Energy Supply Models for Transition to Renewable and Locally Produced Energy: a Study of the Possibilities for the Municipality of Tjörn to Make an Energy Transition

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ENERGY SUPPLY MODELS FOR TRANSITION TO RENEWABLE AND LOCALLY PRODUCED ENERGY

- A STUDY OF THE POSSIBILITIES FOR THE MUNICIPALITY OF TJÖRN TO MAKE AN ENERGY TRANSITION -

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I. Abstract

An energy system that relies on fossil fuel is not sustainable. Emissions, such as carbon dioxide, nitric oxide and corpuscles, affect the climate and pollute the air. Furthermore, the supply of oil, coal and natural gas is located a few places worldwide, which can give provide incentive to geopolitical conflicts for access to these areas. This is not a local issue for Tjörn, nor even a national issue for Sweden, but a global issue that in the end is about the survival of the earth as we know it. Sweden has come far with their transition from fossil fuels in terms of production of electricity and heating. On the other hand, the production system is centralized and nuclear power and hydropower are the main resources for generating electricity. The municipality of Tjörn is a member of Cradle to Cradle Islands, which is an EU-cooperation with focus on e.g. a decentralized energy system. Cradle to Cradle Islands argue that islands have big potential for locally produced, renewable energy since they are surrounded by water, often have plenty of sun hours and the winds are constantly blowing. Samsö is an island in Denmark, also partners in Cradle to Cradle Islands. In less than ten years Samsö succeeded in replacing their energy supply from mainly fossil, imported raw materials to providing themselves with 100 percent renewable electricity and 75 percent renewable heating. With this in mind, this report will study if Tjörn can do the same transposition, based on their own capacity. Natural resources and conditions were analyzed on the island and used to calculate the realistic energy supply from each of the energy sources; geothermal heating, bio fuel, sun energy, wind power and wave power. The knowledge of the total amount of potential renewable energy was later used to make energy production models in four different scenarios.

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1 Introduction

1.1 Background – Islands with possibilities

Worldwide, the need of sustainable development is highlighted. This means to meet our daily needs without compromising them for future generations (Brundtland Report, 1987). A global solution can be achieved by starting the work locally and regionally, to adjust the unsustainable, fossil based energy system we have today towards a sustainable, fossil free and decentralized energy system.

Wallner et al, (1994) argues that the key for developing a sustainable region is to change the intensity and speed of use of external material. The need for materials in a region shall not exceed the local supply. (Wallner et al, 1994).

Islands often have great potential for renewable energy sources, such as solar power, wind power, wave power and biomass. However, difficulties in the islands can be public opposition against wind power for making the landscape less attractive. Expert advice combined with local participation can lead to a sense of local ownership of the energy system and consequently change the attitude towards renewable energy. (Stuart, 2006)

By starting the work locally you may reach an energy transition globally, since the use of resources has very much become an issue that affects us worldwide.

Tjörn; an island with possibilities for renewable energy. Photo by: Ida Ström

1.2 Problems with the current use of resources

The economic system and energy system we use today is dependent on fossil fuel. This creates several issues, such as climate change, pollution and increased sensitivity to geopolitical conflicts. Moreover, fossil fuel is a non renewable resource that will be depleted.

These issues are more or less complex and a transition towards other energy resources and a more energy efficient society is a necessity to reduce these difficulties.

1.2.1 Climate change

Climate change may be the biggest environmental challenge humanity has ever faced. The climate-changing emissions are mainly released from combustion of fossil fuel (Wuebbles et al, 2001). IPCC concludes in their report from year 2007 that global average temperature is expected to increase between 1,1 and 6,4 degrees Celsius over the next 100 years. A temperature increase may lead to sea level rise and changing precipitation patterns and wind systems (IPCC, 2007). Consequences might be great human injuries, material damage and impacts on natural ecosystems and socio-economic conditions (Wuebbles et al, 2001). There is also a risk for an increasing number of epidemics that could affect humanity (Wuebbles et al, 2001).

1.2.2 Air pollution

Burning fossil fuels produces emissions such as nitrogen oxide, sulphur oxide and particles (Granovskii et al, 2007. These are pollutants that affect human health, nature, buildings and infrastructure.

1.2.3 Geopolitical conflicts

Europe is forecasted to have an import quota of over 80 percent of their consumption of oil and gas in year 2030. Though, about 60 percent of the world's remaining oil reserves are located in areas around the Persian Gulf. Therefore, it is crucial for the rest of world which have a fossil-fuel dependent economy that the remaining oil and gas resources from the Persian Gulf area are available on the world market. In addition, various international actors have different interests in the area. Furthermore, the capacity in OPEC's production has decreased lately, which has led to rising oil prices which can escalate conflicts. (Västra Götalandsregionen, 2007).

1.3 Energy objectives

Difficulties with fossil fuel have led to extensive legislation and objectives at all levels of society. Below are compiled the most important decisions and objectives at European, national and regional level. Decisions at all levels affect the assumption for the local planning process for renewable energy.

1.3.1 Environmental targets

Energy transition in Sweden can contribute to an ecologic and economic development of the society by focusing on the 16 targets, decided by the Swedish parliament. When using and producing energy it is particularly important to consider these environmental targets: limited climatic influence, fresh air, only natural acidity and a good built environment. The environmental targets read.

Limited climatic influence – Combustion of fossil fuels, used mainly for electricity and heat production and transport, accounts for the largest amount of greenhouse gas emissions, both in Sweden and internationally. (Swedish EPA, 2010)

Fresh air – Soot particles, sulphur dioxide and other pollutants are released into the air when combusted. (Swedish EPA, 2010)

Only natural acidification – Fossil energy plants is one of the sectors which acidify the most since for example sulphur dioxide and nitrogen oxides formed during combustion are acidifying. (Swedish EPA, 2010)

A good built environment – The buildings represent about 40 percent of the total use of energy in Sweden. (Swedish EPA, 2010)

1.3.2 Local targets for Tjörn

The local level is important to make a transition of energy more sustainable. Local business has great potential to influence and act as role models when it comes to reducing their carbon footprint. According to Tjörn's climate plan, energy should be used effectively with little impact on climate, environment and health, and greenhouse gases and pollutants will be reduced (Tjörn's Municipality, 2008)

Local targets for the energy system on Tjörn are:

- Energy use in public buildings will be reduced by 20 percent by year 2012 compared with year 2000.
- The total amount of carbon dioxide emissions in the municipality will decrease by 40 percent by year 2021 compared with year 2000.
- Oil use for heating public buildings and business premises will be reduced by 75 percent between year 2005 and 2015. In 2018, no heating of public buildings will be with oil.
- In 2010, 20 percent of the energy consumed on Tjörn will be produced from renewable energy sources. In 2013, the share will be up to 30 percent.

