium, the Netherlands, Sweden, Finland, Ireland, Spain, Norway, and Portugal. Finland's 26 MW total capacity represents only 0.2% of total number of installations in Europe.

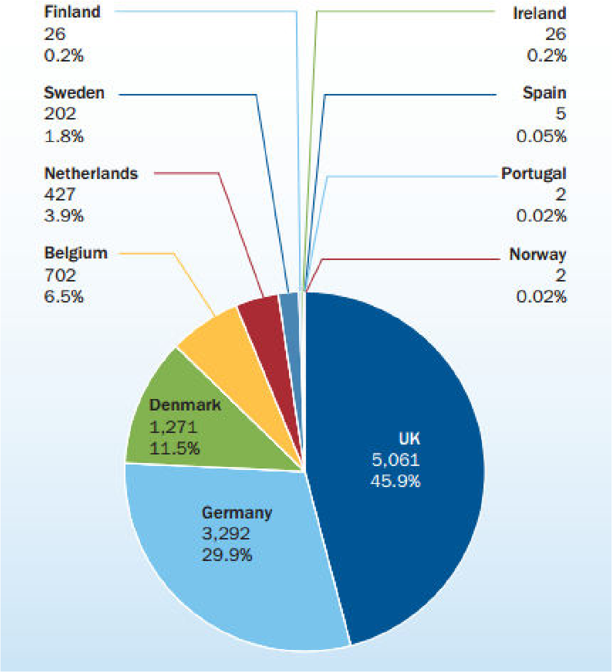


FIGURE 6. Installed capacity - cumulative share by country in 2015 /7/

Figure 7 shows number of grid-connected wind turbines per country. The leader is the UK with 1454 turbines (45%). Germany has 792 wind turbines, and Denmark has 513 turbines that are corresponding 24.5% and 15.9% of total number. The rest 14.6% are shared among the remaining countries including Finland's 9 turbines (0.3%).

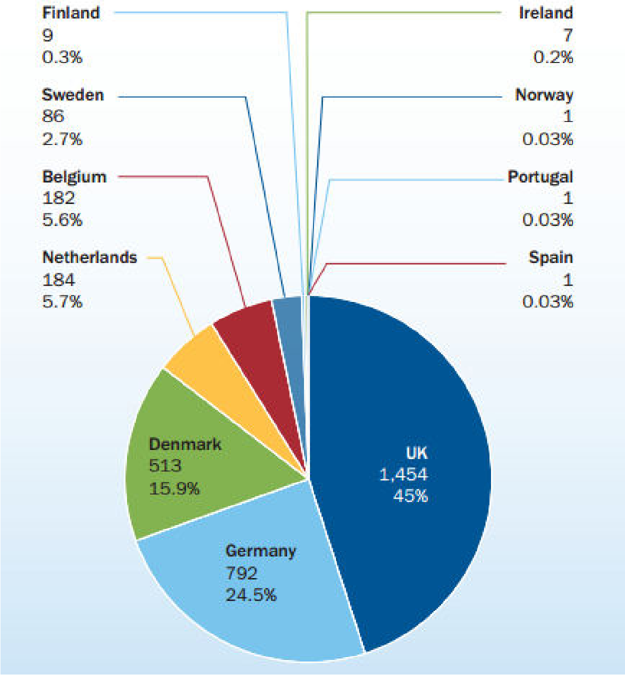


FIGURE 7. Installed wind turbines - cumulative share by country in 2015 /7/

Cumulative share of installed capacity by sea basin is presented in Figure 8. Most of the offshore wind farms are located in the North Sea - 69.9% or 7,656.4 MW capacities. 1,943.2 MW of installed capacity is installed in the Irish Sea, and 1,420.5 MW in the Baltic Sea representing corresponding 17.6% and 12.9% of total share. 7 MW capacity or 0.1% belongs to the Atlantic Ocean.

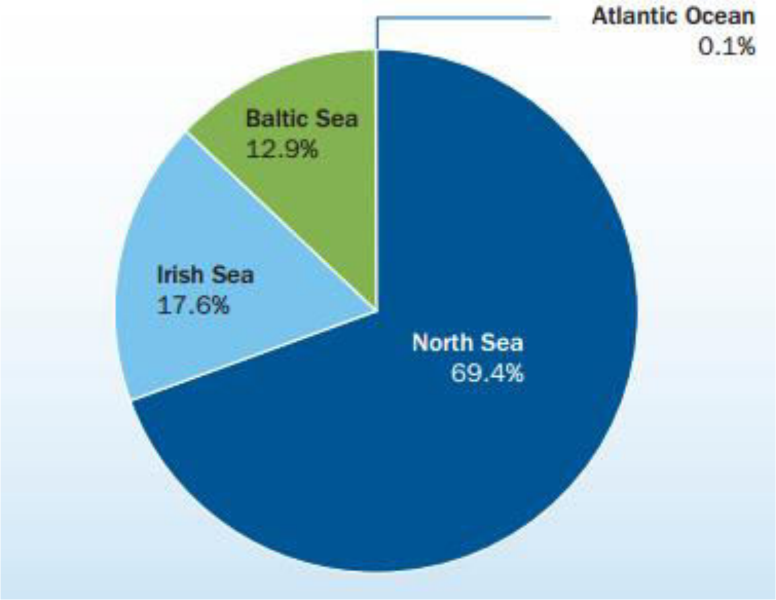


FIGURE 8. Installed capacity, cumulative share by sea basin in 2015 /7/

Wind turbine capacity growth from 2010 to 2015 amounts 41.1%. From 2010 the average capacity of newly installed wind turbine was continuously growing, and it reached 4.2 MW in 2015 (Figure 9).Overall, 754 offshore wind farms were under construction in 2015. All the manufacturers deployed larger capacity offshore wind turbines in comparison with previous 2014 year. Such positive development and improvement rates allow expecting sequential introduction of 6-8 MW turbines closer towards 2018./7./

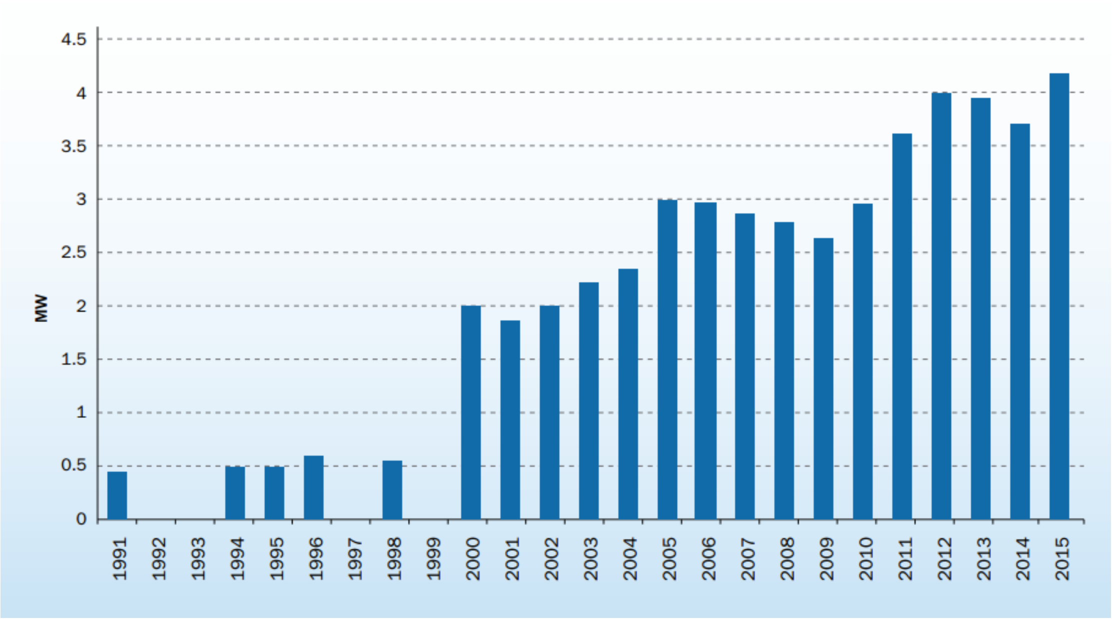


FIGURE 9. Average offshore wind turbine rated capacity in 2015 /7/

Top three of the largest operating offshore wind farms are located in the UK. At present the largest offshore wind farm in Europe is London Array with 630MW capacity. More detailed information about Europe's largest offshore farms is given in the Table 3.

TABLE 3. Three largest offshore wind farms in Europe

Wind farm	Total (MW)	Location	Number of turbines	Turbines model	Commissioning Date	Construction cost, €
London Array	630	North Foreland, Kent, England, the UK	175	Siemens SWT-3.6-120	2012	2.2 billion
Gwynt y Môr	576	North Wales, Wales, the UK	160	Siemens SWT-3.6-107	2015	2.0 billion
Greater Gabbard	504	Suffolk, England, the UK	140	Siemens SWT-3.6-107	2012	1.7 billion

In 2015, the average size of constructed wind farm was 337.9 MW, an 8.2% decrease from the previous year (Figure 10)./7./ Although 576 MW Gwynt y Môr offshore wind farm was completed, and 600 MW Gemini offshore wind farm was constructed, the average site's size was affected by prevailed number of small-scale288 MW offshore farms completed in Germany./5./

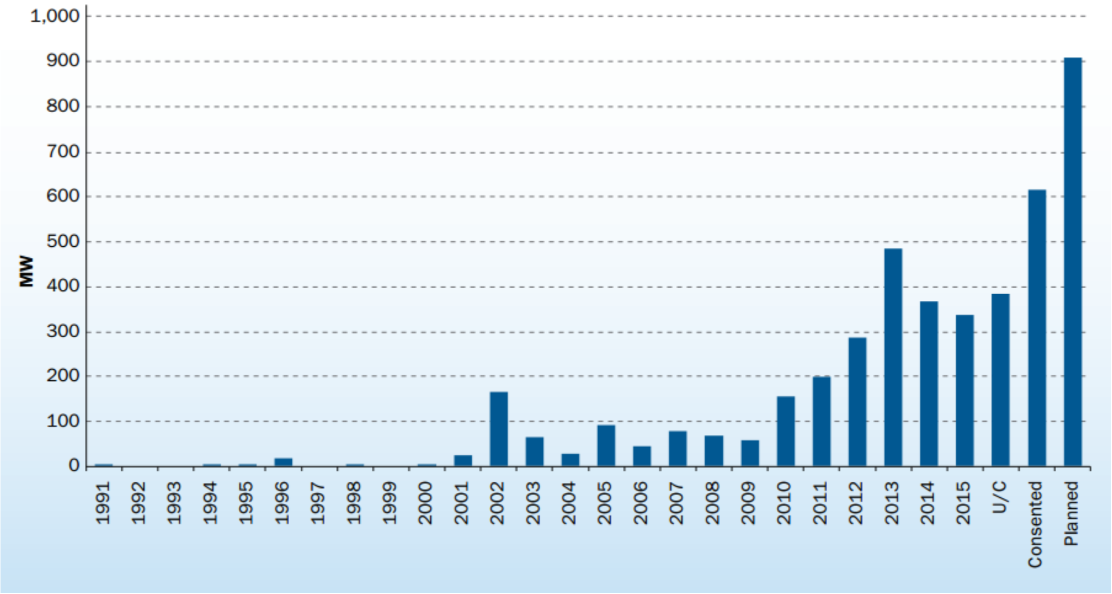


FIGURE 10. Average size of offshore wind farm projects in 2015/7/

Typically, offshore wind farms are built in shallow waters not far away from the coast in order to minimize cables and foundation costs. The average water depth of site construction was 22.4 m in 2014, and it increased to 27.2 m in 2015 (Figure 11).

