A methodology to achieve sustainability within the food & beverage industry

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Abstract

With the world heading towards a global increase of temperature of more than 1.5°C, societies are trying to limit the dependence on fossil fuel by adopting renewable energy sources in order to limit the emission of greenhouse-gases. This master thesis strove to find a methodology to integrate renewable energy and optimisation measures in the industries of food and beverage to make them more sustainable by reducing their CO2 emissions. An existing methodology was used as an inspiration and was applied to two cases: an existing brewery in Sweden and a fishery on Pico in the Azores which is yet to be built. Visits were made to both places and interviews were done to gain a deeper understanding of the cases. The thesis tested the methodology and managed to find a new energy plan for the brewery and optimization methods for the fishery to make them perform better than the European benchmark. The methodology developed for the thesis was successful in its goal but a few aspects were left out of the thesis due to the limitation of the scope of the study.

Introduction

Climate change and political conflicts today have increased the shift from traditional fossil energy to renewable ones. The IPCC has been clear these recent years (see report [20] from 2022): a drastic cut to the greenhouse gas emissions has to be done if we are to pass under the global 2°C temperature rise. Moreover, political conflicts and war poses an energy dilemma for countries that up until now have relied on foreign energy sources. Whether this has been oil, natural gas or even uranium it is clear today that if a country wants to remain sovereign and free to assert its voice on the international scene it needs to be self-sustaining in regard of its energy consumption. Industries, being the one of the main consumer of energy in our societies, have a massive impact on emissions. The 6th IPCC report shows that industry is the second biggest emitter (24%) in our world after energy (34%) and that the sector has increased its net emissions in recent years. Although the consumers can make choices in their consumption it is policy makers as well as companies that have the power to accelerate the energy shift. The IPCC addresses them directly in their report [20]. Some companies are leading by example and are taking their responsibility in terms of emission and includes Company Social Responsibility (CSR) goals as well as a CO2-emission budget in their financial report. This thesis made the attempt of an universal methodology inspired by "The green brewery concept" by Muster-Slawitsch (see study [8]) to improve the sustainability of a factory within the food and beverage industry. The method was tested on two cases: one existing brewery, which requires mainly heat, and a fishery, yet to be built, which will require mainly cooling. The research questions which were answered at the end of the thesis are the following:

- RQ1: Is the "The green brewery concept"-inspired method suitable to be used in evaluating the energy system of a certain industry?
- RQ2: Is the method able to propose an applied energy transition plan to a certain industry?
- RQ3: What are the steps necessary to achieve an industry with 100% renewable energy for the two cases analyzed?
- RQ4: What could the impact (in terms of emission reduction) of this method on a European scale?
- RQ5: Will the method be able to be implemented in other industries?

Contents

1 Background: The Beer Industry

1.1 The Brewing of Beer

The process is done with the following stages: - Malting & Mashing (*Malthantering*), boiling (*Bryggning*), Fermenting (*Jäsning*), Filtering (*Filtering*), Pasteurizing (*pastörisering*), bottling *Tappning*), Packaging (*Förpackning*), storage (*Lagerhantering*). The beer process requires a few ingredients being: water, a starch (made from barley for example), yeast and flavouring (hops and more). Below is a diagram (see figure 1) showing the beer process chart with the different stages mentioned above.

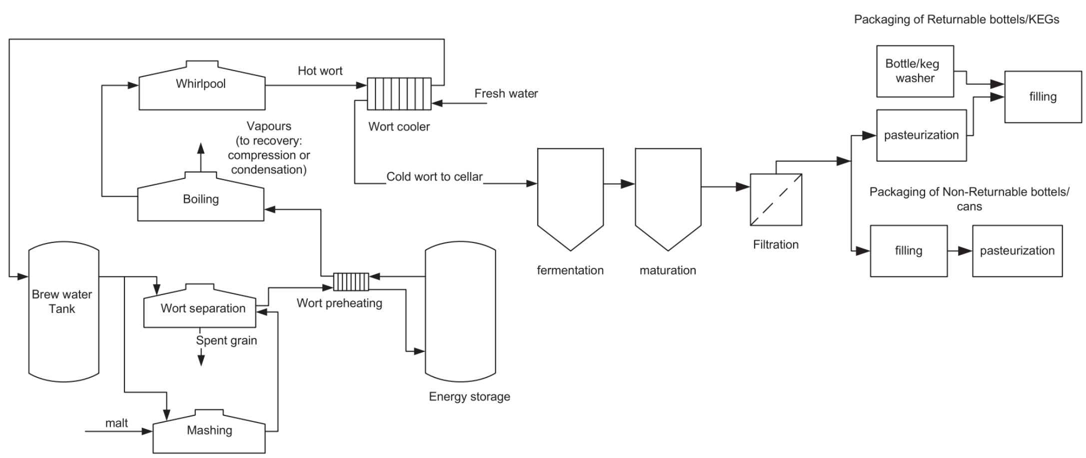


Figure 1: Beer process, from study [15]

Another version of the process but synthesized created by Åbro bryggeri is also shown below in figure 2:

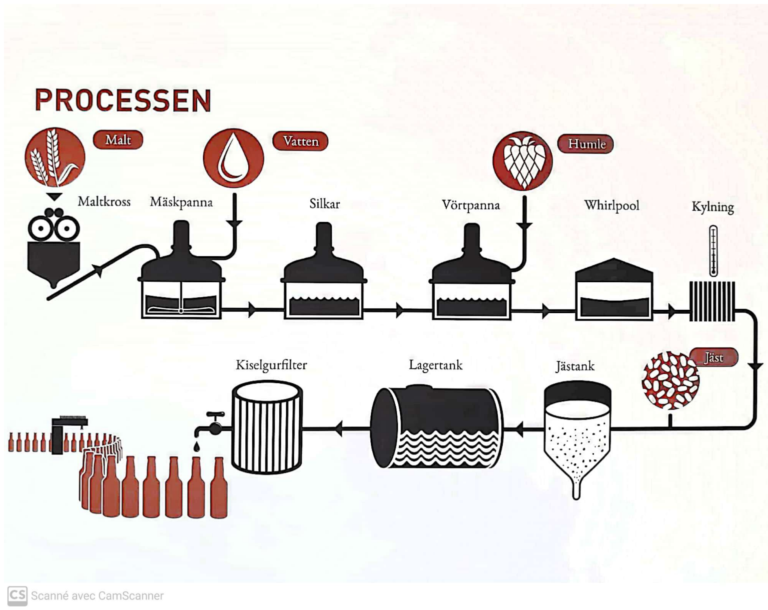


Figure 2: Beer process chart with the different stages in Swedish (image courtesy of Åbro Bryggeri)

The first step of brewing beer is the malting of the cereal, usually raw barley, to prepare it for the brewing. The grain is steeped in water to promote germination and then dried in a kiln. The steeping involves alternating between soaking and draining the grains. They are then kept in a germination room over 4 to 6 days at 16 to 19°C. Then drying is usually done with hot air at 80 or 90°C over 2 to 4 hours. This is to kill the sprouting of the grain and while keeping the nutrients.

The second step is the mashing which consists of crushing and mashing the grains making a *mash* with hot water. This porridge-like mash contains the starch which is transformed into sugars and proteins. The mashing process implies a mixing at a temperature of 65°C over 1 hour. This is to make sure that all the layers of the grain are broken to release the glucose inside the grain. The end product of the mashing is the *wort* ("vört" in swedish).

The next step is the boiling of the wort. The wort is boiled up to a high temperature and flavours are added to it. These are usually hops to give a bitter taste to balance the sweetness of the starch. Other flavours can be added like syrup and more. The boiling has several purposes being:

- inactivation of enzymes from the mash
- isomerization of hop acids to make them soluble in the wort
- sterilization of the wort
- removal of unwanted volatiles
- precipitation of unwanted proteins

- concentration of wort

The heating process is done with an alternating pressure between 1.0 and 1.2 bars at 100°C to 105°C, done usually 6 times under 90 minutes. This is done to evaporate the unwanted volatiles. The boiling occurs in so-called kettles, they usually were made in copper so *coppers* is another term for those devices. In order to maximize the heat transfer, several techniques can be used: The Merlin System, The Stromboli System, The Symphony™System and others aim to maximize heat transfer to shorten the boiling time while keeping the evaporation to a minimum.

The next step after the boiling is the fermentation of the wort. This involves the sugars in the wort being converted by yeast to alcohol and carbon dioxide. The key ingredient to beer excluding the barley and the hops is the yeast. Management of the fermentation process is dependent on a number of factors, including the composition of the wort, the oxygen content, the quality and quantity of the yeast, temperature, time, and the fermenting vessel design. The type of yeast is crucial to the outcome of the fermentation, not only for the metabolizing of the wort to produce alcohol and characteristic flavour but also in the ability of the yeast to handle its own by-products from its metabolism. Brewers keep a catalog of brewing strains for different beers. A well known yeast is the *Saccharomyces cerevisiae* which is used for bread as well as wine. The fermentation temperature dictates more or less the activity of the yeast. Ales are fermented at 16 to 22°C while lager is fermented at 9 to 14°C. Fermentation is a exothermic process which means that heat is produced within the product, this has to be taken into account for temperature control. The fermentation takes place in vessels that are equipped with cooling systems to keep optimal temperatures. Ales require 4 days to finalize fermentation while lagers require up to 10 days.

The following step after fermentation is the filtering which requires the beer to be filtered from unwanted particles.

Pasteurizing is the next essential step for production of beer. This is to inhibit the formation of any unwanted micro-organism as well as to prolong the shelf-life of the beer. This involves heating up the beer to 60°C. For every minute that the beer is kept at 60°C it is said that its been subject to one pasteurizing unit [PU]. 15 [PU] is regarded as a standard in the beer industry. There are several ways to achieve this. One way is to pass the beer through a pasteurizing tunnel. The beer is contained in its bottle or can and is passed through a tunnel which sprays the containers with hot water. If the beer is in kegs it is pasteurized before passing through a heat exchanger at 70°C over 30 seconds: called flash pasteurization.

Next stage is the kegging and bottling. This involves filling the recipient with the beer. This is either a bottle or a keg. The recipient is usually emptied of oxygen and filled with carbon dioxide to provide a beer-friendly environment as well as assuring a similar pressure to the tank delivering the beer to prevent foaming. The beer is usually filled while being cold to prevent foaming as well as preserving the carbon acid, cold as 3°C.

The final stage is the packaging and storage of the beer. After the beer has been cooled to 3for the bottling, the beer is then usually kept at 10°C in storage. This is to prevent condensation unto the labels and the effect of heat on the product.

1.2 Thermal Processes: Heating and Cooling of Beer

As shown above, heat is used throughout the stages in the beer process. The main heat-consuming processes in a brewery are: mashing, wort boiling, clean-in place (CIP)/disinfection, bottle and keg washing, pasteurising and room heating (in cold climates)[5]. The largest single heat consumer will normally be the wort kettle. The main single consumers of electricity in a brewery are instead: packaging area, cooling plant, compressed air plant, CO2 recovery plant, waste water treatment plant and air conditioning [5]. There are also many small consumers of electricity, accounting for a large part of the electricity consumption, e.g. pumps, ventilators, drives and electric lighting.

1.3 Energy and mass balance in a brewery

In order to map energy and mass balances in a factory like a brewery, an energy and mass balance are a helpful illustration to visualize the main flows in a complex process like breweing of beer. Below is an example of an energy and mass balance for 1m3 of beer in a brewery run by Unicer in South Africa, see figure 3.

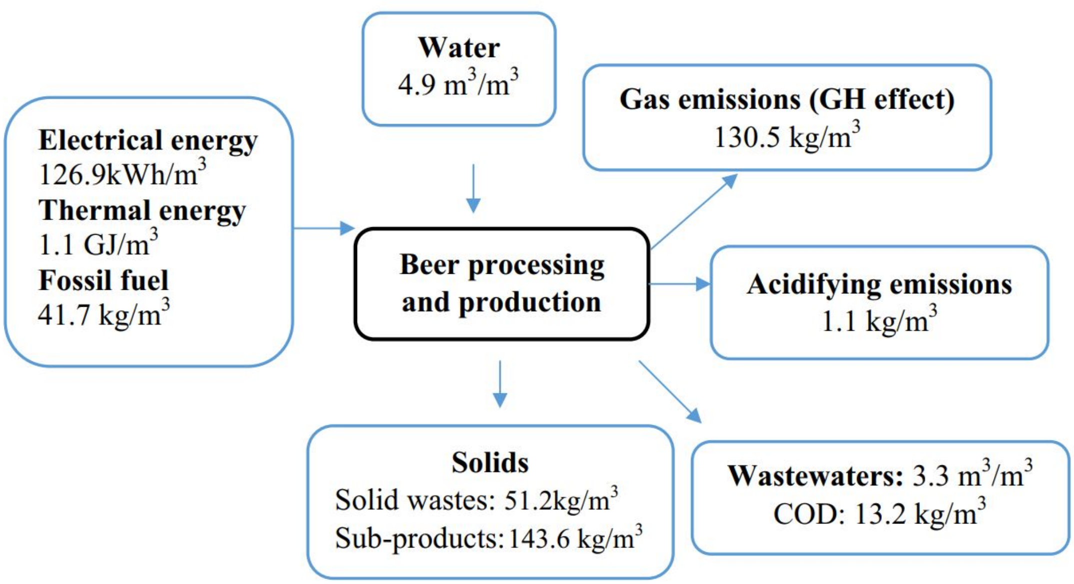


Figure 3: Total mass and energy balance in Unicer brewery, South Africa [4]

This kind of illustration makes it easy to compare with other factories of the same kind but that uses other technologies. For the case of Åbro, it is possible to make an energy and mass balance from knowing the amount of electricity and heat they use to produce their 1,200,000 hectoliters of beer per year. The emissions in relation of electricity production is usually at 20g of CO2 per kWh in the swedish power mix. For the heating, data was taken from Vimmerby Energi which uses biomass to produce the heat: according to the District heating, the heat releases 5g of CO2 per kWh of heat. See below, figure 56 for the energy and mass balance for the brewery.

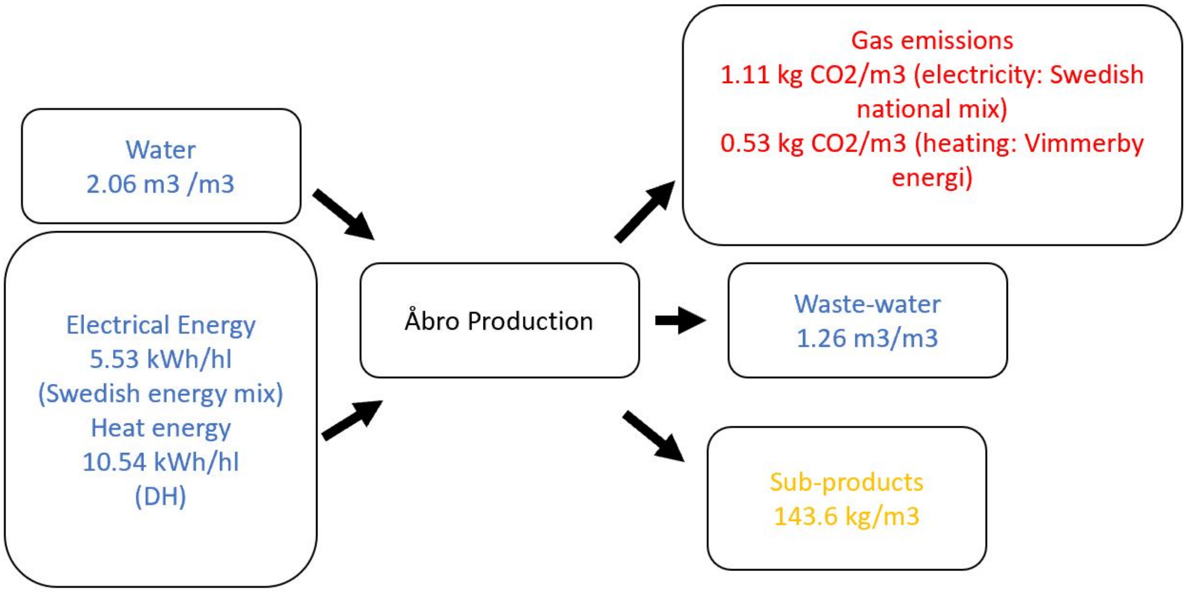


Figure 4: Energy and mass balance of the production of beer at Åbro. Data is estimated from the Nordic electricity mix and with data from Vimmerby Energi

What can be gathered from comparing the figures 56 and 3 is that Åbro has a significantly lower energy consumption as well as a lower water consumption. Section 5 of the thesis analyses more deeply the kind of energy measures which Åbro has undertaken which explains the gap with the Unicer brewery.