(Tjörn's Municipality, 2008)

cradle to cradle islands

1.4 Cradle to Cradle Islands

C2CI is an EU project concerning sustainable development, aimed on a local and regional level to make transition from the current centralized, unsustainable energy systems towards a decentralized, sustainable energy system. Focus is on innovative solutions concerning energy, water and material (Cradle to Cradle Islands, 2010). Both IIIEE and the municipality of Tjörn have been involved in the project since it began in 2009. Tjörn began their involvement in C2CI in small scale, but during the mission it became clear that increased commitment would benefit the municipality (Palm, 2010) In 2010 it was decided that Tjörn's municipality will increase their participation in C2CI to have the opportunity to investigate and study more and significant issues within the project areas (Tjörn's Municipality, 2010a)

Current environmental thoughts encourage us to reduce, recycle and reuse. However, C2CI means that this only leads to a continuation of the traditional society with lots of waste as result. The concept of C2CI is that instead of doing bad things less bad, you should do the right thing from the beginning. Within the area energy, C2CI includes investigation of the role for renewable energy sources, such as solar, wind and wave power. In addition, they tie energy savings to modernizing buildings and use of renewable energy. (Cradle to Cradle Islands, 2010)

1.4.1 Energy transition in Samsö

Another island that participates in C2CI is the Danish island Samsö. In order to reduce its need of fossil fuels and dependence on other producers, Samsö chose to decentralize the energy supply and deliver their own energy (Saastamoinen, 2009).

When the transition started, Samsö did not generate any energy of their own. All fossil fuel was transported to the island by tankers and electricity came through interconnection to the grid on the mainland (Saastamoinen, 2009). Today, ten offshore and eleven onshore wind turbines are installed (Saastamoinen, 2009). Together, the generated electricity surplus the demand for the entire island (Malmborg, 2008). Local agriculture is the base for the production of biomass, mainly straw and wood shavings (Saastamoinen, 2009). Heat from biomass along with 2500 square meters of solar collectors and wind power, delivered 70-75 percent of the entire heat demand on the island during 2008 (Hermansen, 2011).

Excess electricity generated by wind power is exported via the grid to the mainland. This compensates for the equivalent amount of energy that are still fossil on the island, mainly in the transport sector but also some heating (Malmborg, 2008). So therefore, although Samsö is not 100 percent fossil free, they declare themselves to be climate neutral thanks to the power compensation to the mainland.

In less than ten years, Samsö managed to reach their high set goals to become self-sufficient in renewable energy. Hard work to engage all the islanders were required but gave results at last. (Saastamoinen, 2009)

Wind turbines on Samsö. Photo by: Ida Ström

1.5 Research problem and research question

1.5.1 Overall purpose

The inspiration for an energy transition on Tjörn is Samsö, which also is a C2CI-island. Tjörn shares many of the conditions Samsö also had before they made the transition towards renewable energy. Tjörn is dependent on external resources, not just in energy point of view, but also in terms of water and materials (Tjörn's Municipality, 2008). Both islands attract many tourists during summer, causing an uneven need for resources during the year.

The project concept is to design decentralized energy models for Tjörn, with focus on renewable energy sources. The municipality will be able generate energy without fossil fuels and minimizing the importation of external energy.

1.5.2 Research question

The goal fot this thesis is designing various energy supply models for Tjörn, where the desirable outcome is that 100 percent of the energy in the model is generated from renewable resources. Resources for energy generation should, if possible, be produced on the island. The main question is therefore:

How can different energy supply models with renewable energy look for Tjörn?

1.5.3 Limitations

The geographic limitation is made to the municipality of Tjörn, which is an island in western Sweden (*see Figure 1*). Tjörn was chosen because they are involved in C2CI and has a vision to to work with sustainable development. It facilitates to work with islands as they have distinct boundaries and acts as isolated laboratories.

Figure 1. The municipality of Tjörn, located on the Swedish west coast (Reference: Eniro.se, 2011)

This thesis only examines if Tjörn have the potential to make a energy transition and whether resources are sufficient to generate local, renewable energy. Economical, logistical and social conditions are not included.

It is important to stress that this thesis does not deal with energy in the transport sector, but only the energy consumed for heating and electricity on the island. The importance of reducing energy consumption and energy efficiency potentials will be mentioned, but the focus will not be to address a solution for it in this thesis.

No consideration is given to variation in energy consumption during the year. Statistics is taken from the Swedish Bureau of Statistics (SCB) and shows the average during a year. The population during summer increases drastically when all the tourists arrive. Further, the need for heating varies during the year. In addition, energy generation from different sources varies during the year. However, a constant annual generation has been adopted.

Heat and electricity has been treated separately in this paper, despite the fact that in Sweden, electricity still is one of the most common types for heating. Many of the properties on Tjörn use electricity as heat but the amount called “heat” in the paper does not include electric heating, only fuel. In the energy models, it is calculated that solar collectors reduces the amount of direct electric heating by heating tap warm water. Since solar collectors, in this paper, do not replace a fuel, such as oil, it is not located in the “Heat”-section in tables and figures, but in the “Electricity”-section as it reduces the direct electric heating.

The energy sources selected for this thesis are the ones that the Swedish Energy Agency recommends as promising, renewable energy sources; biomass, solar, wind and wave power. In addition, geothermal heating has been added because of the good potential on Tjörn. More renewable technologies exist, but are uncertain and too undeveloped to be included in this thesis.

2 Tjörn

2.1 Short facts about the municipality

Tjörn is an island in western Sweden, located about an hour's journey from Gothenburg. The island is the sixth largest island in Sweden with an area of 16 square kilometers (Tjörn's Municipality, 2010b). In 2008 Tjörn had 15 000 inhabitants and during the summer months the population is tripled (Tjörn's Municipality, 2010b). Seasonal variations in the number of residents on the island, combined with the ambition Tjörn have to increase its population up to 25 000 inhabitants in 2030 (Palm, 2010), means that the energy supply need a flexibility and robustness that can handle these conditions. Realistically, however, is that the population will increase significantly slower. During the last decade the population has increased about 1,5 percent (Tjörn's Municipality, 2010b). New houses are built in order to meet a population growth. Today the buildings are scattered, which makes it difficult for planning infrastructure, such as sewage pipes and public transport, but also for energy planning (Palm, 2010).