The average distances from the coastline were 32.9 km and 43.3 km in corresponding 2014 and 2015 (Figure 11). An increase of the average distance from shore is explained by amount of projects carried in Germany. In Germany, offshore wind farms are located further from the coast compared to other countries.

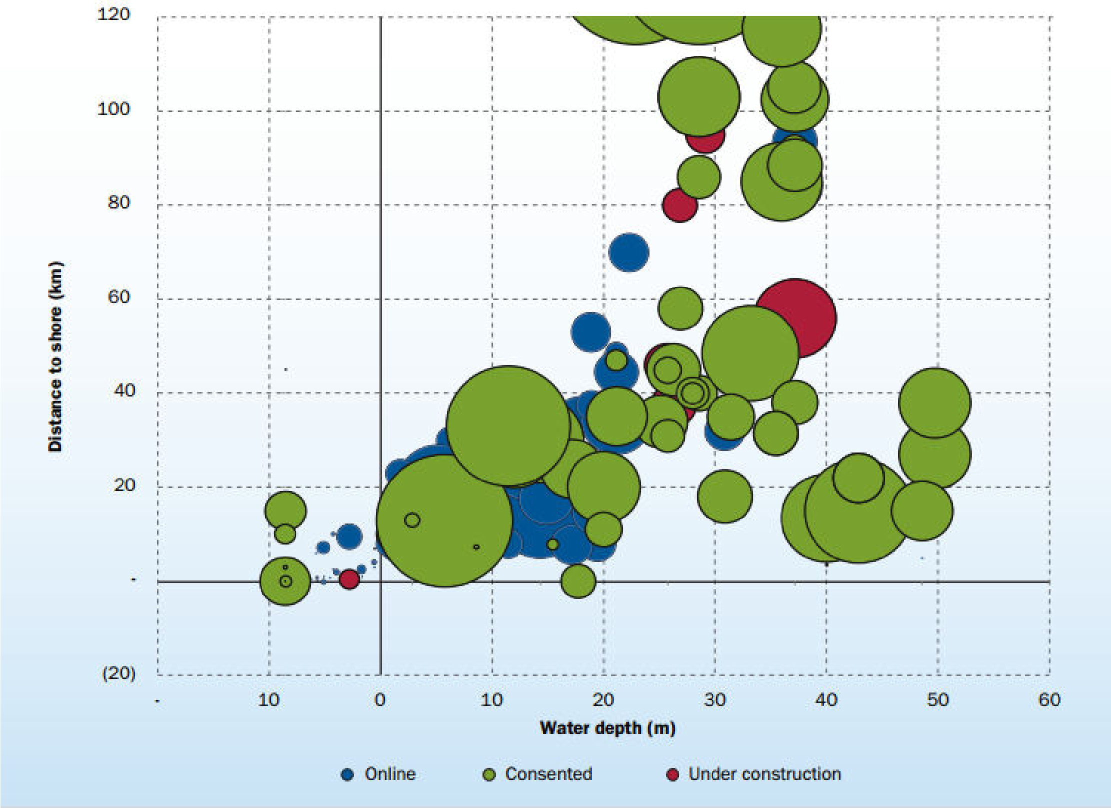


FIGURE 11. Average water depth and distance to shore of online, under construction and consented wind farms in 2015 /7/

5.2 Northern conditions challenges

Cold climate conditions or Northern conditions refer to consistent lower air temperatures compared to wind turbines' normal operation temperatures and icing occurrence possibility. In Europe several Nordic countries: Sweden, Norway, and Finland face cold climate conditions. This chapter provides with information about Northern conditions in general due to the lack of information on the subject of offshore wind.

Northern conditions are supposed to be challenging due to many reasons. Cold climate is detrimental to wind farm effectiveness because it brings about lower energy productions, ice throw, increased noise level, and economical profit drop./8./

In addition, operation and maintenance durations increase, or in case of inaccessible site service and maintenance can be even impossible. Down time is comparatively low but still possible due to weather conditions. Apart from that, specific technology is required to run a turbine at low air temperatures, so operational costs rise./8./

Icing events are possible to affect all wind farms located in North Europe. However, local icing conditions vary a lot depending on topographical location. For example, several sites located in Norway do not experience the same damaging effect as ones in Lapland area even if they are located at the same latitude.

The Atlantic Ocean's warm currents influence on Norwegian Sea temperature; hence, it is comparatively warm in winters, and icing is unlikely to occur. On the contrary, in Lapland, average air temperature drops below -13°C in winter /8/; thus, icing events are inevitable to appear.

Icing impact depends on average height and altitude of wind farm area. The greater average height and the altitude of a site terrain the worse icing conditions are expected. It should be noted that altitude makes a greater impact on icing conditions than average height of a site area./9./

Despite evident disadvantages, wind farms have been built in cold climate conditions all over the world since nineties. Furthermore, development and implementation of Northern projects continue to grow. The main reason is plenty of sustainable wind recourses.

Annual average wind speed reaches up to 8-10 m/s when offshore. According to O2 Vindkompaniet studies (currently OX2 - Swedish renewable energy oriented company) 10 times more energy can be generated in cold climate conditions compared to standard conditions. It means that if detriment due to icing events and low temperatures will be neutralized, the great potential of wind resources will become unlocked.

5.2.1 Technology

In case of Northern location of a site, additional requirements must be met. Wind resources estimation is an important subject in wind energy field. Therefore, measurement devices: wind vanes and anemometers must be capable of performing precisely during low temperatures, so they are typically equipped with heaters./9./

Ice prediction is highly important as well because icing events drastically affect power performance. The current existing methods of ice estimations do not provide with thorough information. Icing maps describing annual active icing time are used to analyze icing conditions./9./

Theoretical information from icing maps in combination with computer software allows making better predictions of amount of icing on wind turbines' rotor blades. However, this is a very difficult method due to initial complexity of ice origins and blades aerodynamics, so this solution is still under development and improvement.

In cold climate conditions, wind turbines are made of low temperature resistant materials. The most critical parts of turbine (gear box and pitch accumulator) must be ensured; therefore heaters are added. Special equipment such as ice detectors and anti-icing (or de-icing) systems started to be developed.

5.2.2 Cold climate experiences in Finland

In Finland, all the existing wind farms are located in cold climate conditions although severe icing events are typical basically for Lapland. Southern Finland has milder climate, so low temperature impact is generally lower. Yet in case of colder than average winters installations all over the country are affected.

VTT Technical Research Centre of Finland provides with comprehensive wind energy statistics publishing annual reports that contain information about the operation of wind turbines and turbines down time./10./ There are available publications from 1999 to 2014 on the official website. 2015 yearly report and forthcoming reports will be published by Finnish Wind Power Association./11./

As stated in the reports annual turbines availability decrease due to low temperatures range from 0.2% and 2.8% since 1997 to 2010. Low temperatures in the period from 1997 to 2010 caused 1 to 27 shut down turbines per year. It is 10 turbines per year on average. The average down time per turbine was amounted to 123 hours that refer to 1.4% of the annual operational hours./9./

The icing events during 1996 and 2010 resulted annual availability decrease per turbine ranging between 0.3% and 4.1%. Average turbine's availability was 114 hours per year corresponding to 1.3% of annual operational hours. On average 16 turbines per year (varying between 4 and 30) have been reported down time due to icing./9./

6 TAHKOLUOTO PROJECT

In 2007, EU set 2020 European climate and energy targets, which include

- 20% greenhouse gas emissions reduction (from 1990 levels),
- 20% generated energy from renewable sources,
- 20% improvement in energy efficiency. /1./

In order to reach these goals Finnish government set a strategy of developing wind power sector. The government of Finland has high expectations about using offshore wind energy, and as a result, Tahkoluoto (Pori 2) project was approved. In November 2014, the Ministry of the Employment and Economy of Finland contributed 20 million euro investment aid when the total project’s cost is 120 million euro.

Tahkoluoto offshore farm is located in Gulf of Bothnia, the Baltic Sea./12./ Tahkoluoto offshore wind farm is the first offshore wind farm in Finland, and at the same time it is the first offshore wind farm designed for icing conditions in the world.

The owner of offshore wind farm is Suomen Hyötytuuli Oy, Finnish company producing wind power. Siemens, a leading supplier of wind power solutions, provides with the turbines and performs commissioning. Siemens is also responsible for service and maintenance.

In 2010, Siemens installed one 2.3 MW capacity wind turbine to Suomen Hyötytuuli Oy for the pilot project Pori 1 that is located 1.2 km off the Finnish coast near Pori. Since then Pori 1 pilot project provides with information about offshore wind energy generation in icing conditions. This pilot turbine will be surrounded by the 10 wind turbines 4 MW capacity each of the Tahkoluoto wind farm./13./

Total offshore wind farm capacity 40 MW. Construction period starts in summer 2017, and completion is expected by autumn 2017. For the purpose of facing cold climate conditions, resisting ice load in particular, Siemens designed gravity-based steel foundations./13./

Tahkoluoto project is about to demonstrate that offshore wind power is a feasible solution for Northern Baltic Sea region and Finnish land in particular. Toni Sulameri, the Managing Director of Suomen Hyötytuuli Oy, said that conditions in Finland are excellent for offshore wind power farm: a hard seafloor, long coastline, shallow waters, and great wind resources. The distance from the coastline is approximately 0.5-3 km, and the water depth range from 8 to 15 m./13./

An expected annual net power production exceeds 155 GWh. Owners said that offshore wind farm is supposed to produce enough power to supply 8,600 electrically heated Finnish single-family houses with green energy.

7 ENERGY CONSUMPTION IN FINLAND

7.1 Electricity consumption in Finland

In Finland, electricity consumption drastically increased over the last 55years (Figure 12). In 1960, annual electricity consumption was about 8,800 GWh. In 2007, it reached the greatest value of 55 years of data collecting –90,388GWh per year./14./ Although total annual electricity consumption slightly decreased to about 82,500 GWh by 2015, extreme cut-down of consumed electricity cannot be expected. Humans' lifestyles and habits, appearance of new technologies, industry, and energy consumption in general have dramatically changed since 60s. Therefore, the demand of electricity is increasing worldwide.