2 Background: The Fishing Industry

2.1 Current Commercial Fishing Practices

In the last decade, the cost of fuel and other energy sources has, on a rising trend, become increasingly volatile, and this instability has had a notably adverse effect on the viability of some fisheries, see study done by FAO [24]. According to FAO, in 2001, fuel was estimated to account for some 21 percent of revenue from landed catch, whereas in 2008, during the first recent period of high oil prices, this increased to about 50 percent. Fuel use varies widely with fishing type and effort level, and profit margins depend on catches and sale values, but as one of the key cost elements over which the sector has little immediate control, profitability and livelihoods are potentially highly sensitive to energy costs.

Consumers are increasingly aware of the products they buy and they are sensitive to the origin of the produce and how it was processed. An example of this shift in consumer habits is the certification CATCH [28]. The EU has established a Community system to prevent, deter and eliminate illegal, unreported and unregulated fishing. The regulation puts in place an EU catch certification scheme which requires that all imports of fishery products are accompanied by a catch certificate validated by the flag states of the catching vessels in order ensure the legality and traceability of the fish. This system has been paper-based since 2010 but is under transformation to an IT system. In the US a similar certification is used: NOAA, which allows US-fisheries to export fish produce that qualifies the criteria used on the european market. NOAA Fisheries assesses and predicts the status of fish stocks, sets catch limits, ensures compliance with fisheries regulations, and reduces bycatch.

2.2 Fish quality: spoilage factors

According to the Food and Agriculture Organization (FAO) [29] there are a few factors that limits the storage life of fish, namely:

- Protein changes. Fish proteins become permanently changed during freezing and cold storage and the speed at which this denaturation occurs depends very largely upon temperature. At temperatures not very far below freezing point, -2°C for example, serious changes occur rapidly; even at -10°C, the changes are so rapid than an initially good quality product can be spoilt within a few weeks. The rate of deterioration due to protein denaturation, however, can be slowed by ensuring that storage is at as low a temperature as possible.

- Oil and fat changes. Fatty fish may become unpleasantly altered during cold storage but they can be protected to some extent either by glazing or by packaging in plastic bags sealed under vacuum. These oxidation changes take place more rapidly at higher temperatures and storage at a low temperature is an effective means of slowing the rate of spoilage by this method.

- Colour changes. The quality of fish is often judged by appearance, and colour changes which are not otherwise significant can result in fish being downgraded. The changes in the fish flesh which bring about these colour changes are also retarded at lower temperatures.

- Moisture loss. Dehydration of the product is probably the major concern of the cold store operator and the rate of drying can be linked with a number of factors in cold store design and operation. When fish get badly dehydrated in cold storage, the surface becomes dry, opaque and spongy. As time progresses, these conditions penetrate deeper into the fish until it becomes a fibrous, very light material. Visible effects of severe dehydration on the surface of the fish are known by the term "freezer burn". This is an unfortunate choice of term since the effect is unlikely to result from freezing in a properly designed freezer, and appears only after periods of storage in a cold store. Frozen fish may dry slowly in cold storage even under good operating conditions. This is undesirable for reasons other than the obvious one that the product will lose weight. Drying also accelerates denaturation of the protein and oxidation of the fat in the fish. Even totally impervious wrappers used to protect the product do not give full protection if the cold store operating conditions are favourable for desiccation within the pack. In-pack desiccation prevails when there is some free space within the wrapper and the temperature of the store fluctuates. When this occurs, there will be times when the wrapper is colder than the fish and moisture will then leave the product and appear as frost on the inner surface of the wrapper. The total weight of the product and package will not change but if the in-pack dehydration is severe, the fish will have the quality defects of excessive drying.

Different species of fish spoil at different rates. In general it can be stated that larger fish spoil more slowly than small fish, flat fish keep better than round fish, lean fish keep longer than fatty fish under aerobic storage and bony fish are edible longer than cartilaginous fish. Several factors probably contribute to these differences and whereas some are clear, many are still on the level of hypotheses. Below are a list of intrinsic factors that contribute to the spoilage rate

Intrinsic factors	**Relative spoilage rate of fish stored in ice**	
	Slow rate	**Fast rate**
Shape	Flat fish	Round fish
Size	Large fish	Small fish
Fat content in the flesh	Lean species	Fatty species
Skin characteristics	Thick skin	Thin skin

Figure 5: Intrinsic factors affecting the spoilage rate of fish [29]

Factors affecting spoilage rate	**Relative spoilage rate**	
	fast	**slow**
size	small fish	larger fish
post mortem pH	high pH	low pH
fat content	fatty species	lean species
skin properties	thin skin	thick skin

Figure 6: Other factors affecting the spoilage of fish [29]

The spoilage rate is a parameter that helps to quantify the speed of the deterioration of the fish. Below is a table and a graph illustrating this dimension. To use the graph find the actual storage time on the bottom axis, and then trace up to the temperature and then across to the left vertical axis to read the equivalent days on ice.

Temp		Relative rate	Equivalent days on ice with time							
°C	°F	of spoilage = *r*	4 hr	8 hr	12 hr	18 hr	24 hr	36 hr	48 hr	72 hr
–2	28.4	0.64	0.11	0.21	0.32	0.48	0.64	0.96	1.28	1.92
0	32.0	1.00	0.16	0.33	0.50	0.75	1.00	1.50	2.00	3.00
2	35.6	I .44	0.24	0.48	0.72	1.08	1.44	2.16	2.88	4.32
4	39.2	1.96	0.33	0.65	0.98	1.47	1.96	2.94	3.92	5.88
6	42.8	2.56	0.43	0.85	1.28	1.92	2.56	3.84	5.12	7.68
8	46.4	3.24	0.54	1.08	1.62	2.43	3.24	4.86	6.48	9.72
10	50.0	4.00	0.66	1.33	2.00	3.00	4.00	6.00	8.00	12.00
12	53.6	4.84	0.81	1.61	2.42	3.63	4.84	7.26	9.68	14.52
15	59.0	6.25	1.04	2.08	3.12	4.69	6.25	9.38	12.50	18.75

Figure 7: Relative rates of spoilage and loss of equivalent days on ice for different temperatures and times, [22]

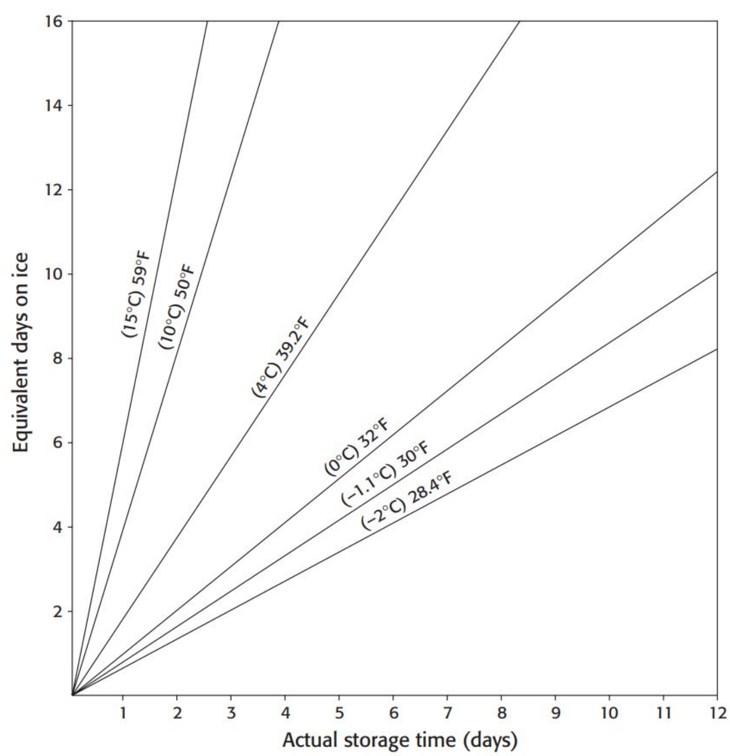


Figure 8: graph with the equivalent days on ice at selected storage temperatures compared to actual storage times, [22]

Apart from the actual storage temperature, the delay before chilling is of great importance. Thus, it can be observed that if white-fleshed, lean fish enter rigor mortis at temperatures above + 17°C, the muscle tissue may be ruptured through severe muscle contractions and weakening of the connective tissue. The technological significance of rigor mortis is of major importance when the fish is filleted before or in rigor. In rigor the fish body will be completely stiff; the filleting yield will be very poor, and rough handling can cause gaping. See figure **??**.

It is a common experience that the quality and storage life of many fish decrease if they have not been gutted. During feeding periods the fish contain many bacteria in the digestive system and strong digestive enzymes are produced. The latter will be able to cause a violent autolysis post mortem, which may give rise to strong off-flavour especially in the belly area, or even cause belly-burst. On the other hand, gutting means exposing the belly area and cut surfaces to the air thereby rendering them more susceptible to oxidation and discoloration. Thus, many factors such as the age of the fish, the species, amount of lipid, catching ground and method, etc., should be taken into consideration before deciding whether or not gutting is advantageous. In most North European countries, the gutting of lean species is compulsory. It is based on the assumption that the quality of these species suffers if they are not gutted. In the case of cod, it has been shown that omission causes a considerable quality loss and a reduction in the storage life of five or six days. After only two days from catch, discoloration of the belly area is visible and the raw fillet acquires an offensive cabbagey odour. As seen in Figure 6.10, these odours are removed to some extent by boiling. See figures **?? ??**.

A general description for the assessment for quality of fish has been provided by the EEC. The guidelines is shown in Table below. The suggested scale is numbered from 0 to 3, where 3 is the best quality. See figure **??**.

2.3 Thermal Processes: Freezing of Fish

2.3.1 Freezing temperature and freezing time

There are numerous studies that have been produced since 1950s on optimal fishing practices, freezing methods are handling in general. Fish can be found in many different sizes and also in different compositions from a physiological perspective. White fish and Tuna have different compositions in their meat and this impacts how the fish reacts to freezing. The study done by K.Jensen et al. [14] showed that depending on the fish (cod and tuna in the study) the meat would freeze at different rates. This is because of the difference in proteins and oil-content naturally found in the fish's muscles. The study by S. Radhakrishnan [32] summarized freezing data of different fish species and could attribute specific thermal properties for different species of fish, these are shown in figure 11. The study [14] also have acknowledged that the lower the temperature the better the quality is after thawing. The study mentions a doubled shelf-life for tuna meat when preserved at -30°C instead of -18°C. But the benefits reaped past a temperature does not necessarily motivate the much higher energy consumption. Several other studies like the one done by I. Tolstorebrov et al. [12] and E. Svendsen et al.[9] recommended a temperature of around -35$^{\circ}C$ is sufficient to have a reasonably long shelf-life.

Below are quotes from the studies that comments the freezing temperatures for fish:

- "The recommended storage temperature for high-quality long-term storage of fish is 35.0°C. Further decreasing storage temperature is unnecessary for industrial needs." I. Tolstorebrov et al. (2015)
- "In this review, the authors suggests that for most fish, the most optimal temperature for high-quality long-term storage (given the trade-off between product quality and energy use) is approximately 35 ∘C" E. Svendsen et al. (2022)

- "The impact of freezing temperatures on the quality of farmed cod therefore appeared to be complex, but no overall beneficial effects were found by decreasing the freezing temperature below40C." T. Mørkøre et al. (2007)

The freezing process can be seen as the elimination of heat. When freezing a material there is essentially the elimination of two types of heat: sensible heat and latent heat. Sensible heat is the heat that one can feel when putting the hand close to a hot stove. Latent heat is the activation energy required for the phase transformation of the material: turning liquid water to solid ice. When bringing the water temperature to 0°C the water would not start to crystallize. The water would allow start to switch phase when the temperature is brought down further to -1°C. As can be seen in the diagram in figure 9 the elimination of latent heat is a considerable part of the freezing process.

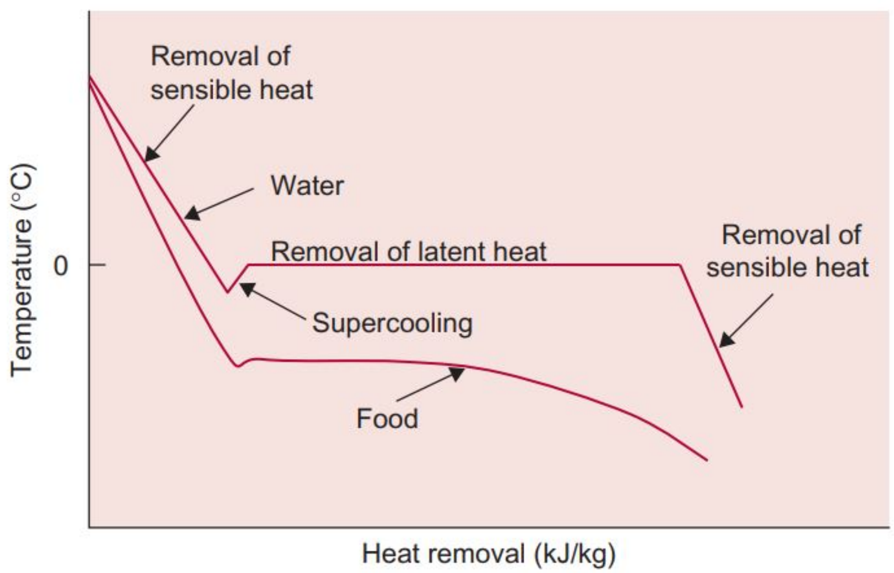


Figure 9: Freezing curves of pure water and food

During the removal of the latent, crystallization takes place. The rate at which this occurs can be quantified with the help of Planck's equation. The formula given below gives the time necessary for the elimination of the latent heat of a material subject to convection by air. The material has a certain thickness but is indefinitely wide, see figure 10. This is suitable for steaks or thin products :

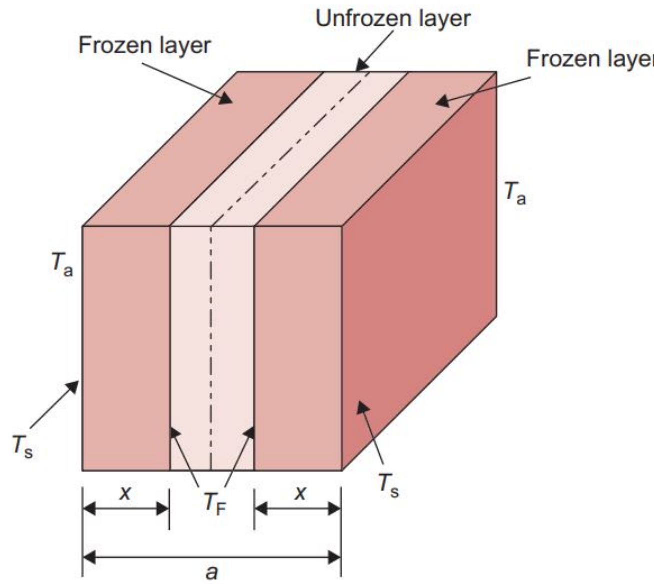


Figure 10: Planck's equation applied for the freezing of an indefinitely large material with finite thickness