The Tjörn bridge. Photo by: Ida Ström

2.1.1 Layout plan for Tjörn's municipality

The current layout plan for Tjörn's municipality is from 2003 and another layout plan is currently under preparation. In the current plan, there is a restrictive approach to wind power because of its, according to politicians on Tjörn, impact on the landscape as well as the costs. Four different areas and a spare area is marked as suitable for wind power (*see Figure 2*), no area is marked offshore. Instead the plan refers to the importance of examining the possibilities of using local energy sources, particularly solar, geothermal and water power. (Tjörn's Municipality, 2003)

In the concept document for the new layout plan, suitable areas for wind power will be marked, as well as sites for wave power. Two areas are assessed as appropriate for wave power. These areas are marked as non-appropriate fishing areas and are located outside the archipelago. The new layout plan is expected to be admitted in 2011 or 2012. (Tjörn's Municipality, 2010c)

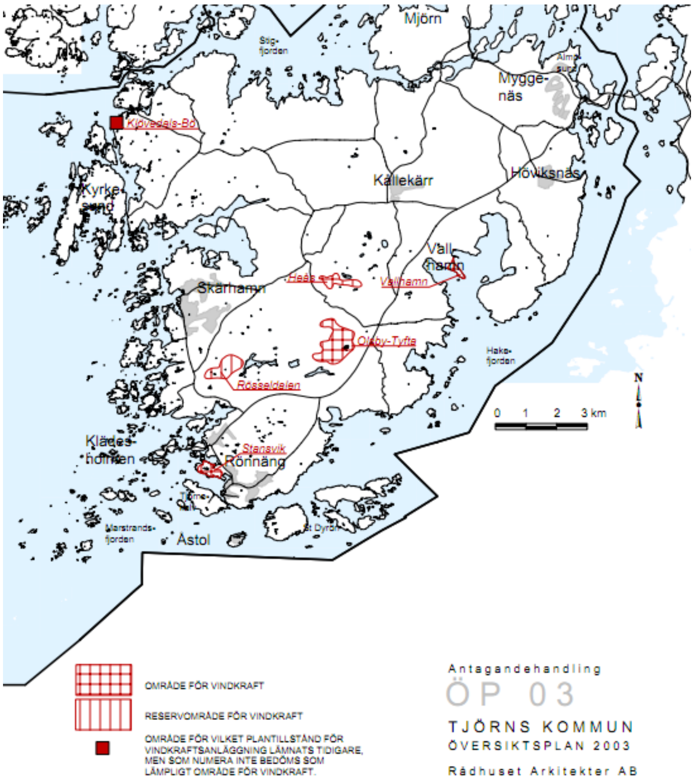

Figure 2. Layout plan 03 for Tjörn's municipality.

2.2 Energy situation in the municipality of Tjörn

2.2.1 Energy supply to the municipality

In 2008, the gross supply of energy to Tjörn's municipality was approximately 356 000 MWh, of which 194 000 MWh was in form of fuel, such as biofuels, oil, gasoline, LPG, wood etc. 153 000 MWh of the fuel was used in the transport sector and are not included in this thesis. Other fuel is considered to go into heating the houses and hot water, consequently 41 000 MWh. 162 000 MWh of the energy was used as electricity. (SCB, 2010)

Fuel consumption on Tjörn is decreasing due to better insulation and more energy efficient buildings. Furthermore, more people are switching from oil-fired boilers to heat pumps (Grönlund, 2010). Electricity consumption on Tjörn is relatively high since many people use heat pumps, but mainly because many houses heat with electric heating (Sandberg et al, 2003).

2.2.2 Use of fuel

The transport sector accounted for the largest use of fuel in 2008, but this is not included in this paper. Second largest user of fuels is households, which accounted for 22 000 MWh per year (*see Figure 3*). The primary fuel source in 2008 on Tjörn was wood, closely followed by oil (*see Figure 4*). (SCB, 2010)

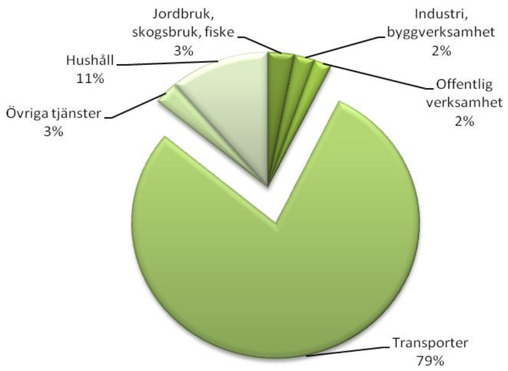

Figure 3. Use of fuel in different sectors in 2008, %.

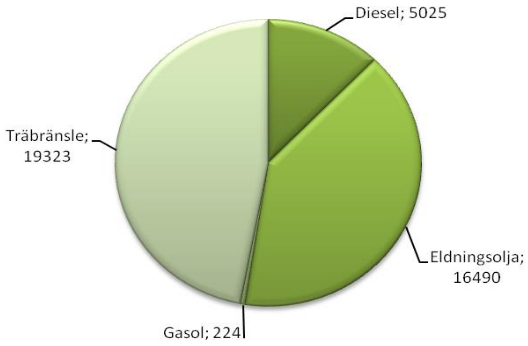

Figure 4. End use of various fuels among all sectors in 2008, excluding transport, MWh. If diesel is used for heating is unclear, but will be assessed in the paper as if it does.

In 2008, 97 000 MWh of electricity was consumed by the households (*see Figure 5*). Second most electricity was consumed by the service sector, about 24 000 MWh. Agriculture, forestry, fisheries, industry, construction, public sector and transport consumed just under a fifth each of the total electricity consumption. (SCB, 2010)

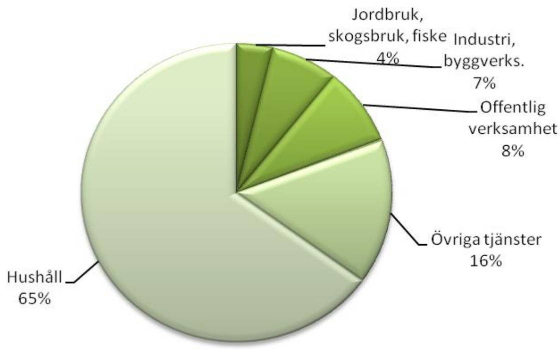

Figure 5. Use of electricity in different sectors in 2008, %.

2.2.3 Locally produced energy and potential in the municipality

Very little energy is produced locally, although 80 percent of the oil in public buildings has been removed in the last four years (Grönlund, 2010). The oil has been replaced with heat pumps and pellet (Grönlund, 2010). The pellet is, however, imported from other municipalities (Grönlund, 2010) instead of taking advantage of waste products from local agriculture and forestry. Today, crotch, chips and other waste products is either remained on the ground or transported to the heating plant in Kungälv (Tjörn´s LRF, 2010). According to farmers on Tjörn, arable land on Tjörn generates more biomass than required to feed the livestock (Tjörn´s LRF, 2010).