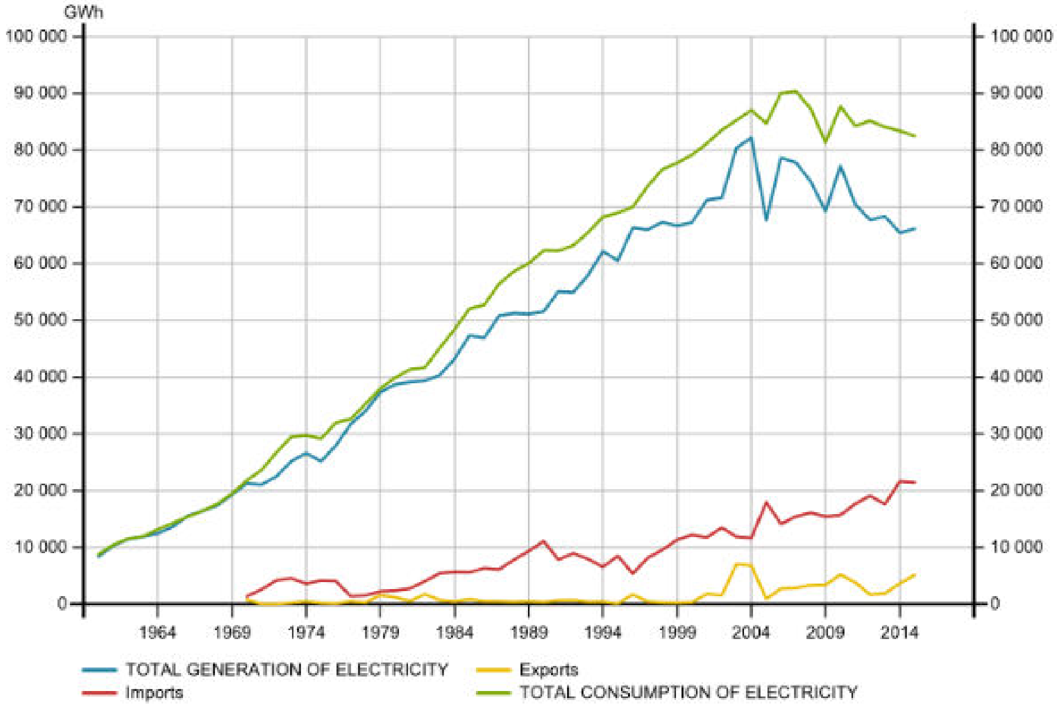


FIGURE 12. Electricity supply and total consumption in Finland 1960-2015 (Source: Statistics Finland /14/)

As can be seen from the Figure 13 the greatest part of electricity consumption (45%) belongs to industry. However, households have a significant influence on total electricity consumption as well. Firstly, because 26% of total consumed energy is used for space heating. Secondly, because individual consumers can choose the energy source they use.

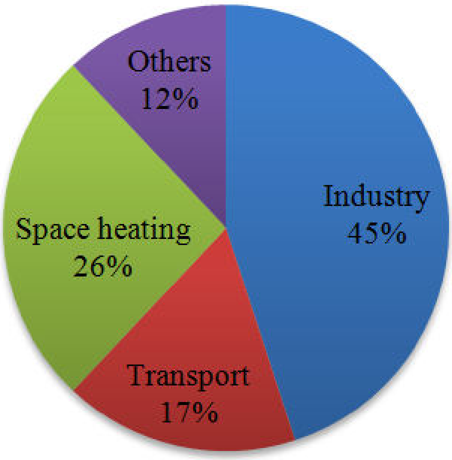


FIGURE 13. Final energy consumption by sector 2014(Source: Statistics Finland /14/)

The choice of environmentally friendly energy sources has a positive impact on total primary energy supply. In Finland, government is concerned about increasing electricity need, because it is also related to larger amount of green house gases emissions. The curves on the Figure 14 represents relation between total energy consumption growth and CO_2 emissions.

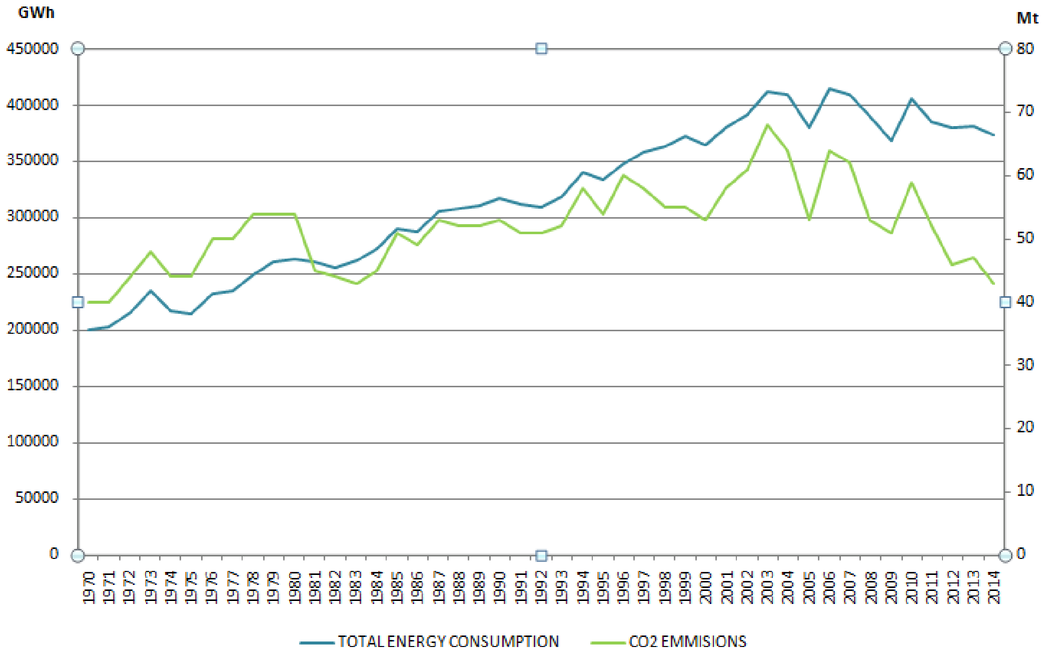


FIGURE 14. Total energy consumption and CO2 emissions 1970-2014 (Source: Statistics Finland /14/)

7.2 Heating energy consumption in residential buildings

Electricity generated by wind turbines can be effectively utilized in residential buildings to cover HVAC systems needs. Many elements of the HVAC systems need electricity to operate. For instance, electricity is essential for running electric heating systems, all kinds of pumps including heat pumps, or AHU. When HVAC systems are selected equipment's energy consumption should be carefully evaluated, because high-energy consumption leads to greater operational costs and more expensive net energy price to consumers.

According to Finnish guidelines and regulations, residential buildings are categorized as detached houses, terraced houses, block of flats, and free-time residential buildings. In residential buildings, the greatest part of heating energy consumption accrues to a main heating system demand. The rest of consumed heating energy is divided between additional heating systems, ventilation, domestic hot water, saunas, and heat distribution.

Statistics Finland reports that total energy consumption in residential buildings amounted 55,576 GWh in 2014. Detached houses corresponded to 32,083 GWh, and 5,508 GWh of energy was consumed in terraced houses. Hereof, single-family households account for 37.591 GWh per year. 15,318 GWh accrues to block of flats, and free-time buildings consumed 2,667 GWh in 2014. Total consumption of heating energy in residential buildings by source of energy is shown in Figure 15.

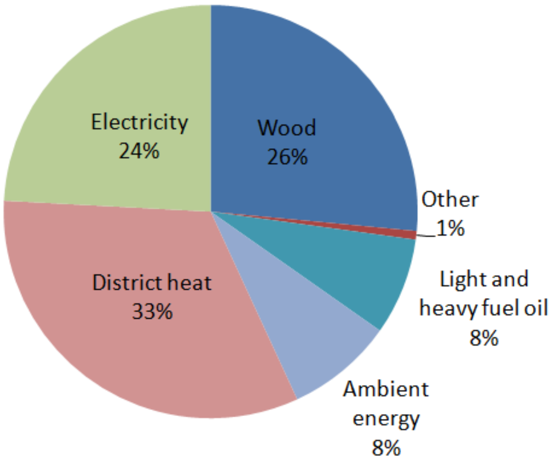


FIGURE 15. Consumption of heating energy in residential buildings 2014 (Source: Statistics Finland /14/)

The most popular energy sources are district heat, electricity, and wood. Ambient energy and light fuel have the same share - 8% of total energy consumption. Peat, coal, natural gas, and heavy fuel oil are rarely used. Their summarized share corresponds to 1% of total consumption. The general changes of energy sources choices between 2008 and 2014 years are represented in Figure 16.

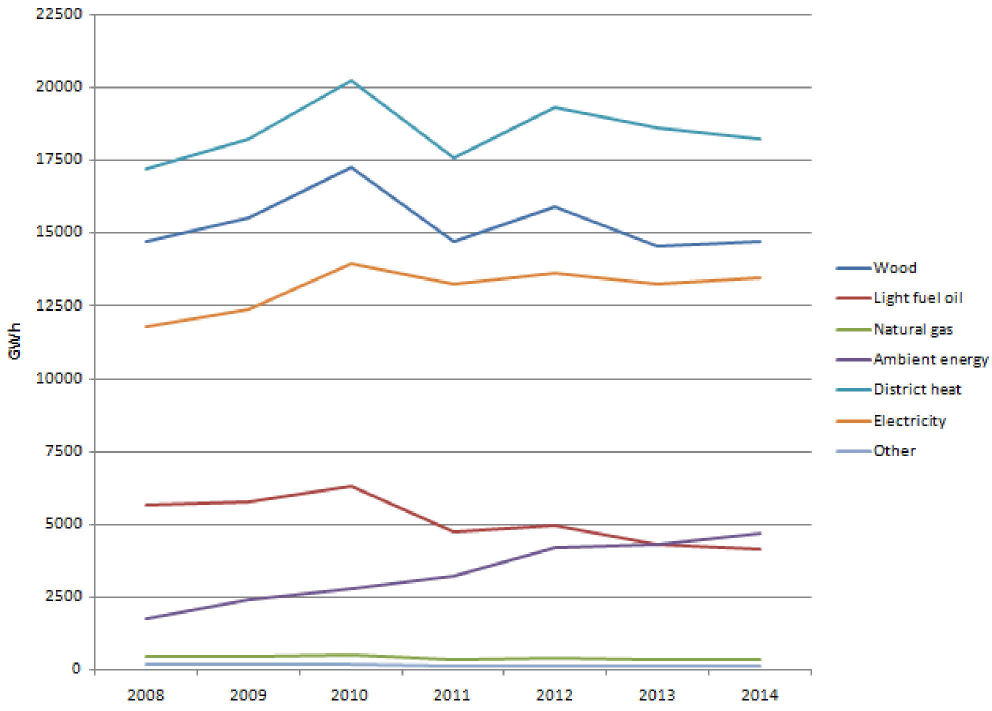


FIGURE 16. Consumption of heating energy in residential buildings 2008-2014 (Source: Statistics Finland /14/)

7.3 Heating energy consumption in single-family houses

In this thesis, single-family house energy consumption is studied. Single family houses heating market as well as preferred energy source distinguish depending on the category of residential buildings. To have a better overview on single-family house sector terraced houses and detached houses are analyzed separately. The comparison with blocks of flats is given as well for the better understanding of heating options choices. The share of heating sources in different categories of residential buildings is given in the Figure 17.