For the freezing of a tuna steak, Planck's equation gives a good approximation of the time t_F required to freeze it. The equation is shown below:

$$t_F = \frac{\rho_f L_f}{T_F - T_a}(\frac{aP'}{h} + \frac{a^2 R'}{k_f})$$

- t_F: time until latent heat is completely eliminated i.e water is solidified
- ρ: density of the tuna
- L_f: Latent heat of fusion of the tuna
- T_F: Freezing temperature
- T_a: Temperature of air
- a: thickness of the tuna
- P': size factor
- R': size factor
- h: convection coefficient
- k_f: conductivity coefficient of frozen tuna

As can be seen in the formula, the initial temperature nor the final temperature play a role. These are some of the limitation of the formula, but it still gives a good idea over the freezing time. Knowing the latent heat of the food, as well as the conductivity, latent heat of

Species	Moisture Content %	Fat Content %	Thermal Conductivity* W/m•°C	Thermal Diffusivity* 10^{-7} m^2/s	Enthalpy** kJ/kg	Specific Heat* kJ/kg•°C
Bluefish	78.125	3.740	0.4890	1.4007	302.27	3.4095
Croaker	79.605	0.915	0.4866	1.6155	275.65	3.2028
Salmon	72.513	3.898	0.4711	1.3944	302.58	3.5894
Seabass	79.800	0.253	0.4859	1.5462	341.17	3.6883
Shrimp	84.655	0.031	0.5430	1.5212	364.75	3.3828
Mackerel	73.081	9.138	0.4246	1.5197	322.79	3.5061
Spot	63.737	15.938	0.4011	1.5417	331.04	3.3550
Tilapia	77.712	0.747	0.4961	1.5816	325.15	3.5133
Trout	79.080	2.857	0.5186	1.4247	333.24	3.5639
Tuna	73.107	0.016	0.4687	1.5275	287.81	3.3567

* Average values of thermal properties measured at about 5, 10, 15, 20, 25 and 30 °C.

** Values at 0 °C. Temperature datum at -40 °C

Note: All thermal property values are the average of three replications.

Figure 11: table over the thermal properties of different fish from the study [32]. The thermal conductivity of tuna was used in the calculations below

water, convection coefficient as well as it is possible to calculate the crystallization of a piece of fish. Below is the freezing time of different thicknesses of fish steaks. Calculations were done in $MATLAB$ and the code is shared in the Annex.

0.07m thick	0.14m thick	0.28m thick
27 minutes	96 minutes	360 minutes

As can be seen from the table above, the value of a, thickness of the steak, has a huge impact on the freezing time. Another parameter that has a high impact on the freezing is the convection coefficient h. The coefficient is dependant on the speed of the air as well as its temperature. Its relation to the freezing time can be seen below in the two tables.

Air temperature -30°C				
Air Speed $[m/s]$	5	10	15	20
Convection Coefficient $[W/m^2K]$	60	90	140	150
Time $[min]$	345	320	301	299

Table 1: Table of freezing time obtained by varying air speed

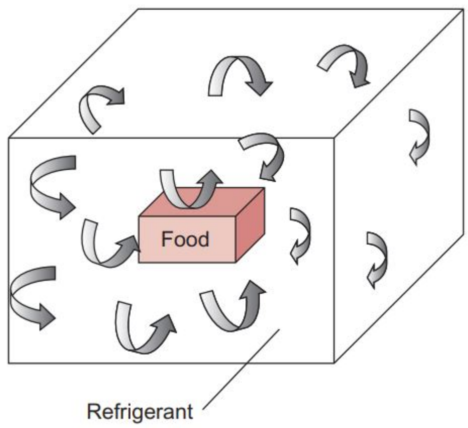
Air temperature -40°C				
Air Speed $[m/s]$	5	10	15	20
Convection Coefficient $[W/m^2K]$	100	145	180	220
Time $[min]$	314	300	294	289

Table 2: Table of freezing time obtained by varying air speed

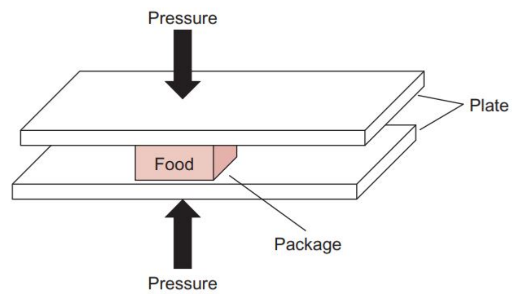
The tables show that a higher speed of air increases the convective coefficient which improves the freezing time. Unsurprisingly, a lower temperature also allows to decrease the freezing time.

2.3.2 Commercially available methods

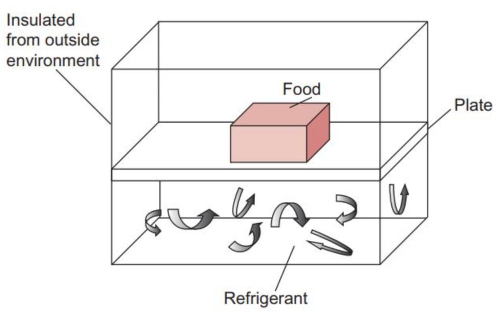
There are several methods to freeze fish and food in general. The choice depends on the produce that needs to be frozen. A book on food engineering chose to classify freezing methods as either direct (convection by air or cryogenics) or indirect freezing (with conduction).



(a) Freezing by convection



(b) Freezing by conduction by pressing together two cold surface on either side of produce



(c) Freezing by conduction through indirect cooling

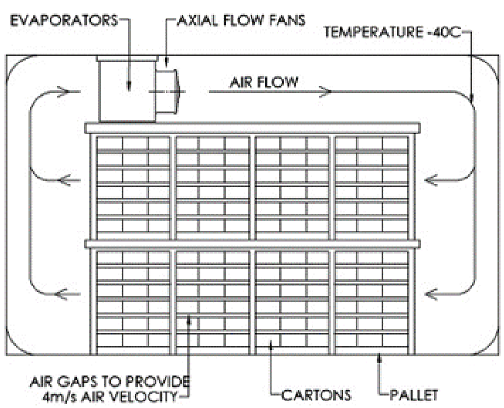
The most used commercially available methods are the following:

- Air-blasting chambers (ABC)
- Individual quick-freezing (IQF)
- Plate-freezing (PF)

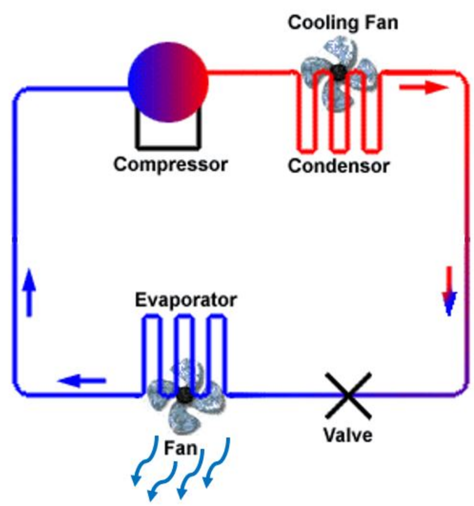
Air-blasting chambers (ABC) was the first industrial method of freezing large quantity for a commercial purpose. It was done in New Zealand for the export of the lamb and sheep meat. The technology is relatively simple: it consists of blowing cold air against produce over a long period of time. The produce, being subject to convective cooling, will be frozen after some time. The system is composed mainly of a series of fans blowing air, an evaporator which cools the air being blown across it, a compressor which pumps the coolant, a condenser to reject the heat and an expansion valve. The system is illustrated below in the figure 13d. For a uniform cooling across the chamber, when designing the ABC, it is crucial to take into account the air flow and make sure proper spacing to allow unobstructed air-flow: this limits the amount of produce and the equipment as well as the positioning of them in the chamber, see figure 13c.

(a) ABC with whole fish stored

(b) tuna rail used in the chambers to move around large fishes in the room

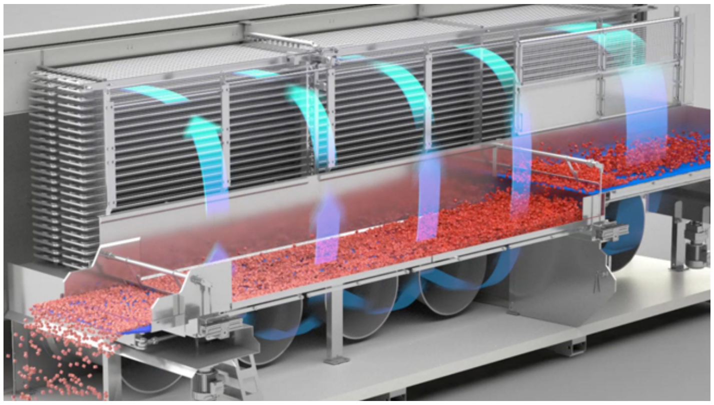


(c) Diagram illustrating the air flow inside a ABC



(d) refrigerent cycle which operates the ABC

Individual Quick Freezing (IQF) can be considered as a modern take on the ABC in the sense that it utilizes convection by air but in a more efficient and effective way. The limitations of the ABC is the high consumption by the fans and compressor for a very diffuse and scattered air flow which renders the freezing relatively slow (and thus inefficient and costly). IQF relies on directed air-flow at the produce in a closed space in order to maximise the convection potential. The produce is moved along a conveyor belt and the stream of air is directed at the belt with the produce. The air can be flowing from above unto the produce or from under. Blowing air under the produce can allow to create a fluidized bed which the produce is laying on. The suspension of the produce in the air for a short time allows the cold air to envelop the produce and freeze from all sides. This is suitable for uniform products like dice or small cuts but undesirable for fillets for example since it would be prone to be deformed or folded.



(a) IQF model by Octofrost ™

(b) IQF model by Octofrost ™

Figure 14: Products from Octofrost

Plate freezing (PF) is the freezing method which relies on conduction. The produce is poured into pockets with plates that have a refrigerant flowing inside. The produce, in contact with the plates, with then get frozen by conduction from the contact with the cold plates. These plate freezers can either be vertical (with produced poured from above into the pockets like mentioned above) or horizontal. In a horizontal plate freezer the produce is placed in between the plates that are arranged like shelves and the plates can then be pressed together by a piston from above pushing down. For the vertical PF it is possible to make it automated by having the produce poured into the pockets and then rejected automatically when freezing is complete. For the horizontal freezing it requires careful placement on trays since if the plates are pushed together it is important that the produce is evenly distributed across the surface.

(a) left: horizontal PF, right: vertical PF

(b) Horizontal PF showing the piston above which applies the pressure.

Below is a table summarizing the main advantages and disadvantages of each method discussed in the studies [9] [12] and interviews with Octofrost and ColdEnergy, see interviews in annex.

Freezing	Pros	Cons	Costs	Produce type
ABC	Versatile, can store entire fish or shelves and carts of produce	Fans are heat loads. Have to take into account thermodynamics of air flowing in the chamber. Slow freezing. Risks of freeze burning (unpackaged)	Cheap to build. High energy consumption	Suitable for any size
IQF (air)	Fast freezing time: high quality possible	unsuitable for certain products. Requires high initial investment as well as proper expertise	High initial cost. Cheap operational costs	Suitable for small products: fillets or diced produce
IQF (cryo.)	Very fast freezing time: high quality preserved	Liquid gas expensive: requires high volume for break-even	High initial cost. High operational cost. Hazardous systems requires proper care and safety regulations	Suitable for small products: fillets or diced produce
PF	Fast freezing time. More or less versatile with adjustable plates	Not suitable for any produce	High capital initial capital cost especially if automated	relatively small produce: sliced, diced or small fishes

Table 3: Advantages and disadvantages of the different freezing technologies based on studies and interviews with ColdEnergy and OctoFrost.

Freezing	Produce	Rated Power [kW]	Volume [kg/h]	Purchase Cost [€/kW]
ABC	Whole fish / Fillets	310	500	4,787 (*)
IQF (air)	Fillets	167	500	8,404 (#)
IQF (cryo.)	Fillets	35	227	2,971
PF	Fillets / small fish	45	365	436

Table 4: Energy consumption and cost of the different freezing technologies (*: based on information given by Cold Energy, #: based on information given by OctoFrost)

Cryogenics is the use of liquid gases that are ultra-cooled like liquid nitrogen or liquid carbon dioxide. These cold liquids are poured unto the produce to rapidly cool them and to freeze them in a very short amount of time. Cryogenics are generally used in combination with an IQF. Although the method is very time-efficient the continuous supply of liquid gas is very costly. This can be acceptable if the produce volume is high and easy to freeze (like small shrimps or diced vegetables).

2.4 Energy and mass flows in fisheries

The study [10] compared the energy use and waste from different activities within a fishery: the Process and Packaging (PP), the Distributing and Marketing (DM) and Handling and Storage (HS). The study uses the nexus-framework in order to not measure the depletion and environmental impact of the measures in isolation: it allows are more holistic and accurate accounting of the effect of the measure. The study concluded that the PP accounts for the most energy use (52%) and water use (82%) and is also the least efficient, see figure 16 below.