Tjörn has two big fishing industries, whose waste products are transported to Trollhättan to be digested into biogas (Dahllöf, 2010). It is a transport that is both long and expansive (Dahllöf, 2010). Moreover, Tjörn´s municipality has four sewage plants, where the one in Skärhamn through a digester annually produces about 30 000 cubic meters of methane gas from 230 tonnes of sludge (Tjörn's municipality, 2008). The gas is used for heating and operation of the digester (Tjörn's municipality, 2008).

Tjörn has five privately owned wind turbines (Tjörn's municipality, 2008) with a total installed capacity of 1750 kWh (Swedish Energy Agency, 2010a). Estimated from turbines in the same size (four 225 kW plants and one 850 kW plan) these plants generate a total amount of 4000 MWh per year. According to Grönlund (2010) there are plans to install four new plants with an installed capacity of at least 2 MW each (Triventus Consulting AB, 2009). Each plant is calculated to generate 7000 MWh annually (Triventus Consulting AB, 2009). However, this calculation is very optimistic. Other references find an average production of 6000 MWh annually more likely.

3 Energy potential on Tjörn

Tjörn's municipality has the potential for generating renewable energy. Following are the estimated, realistic potentials for all types of energy sources included in this thesis. The renewable energy sources described are those the Swedish Energy Agency advocates, and also geothermal heating, which has great potential on Tjörn.

3.1 Geothermal heating

The technology behind geothermal heating is that a borehole flows through with groundwater and a pipe is inserted into that hole. A solution circulates in the pipe between the borehole and a heat pump. The relatively low temperature of the solution is raised using the heat pump compressor. (Swedish Energy Agency, 2010b)

3.1.1 Potential

A heat pump in Skärhamn on Tjörn can deliver about 160 kWh of heat per meter borehole annually (not electricity included) (Sandberg, 2011). Roughly calculated, a 150 meter deep borehole with this energy output gives about 24 000 kWh heat per year and additionally 11 000 kWh electric heat from the compressor (*see Table 1*). That is quite enough to heat a house (16 000 kWh for heating and 5000 kWh for hot water according to the Swedish Energy Agency, 2010c).

Geothermal heating is solar energy stored in the ground and is nothing we can affect. Therefore, the energy output per meter will probably not be better than it is today (Bertenstam, 2011). However, there is research going on in order to improve the heat factor and consequently use less electricity for the compressors (*see Table 1*).

Table 1. Energy potential from geothermal heating with today's and tomorrow's technology.

	Potential today (per borehole and year)	**Potential tomorrow (per borehole and year)**
Geothermal heating	24 000 kWh + 11 000 kWh electricity	24 000 kWh + 10 000 kWh electricity

3.1.2 Replacing

Geothermal heating could replace oil or electric heating. Though, one prerequisite is that you have a water heating system.

3.1.3 Pros and cons

The temperature in the bedrock is essentially the same the year round. The use of geothermal heating is a safe and environmentally friendly heating technology and the heating source is free. (SVEP)

One drawback of geothermal heating is the high installation costs. However, while the heat pump lasts in 15-20 years, the borehole can be operated for up to 60 years (Bertenstam, 2011). Another drawback is that a heat pump requires electricity.

3.2 Bio energy

Sweden has plenty of forest and as a result of it; mainly bio fuel is used (Swedish Energy Agency, 2010d). Some waste also serves as materials for bio fuel (Swebio, 2010).

Combined power and heat production is very effective, both at generating electricity and utilizing heat. A turbine generates electricity while the heat in the cooling water is distributed in the district heating system. According to Murphy et al. (2004) about a third of the energy becomes electricity while the remaining two thirds of energy become heat.

3.2.1 Potential

According to Tjörn's LRF (2010), at least 18 000 tonnes of residues from agriculture and forestry occurs annually on the island. Calculations show that this, together with material from ditch cleaning would thus be able to generate 12 000 MWh of energy per year through combustion (*see Table 2*). However, it is difficult to optimize bio fuel production further, since the land on Tjörn is very hard to farm.

Including all organic, digestible waste on Tjörn, such as agriculture and forestry residues, food waste and fish waste, about 3 600 000 cubic meters of biogas would be possible to produce. This gascould generate approximately 23 000 MWh of energy (*see Table 2*). If the population increases to 25 000 inhabitants the total amount of digestible waste will rise to over 15 000 tonnes, which instead could generate about 25 000 MWh of energy.

Currently, about 50 percent of the residents on Tjörn are connected to the public sewage plant (Egriell, 2009). Gas production from sewage digestion would, according to Egriell's calculations, produce approximately 600 MWh of energy each year (*see table 5*). If instead 20 000 people would be connected to the sewage plant, 1900 MWh of energy would be possible to utilize annually.

Table 2. Energy potential from bio fuel with two different population scenarios.

	Potential 15 500 people (MWh per year)	**Potential 25 000 people (MWh per year)**
Bio fuel		
Combustion	12 000	12 000
Gas	23000 + 600	25 000 + 1900

3.2.2 Replacing

Heat from bio fuel can replace oil or electric heating. Though, one prerequisite is that you have a water heating system. Electricity from bio fuel can replace imported electricity.

3.2.3 Pros and cons

Handling the local produced bio fuel for energy production can reduce import of bio fuel and generate work opportunities. In addition, cutting organic material can open up the landscape.

To avoid a depletion of the soil, ashes and sludge should be returned to the soil. Co-digestion with sewage sludge can make this process difficult since it may contain medical residues or pathogens.

3.3 Solar energy

In just ten minutes the sun radiates as much energy into the Earth's surface that the whole humanity consumes in a year (Ståhl et al, 2009). In Sweden we use the sun´s rays to both heat (solar collectors) and electricity (photovoltaic).

In Sweden there are several major facilities for the production of solar energy. Some nearby examples for Tjörn is Kungälv, where a facility of 10 000 square meters of solar collectors deliver 4000 MWh of heat annually for district heating. The sport stadium Ullevi in Gothenburg has 750 square meters of solar cells placed on its roof, which generates approximately 65 000 kWh of electricity per year. (Ståhl et al, 2009)

A house with solar collectors on Åstol, Tjörn. Photo by: Ida Ström

3.3.1 Potential

There is only potential for solar energy a limited part of the year. Solar radiation is highest during the summer, and both solar collectors and photovoltaic generate energy primarily during summer months. Since the need to heat houses during summer often is low, it is calculated in this thesis that only water is heated with solar collectors. This means a saving up to 2500 kWh per year and house. About 40 percent of the small households in Sweden are heated by electric heating (Mahapatra et al, 2008). In the calculations it is therefore expected that 40 percent of all full-time residents and all summer residents on Tjörn heat their water with electricity and have the opportunity to install solar collectors. This would result in a reduction of electric consumption with about 14 000 MWh annually (*see Table 3*). Because of seasonal changes it is not possible to improve the efficiency of solar collectors. Note that solar collectors do not generate electricity but is expected to save electricity.