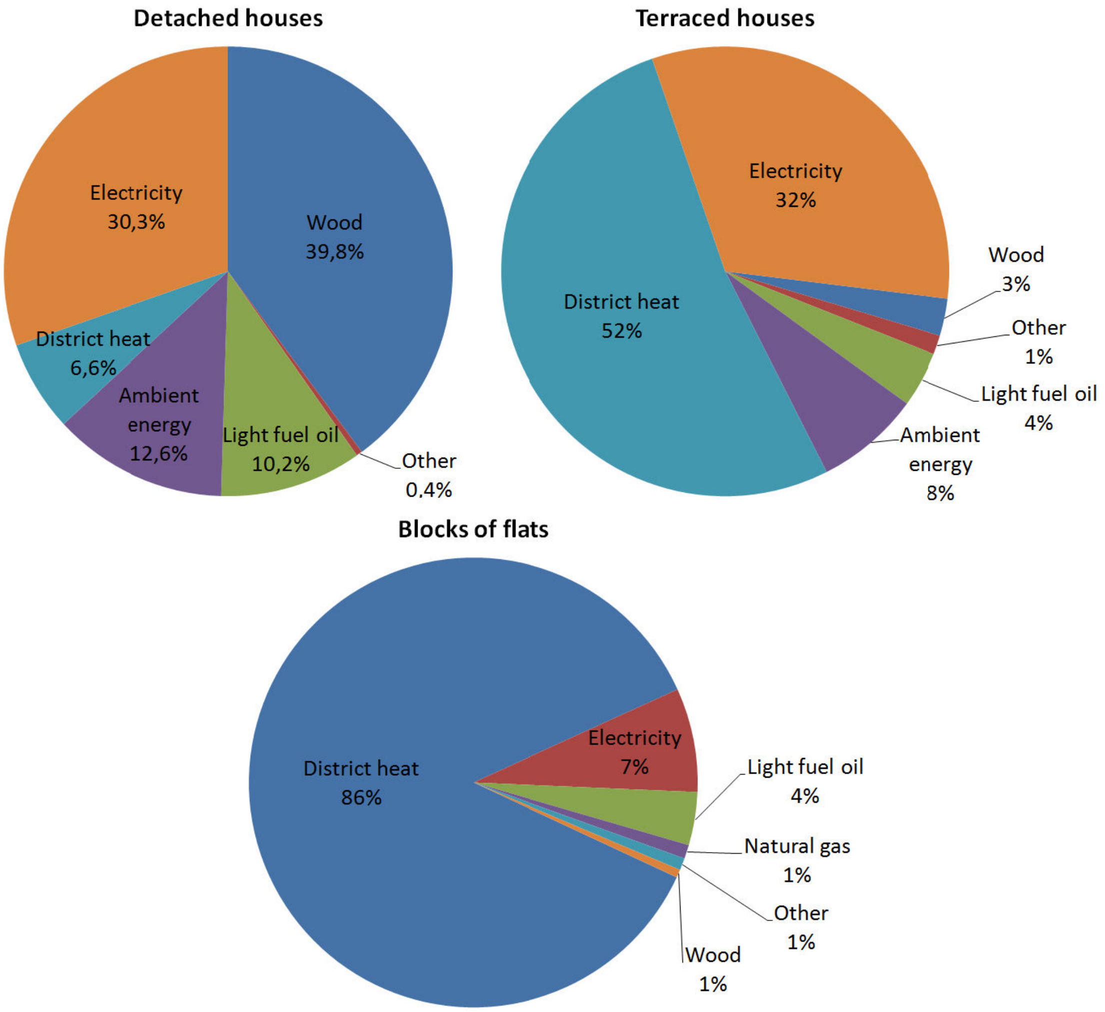


FIGURE 17. Energy consumption in by source in 2014 (Source: Statistics Finland /14/)

According to the latest statistics /14/, the most common heating source in residential buildings is district heat, which represents 33% of total heating energy consumption (Figure). However, the share is not equal for different categories. District heat is prevailed energy source in blocks of flats (86%) and terraced houses (52%). On the contrast, it is accounted for only 6.6% of total heating energy consumption in detached houses.

The second choice of heating energy source in residential buildings is wood (27%). Again, the share is completely dissimilar if compared between different categories. Unlike detached houses where wood is primary source of heating energy (nearly 40%), wood is scarcely ever in multistory residential buildings or blocks of flats (1%) and terraced houses (3%).

The share of 24% corresponds to using electricity as heating energy in residential buildings in general. Electricity is mostly consumed in detached and terraced houses with corresponding shares of 39.8% and 32% of total heating energy consumption. In blocks of flats, electricity is uncommon solution representing only 8%.

Electric heating of residential buildings includes direct electric heating, electric storage heating, under floor heating, electric heating of domestic hot water and saunas. Heat pumps electricity consumption also is taken into account. The rest part of consumed energy relates to electricity needed for operation of heating systems and heat distribution equipment.

Light oil fuels cover 7% of total heating energy consumption. The trend is degrading use of light oils due to increase of fuels' prices and high dependence on suppliers.
While the share remains significant in detached houses (10.2%) it occurs to be quite small in terraced houses and blocks of flats (4%).

Ambient energy is energy that is extracted with heat pumps from the environment (ground, air or water) for space heating. Ambient energy is almost never used in blocks of flats, but it is becoming more and more popular energy source in single-family houses sector, especially in detached houses. In 2014, ambient energy share was accounted for 12.6% of total heating energy consumption in detached houses and 8% in terraced houses.

Other sources work out only 1% of total heating energy consumption. Other sources include peat, coal and heavy oil. The used energy sources diverse in dependence to building's categories. For example, in detached houses the share of other sources consists of peat, coal, and natural gas; in terraced houses - peat and natural gas; in blocks of flats – peat, heavy oil, and ambient energy.

In single-family households, heat energy is mostly used for space heating, ventilation, and water systems. Average single-family house heat demand is about 100-120 kWh/m2. Approximately 10,000-15,000 kWh of energy is used for space heating and domestic hot water heating annually. In low energy houses, half of that amount is needed to cover the heat energy demand. Passive houses consume only 20-30 kWh/m2 per year./15./

No doubt, the bigger the area of the building the more energy is needed to satisfy the demands. Besides, energy consumption also depends on other factors like the way of use, weather zone, buildings’ envelope tightness, U-values of constructions, designed heating system, equipment efficiency, etc.

8 HEATING OPTIONS

In this chapter, the most typical heating options for single-family houses are discussed providing with description of district heating, ground source heat pump, and electric heating.

8.1 Electric heating

Electric heating include under floor heating systems, ceilings, and electric radiators. Electric heating was the most popular heating option in 60s. The popularity can be explained with relatively low capital costs and user friendliness. Since that time, electric heating market share has significantly gone down./15./ As shown in Figure 18 electric heating market breakdown prevailed 20% between 2000 and 2008.

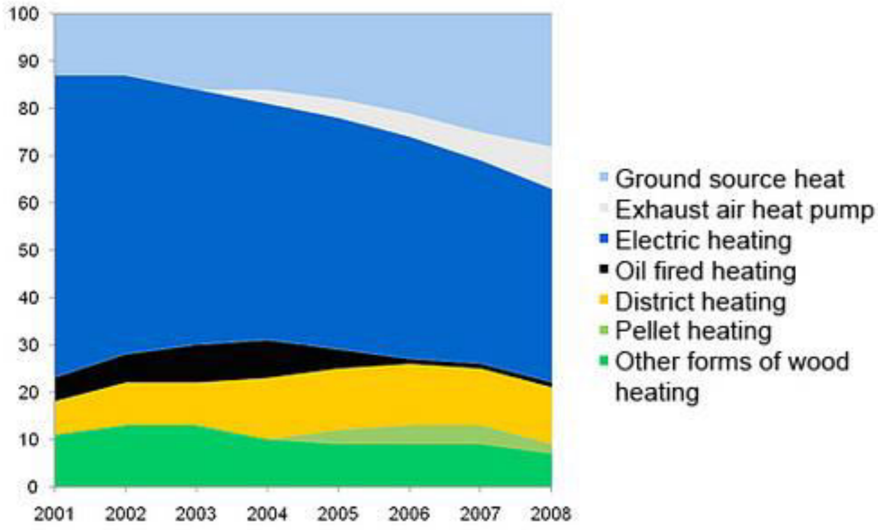


FIGURE 18. The market share of heating systems in new small houses 2001-2008(Source: Rakennustutkimus RTS Oy) /16/

The main reason of negative trend is high operation expenses compared to other heating modes. The increase of electricity demand and rising electricity costs are accounted for drop of popularity. Besides, introduction of new energy efficient heating systems like heat pumps had an impact on single-family market.

Electric heating systems are still beneficial option in case of building's low energy demands. Electric heating is probably the best solution to small area houses or passive houses that require little amount of heating energy to satisfy the needs.

Another reasonable disadvantage of electric heating systems is poor environmental impact due to emissions of CO_2. Environmental impact is proportional to energy generation: the more energy is consumed the worse effect using of electric eating has on environment.

For instance, based on Motiva Ltd 2009 statistics, a single-family house with annual heating energy consumption 10,000 kWh produces 3.5 t of CO2 emissions per year (Figure 19)./15./ The Figure also represents the fact that electrical heating is the worst option from environmental point of view.

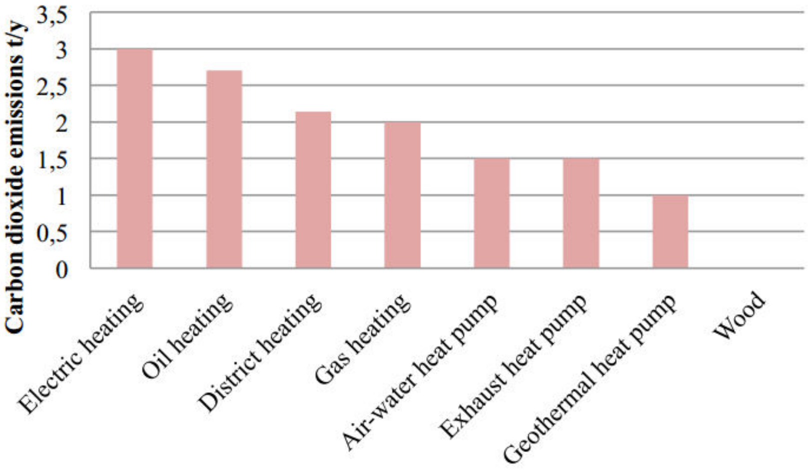


FIGURE 19. Average annual CO2 emissions of different heat sources of a single-family house that consumes 10,000 kWh heat energy in a year. (Source: Motiva Ltd 2009) /15/

However, from 2008 to 2014 heating energy consumption for electric heating increases in residential buildings probably because of overall increased energy consumption and colder than average winters.