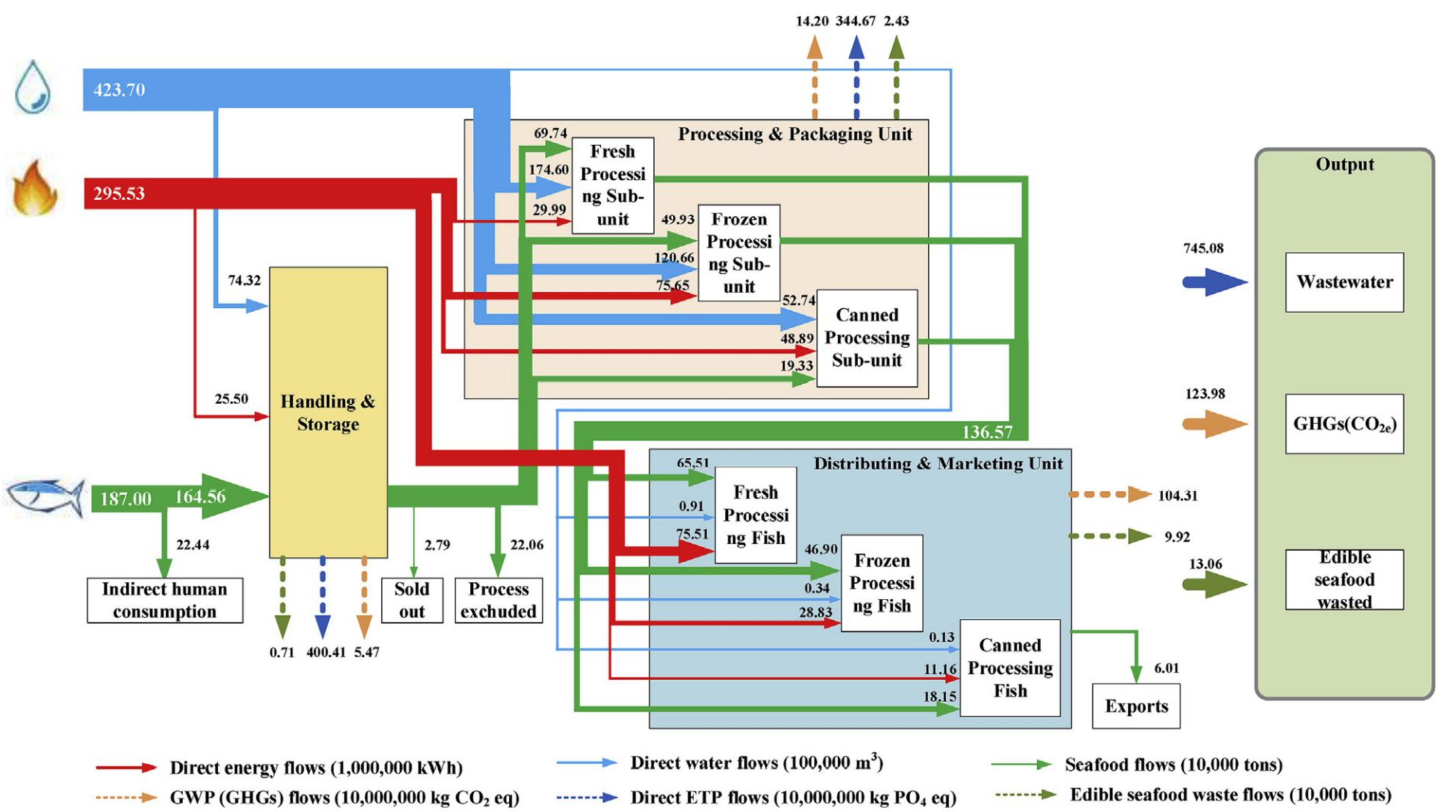


Figure 16: Seafood, energy, water flow along the chain, from study [10]

The study mentioned above compared three different lines (sub-units): a fresh processing-line of fish, a freezing processing-line and a canning-line. The authors concluded the following in regard of the emissions: *in the three sub-units, the canned unit accounted for the highest emissions (releasing 22.32% of the 52.20%), followed by the frozen unit 13.38% and the fresh unit 4.00%. Out of the total emissions discharged by the various sub-units, the canned, frozen, and fresh units released 21.18%, 12.36%, and 2.88% of emissions directly along the chain. However, the opposite was observed during the distribution. It was shown that fresh tilapia distribution generated higher emissions (releasing 18.22% of the 39.50%), followed by the distribution of frozen 11.66% and canned tilapia 9.71%.* . Furthermore, in regard of water use the authors came also to the fact that *In view of the processing types (equal units of 1 t), the fresh, frozen, and canned processing of tilapia consumed 25m3, 24m3, and 27m3 of total water, respectively*

[...] Therefore, among these three sub-units, the processing of canned tilapia used more direct water than the remaining (frozen and fresh) processes. Thus, it can be said that the process of freezing fish has a lower impact on the environment in the sense of emissions than canned fish. Moreover, the frozen fish has a lower emissions than the fresh fish when being distributed. In regard of water, the freezing line uses the less water than all of the lines. It is therefore more sustainable to keep the fishery on Pico as a freezing fishery than that of a canned one or a fresh one.

3 Background: Sustainability

3.1 State of the Art: Sustainable Brewery Concept

3.1.1 Benchmark Brewery: existing sustainable breweries

As identified in the section 1, the main heat consumer in the brewery is the actual brewing process. There are a number of breweries in Europe which have worked to achieve sustainable factories and to use as much renewable energy as possible. A few examples of these are the Hofmühl brewery in Eichstätt, Bavaria, and the Göss brewery in Austria.

(a) Gösser is an old beer brand in Austria famous for its ubiquity and quality

(b) Picture of the brewery in the Austrian scenery, image by Freisinger

(c) Hofmühl is a privately owned beer brand. The size of the company is smaller than Gösser

(d) Picture of the brewery with the Eischätt castle in the background

The two breweries are different in the sense that Hofmühl is a privately owned company while Gösser belongs to the publicly traded Heineken group. Hofmühl uses solar heating to fill up their storage tanks for the brewing process. The company has a 1000m2 wide park of evacuated tube collectors which is installed on top of the warehouses. The company Solarbayer is specialized in delivering solar heat for brewing houses and has developed a compound parabolic concentrator (CPC). Below is a figure from a brochure produced by the BRINE institute which supports projects of the sort, [31].

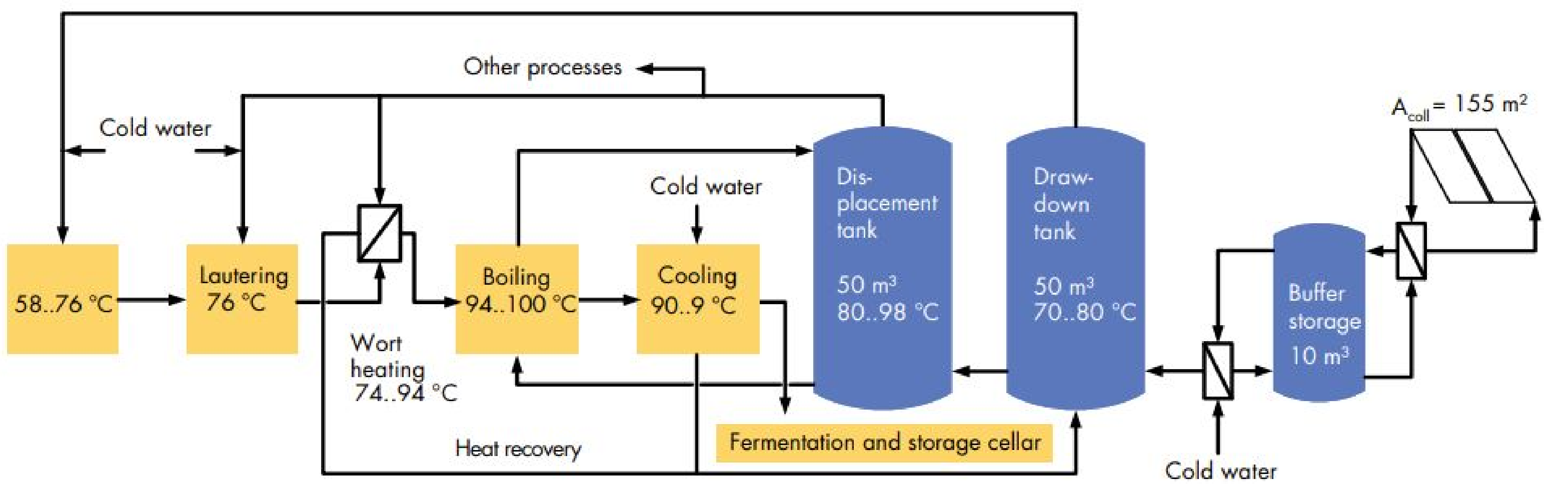


Figure 18: Diagram showing the system comprised of the energy source as well as the storage and brewing process's benefiting from the solar output, [31]

The supplier Solarbayer claimed at the inception of the project that the solar system could deliver heat up to 130°C. The BRINE institute on the other hand claims that the system has only been able to reach a few times 120°C in the storage tanks, [31]. The brewery chooses to have the output temperature of the solar system set at 80°C instead, this has the advantage to supply renewable energy to the processes even on days with low solar irradience.

Gösser brewery utilizes a set of energy sources which makes its energy regime flexible, see figure 19.

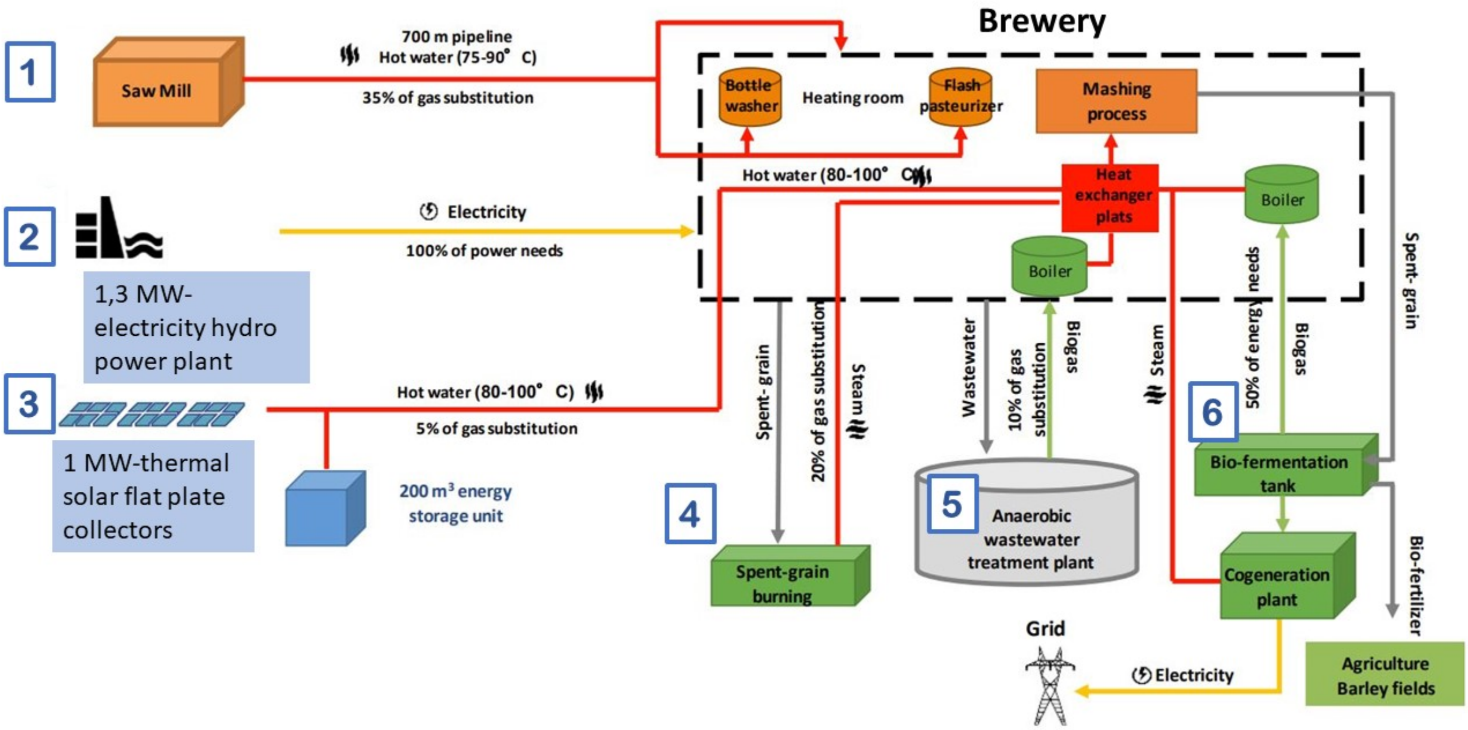


Figure 19: Diagram of the renewable energy supply of Heineken Göss brewery, diagram adapted from the study [33]

The energy sources of the Gösser brewery can be described as the following:

- 1. Waste heat. A saw mill located in the vicinity of the brewery. 40% of the heat demand is covered by the wood processing industry
- 2. Hydro power.
- 3. Flat plate collectors.
- 4. Grain burning.
- 5. Anaerobic plant. 5–10% of the heat demand is covered by the anaerobic waste water treatment plant.
- 6. Bio-fermentation tank. 50% of the heat demand is covered by the biogas from the spent grain. According to the case study done IEA [30], from each tonne of spent grain for the brewing, approximately 75 Nm3 of methane can be produced. This biogas can then be burned in a Combined Heat and Power plant (CHP): in this way the brewery's electricity needs can be covered as well as steam can be produced from the heat exchange. The anaerobic digestion of the waste from the brewery is done in two steps: first a bilogical acidification is done. In this process starch, cellulose, proteins and fats are

hydrolised to sugars, amino acids and fatty acids. These acids are then converted into acetic, propionic and butyric acids. After these last mentionned acids are formed they are pumped into the methane digester for the second step of the digestion process. The acids are stored in a digester which is a continuous stirred tank reactor system. The methane is then stored in a bigger tank which supplies the boiler. To suppress the sulphur content the plant utilizes two strategies: first ion hydroxide is added to bind the H2S during the anaerobic digestion. Secondly, a microbiological removal is achieved by adding a small amount of air: the surplus of O2 allows the H2S to oxidize either to S2 or H2SO4. Below is a table showing the numbers from the study [30] which summarizes the output from the treatment of spent grain.

Input		Output	
Spent Grain	13,621 tons/year	biogas produced	2.3 million m3/year
		biogas supplied to boiler	3.3 million kWh/year
		Electricity from CHP	4.3 million kWh/year
		Heat from boiler	2.2 million kWh/year

The treatment of digestate is limited due to odour emissions as the brewery is located in a residential area. Already in the planning and approval phase the neighbourhood of the brewery was involved in the discussions with respect to potential odour emissions. Thus, no additional digestate treatment is installed at the site. Currently, after storing the digestate in a covered post digester, the digestate is transported to the surrounding farmers and applied as fertiliser on arable land.

Another relevant aspect is the potential energy in the by-products of the brewing. A sub-product from the brewing of the wort is the so-called ”brewer's spent grain”. This material is the product of the boiling of the malt. It can be considered as a biomass which can be used as a fuel. In the study by S. Głowacki et al. [6] the authors analyzed the embedded energy within the brewer's spent grain and estimated the energy that could be harvested. They estimated that 17 MJ are stored in the heat combustion per kilogram of dried grain.

The economical aspect of using the by-product of a process as a fuel is undeniably an advantage. Were the spent grain to be discarded initially and not used for something else, then the aspect of sustainability plays a part and using the spent grain as biomass would increase the overall sustainability of the brewery. Today, Åbro has a deal with the nearby farmers: they can come to the brewery and collect the spent grain as they want (for a fee) and to use it as fodder for their cattle. From the sustainability aspect, using the spent grain as food is a smarter use than fuel. Having to transform the spent grain to fuel requires treating of the spent grain. The grain can only be used as a fuel if it is dried to at least 60%, [6]: this requires a press and a dryer and therefore mechanical work and energy.

3.1.2 Optimization measures in breweries

From the studies [5] [8] [31] [33] the following efficiency measures are worth to study when analyzing the potential sustainability shift of a brewery:

- 1. Improve the energy management
- 2. Improve boiler system

- 3. Implement use of waste heat
- 4. Automation of processes
- 5. Water optimization
- 6. Optimization of air ventilation
- 7. Energy use from by-products

3.2 State of the Art: Sustainable Fishery Concept

3.2.1 Benchmark Fishery: Latest advances and technologies

Regarding fisheries, there are a numerous projects which have taken up the challenge to make fisheries less dependant on fossil fuel and more sustainable. The fishing fleet in the world is highly disproportionate in terms of fishing volume and number of workers. A study done by the UN organisation FAO [25] showed that some 57 percent of vessels in the global fleet are motorized, of which 79 percent (2.1 million vessels) are less than 12m long. These smaller boats are operated by so-called artisan fishermen and operate often close to shore and are gone up to 1-day at a time when fishing. FAO claims that small-scale fisheries are particularly at risk from competition from the increased fishing effort of larger vessels in inshore waters, for which illegal, unregulated and unreported (IUU) fishing is a very widespread issue, and may also increase with higher fuel costs. This suggests that fisheries in developing countries would be far more susceptible to increased fuel prices. To help these smaller fisheries to compete with the larger vessels projects like the ones done by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) promotes the use of renewables to make fishermen more independent from fossil energy. The GIZ helped indonesian fisherman use the energy from solar panels to produce ice and thus allowing them to cool the fish enough for selling them on the bigger markets [27]. This also allows them to skip the use of a diesel generator to make the ice.