On Tjörn there are about 100 000 square meters of public roof (Tjörn's Municipality, 2010d). A reasonable estimate is that at least 15 000 square meters of the roof is in favorable position for solar cells. The facility at Ullevi in Gothenburg generates approximately 87 kWh per square meter and year. If the facility on Tjörn generates the same amount of energy per square meter, it would generate about 1000 kWh annually. If there will be a technical improvement of solar cells and they in the future generates 150 kWh per square meter and year (Ståhl et al, 2009), the same number of square meters (15 000 square meters) would provide approximately 2000 MWh per year (*see Table 3*).

Table 3. Energy potential from solar energy with today's and tomorrow's technology.

	Potential today (MWh per year)	Potential tomorrow (MWh per year)
Solar energy		
Solar collectors	14 000 (electricity saved)	14 000 (electricity saved)
Solar cells	1000	2000

3.3.2 Replacing

Solar collectors do not generate electricity, but will save electricity from being used if you previously heated warm water with electricity. Solar cells would replace imported electricity.

3.3.3 Pros and cons

Despite the potential of solar energy it is barley used in Sweden, due to the reason that the availability of sunlight is at its lowest during the winter months when the demand for heating and electricity is at its peak (Swedish Solar Energy). Furthermore it is not possible to turn on the solar heating system if it is not enough sunlight or heat stored in the system (Swedish Solar Energy).

Because of high installation costs for solar electricity, it is only competitive with solar cells in areas where it is too expensive or complicated to draw electricity from the public grid. Solar collectors on the other hand, are a relatively inexpensive technology that can save electricity. However, once the installation is done for each energy source, the fuel – solar radiation– is free.

3.4 Wind power

Sweden has the benefit that the wind strength increases during the winter months, when the demand for electricity is at its peak (Swedish Energy Agency, 2010e). The wind power company O2 ranks all municipalities that are suitable for wind power. In 2010, Tjörn ended up in place 82 out of 290 municipalities (O2, 2010).

Wind power in Rönnäng, Tjörn. Photo by: Ida Ström

Since the mid-80s, the wind power turbines have doubled in size about every four year. Today, the largest Swedish commercial plants have a 108 meter high tower and a rotor diameter of 100 meters, 3 MW installed capacity and produces approximately 8000 MWh of electricity per year (Swedish Wind Power Association, 2010). Wind power plants with an installed capacity up to 6 MW are being installed in Sweden (Swedish Energy, 2011).

3.4.1 Potential

A modern wind turbine onshore, in good wind conditions and with an installed capacity of 1 MW, generates about 2000 MWh annually (Swedish Wind Power Association, 2010), while a 2 MW plant onshore generates approximately 6000 MWh (Swedish Wind Energy, 2010). Larger plants can take advantage of the wind more efficiently and thus get a larger amount of energy.

The future potential for wind power lies in larger plants, but on Tjörn permission will not be given to plants larger than 2 MW. Furthermore, the municipality has a scattered settlement and thereby causing few areas suitable for wind power. Only four areas are highlighted in the layout plan. The area in Rönnäng has already four small wind turbines and is therefore not suitable for more plants. Two wind turbines can be erected in Heås as well as two plants in Vallhamn. The largest area marked out for wind power is Olsby-Tyfta and is expected to be able to incorporate four wind turbines. All in total, eight new wind turbines with an installed capacity of 2 MW each would be possible to erect, based on Layout plan 03, earlier wind energy plans (Bendix 2007) and the Wallhamn Company's ongoing licensing (Triventus Consulting AB, 2009). If each plant generates 6000 MWh, they would collectively generate 48 000 MWh of electricity annually. Would the five existing wind turbines be replaced with five new and bigger plants, another 30 000 MWh of electricity could be generated, minus the 4000 MWh of electricity as they generated earlier (*see Table 4*).

No area is selected in the layout plan for offshore wind power. Though, there might be possibilities to place wind power in the same areas where wave power is highlighted in the layout plan. Offshore, it would be possible to install turbines with a capacity of 3 MW, which according to Favonius generate up to 10 000 MWh electricity each year.

Table 4. Energy potential from wind power excluding and including replacement of old wind power plants.

	Potential excluding replacing old wind power plants (MWh per year)	**Potential including replacing old wind powerplants (MWh per year)**
Wind power	48 000 + 4000	48 000 + 30 000

3.4.2 Replacing

Wind power generates electricity that replaces imported electricity.

3.4.3 Pros and cons

Wind power is a clean energy source and the availability of wind is endless. However, noise and shadows from the rotating rotor can be disturbing (Swedish Wind Power Association, 2010). Also, onshore wind power is competing for space and against the debate that wind power disfigures the landscape (Esteban et al, 2010).

3.5 Wave power

Waves can hold lots of energy and wave power are an unexploited source of renewable energy. The kinetic energy of the waves is converted in a wave power plant into electricity. (Vattenfall, 2010)

In Sweden, wave power is only at an experimental stage. One prototype park is located in Lysekil, north of Tjörn.

Tjörn is surrounded by water. Photo by: Ida Ström

3.5.1 Potential

Tjörn is an island and has great access to water. In the upcoming layout plan, two areas are highlighted as suitable for wave energy. If a park in the same size as the one in Lysekil be will built, approximately 100 GWh of electricity could be generated. This is more than half of the electricity consumed in the municipality in 2008 (*see Table 5*)

Table 5. Energy potential from wave power with today's and tomorrow's technology.

	Potential today (MWh)	Potential tomorrow (MWh)
Wave power	-	100 000

3.5.2 Replacing

Wave power generates electricity that replaces imported electricity.

3.5.3 Pros and cons

An advantage of wave power is that it is neither visible nor hearable, in the same way as wind turbines. Neither does it compete for land onshore. However, it can compete with fishing grounds offshore.

Today it is still too expensive for wave power to become economically viable. Even in large scale installations, the cost will be several "kronor" per kWh. (Sidenmark, 2010)

4 Energy supply models for the municipality of Tjörn

4.1 Scenarios

To be able to build the energy supply models, an energy forecast scenario developed by the Swedish Energy Agency (2009) was used. Also, another two dimensions was considered; population growth on Tjörn and technological development (*see Figure 5*). The two dimensions reflect the major uncertainties that affect the transition to renewable energy. The goal with creating different scenarios is to show flexibility and robustness of fossil-free technologies.