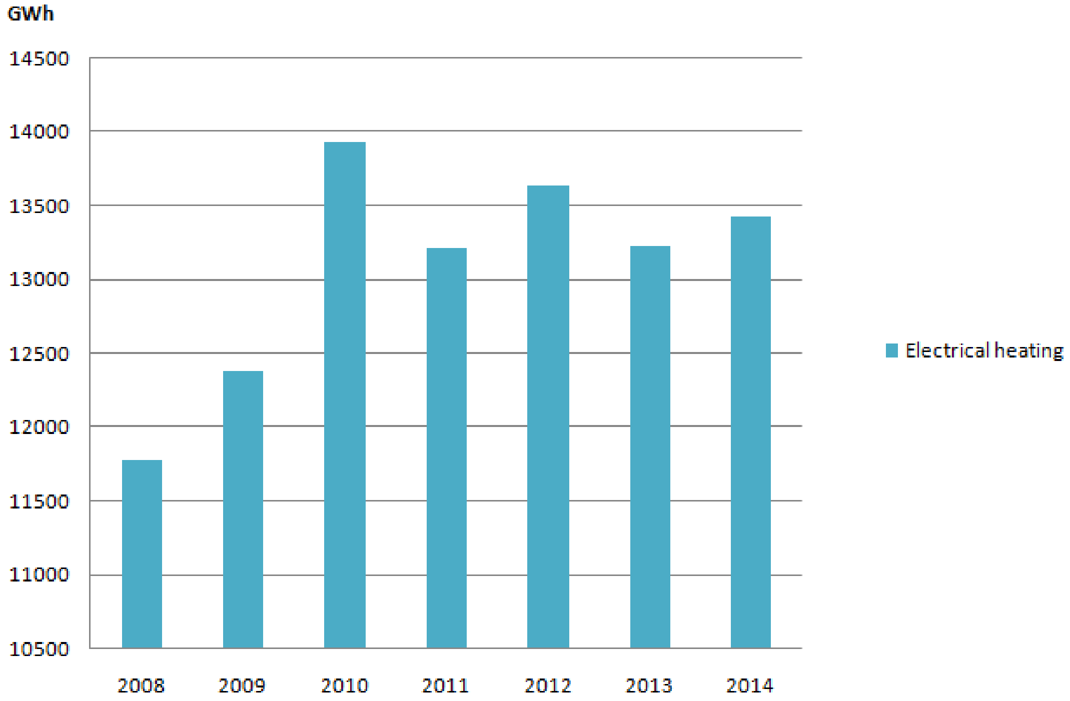


FIGURE 20. Consumption of heating energy in residential buildings 2008-2011 (Source: Statistics Finland /14/)

8.2 District heating and CHP

District heating (DH) is centralized heating system, which provides large areas like cities, quarters, or groups of buildings with heat. District heating system consists of three main components (Figure 21):

1. Heat plant where heat is generated,
2. DH network, through which heat is delivered to consumers
3. Customer connection including DH substation (4) and metering center (5)./17./

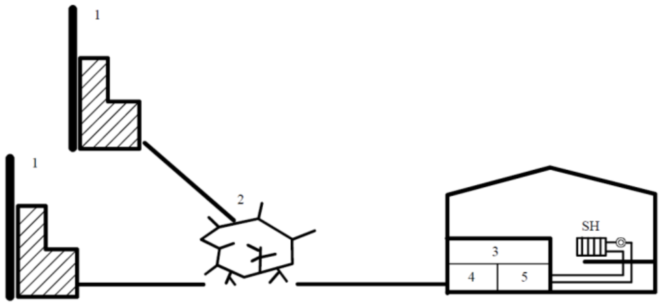


FIGURE 21. District heating components /17/

Heat transfer media in DH systems is water. In Finland, low-temperature DH is used in new buildings, so on secondary side, typical dimensioning temperatures of supply and return water are 45-30ºC. In existing buildings, that were built in 60-70s, secondary side supply temperature range from 60ºC to 70ºC, and return temperature is 40ºC.

Real case supply temperatures depend on outdoor climate conditions. The relation between supply temperature and outdoor air temperature is represented in a heating curve: the lower air temperature is outside the higher district heating supply temperature is.

Supply water temperature from a plant (primary side) range from 65 to 120ºC, although the highest possible supply water temperature cannot exceed 115ºC due to distribution losses. Return water temperature from a consumer must be at least 25 ºC and cannot be higher than 65ºC.

District heat can be produced in conventional power plants, combined heat and power (cogeneration heat and power) plants CHP and boiler plants HOB. Figure 22 illustrates schemes of power plant (P) and combined heat and power plant (CHP).

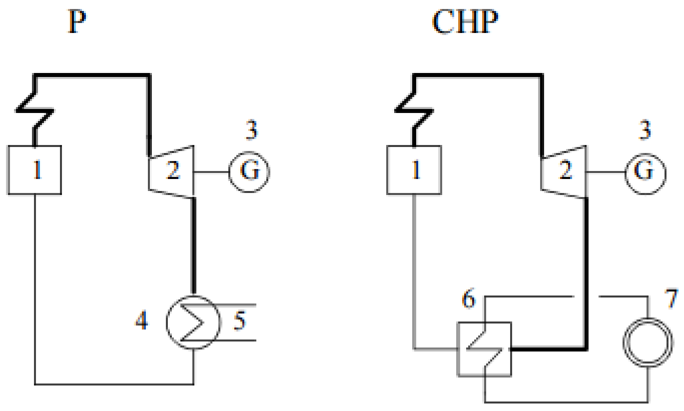


FIGURE 22. Conventional power plant and Combined Heat and Power plant /17/

1. **Steam boiler**
2. **Turbine**
3. **Generator**
4. **Condenser**
5. **Losses in condense**

6. **DH heat exchanger**
7. **DH network**

In convectional power plant thermal energy generated in steam boilers is turned into mechanical energy to rotate generator's blades, this energy is converted to electricity. High temperature steam must be cooled down in condenser and condensed steam is returned back to boilers. Steam is cooled down in cooling towers, rivers or lake, so thermal energy is wasted in the environment.

Combined heat and power plant produces both electricity and heat. Thermal energy is recovered and used for district heating. Cogeneration is commonly used in Finland. Three quarters of thermal energy is produced in CHP./19./DH production in 2010 was 38.6 TWh and share of CHP was 27.2 TWh, representing more than 70% of total heat production (Figure 23).

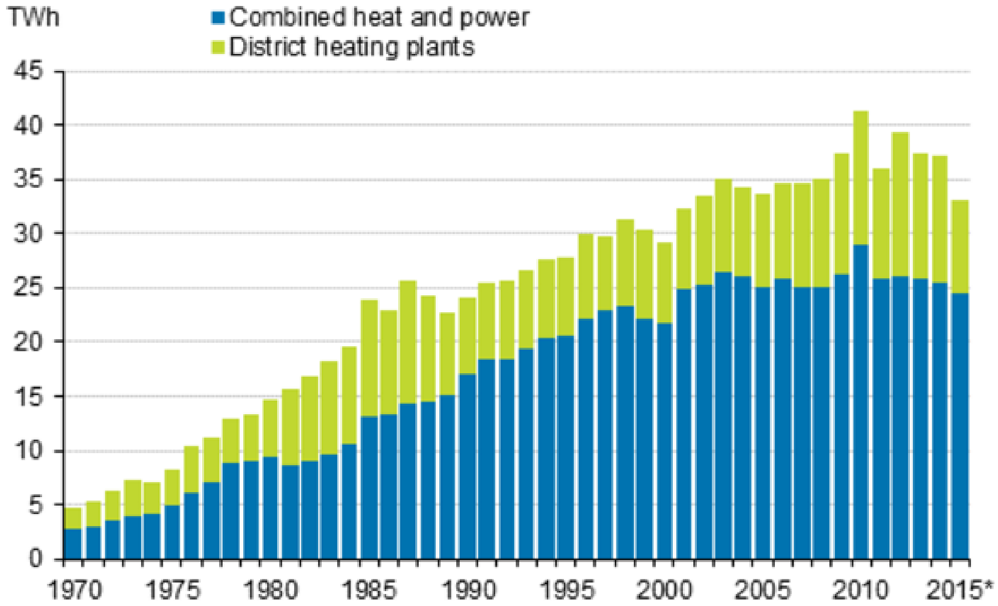


FIGURE 23. Production of district heat 1970-2015* (*preliminary) (Source: Finnish Energy Industries) /19/

Cogeneration makes district heat a very beneficial source of heating energy. The advantages are energy efficiency, environmental friendliness, economy and reliable operation. CHP achieves 80-90% efficiency when conventional power plant reaches only 35-40%. In Finland district heating is highly reliable - 99.98%, it means that CHP operate without interruption during heating season./19./

Economy can be explained with high level of automation and minimised number of staff required. Besides using less fuel in cogeneration, CHP provides saving the amount of energy corresponding to over 20 per cent of Finland's fossil fuel consumption annually./19./

High efficiency of CHP makes possible significant reduction of consumed fuel. Less consumption leads to green house gas emissions decrease, therefore CHP is considered to be environmentally acceptable.

District heating is the most popular form of heating in Finland. Figure 24 represents the growth of district heat use between 1972 and 2014 years. District heating is the most common option in urban areas or density built areas. As district heating network is the most expensive part of the system in may not be available in remote villages or places. So detached houses located far away from the cities may not be connected to DH network. Although about 48 % of Finnish population are connected to DH. In 2008 only 14% of single-family houses were supplied with heating energy by DH.