Another aspect that need to be taken into consideration is the use of water. A study by S. Murali [16] on the efficiency improvements in fisheries mention several measure to improve a fishery's sustainability. Energy-use for the freezing method is one but also the overall energy management of the fishery as well as the water usage. Below is figures showing the typical energy and water flow in a fishery. The figure is taken from the study done by [10]. An energy and balance flow using the numbers from the same study was created and is shown in figure 21.

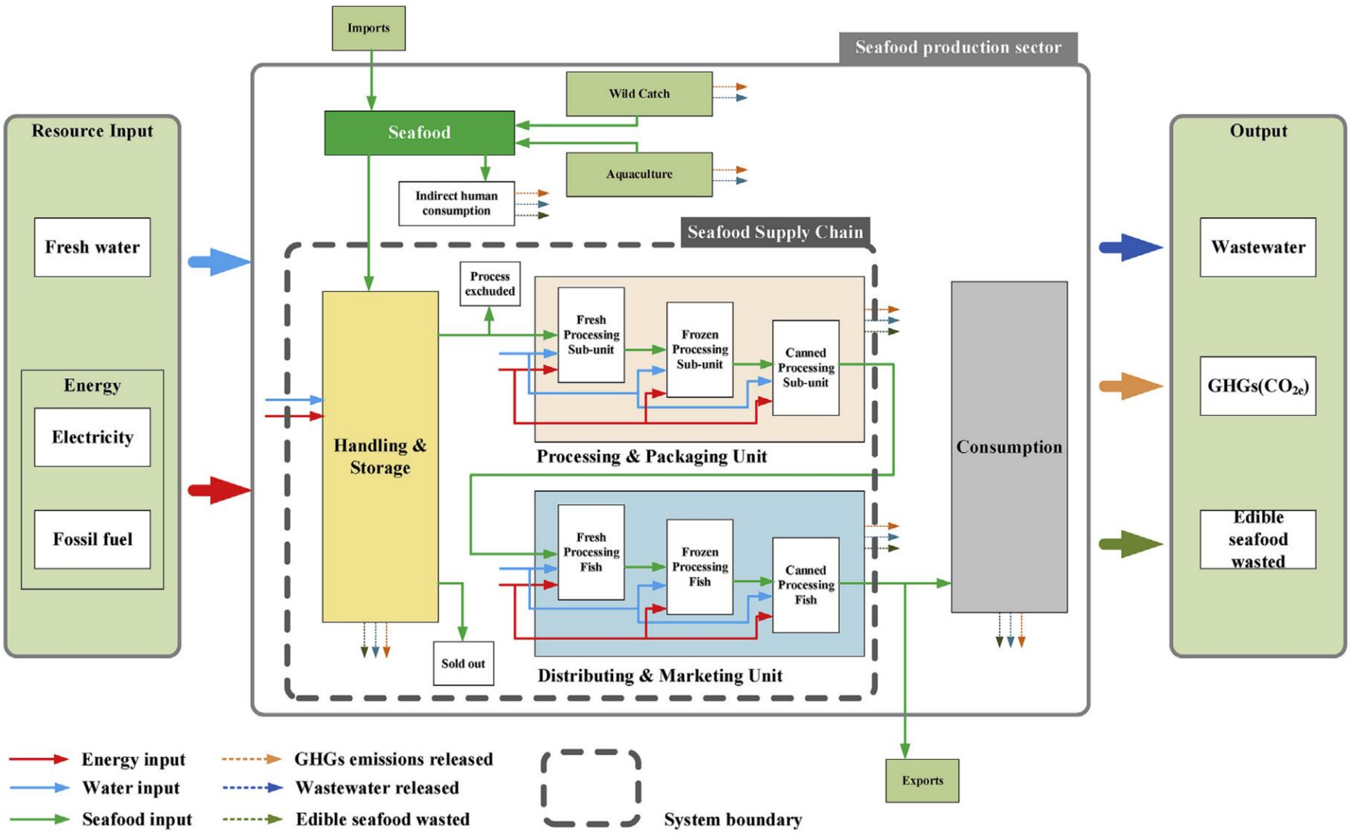


Figure 20: A framework of seafood, energy and water nexus., from study [10]

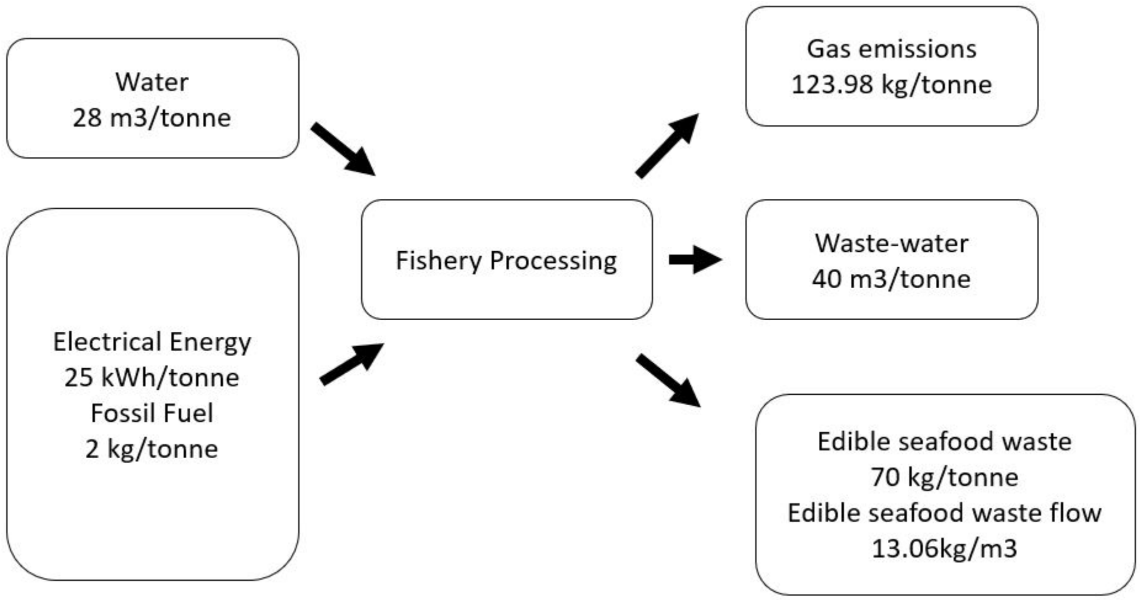


Figure 21: An energy and mass balance created for a fishery, numbers taken from [10]

Another solution which can be implemented within the fishery industry is a cold thermal energy storage (CTES). This has the advantage to be combined with the intermittent nature of renewable energy production and flatten the production curve of the energy supply to better match demand. The study done by A. Hafner et al [3] showed that using a CTES with the coolant CO_2 allowed the refrigeration system to save 30% of the energy consumption.

3.2.2 Optimization measures in Fisheries

Other methods to achieve an overall better energy efficiency of the plant is discussed in S. Murali et al. [17] can be summarized:

- 1. Refrigeration system management
- 2. Automation of existing process line and overall workflow optimization. This can be done with proper timely switching on & off of equipment minimizing downtime of machines.
- 3. Energy generation from food waste. In regard of municipal and food waste generated from the food industry studies had the following quotes:
  - (Themelis et al., 2007) *One ton of municipal solid waste generates 50 Nm3 of CH_4 [...] Less than 10% of this potential is captured and utilized at this time in the US.*
  - (Lou and Nair, 2009; Venkat, 2011) *Uneaten food imparts 23% of all CH_4 emissions in the US, which has increased to 90%, thereby accounting for 16% of the total CH_4 emissions that originate from landfills in the US*
  - (Kumar et al., 2004; Dodman, 2009) *Municipal solid waste accounts for 11% of the total global CH_4 emissions (GHG with a GWP of at least 25 times greater than that of CO_2), and food loss contributes highly to this impact*

- (Waste and Resources Action Programme (WRAP), 2022) *the level of GHG emissions that would be reduced if food waste were prevented from entering landfills is equivalent to eradicating the operation of 20% of all the cars in the country, thereby reducing one-fifth of the GHG emissions generated by cars in the country* (United Kingdom).

  Thus, if the fisheries are to be more sustainable by lowering their emissions of CO2 (by wasting less energy and water on discarded food)and of CH4 (from landfills) it is clear that they must make the most out of the fish they process creating less waste and to treat the by-products and waste from the process. The study by M. Franchetti [26] claimed that a *two-stage anaerobic digestion system using ultrasound pre-treating was the most preferred system in terms of cost and greenhouse gas emissions* compared to the alternative of just dumping the food waste in landfills. The fishery on Pico will therefore have the goal of minimizing fish waste to prevent unnecessary energy waste and to have a plan to treat the fish waste to prevent it from being transported to a landfill.

- 4. Water optimization methodologies

Another study was done by K. Norne Widell [34] looked specifically at the batch freezing process in tunnel freezers and found ways to improve the efficiency. The author proposed the following measures:

- 5. Improving compressor work. For industrial ammonia systems, reciprocating and screw compressors are the most common. Reciprocating compressors can have more energy efficient capacity regulation and operation but require more service According to K.N. Widell. Screw compressors are more reliable and can also work across larger pressure differences. Screw compressors are also more common when larger cooling capacities are required. When only one screw compressor is necessary, compared with two or more reciprocating compressors, the investment costs will also be lower. A screw compressor has a built-in volume ratio, which does not necessarily correspond to the system pressure ratio. There will be non-productive work and losses if the pressure ratio between the discharge line and the suction line is different from the built-in ratio. The figure 22 shows overcompression and under-compression, where in both cases the losses come from unrestrained expansion of the gas. Due to pressure losses in the suction line, the refrigerant will be superheated when entering the compressor. This is lost refrigeration effect and the suction line pressure drop should therefore be minimized. Regular servicing of the compressors is necessary, to clean and exchange dirty and worn parts. Oil levels also need to be supervised. Too little oil in the compressor will lead to increased wear and higher friction.

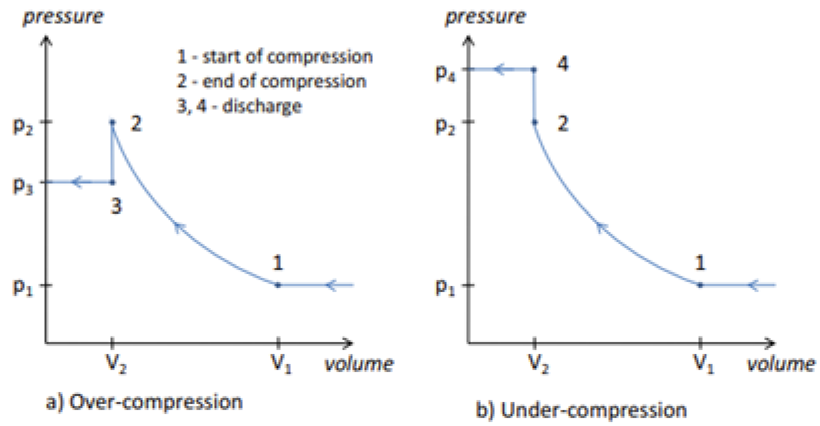


Figure 22: Figure showing the result of an over-compression and an under-compression. The excess work can be quantified with the area under the line. Image from [34]

- 6. Improving fan operation and air velocity field. In addition to requiring electricity, the fans will add heat to the refrigeration system. Installing the fan motor outside of the freezing tunnel would decrease the heat load, but only to a limited extent, since most of the heat would still be released inside the tunnel. Thicker and better insulation will prevent heat ingress through the walls, floor and ceiling of the tunnel. However, losses in efficiency from this heat transfer are small and it is more important to have a complete vapour barrier. Vapour inside the insulation will increase the heat transfer and could also damage the insulation (when it freezes). The largest heat leaks often occurs by the doors, so these should be properly constructed. If moist air leaks into the tunnel, this will lead to more frost on the evaporators. Batch freezing tunnels for fish, especially pelagic fish, often have very varied operation over a year. In some periods, the tunnels might be running for many days, with loading and unloading every day. Some defrosting may be needed during these periods. A uniform air velocity field inside a freezing tunnel provides uniform freezing times for products, but it is complicated to achieve. Products with uniform freezing times will have similar temperatures when they are transferred to storage facilities, which gives predictability. If products are transferred too early, after-freezing in the cold store is necessary and this will be slower than in the freezing tunnel. Longer freezing times ensure the correct temperatures, but will have higher energy consumption. Figure 23 shows the structure of a freezing tunnel where the air flows across a false ceiling, through the product racks and finally through the evaporators. The air velocity field can be improved by construction design changes. The general idea is to force the air to flow across the products, and not to take short-cuts where it does not remove heat. The challenge is where to place the extra baffles so that the velocity distribution is improved without affecting other operations, such as the loading and unloading of products. Alonso et al. (2011) simulated different design alternatives and found that a thick ceiling with a vertical guide plate was better than the normal (thinner) false ceiling. This design decreased backflow through the evaporator and increased velocities across the products. Kolbe et al. (2004) used plywood and plastic sheeting to prevent air by-pass in a freezing tunnel which resulted in 15% shorter freezing time and reduced fan energy use of 6%. The freezing times of the products were also more equal.

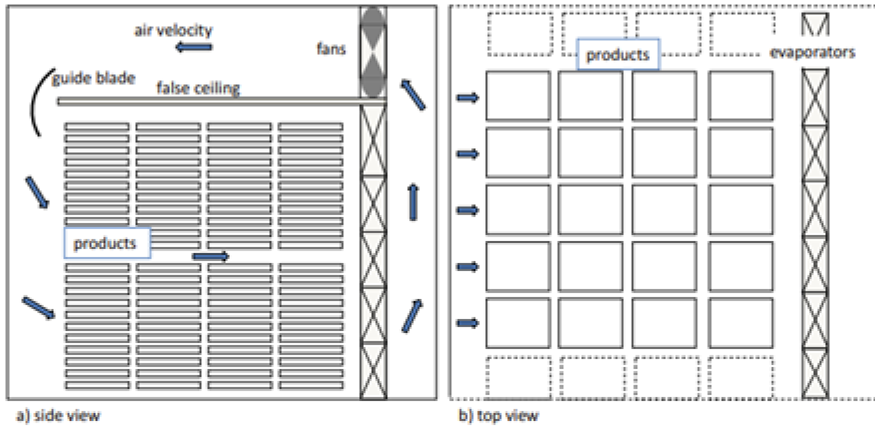


Figure 23: Figure showing the airflow in a freezing tunnel with produce. Image from [34]

- 7. Reducing heat loads. Energy saving measures of an existing system can begin with reducing heat loads, which will reduce the cooling demand. The different contributors to the heat load have to be surveyed to determine where most savings can be had. In an air-blast batch freezing tunnel, heat loads are typically distributed as is shown in figure 24. Other heat loads include insulation ingress, air infiltration, equipment, etc. Pull-down heat load is present if the tunnel has been off. Heat loads from people, trucks and lightning should be excluded during the freezing period. Installing the fan motor outside of the freezing tunnel would decrease the heat load. The largest heat leaks often occurs by the doors, so these should be properly constructed. If moist air leaks into the tunnel, this will lead to more frost on the evaporators.

product	50–80 %
fans	10–40 %
pull-down	< 10 %
defrost	< 5 %
other	< 5 %

Figure 24: Table of the components that contribute to the heat load and their percentage, for air-blast freezing (Valentas et al. 1997)

- 8. Integration with a heating system. The vapour compression system pumps heat from a cold area to a warm area. The cold side is the main focus, but if the excessive heat is used cleverly, total system energy consumption can be decreased. The main heat sources are the compressor oil cooling and the condensers. Compressors in industrial refrigeration systems need oil for lubrication and seals between the moving and static parts. After the compressor, the oil is separated from the refrigerant. Since the refrigerant and the oil are heated in the compression process, it is necessary to cool the oil before re-injecting it into the compressor. Typical oil temperatures are 50 - 70C. K.N. Widell indicates that 25% of the total heat input (compressor work and refrigeration load) is absorbed by the oil cooling system. Even though the temperature is not very high, it is enough for preheating cleaning water and for floor heating. Condensing temperatures are about 20$\circ$C and the exergy of this heat is therefore low, but this heat could be used with a heat pump to heat buildings or a swimming pool, for example.