The horizontal axis shows from a slow population growth to the target Tjörn municipality has set for 2030. The vertical axis shows the technological development. Today's technological development include the effectiveness the renewable energy sources have today, while tomorrow's technological development will be based on the effectiveness each technology is expected to have in 2030. Based on these assumptions four scenarios have been developed and named; Brave, Visionary, Safe and Intense.

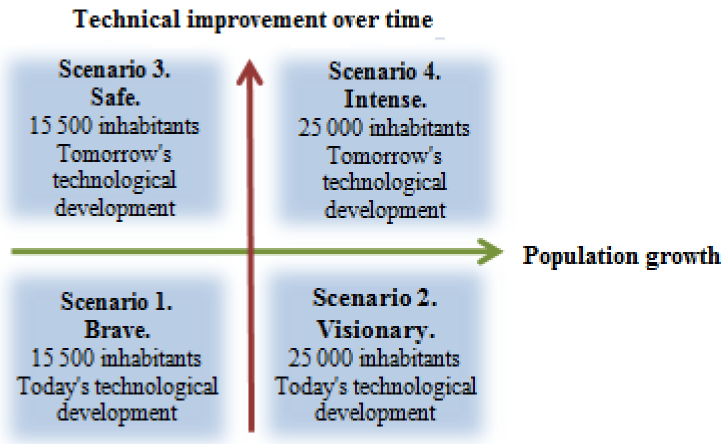

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Figure 5. Four different scenarios of what drives Tjörn's energy demand and energy supply in 2030.

4.1.1 Make a transition today with a slow population growth – Brave

In the scenario, the brave shift happens immediately and the municipality can act as an initiator of a sustainable development. Today's technological potential is available to provide.

Calculated from the Swedish Energy Agency´s future scenario, the fuel demand is estimated to around 40 000 MWh per year for 15 500 inhabitants, while the electricity demand is estimated to approximately 160 000 MWh per year.

4.1.2 Make a transition today with a rapid population growth – Visionary

In the scenario, there is a vision of a population growth and the municipality chooses to make the transition today. This to be a pioneer as a sustainability community. Today's technological potential is available to provide.

Calculated from the Swedish Energy Agency´s future scenario, the fuel demand is estimated to around 55 000 MWh per year for 25 000 inhabitants, while the electricity demand is estimated to approximately 250 000 MWh per year.

4.1.3 Make a transition tomorrow with a slow population growth – Safe

To be sure of the result, the municipality chooses to wait with the transition. They want to learn from other municipalities and allow new technologies to develop and mature. All the techniques are considered to have high efficiency in this scenario.

Energy demand is the same as in scenario Brave.

4.1.4 Make a transition tomorrow with a rapid population growth – Intense

In order to effectively supply all inhabitants with energy, the municipality waits to make a transition. Technologies can reach a higher level of efficiency when the knowledge of them is better. An intense transition starts a few years before 2030.

Energy demand is the same as in scenario Visionary.

4.2 Considerations for creating energy supply models

The scenarios, the realistic potential and the attitude to the various energy technologies are the basis for how the energy sources have been given priority, when developing the energy models. Parameters that have been taken into account when deciding priorities in the paper are:

• The potential for geothermal heating is large in the municipality. However, a borehole is an expensive investment. In addition, the compressor consumes electricity. Geothermal heat= Low priority.

• Many inhabitants use their own bio fuel boiler, with mainly imported pellets. This results in unnecessary transportation and economic leakage, when the potential on the island instead can be utilized. Burning biomass = Medium priority.

• Sewage and waste should be handled locally as biogas production, instead of being transported to neighboring municipalities. Biogas production of local bio fuel = High priority.

• Solar cells are still an expensive technology compared to the traditional ways to generate electricity. To increase acceptance of the technology, the municipality should take the lead and show its potential. Photovoltaic = Medium priority.

• Solar panels have great potential to save electricity for those who currently heat their water with electric heating. Moreover, the technology is cheap. Solar panels = High priority.

• Nature and landscape view often plays a big role when people choose to live on Tjörn. More wind turbines may conflict with the municipality's desire to have a population growth. Since the politicians on Tjörn considers wind turbines to disturb the landscape, in the assessment wind turbines is only placed at the selected locations in the Layout plan. Wind Power = Low priority.

• Wave energy has great potential in the area and does not disturb the landscape in the same way as wind turbines. However, the technology is immature and relatively expensive. Wave Power = Medium priority.

These conditions, in conjunction with energy the demand and energy supply has in this thesis led to the order of priority:

Heat

1. Locally produced bio fuel for burning and biogas
2. Imported bio fuel for burning
3. Geothermal heating

Electricity

1. Solar panels (to save electricity from being used)
2. Biogas
3. Photovoltaic
4. Wave power (if it is developed)
5. Wind power

4.3 Proposals for energy supply models

4.3.1 Make a transition today with a slow population growth – Brave

To make a transition today takes courage. A transition may initially be costly and public acceptance may be weak. However, by investing today the interest for the municipality can increase. chips for fuel in private heating plants. Biomass is calculated to generate 12 000 MWh per year.

Heat

Wood products are currently the dominant fuel on the island (*see Figure 4*). However, mainly imported pellet are used, even though materials are available for Tjörn to manufacture own chips. Biomass on Tjörn is calculated to generate 12 000 MWh per year. According to statistics, approximately 20 000 MWh of wood fuel is annually used on Tjörn (*see Figue 4*). So even if more bio fuel should be produced locally, not more than 12 000 MWh can be generated per year on the island. Therefore the remaining 8000 MWh per year has to be imported to the island. Since biomass is considered an environmentally friendly way of heating, a transition away from biomass is not to be recommended even if Tjörn have to import wood fuel. Food waste and fish waste can generate almost 2300 MWh of energy per year through biogas production. The sewage sludge can approximately give an additional 600 MWh per year. Of all the biogas, approximately 1000 MWh per year can be used as electricity and 2000 MWh per year can be used as heat. The remaining 18 000 MWh of heat used per year on Tjörn can come from geothermal heating. (*See Table 6*)

Table 6. Heating supply in scenario Brave.