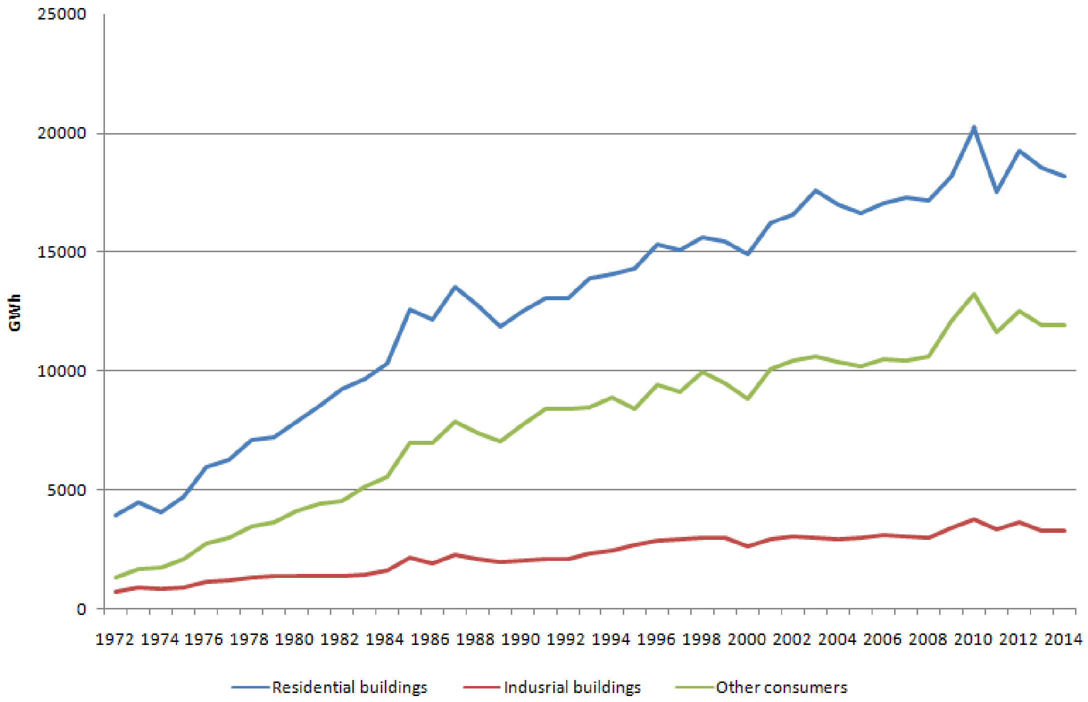


FIGURE 24. District heating by consumers 1972-2014 (Source: Statistics Finland /14/)

8.3 Heat pumps

Heat pump is a device that transfers thermal energy from low-temperature heat source to space with higher temperature. It can operate as a heating device in winter and as a cooling device in summer.

Heat pump's operation is opposite to a mechanical-compression cycle of refrigeration system. As a cooling machine heat pump, consist of compressor, condenser, evaporator, and expansion valve. It takes the heat from surroundings and transfers it to space./20./

Heat pump can take the heat from:

- outdoor air,
- exhaust air (from buildings),
- ground heat (from rock or soil),
- solar energy,
- seawater (surface water or deep water),
- ground water,
- sewage, and
- waste energy (from industrial processes)./20./

Depending on the type of heat, source heat pumps are air, ground, exhaust air, and water source heat pumps. In this chapter ground source heat pump (GSHP) will be discussed as it is the most popular solution for space heating in detached and terraced houses. Application of GSHP in detached houses has grown since 2000s due to increased prices of electricity and oil (Figure 25)./15./

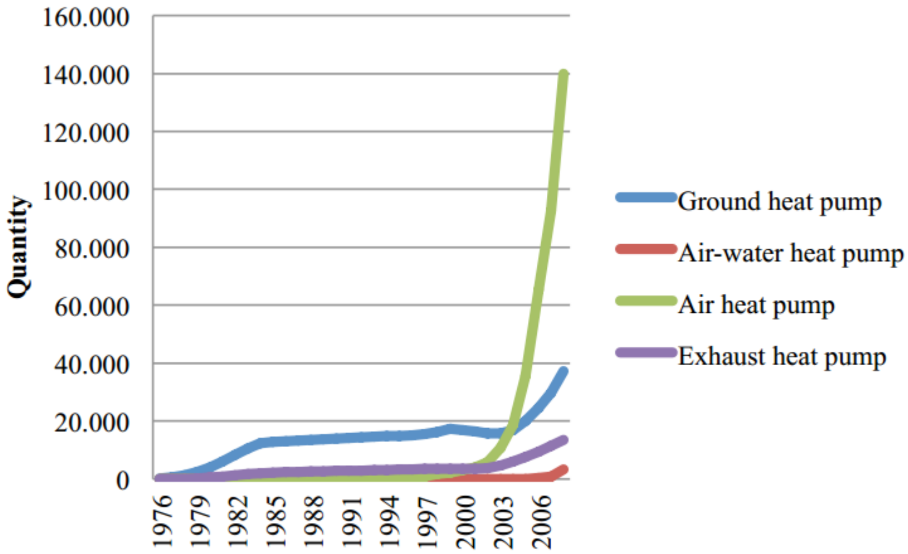


FIGURE 25. Heat pumps of detached houses in Finland between 1976 and 2008/15/

GSHP is highly efficient because it takes heat from ground or groundwater that has relatively constant temperatures during all year round. Performance of the GSHP depends on the season, COPs is about 3.0 during heating season and it is little bit lower in summer. GSHP effectiveness and performance are improved with larger areas of houses. If area is more than 150 m^2 , GSHP is probably the best solution

GSHP installation costs are mainly higher than other heat pumps due to drilling of boreholes for vertical installation or the digging of trenches for horizontal installation. However, GSHP is considered to be a cost-effective option because of low operational costs. It usually pays back during whole life cycle that is about 15-20 years.

GSHP is considered to be renewable source of energy because it utilizes ambient energy. At the same time, GSHP requires electricity to run a compressor, so operational costs are in direct relation with electricity costs. Environmental impact depended on method of electricity generation.

If the COP of GSHP is 3 it CO2 emissions can be roughly estimated. For instance, a house consuming 10,000 kWh for heating creates 0.7 to 1.3 tons of CO2 depending on the multipliers used./16./

9 SIMULATIONS OF ENERGY CONSUMPTION IN SINGLE-FAMILY HOUSE

9.1 Simulation model

Studied building is one-storey single-family house with the net heated area 138 m^2. The floor layout is given in the Appendix 1. Volume of the house is 414.2 m^3. The facade of the building is oriented to North. The building is located in Pori, weather zone I. The assumed climate data is Helsinki – Vantaa 2012 reference weather data, because Pori is located in the same weather zone as Helsinki. Figure 26 shows simulation model.

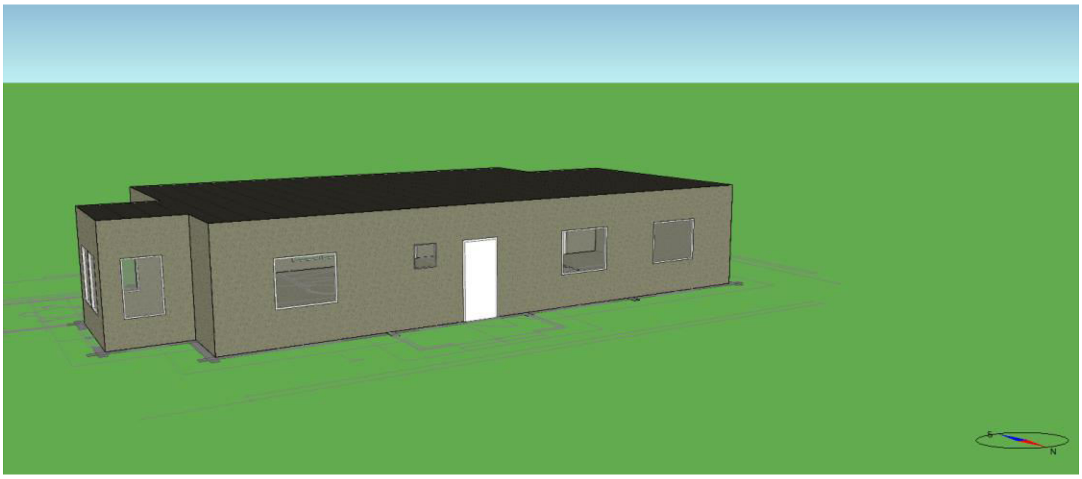


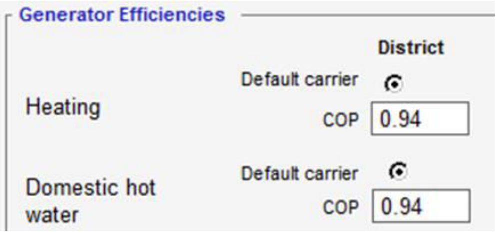
FIGURE 26. Single-family house

The chosen structures of the building are typical for wooden single-family house in Finland. Building's structures: walls, roof, floor, doors, and windows are taken in accordance with Finnish National Building Code D3 in such way that calculated by the program U-values don't exceed the required values./21 p.13./ Thermal bridges are taken from the Table 3.1 in Finnish National Building Code D5./22 p. 17./ Leakage air is calculated in accordance with D3./21 p. 19./

Sizes of windows and doors are taken from the drawing. Shading and solar radiation is neglected. Heating system is an under floor heating. Maximum supply water temperature is 40 °C. As stated in Table 6.2 /22 p. 40/ under floor heating efficiency η=0.85; hence, distribution heat losses to zones amounts to 15%. There is no cooling demand in this simulation. Heat recovery efficiency is at least 45% based on D3 guidelines./21 p. 15./

9.2 DH simulation

Figure 26 shows generator efficiencies used in district heating simulation.



Generator Efficiencies

District

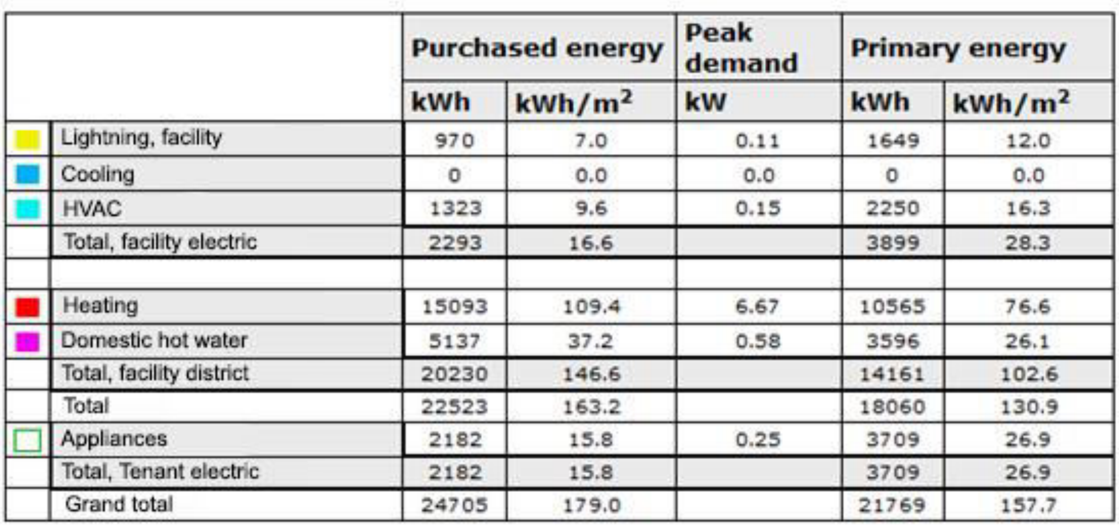
Heating
Default carrier ●
COP 0.94

Domestic hot water
Default carrier ●
COP 0.94

FIGURE 27. Generator efficiencies of district heating

Following Table 4 represents delivered energy overview, and Figures 27 and 28 show delivered and primary energy per months.