- 9. Optimizing with cold thermal energy storage (CTES): Carbon dioxide is frozen in a shell and a tube heat exchanger and used later in the process when the compressor is off, see figure 25. The part-load operation of the compressor can thus be avoided. They found that 30% of the energy consumption can be saved by using this system instead of a conventional system where the compressors are operated at part-load during the freezing process.

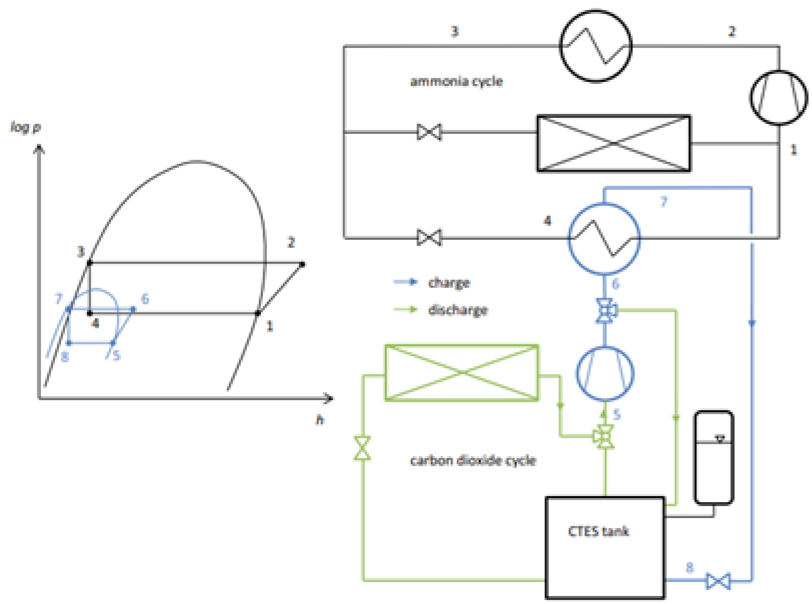


Figure 25: Figure of a refrigeration system with a CTES. Image from [34]

The author looked specifically at Tunnel freezers but these measure can be implemented for a air-blasting chamber which requires compressors and condensers too.

3.3 The challenge of using renewable energy today

Variable Renewable Energy (VRE) can be characterized by the following 5 factors according to the IEA, see report [2]:

- Their maximum output fluctuates according to the real-time availability of wind and sunlight.
- These fluctuations can only be predicted fairly accurately up to a few days in advance and forecasts improve greatly if they are only for a few hours ahead.
- They connect to the grid via power converter technology. This can be relevant in ensuring the stability of power systems, for example following the unexpected shutdown of a generator.

- They are more modular and are deployed in a much more distributed fashion.
- Unlike fossil fuels, wind and sunlight cannot be transported, and locations with the best resources are frequently at a distance from load centres.

	Wind power	Solar PV
Variability at plant level	Often random on subseasonal timescales; local conditions may yield pattern.	Planetary motion (days, seasons) with statistical overlay (clouds, fog, snow etc.)
Variability when aggregated	Usually with a strong geographical smoothing benefit.	Once "bell shape" is reached, limited benefit.
Uncertainty when aggregated	Shape and timing of generation unknown.	Unknown scaling factor of a known shape.
Ramps	Depends on resource; typically few extreme events.	Frequent, largely deterministic and repetitive, steep.
Modularity	Community and above.	Household and above.
Technology	Non-synchronous grid connection and mechanical power generation.	Non-synchronous grid connection and electronic power generation.
Capacity factor	Approximately 20% to 50%.	Approximately 10% to 25%.

Figure 26: Advantages and disadvantages of solar and wind power. Inspired from report by IEA [2]

An issue to bear in mind is the challenge of balancing the power systems from the perspective of the network. Installing large sources of renewable energy means an intermittent source of power which can be a problem if the network cannot match the demand with the output. This raises the aspect of energy flexibility. Flexibility, in power systems, is usually associated with fast ramping-up generators. But balancing a power system network is not just about energy production sources. While existing power plants are important for the grid, other resources that can be used for balancing are storage and demand-side management. Interconnection to adjacent power systems and grid infrastructure can also provide flexibility by smoothing variable generation and linking distant flexible resources together. In addition, flexibility often has several aspects. A power plant is more flexible, if it can: 1) start its production at short notice; 2) operate at a wide range of different generation levels; and 3) quickly move between different generation levels. VRE can offer this flexibility to a certain degree. Sources outside the electricity sector can also contribute to flexibility. In the heat sector space and water heating improved by thermal storage systems and co-generation can create opportunities to meet more volatile net load. Electric vehicle (EV) fleets may provide an opportunity for greater energy storage and enable better use of VRE output that is in surplus.

The IEA in their report writes the following: *The historical paradigm of power system operation can be summarised in a simplified form as follows: "We cannot control load, so we must control generation to keep the lights on. VRE is not controllable, so we cannot use it as a main source of electricity." However, this view neglects the fact that all power systems already command a significant amount of system flexibility to balance power demand.* (see figure 27) *Indeed, demand itself is variable, only partially predictable, location-constrained, often small scale and non-synchronous. Differently put: demand and VRE generation have similar properties. Consequently, the same resources that are used to balance demand may be mobilised to integrate VRE.*

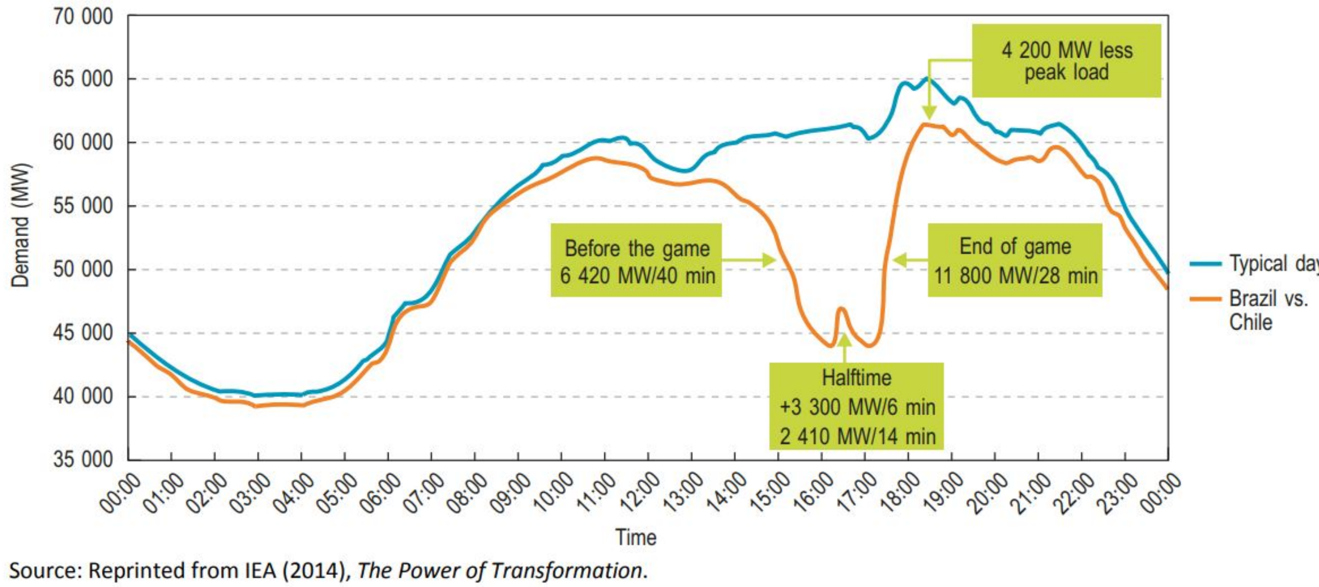


Figure 27: Example of how the demand can fluctuate greatly, similarly to how VRE can produce, [2].

The inverter is an important component of the PV system. In addition to converting the direct current into alternating current, it ensures that so-called islanding cannot occur. Islanding means that the plant continues to supply energy in the event of a grid failure. In order to avoid personal danger for those working with the grid, the inverter must interrupt the power supplied by the solar plant in the event of a power failure at grid. If the frequency or voltage of the grid does not remain within certain limits the inverter must disconnect from the grid. A study done by J. Benjaminsson and L. Hodzic evaluated the effect of installing a solar park on the voltage and power of the network [13]. In this study the authors simulated the installment of 765 kW of solar power and analysed the effect on the network. As a general rule of thumb, the results of the study suggest that the installed power in total well could be equal to the average power during periods of low energy use. The results also show that certain plants may produce relatively large amounts of energy without inducing inappropriate impact on the voltage levels. Energimyndigheten issued a report written by T. Walla et al. [18] which point to that about 30% of the annual consumption in local electricity grids can be accounted for by solar-generated electricity while maintaining power quality.

3.4 A method to increase the sustainability in industries

There are several ways to integrate VRE into a grid. In this thesis, the study was focused on integrating the VRE to factories. A study done by Muster-Slawitsch et al. [8] devised a plan to integrate VRE into existing breweries. The authors used a step-by-step approach to take a traditional brewery to a more sustainable one with optimised energy flows and renewable energy sources. Another term for the strategy is a "pinch"-analysis which is a methodology for minimising energy consumption of processes by calculating energy targets and achieving them by using heat recovery systems, energy supply methods and improving operating conditions. Below is the matrix the authors used to achieve the sustainability transition, see figure 28.

Methodology for a Green Brewery

Steps	Methods	Results	Corresponding section in the Green Brewery Concept
Data aquisition	- On-Site visits - Network of important measurements	Thermal energy streams (load profiles of energy demand and availability) & existing storages	Section 1.1 Checkpoints – entry of key figures
Energy demand analysis - Energy balancing - Comparison of actual demand figures vs. benchmarks - Identification of process efficiencies, distribution losses	- Thermal energy balance -Benchmarking - Calculation of thermodynamic minimum energy demand	- Thermal energy balance - Identification of areas with high optimization potential	Section 1.1.a – 1.1.e Thermal energy balance of each production area Section 1.2. Checkpoint Analysis – Benchmarking and visualisation of process inefficiencies Section 1.3. Overall thermal energy balance, visualisation of distribution losses
Energy demand reduction - Process optimization/ technology change - Heat integration	- Cleaner Production measures - Technology evaluation - Pinch Analysis incl. storage considerations - Annual load curves of remaining thermal energy demand by temperature levels	- Identification of savings due to technology change - Heat Exchanger Network - Exergetic analysis of remaining energy demand profile	Section 2.1 – 2.4. Catalogue of energy efficient technologies & optimization measures (brew house, packaging, boiler house, cooling.) Section 1.4. Generic list of heat sources and sinks & visualisation of heat integration potential
Integration of renewable energy	- Techno-economic evaluation for implementation of renewable energy resources - Specific design tools (T-Sol) for renewable energy implementation	Concepts for integration of renwable energy resources	Section 3.1. – 3.7. Description, potential & applicability of renewable energy integration (solar thermal, biogas, biomass, heat pumps, photovoltaic, district heat, geothermal energy)

Figure 28: Matrix from the study by Muster-Slawitsch [8]

4 Method: Creating a sustainability report

4.1 A Methodology how to integrate renewable energy into two factories

The method which was used to assess the integration of renewable energy to the industries is one inspired from the study by B. Muster-Slawitsch et al. [8]. In this thesis, a similar methodology was used but in a modified way which allows it to be used for any industry within the food and beverage. The methodology was also used as a tool to plan a future factory. Using the step-by-step approach to support the design of the factory. The modified methodology can be summarized in the matrix shown below in figure 29. Some simplifications were done to the old matrix, see figure 28, by [8] to have a more generic approach so that the terms are applicable for industries other than breweries.

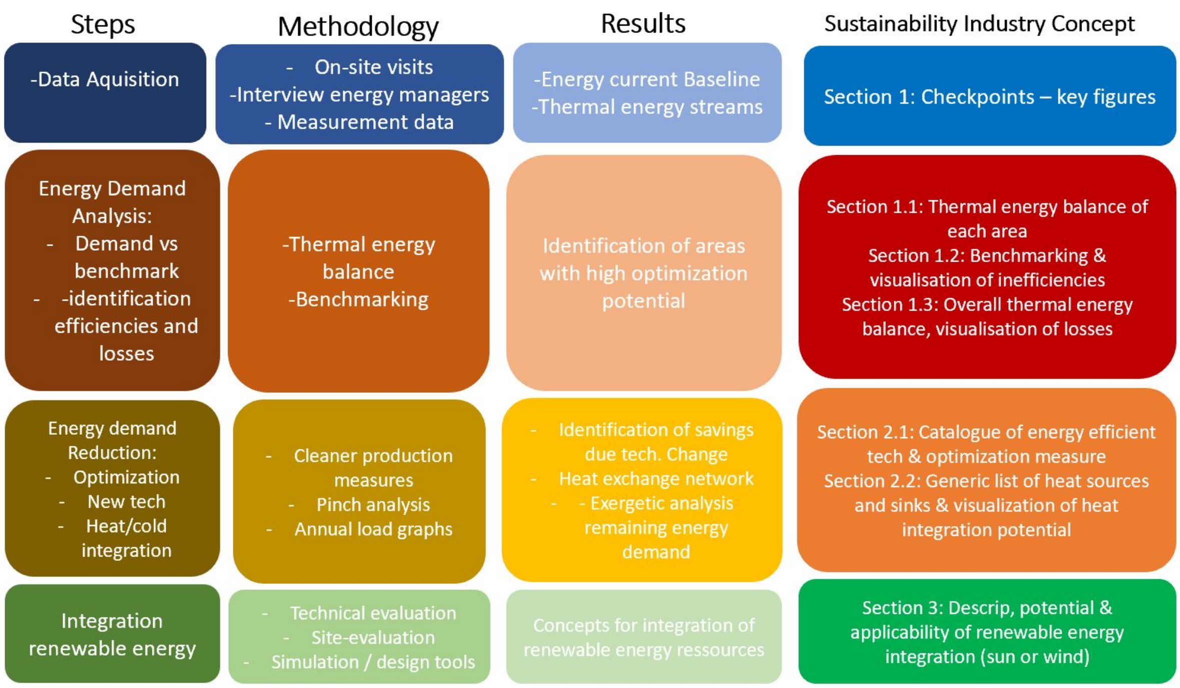


Figure 29: New matrix used in this thesis for a sustainable industry adapted from figure 28

The matrix is divided into rows and columns. The columns being: Steps, Methodology, Results and the drafting of the sections of the so-called "sustainability report". The sections within the Steps-column are the goal to be achieved in each row. The methodology is the approach which will be used to have material and data to reach the goal presented in Steps. Results is the summary and illustration of the data which has been obtained. The sustainability industry concept is the report with each section (or row) being the different chapters of the report produced at the end of the study. This report acts as a summary and a final text which gives the feasibility of integration of renewable energy and quantifying the improvement. For this thesis, this matrix was applied to two different cases to assess its effectiveness and potential applicability for other sectors. First one being an existing brewery and the other one being a fishery yet to be built.

4.2 "Section 1": Mapping the energy and mass flows

The first section of the report consists of an energy and mass balances. These were defined from data obtained by the technical department of the factory (brewery), interviews with relevant workers, measures taken at the site etc. The goal of the section 1 is to create an accurate depiction of the activity of the factory so that the next section, section 2, will have a background to analyse possible improvements. For the case of the fishery, the use of benchmark values will be used for the section 1. In this way the fishery will have reference values to start with and that will be improved in section 2.