	MWh per year
Locally produced chips	12 000
Imported chips	8000
Biogas - heat	2000
Geothermal heating	18 000
Total	40 000

Electricity

Out of the 160 000 MWh assumed to be consumed in year 2030, 4000 MWh can be discounted since they already are generated from local wind turbines. To reduce the electricity demand, solar collectors should be installed to heat hot water. If all houses who can install solar collectors do it, it would reduce electricity consumption by 14 000 MWh per year. The municipality can lead the way and put solar cells on their properties. These could generate around 1000 MWh of electricity annually. Cogeneration from biogas can generate 1000 MWh of electricity per year. New wind turbines on shore can deliver 48 000 MWh annually. If you go further and also change the five existing wind power plants with five new 2 MW turbines, all plants in total would generate 78 000 MWh of electricity per year. If Tjörn should be able to generate as much electricity as is consumed on the island, wind power offshore is needed. Depending on whether you are replacing the old turbines on land or not, seven or ten 3 MW plants offshore are needed. (*See Table 7*)

Table 7. Electricity supply in scenario Brave, excluding and including replacement of old wind power plants.

	MWh per year (excluding replacing old turbines)	MWh per year (including replacing old turbines)
Present wind power	4000	-
New wind power - Onshore	48 000	78 000
New wind power - Offshore	92 000	66 000
Solar cells	1000	1000
Solar collectors	14 000 (in decreased electricity need)	14 000 (in decreased electricity need)
Wave power	-	-
Biomass - Electricity	1000	1000
Total	146 000 (160 000)	146 000 (160 000)

4.3.2 Make a transition today with a rapid population growth – Visionary

You need to be, as mentioned earlier, brave to make a transition today. An investment today, with the vision of a major population growth, requires a lot of courage for a small municipality.

Heat

In this scenario, it is considered that residues from agriculture and forestry are best suited for wood chips. Burning biomass can generate 12 000 MWh of heat. Since 20 000 MWh of heat per year is generated from biomass, 8000 MWh have to be imported to Tjörn. Due to a larger population biogas would produce approximately 6000 MWh of energy per year, from wheras about 4000 MWh can be used for heating. The remaining 31 000 MWH per year for heating can be achieved with geothermal heating. (*See Table 8*)

Table 8. Heating supply in scenario Visionary.

	MWh per year
Locally produced chips	12 000
Imported chips	8000
Biogas - heat	4000
Geothermal heating	31 000
Total	55 000

Electricity

Just as in scenario Brave, solar collectors can reduce the electricity consumption by 14 000 MWh. However, when the number of geothermal heating drills must increase as much as to utilize 31 000 MWh, it will increases the electricity consumption more than the Swedish Energy Agency estimates in its long-term forecast (2009). Therefore, an estimated increase of 5000 MWh electricity is added per year. Solar cells can provide 1000 MWh of electricity annually, while biogas can provide approximately 2000 MWh per year. Onshore wind power can generate 48 000 MWh of electricity per year and an additional 4000 MWh per year if the old mills are not exchanged. If replacing the old mills with new 2 MW wind turbines, onshore wind power would generate 78 000 MWh electricity annually. To meet the electricity demand in the scenario, 19 offshore wind turbines with an installed capacity of 3 MW are needed if the old mills are not replaced, while 16 wind turbines are needed if the old wind mills are replaced. (*See Table 9*)

Table 9. Electricity supply in scenario Visionary, excluding and including replacement of old wind power plants.

	MWh per year (excluding replacing old turbines)	MWh per year (including replacing old turbines)
Present wind power	4000	-
New wind power - Onshore	48 000	78 000
New wind power - Offshore	186 000	160 000
Solar cells	1000	1000
Solar collectors	14 000 (in decreased electricity need)	14 000 (in decreased electricity need)
Wave power	-	-
Biomass - Electricity	2000	2000
Total	241 000 (255 000)	241 000 (255 000)

4.3.3 Make a transition tomorrow with a slow population growth – Safe

If Tjörn wait to make a transition they will have time to see the development of several techniques and can chose those who are both technology and cost effective.

Heat

In scenario Safe all the biological material is used for biogas production instead of, as in previous scenarios, also wood chips. This is for showing two different applications. This means that 20 000 MWh of fuel which is already used on the island need to be imported annually. If all the biological material from agriculture, forestry, fish waste and food waste is used for biogas production, 14 500 tonnes of material would generate approximately 24 000 MWh of energy annually. Further, just over 500 MWh of biogas energy can be generated annually from sewage sludge. Approximately 16 000 MWh per year of all biogas can be utilized as heat from cogeneration of power and heat. To meet the heat demand, 4000 MWh need to come from geothermal heating. (*See Table 10*)

Table 10. Heating supply in scenario Safe.

	MWh per year
Locally produced chips	-
Imported chips	20 000
Biogas - heat	16 000
Geothermal heating	4000
Total	40 000

Electricity

If there is a development in the wave power field, Tjörn has great opportunities in the future to become self-sufficient in electricity. A wave energy park in the same size as the one in Lysekil can generate 100 000 MWh of electricity per year. Installation of solar collectors can reduce electricity consumption by 14 000 MWh annually. Furthermore, the sun can contribute to electricity generation by solar cells. In the future, solar cells on the public facilities can generate approximately 2000 MWh electricity per year. Cogeneration from biogas can generate about 8000 MWh electricity per year. By replacing the existing wind mills, onshore wind power can generate 30 000 MWh annually. Only one additional 2 MW power plant has to be erected on land to meet the electricity demand. (*See Table 11*)

Table 11. Electricity supply in scenario Safe including replacement of old wind power plants.

	MWh per year (excluding replacing old turbines)
Present wind power	-
New wind power - Onshore	36 000
New wind power - Offshore	-
Solar cells	2000
Solar collectors	14 000 (in decreased electricity need)
Wave power	100 000
Biomass - Electricity	8000
Total	146 000 (160 000)

4.3.4 Make a transition tomorrow with a rapid population growth – Intense

Tjörn can wait to make the transition, as in scenario Safe, to see the development for the different techniques. However, if the population increases, Tjörn must work intensively with the transition to reach the goal before 2030.

Heat

The wood fuel that is already burned on the island, shall as in previous scenarios not be replaced, since the installation of heating boilers already have been made. Therefore, 20 000 MWh of wood chips need to be imported annually. Biological waste and sewage sludge on the island can be used to generate almost 27 000 MWh of biogas energy per year. From the biogas, almost 18 000 MWh can be used annually for heating. The remaining 17 000 MWh of heat used per year can be extracted from geothermal heating. (*See Table 12*)

Tabell 12. Heating supply in scenario Intense.