TABLE 4. Delivered energy overview of district heating



		Purchased energy		Peak demand	Primary energy	
		kWh	kWh/m²	kW	kWh	kWh/m²
🟨	Lightning, facility	970	7.0	0.11	1649	12.0
🟦	Cooling	0	0.0	0.0	0	0.0
🟦	HVAC	1323	9.6	0.15	2250	16.3
	Total, facility electric	2293	16.6		3899	28.3
🟥	Heating	15093	109.4	6.67	10565	76.6
🟪	Domestic hot water	5137	37.2	0.58	3596	26.1
	Total, facility district	20230	146.6		14161	102.6
	Total	22523	163.2		18060	130.9
☐	Appliances	2182	15.8	0.25	3709	26.9
	Total, Tenant electric	2182	15.8		3709	26.9
	Grand total	24705	179.0		21769	157.7

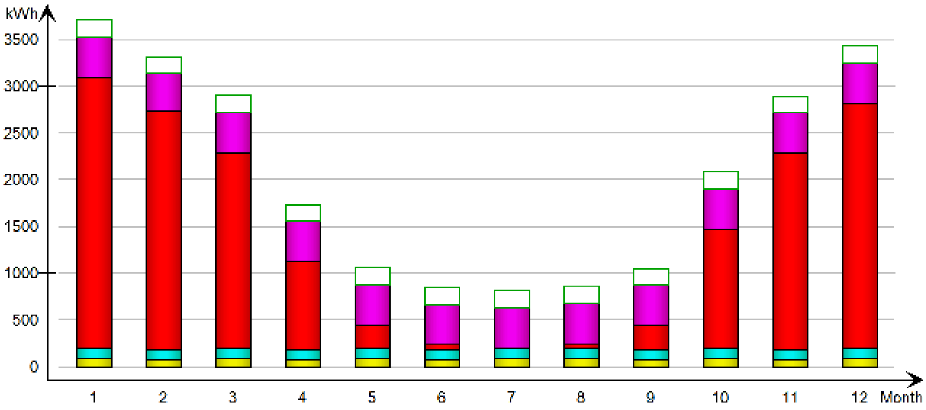


FIGURE 28. Monthly delivered energy

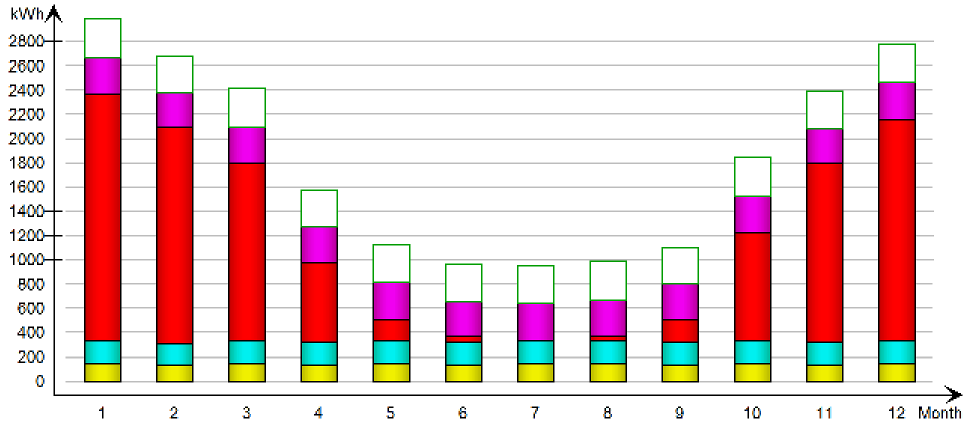
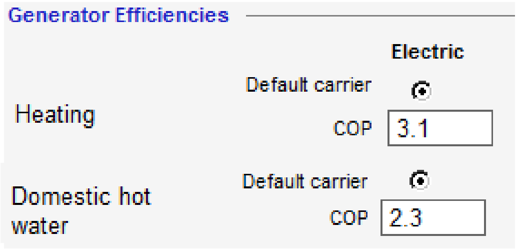


FIGURE 29. Monthly primary energy

9.3 GSHP simulation

Average temperature of the heat collection returning pipe (in bore hole) is +3°C. Generator efficiencies are shown in Figure 30.



Generator Efficiencies

Electric

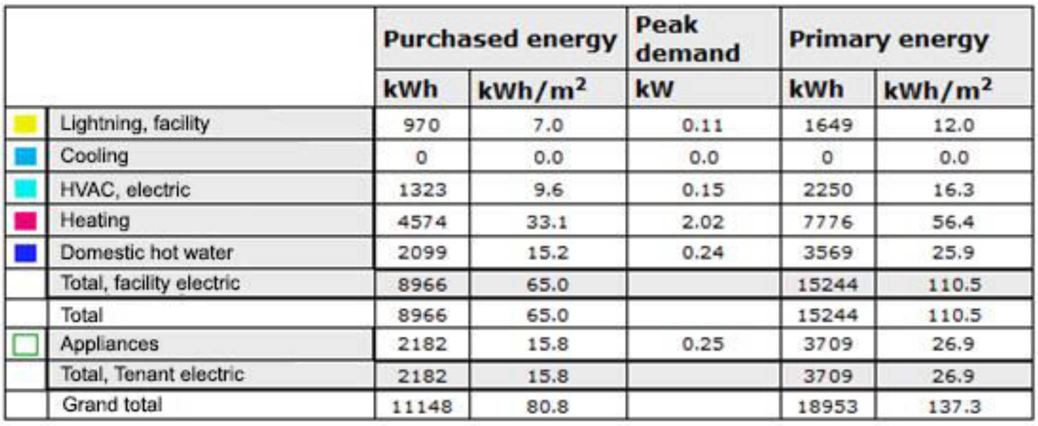
Heating — Default carrier ● — COP 3.1

Domestic hot water — Default carrier ● — COP 2.3

FIGURE 30. GSHP generator efficiencies

Delivered energy overview is given in the Table 5; Figures 31 and 32 show corresponding monthly delivered and primary energy.

TABLE 5. Delivered energy overview of GSHP



		Purchased energy		Peak demand	Primary energy	
		kWh	kWh/m²	kW	kWh	kWh/m²
🟨	Lightning, facility	970	7.0	0.11	1649	12.0
🟦	Cooling	0	0.0	0.0	0	0.0
🟦	HVAC, electric	1323	9.6	0.15	2250	16.3
🟥	Heating	4574	33.1	2.02	7776	56.4
🟦	Domestic hot water	2099	15.2	0.24	3569	25.9
	Total, facility electric	8966	65.0		15244	110.5
	Total	8966	65.0		15244	110.5
☐	Appliances	2182	15.8	0.25	3709	26.9
	Total, Tenant electric	2182	15.8		3709	26.9
	Grand total	11148	80.8		18953	137.3

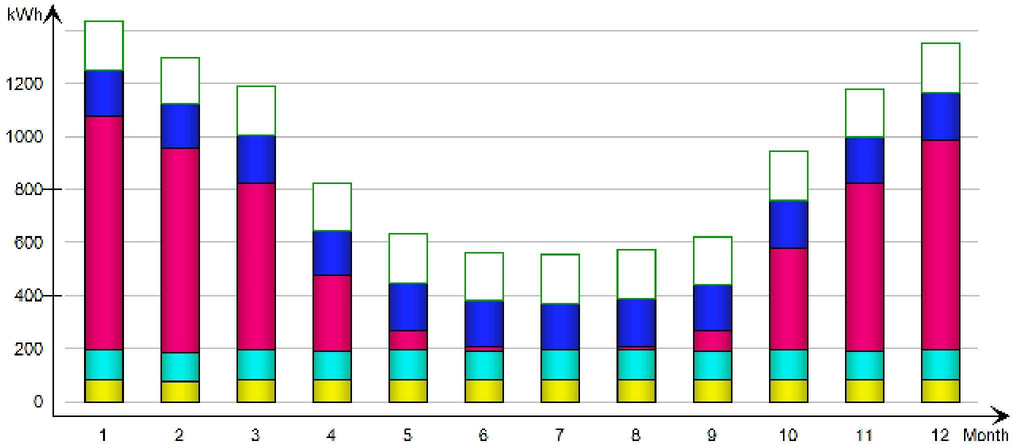


FIGURE 31. Monthly delivered energy

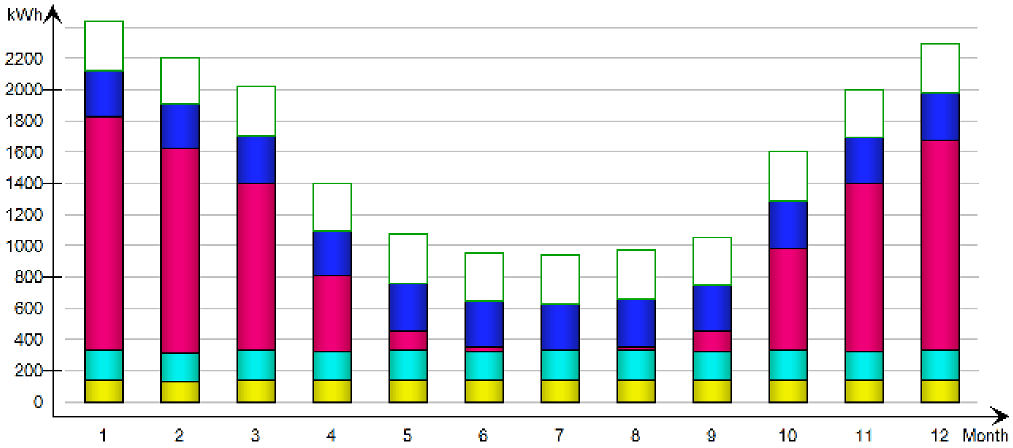
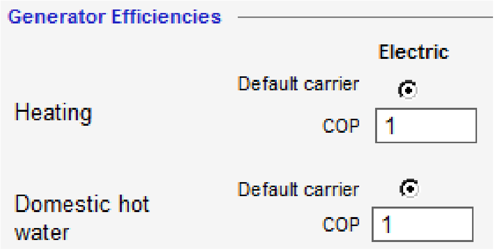


FIGURE 32. Monthly primary energy

9.4 Electric heating simulation

Generator efficiencies for the third simulation are shown in Figure 33.



Generator Efficiencies

Electric

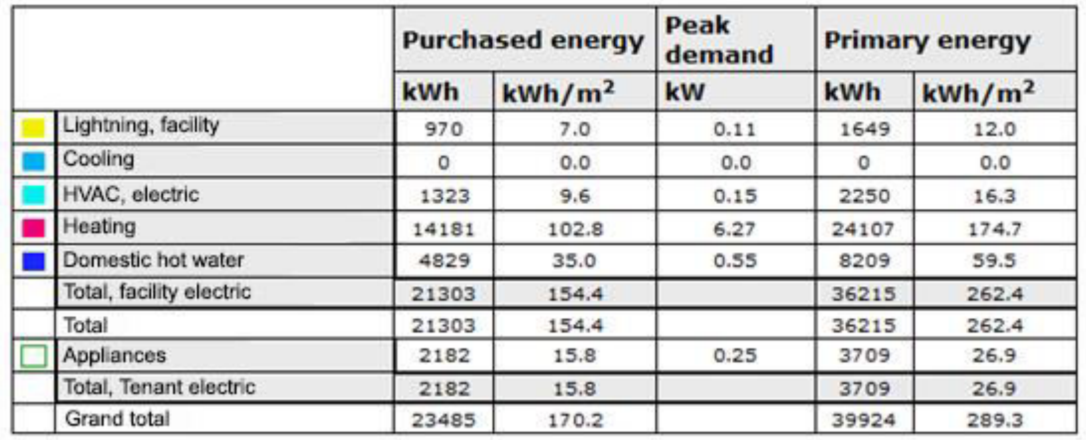
Heating
Default carrier ●
COP 1

Domestic hot water
Default carrier ●
COP 1

FIGURE 33. Generator efficiencies of electric heating

Delivered energy overview is given in the Table 6; Figures 34 and 35 show corresponding monthly delivered and primary energy.