4.3 "Section 2": Identification of optimization potential

With the energy consumption and material flow mapped in section 1, section 2 attempts to find measures to reduce this consumption and minimizes flows. A series of potential measures will be studied for each case: for the brewery the list of optimization methods mentioned in Section 3.1.2. and for the fishery the measures in question are listed in 3.2.2
The point of section 2 is to offer a trimmed factory with improved processes leading to a lowered energy and material consumption while still having the same output.

4.4 "Section 3": Assessing the potential for renewable energy

Section 3 consists to take the new needs of the improved factory in section 2 and to cover them with the help of renewable energy. To do this, several sources are possible but for this thesis it was limited to the energy sources listed below, namely: wind, solar and bio-energy.

4.4.1 Wind power

There are a number of ways to assess the suitability to install wind power on a site. For this thesis the guideline set by the NREL were used, see the report written by T. Olsen [7]. The parameters looked at to assess the potential were the following:

- 1. Property boundaries
- 2. Owner/neighbour view impact
- 3. Soil conditions
- 4. Construction access
- 5. Interconnection requirements and wire run routing
- 6. Safety
- 7. Wind Resource Data

Both for the brewery and fishery a study will be carried out of the prospect of building a wind turbine park next to the factory and have an ideal case to compare: thus, two locations will be studied for the wind energy production. The data which will be used for this matter will be taken from the resource Global Wind Atlas (GWA) which is an online tool developed by the Energy Sector Management Assistance Program (ESMAP), Vortex (private consulting company) and the Danish Technical University (DTU). The following description was taken from the GWA site to explain the method used by the tool to assess the wind energy potential: *The GWA uses a downscaling process. We begin with large-scale wind climate data and end with microscale wind climate data. The large-scale wind climate data is provided by atmospheric re-analysis data, in GWA version 3, the ERA5 dataset from the European Centre for Medium-Range Weather Forecasts (ECMWF) is used for the simulation period 2008-2017. The data are located on a grid with a spacing of approximately 30 km. This data is used to force the WRF mesoscale model using a grid spacing of 3 km. We perform a generalization process on this data. The result is a set of generalized wind climates that have the same spacing as the mesoscale data that was used to create them. Next, we take this set of generalized wind climates and apply them in our (DTU Wind Energy) microscale modeling system over the globe (except the North and South Poles and far offshore ocean areas).*

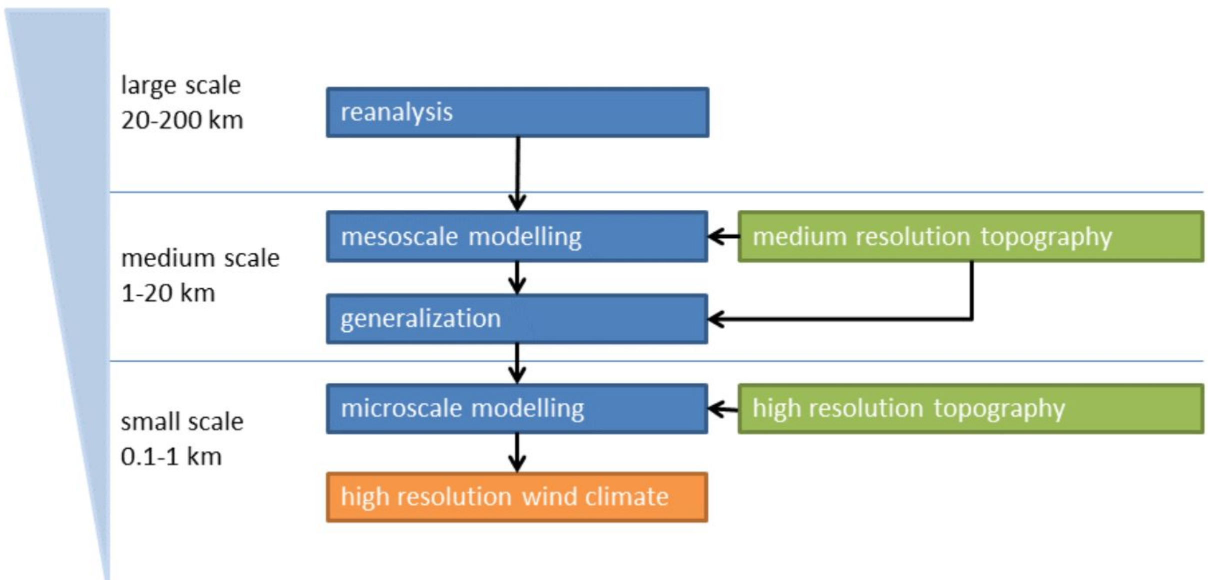


Figure 30: The Downscaling-method used by GWA to assess the wind energy production for a certain location

The output will be calculated with the help of the average wind speed provided by the GWA and with the use of a Vestas 600kW wind turbine, model V44. Below is the power curve of the turbine, see figure 31:

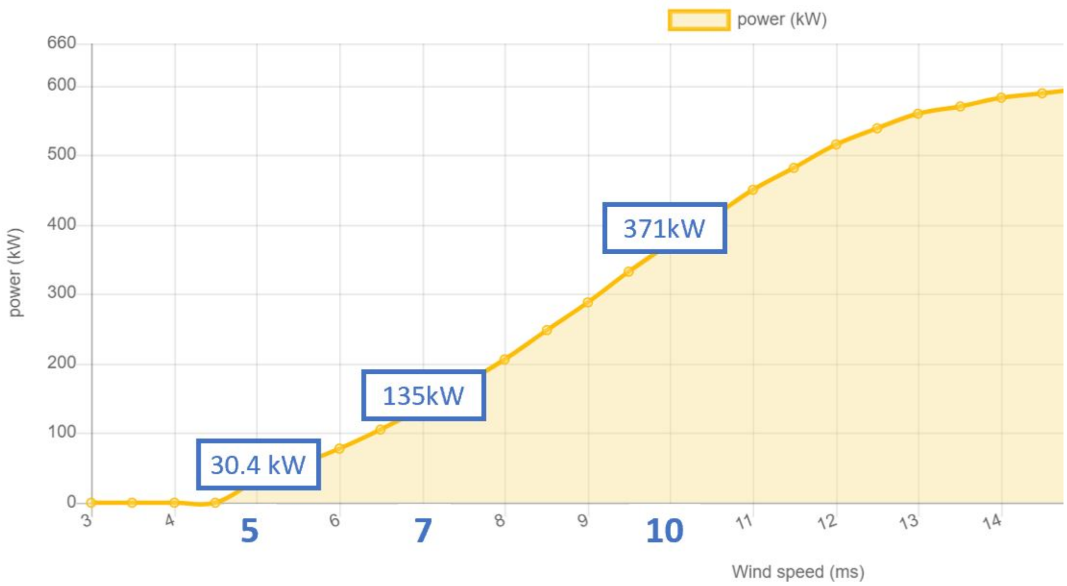


Figure 31: Power curve of the Vestas wind turbine V44

4.4.2 Solar power and heat

To assess the production potential of a site one needs to find out the solar irradiation. This can be easily done with the help of the SOLARGIS resource. The tool calculates the yearly irridiation in three steps (see figure 32):
- First, the clear-sky irradiance (the irradiance reaching ground with assumption of absence of clouds) is calculated using the clear-sky model. - Second, the satellite data (information from several geostationary satellites) used to quantify the attenuation effect of clouds by means of cloud index calculation. The clear-sky irradiance is coupled with cloud index to retrieve all-sky irradiance. The outcome of the procedure is direct normal and global horizontal irradiance. - Third, direct normal and global horizontal irradiance are used for computing diffuse and global tilted irradiance (irradiance in plane of array, on tilted or tracking surfaces) and/or irradiance corrected for shading effects from surrounding terrain or objects.

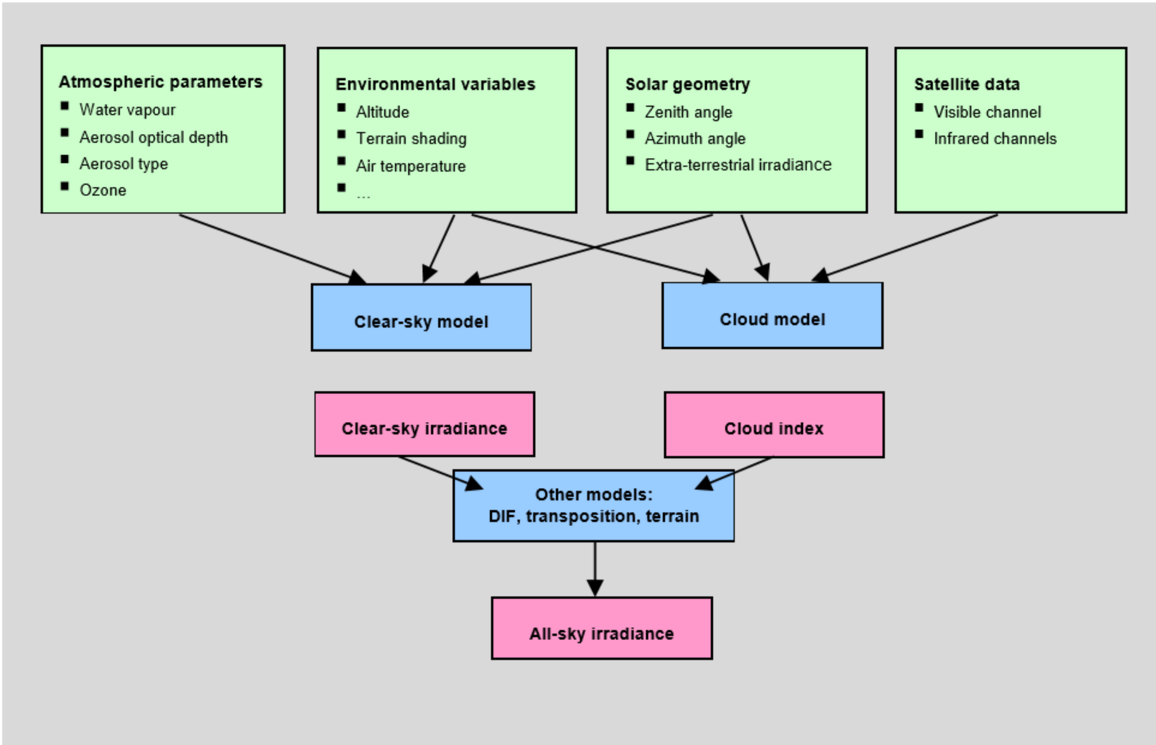
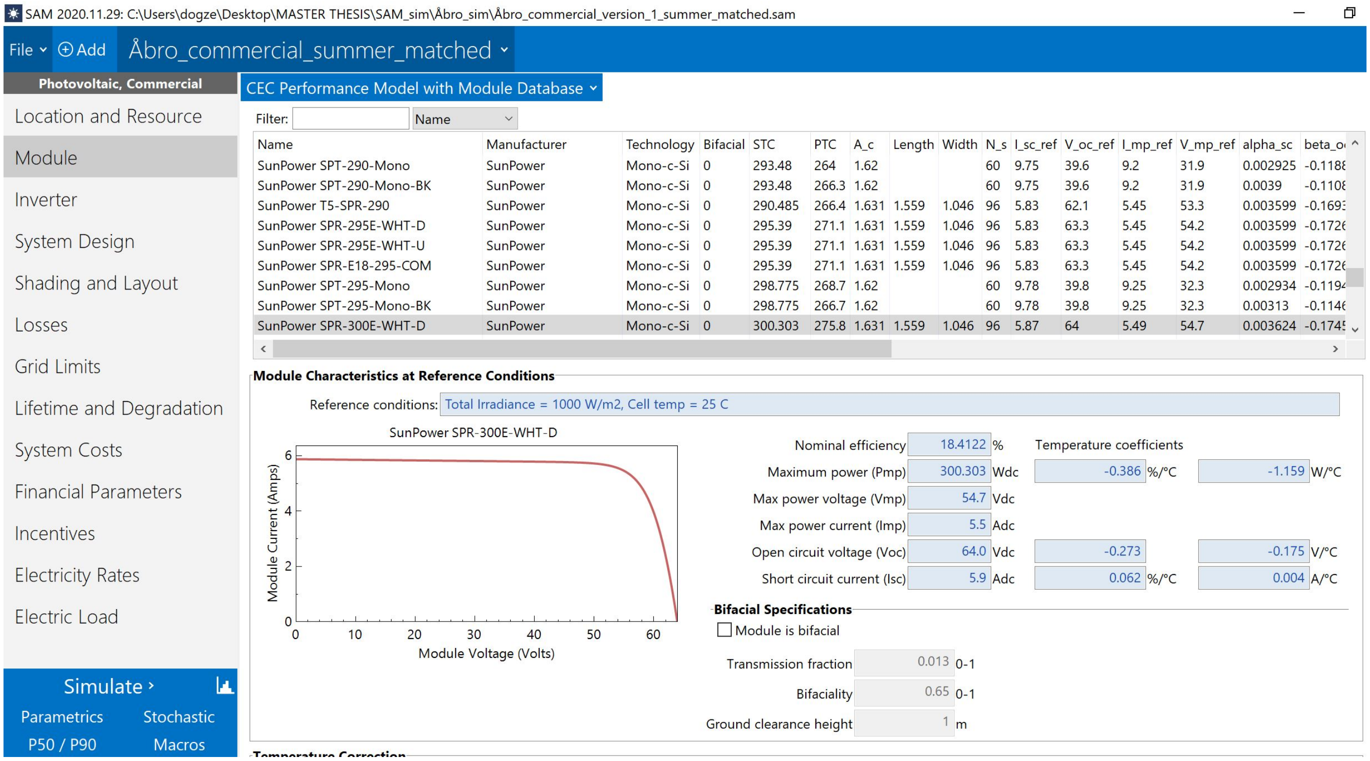


Figure 32: The algorithm SOLARGIS uses to produce a irridiation value for a certain location

The data from SOLARGIS is then used by several tools that can calculate the output of the solar park. One tool which was used in the thesis to assess the production from a PV-cell park is SAM software. This tool allows to choose a commercially available PV-module and inverter and to design the layout of the array. See below for pictures taken from the SAM software: figure 33, 34, 35. Knowing the yearly demand, month by month, of the factory the software is able to be used to match and find a suitable system, with module and inverter, to match the demand.