	MWh per year
Locally produced chips	-
Imported chips	20 000
Biogas - heat	18 000
Geothermal heating	17 000
Total	55 000

Electricity

If the population increases as much as the municipality has projected for 2030, the electricity consumption will increase significantly. However, if Tjörn will build a wave energy park in the same size as the one in Lysekil, they could have 100 000 MWh of the electricity demand covered by the park annually. As in all the other scenarios, installation of solar collectors can reduce electricity consumption by 14 000 MWh per year. Solar cells can contribute with 2300 MWh of electricity annually. Electricity production from biogas can generate 9000 MWh per year. If not replacing the five current wind turbines, they will generate 4000 MWh per year. If instead replacing the old turbines with five new and more efficient 2 MW-plants, these new plants would generate approximately 30 000 MWh per year. By further installing eight 2 MW-plants, they could generate an additional 48 000 MWh per year. To cover Tjörn's electricity demand, eight offshore 3 MW wind turbines are needed if the old onshore wind turbines are not replaced. Though, if the old wind turbines onshore are replaced, only five 3 MW wind turbines are required offshore for the municipality should be able to generate as much electricity as they consume. (*See Table 13*)

Table 13. Electricity supply in scenario Intense, excluding and including replacement of old wind power plants.

	MWh per year (excluding replacing old turbines)	**MWh per year (including replacing old turbines)**
Present wind power	4000	-
New wind power - Onshore	48 000	78 000
New wind power - Offshore	73 000	47 000
Solar cells	2000	2000
Solar collectors	14 000 (in decreased electricity need)	14 000 (in decreased electricity need)
Wave power	100 000	100 000
Biomass - Electricity	9000	9000
Total	236 000 (250 000)	236 000 (250 000)

5 Analysis and discussion

This section will summarize the findings and discuss selected techniques. Possible further studies are also discussed.

5.1 Discussion

The various proposed energy models indicate that a transition is technically feasible, both with well-proven, renewable energy sources as well as with the newer technologies if they continue to progress.

The transition towards renewable fuel for heat production has already come a long way on Tjörn; almost half of the fuel comes from wood fuel. However, in order to achieve a decentralized energy system the material should be produced locally, especially when they have the potential on the island. Import of external raw materials increases transports and the economic leakage. Furthermore, own production of biofuel can generate jobs, when if the income is spent locally, can provide a significant additional effect on the local economy. However, some imports of wood fuel are required on Tjörn if they do not replace all existing biomass-fired boilers. Today, 20 000 MWh of the heat comes from fuel wood. That much fuel wood cannot be generated locally and the difference needs to be imported. Imports should, if opportunities exist, come from neighboring municipalities to minimize transportation. If Tjörn instead choose to make biogas of all materials, all wood fuel for heating boilers needs to be imported. My calculations show that you extract more energy from biomass if you use it for producing biogas instead of wood fuel. Therefore, to effectively manage the supply of materials, all biomaterials should be digested into biogas. The potential from biogas is also greater than from burning wood fuel. If it in the future become more financially viable to upgrade biogas into fuel, then Tjörn to some extent can become self-generating of biofuel. For example, some of the municipal vehicles can use the biofuel.

Solar collectors can heat hot water while saving electricity, since it is assumed in the paper, that those who install solar collectors previously heated their water with electricity. Solar collectors are also cheap to install and relatively harmless to the landscape.

Potential for geothermal heating is great on the island. However, installation is expensive. Instead, geothermal holes can be drilled deeper in order to extract more energy per hole. Several houses may share a number of holes, as a form of local heating system. It is debatable whether geothermal heating is a good renewable energy source when their compressors consume electricity. For this reason, geothermal heating ended up last in the priority order for heat in the energy supply models. Heating should as far as possible be met without electricity. High-quality electricity should not be used as low-quality heat.

In Sweden, the largest supply of electricity comes from nuclear power and hydropower. An expansion of both is not compatible with sustainable development. Nuclear power is based on a finite resource and generates hazardous waste while extensions of hydropower disturb habitats and biological life. Leaving the idea of a totally decentralized energy solution may on Tjörn be the most sustainable solution. Instead of increasing the use of geothermal heating and thus the electricity consumption, Tjörn can meet the heating needs by importing additional biomass for burning or biogas production.

To become self-sufficient in electricity, massive investments in renewable energy is required. Local production of electricity on Tjörn is today only 4000 MWh per year, made from wind power. One difficulty for electricity generation on Tjörn is the resistance to wind power. For many people who live on Tjörn, both permanent residents and seasonal residents, the landscape is crucial for the living site. In addition, the buildings are scattered causing only few sites suitable for wind power. For the municipality, a development of wind power, perhaps mainly on land but also offshore, can cause economic losses if tourists and new, potential permanent residents choose other places to visit and live. Tjörn risks the vision of a strong population increase if an increased number of wind turbines are perceived as negative. Placing wind turbines offshore can perhaps reduce the resistance. The plants will be further from the residents, and thereby both seen and heard less. Moreover, it is possible to place larger plants offshore which have higher efficiency. This means that fewer plants can generate the same amount of energy. However, it is more expensive to place wind turbines offshore and therefore, in the energy supply models, offshore wind power is only a supplement to other energy sources.

Wave power can in great extent contribute to make Tjörn municipality self-sufficient in electricity. However, the technology is immature. By waiting for the results for how the development goes on in Lysekil, Tjörn can make more deliberate decisions. An installation of a wave energy farm does not affect the landscape in the same way as wind turbines. Buoys to the wave power station are located offshore and lies just above the surface. Wave power can on Tjörn contribute to a sustainable development without impact on the landscape and tourism.

C2CI has a role to help Tjörn with a transition. Through a partnership in C2CI, Tjörn can learn and find inspiration from other islands with similar conditions, for example Samsö. Tjörn must adjust the transition to their own conditions, but C2CI can help with technical and practical information including mental support from like-minded people who want to achieve a sustainable development.

There is potential on Tjörn to make a transition. The energy supply models show that the supply can meet the demand, but only if the amount of wind turbines is increases. My point of view is that a sustainable development requires not just renewable energy but also a reduced and more efficient energy use. Before Tjörn goes on to examine financial incentives and implementation strategies they need to realize a more efficient energy use. Large potential energy savings are available when many buildings are old and poorly insulated. Moreover, in the initial stage, the residents on Tjörn that heat their buildings with direct electric should switch to, for example, wood fuel. However, it requires a costly conversion to a hydronic heating system but a more efficient energy use can reduce the need for wind power.

5.2 Further studies

- To estimate the real potential for an energy transition, it is important to know what the different energy supply models proposed in the paper will cost, how the ownership might be shared and how long the payback time would be.

- It would be interesting to further study the variations of energy demand and energy supply, to be able to make energy supply models more detailed. For example, how the supply and demand varies from month to month during a year.

- Further study how wave power can be implemented on Tjörn. This, can both put Tjörn on the map as an innovative municipality, and help with research and knowledge in the development of sustainable energy.

Will Tjörn be a sustainable island in 2030? Photo by: Ida Ström

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