TABLE 6. Delivered energy overview of electric heating



		Purchased energy		Peak demand	Primary energy	
		kWh	kWh/m²	kW	kWh	kWh/m²
🟨	Lightning, facility	970	7.0	0.11	1649	12.0
🟦	Cooling	0	0.0	0.0	0	0.0
🟦	HVAC, electric	1323	9.6	0.15	2250	16.3
🟥	Heating	14181	102.8	6.27	24107	174.7
🟦	Domestic hot water	4829	35.0	0.55	8209	59.5
	Total, facility electric	21303	154.4		36215	262.4
	Total	21303	154.4		36215	262.4
☐	Appliances	2182	15.8	0.25	3709	26.9
	Total, Tenant electric	2182	15.8		3709	26.9
	Grand total	23485	170.2		39924	289.3

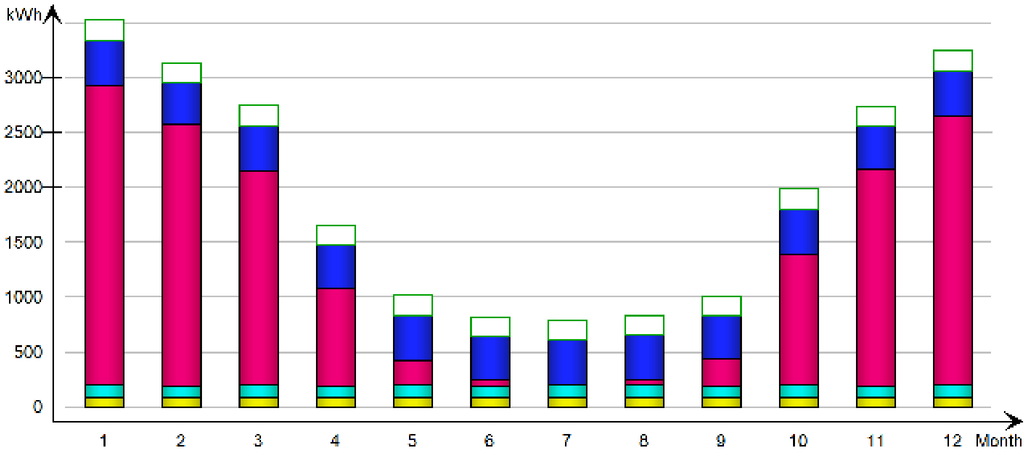


FIGURE 34. Monthly delivered energy

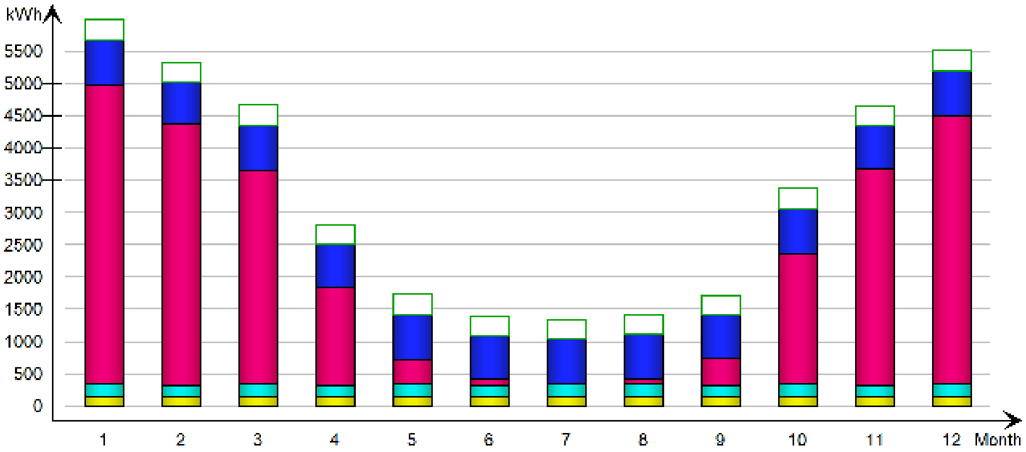


FIGURE 35. Monthly primary energy

9.5 Results analysis

According to Finnish National Building Code D3 /21 p.9./ E-value for a single-family house with net heated area 138.0 m2 must not exceed 178.8 kWh/m^2. Comparison of obtained results is given in the Table 7.

TABLE 7. Comparison of different heat sources

Heating system	E-value, kWh/m2	Delivered energy, kWh	Primary energy, kWh
District heating	157.7	24705	21769
GSHP	137.3	11148	18953
Electric heating	289.3	23485	39924

Energy simulation shows that ground source heat pump is the most effective heat source with lowest primary energy demand. When district heat is consumed, E-value also meets the requirements although the amount of delivered energy is higher. Electricity, as the heating source, is the worst solution: E-value is not satisfactory, so buildings improvements are necessary to compensate high energy consumption, and primary energy is the greatest compared to other options.

10 ENERGY COSTS AND GHGE CALCULATIONS

The source of energy prices is Statistics Finland. /14./ District heating prices refer to average price EUR/MWh for a standard detached houses (600 m3, 18 MWh/a) in 2015. The charges include energy charges and fixed charges (demand charges) with taxes (value added tax, excise duties on fuels).

The electricity prices are tax-inclusive averages weighted by the sales volumes of liable electricity retailers. Statistics Finland provides with average prices per month (c/kWh); however, for convenience of calculations annual average price of electricity is used.

The electricity prices differ by consumer: in 2015 for detached house with direct electric heating (18,000 kWh/a) electricity cost 12.68 c/kWh, and for detached house, partly accumulating electric heating (20,000 kWh/a), electricity price is 11.89 c/kWh. Table 8 represents energy costs calculations per year.

TABLE 8. Annual energy costs (2015 prices)

Heating system	Delivered energy, kWh	Energy price, EUR/kWh	Energy cost per year, EUR
District heating	24705	0,08417	2079
GSHP	11148	0,1189	1325
Electric heating	23485	0,1268	2978

Comparison of annual costs shows that GSHP seems to be the cheapest alternative, while electricity is about 2.2 times more expensive than GSHP. District heating is comparatively good solution, but still costs are approximately 1.6 higher than GSHP.

Table 9 presents approximate green house gas emissions of a single-family house. It is assumed that district heat is produced in CHP, and district heating annual efficiency $\eta=0.94$. For GSHP and electric heating efficiencies are COP=3.1 and COP=1 respectively.

Emission factor for electric heating is 400 gCO_2/kWh /23/, and average emission factor for DH (combined heat and power generation) is 183 gCO_2/kWh./24./ The life cycle CO_2 emissions from offshore wind energy turbine is very low, it is about 12 gCO_2eq/kWh of generated energy./25./

TABLE 9. CO_2 emissions calculations

Heating system	Delivered energy, MWh	CO_2 emissions, kg CO_2/MWh	CO_2 emissions, kg CO_2	Offshore wind, kg CO_2	CO_2 reduction, kg CO_2
District heating	24,705	183	4810	-	-
GSHP	11,148	400	1438	134	1305
Electric heating	23,485	400	9394	282	9112

According to the estimated values, GSHP is the most environmentally safe source of heat. District heat is also a good option, whereas electric heating is unacceptable in terms of CO_2 emissions. Offshore wind farm generates the necessary amount of energy producing very little quantity of carbon dioxide over the whole life cycle of a turbine. Theoretically, if instead of conventional electricity, energy generated by offshore wind turbines will be used, vast amount of carbon dioxide can be reduced.

11 DISCUSSION AND CONCLUSION

The main aim of the thesis was to find out how offshore wind energy can be used in single-family houses in Finland. This study was designed to analyze offshore wind feasibility in Finland exposing all the positive and negative aspects. To answer research questions different literature sources were examined; finally, social, economical, and environmental benefits were discovered that proved sustainability and great potential of energy generated offshore.

The analysis of energy consumption of single-family houses showed that offshore wind energy is sufficient source of energy and can be used to cover space heating needs in Pori, Finland. Therefore, greater offshore wind energy development and deployment can be expected in the near future.

Simulation part showed that the most clean and cost-efficient heat source is GSHP. So growing application of GSHP makes sense, since it is the best solution for newly-build detached single-family houses: it is environmentally friendly, energy-efficient, and cost-saving heat source.

District heating can be potentially clean. An ecological aspect relies on the fuel of district heat production. As the cogeneration is highly spread in Finland, district heat is assumed clean and safe energy source. Obviously, district heat is the perfect option in places where DH distribution network exists: district heat is cheap, reliable, and safe option. The problem is that very small percentage of detached housed are connected to DH network.

Electric heating is the worst choice due to all the examined factors: energy demand is too great, costs are higher, and CO_2emissions are impressive. However, there are still many remote households that rely on electric heating.

In such a case, offshore wind energy may come in handy. Unfortunately, there was no possibility to estimate generated electricity output of the wind farm, but relying on the owner’s investigation Tahkoluoto offshore wind farm capacity is sufficient to cover a significant part of energy demand and provide households near Pori with green and inexhaustible energy.

In this thesis, approximate calculations of diminishing CO_2 emissions were made, but even such rough results stated that offshore wind energy makes measurable contribution to GHGE reduction.

As for possible environmental drawbacks, it is still complicated to make conclusions about. Available data is too contradictive and unclear, so more studies must be carried out. At present moment, disadvantages are not so drastic, so they are assumed to be neglected.

Although offshore wind energy is more expensive than other sources of energy, it is beneficial renewable energy source. Most of the economical advantages have a long termed-effect that may not be evident at the start of the project. However, the advantages are worth of efforts and costs, because they include not only environmental issues, but also touch upon social, economical, and geopolitical problems. Moreover, offshore wind energy has a potential to become cost-competitive in near future.

Finally, greater offshore wind energy application is to be expected worldwide. In Finland, offshore wind energy generation experiment has only started with construction of Tahkoluoto offshore wind farm that seems to be promising in many ways. It is expected to not only reduce harmful impact of GHGE, but also create a sustainable source of clean electricity in Pori region that would satisfy the heat energy demands and keep electricity prices from rapid growth.

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APPENDIX 1.

Floor layout