Name	Manufacturer	Technology	Bifacial	STC	PTC	A_c	Length	Width	N_s	I_sc_ref	V_oc_ref	I_mp_ref	V_mp_ref	alpha_sc	beta_o
SunPower SPT-290-Mono	SunPower	Mono-c-Si	0	293.48	264	1.62			60	9.75	39.6	9.2	31.9	0.002925	-0.1188
SunPower SPT-290-Mono-BK	SunPower	Mono-c-Si	0	293.48	266.3	1.62			60	9.75	39.6	9.2	31.9	0.0039	-0.1108
SunPower T5-SPR-290	SunPower	Mono-c-Si	0	290.485	266.4	1.631	1.559	1.046	96	5.83	62.1	5.45	53.3	0.003599	-0.1693
SunPower SPR-295E-WHT-D	SunPower	Mono-c-Si	0	295.39	271.1	1.631	1.559	1.046	96	5.83	63.3	5.45	54.2	0.003599	-0.1726
SunPower SPR-295E-WHT-U	SunPower	Mono-c-Si	0	295.39	271.1	1.631	1.559	1.046	96	5.83	63.3	5.45	54.2	0.003599	-0.1726
SunPower SPR-E18-295-COM	SunPower	Mono-c-Si	0	295.39	271.1	1.631	1.559	1.046	96	5.83	63.3	5.45	54.2	0.003599	-0.1726
SunPower SPT-295-Mono	SunPower	Mono-c-Si	0	298.775	268.7	1.62			60	9.78	39.8	9.25	32.3	0.002934	-0.1194
SunPower SPT-295-Mono-BK	SunPower	Mono-c-Si	0	298.775	266.7	1.62			60	9.78	39.8	9.25	32.3	0.00313	-0.1146
SunPower SPR-300E-WHT-D	SunPower	Mono-c-Si	0	300.303	275.8	1.631	1.559	1.046	96	5.87	64	5.49	54.7	0.003624	-0.1745

Figure 33: Screenshot from the SAM software. Image showing the "Module" parameters. Here the SunPower 300W module was selected

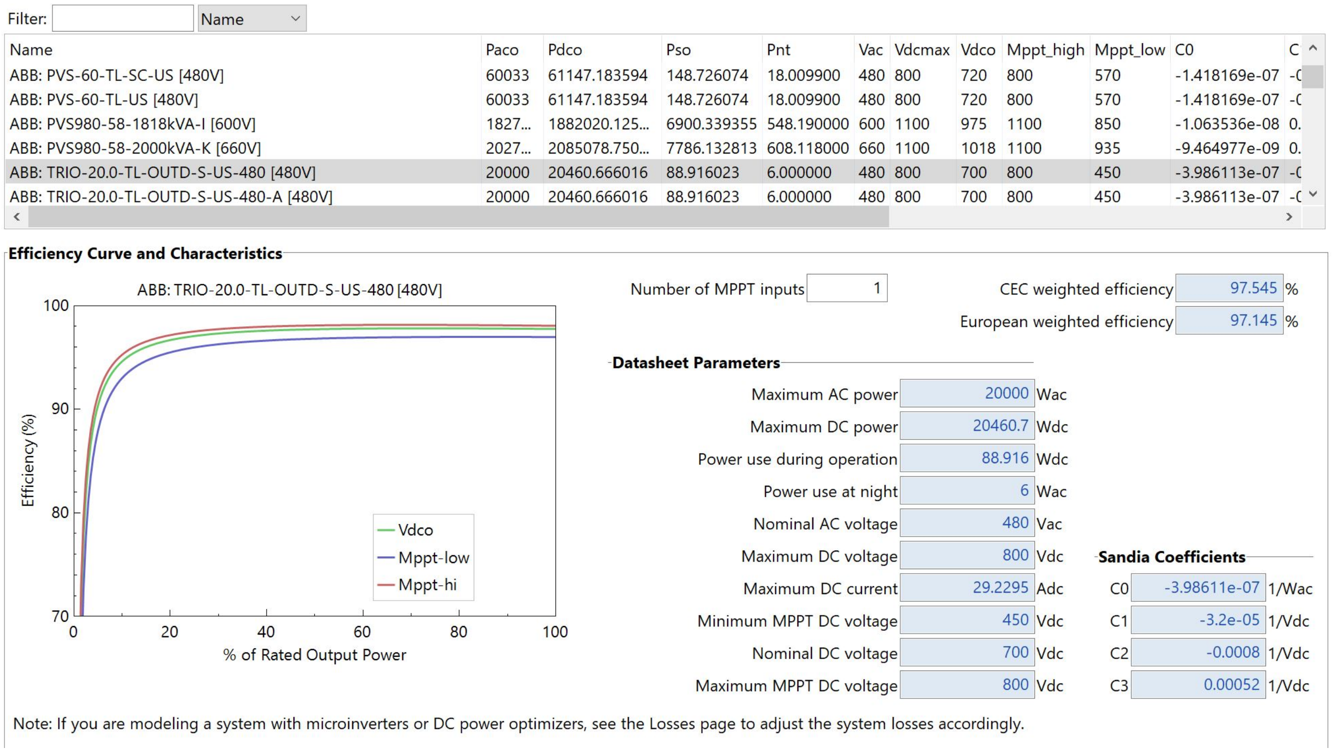


Figure 34: Screenshot from the SAM software. Image showing the "Inverter" parameters. Here the inverter by ABB was selected

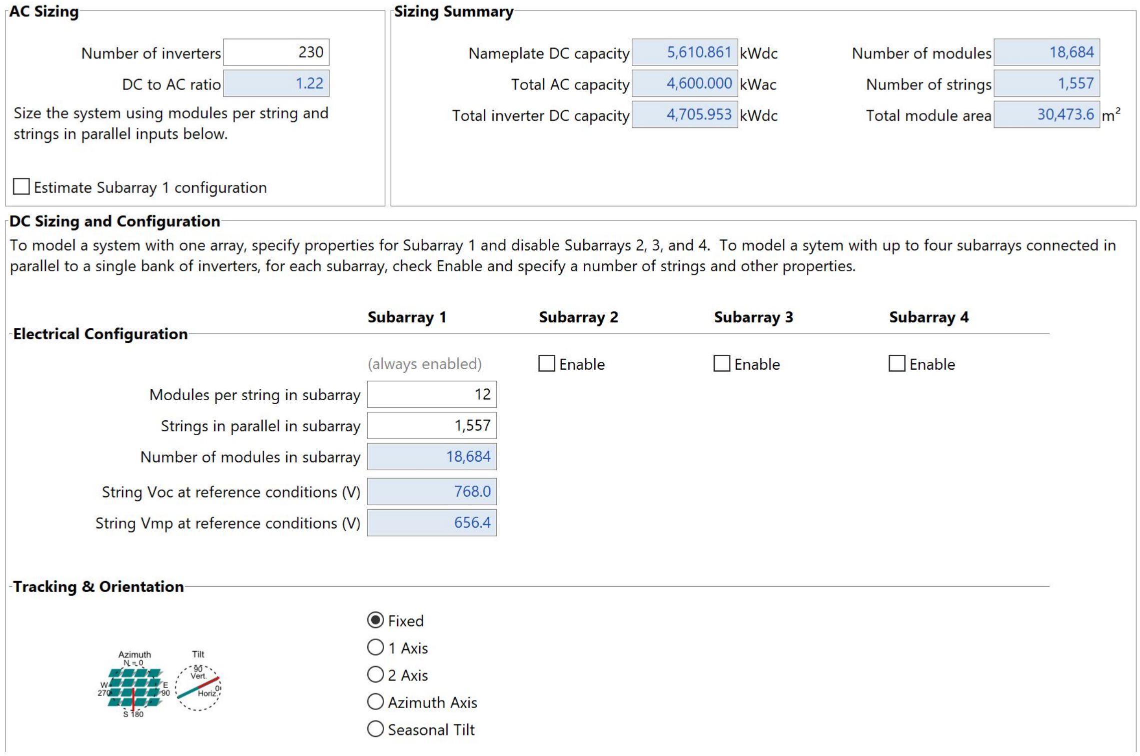


Figure 35: Screenshot from the SAM software. Image showing the "System Design" parameters

A limitation of the SAM software is that it is not able to show the production on a hourly basis. Therefore, the PVGIS resource on the European Commission site [21] was used as another tool to assess the PV-production, see figure 36.

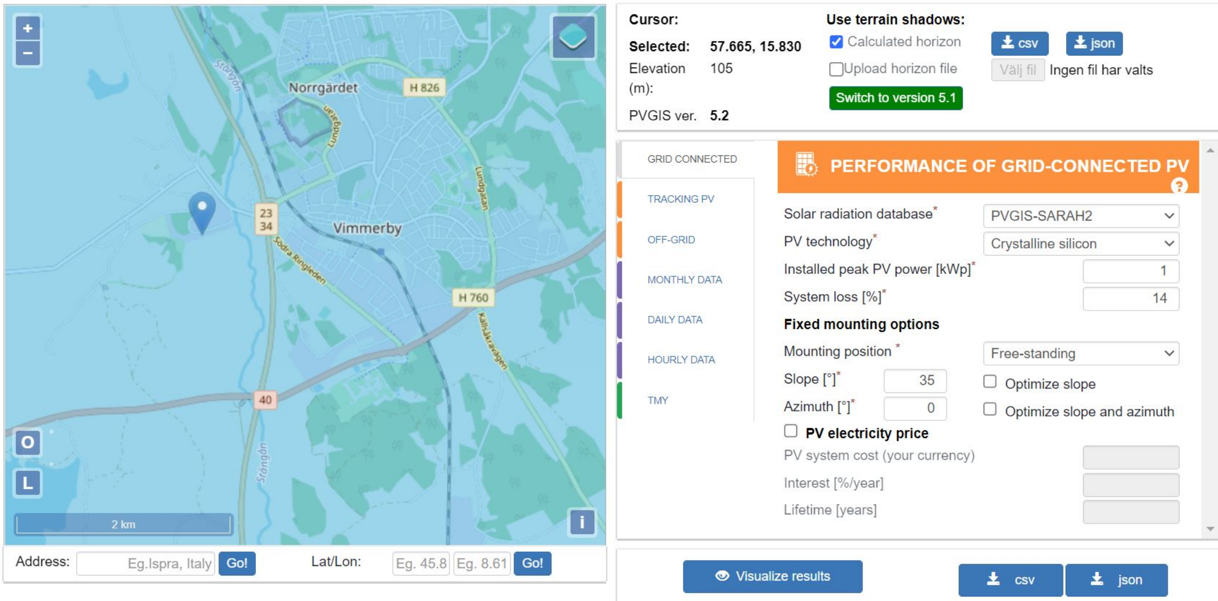


Figure 36: PVGIS tool which was a used for the calculation of the PV output on an hourly basis.

For the solar heat, the company Absolicon offers a simulator tool on their website which allows to calculate the yearly production of the solar collector park by choosing the size, operating heat, previous heating method, CO2-tax and efficiency of boiler. The simulator allows to choose a specific location in the world and uses the solar data from SOLARGIS to retrieve necessary solar constants. See figure 37.

Figure 37: Absolicon field simulator tool which calculate the output of a solar collector park (using their product T160)

4.4.3 Bioenergy

For both cases the potential for the use of the waste products for energy or other purpose will be evaluated according to the optimization measure on using waste for energy production mentioned in Section 3.1.1 for breweries and 3.2.2 for fisheries. For the brewery case the thesis looked into the study by [6] while for the fish the study used as a benchmark was [**empty citation**].

5 Results: Sustainable Brewery

5.1 Background: Vimmerby

Åbro Bryggeri is one of the main breweries in Sweden. They are based in Vimmerby where they produce all their beer and cider. They own a network of restaurants under different branding to promote their new products and as a platform to gather customer feedback. Most of the cider that Åbro produces is shipped to Great Britain while most of the beer is sold on the domestic market. Åbro produces annually around 1.2 million hectoliters of beer, cider and softdrinks which puts it as a major producer in Sweden but at a small-size position among other European breweries: Carlsberg Group produced 120 million hectoliter of beer in Europe, 2021. For the purpose of the thesis a visit was done at the brewery in Vimmerby during the fall 2021. A report was also issued from which the data presented below comes from.

5.2 The Sustainable industry report

5.2.1 Section 1: key figures

(kWh)		KÖPT					PRODUCERAD	
Område	Affärsområde	El	FJV	ÅNGA	OLJA	Drivmedel	Sol-El	S:a (kWh):
Verksamhet	Bryggeriet	4 531 618	1 431 000	8 193 760	1 417 766		570 151	16 144 295
	Ciderfabriken	516 994	273 184					790 178
	Hyrda lokaler	920 000						920 000
								17 854 473
Transporter	Bryggeriet	327 063				1 912 000		2 239 063
	Ciderfabriken							0
								2 239 063
Byggnader	Bryggeriet	2 481 319	1 609 300					4 090 619
	Ciderfabriken	121 349	63 476					184 825
	Hyrda lokaler	50 000	110 000					160 000
								4 435 444
	TOTAL (MWh):	**8 948**	**3 487**	**8 194**	**1 418**	**1 912**	**570**	**24 529**

Figure 38: Table from the energy report given by Åbro. It summarises the consumption and the production of energy over the whole factory.

The biggest consumers of electricity in the brewery (top 80%) are summarized in figure **??** is the product processing before the brewing: 19%, lighting: 15% and cooling of the beer: 13% and dehumidification: 12%. These 4 posts represents 60% of the total consumption of power. In regard of heat according to the report, the brewing part of the line represents more than 60% of the overall heat consumption. The two other sectors that uses the most heat is the air conditioning and the heating of the products for the brewing (both represents 10% each). The other sectors are heating of buildings as well as cleaning of the bottles and pipes and more.

As established above the biggest heat consumer is the boiling of the wort. Below is a diagram (figure 39) illustrating the current system employed at Åbro.

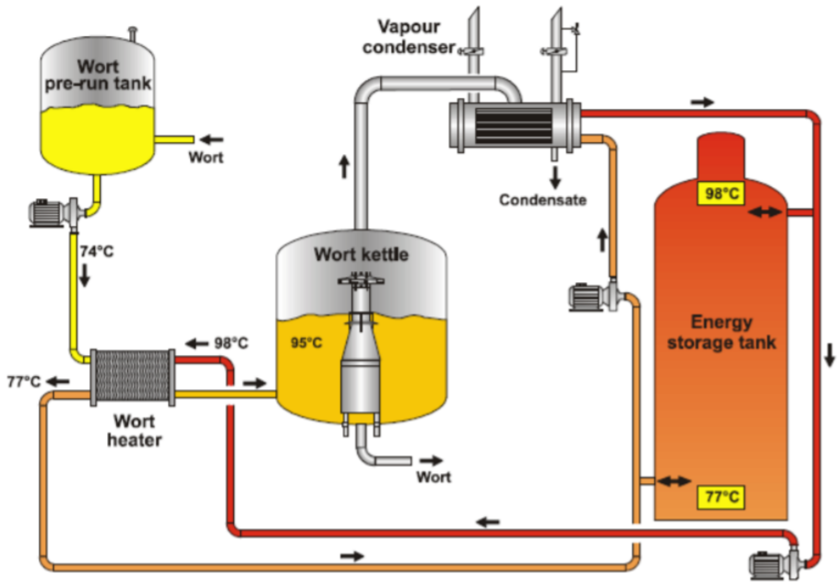


Figure 39: The boiling of wort process

The wort is preheated with an energy storage tank which is recharged with heat coming from the steam from the boiling.

In regard of the daily power usage, the power is overall constant. The reason for this is that the brewery works in batches which requires processes to run over a long periods of time: therefore the boiler might be on during the night and might be off at noon the next day of the next batch is still not started. During the weekends the brewery is closed down except core processes like fermentation and ventilation.

5.2.2 Section 2: optimization & recovery

After the data was gathered, the efficiency measure presented in section 3.2.2 page 27 were analyzed for the case of Åbro.

Measure 1. Improve the energy management A report by the EU commission explains the best available techniques (BAT) for the production of beer [5]. In this report the authors present the average energy consumption of standard breweries, see figure 40.

Department/ Process	Minimum	Mean	Maximum	Literature ([1])	Measured ([2])
	Figure			Range	
	(MJ/hl beer)			(MJ/hl beer)	
Brewhouse	87	92	121	84–113	50–80
Bottling installation	58	86	94	25–46	38–58
Kegging installation	8	11	13	8–13	NI
Process water	3	4	8	4–8	NI
Service water	NI	NI	NI	8–17	NI
Miscellaneous	NI	NI	NI	33–46	95
Total	156	193	236	162–243	183–233
	(kWh/hl beer)			(kWh/hl beer)	
Brewhouse	24.17	25.56	33.61	23.33–31.39	13.89–22.22
Bottling installation	16.11	23.89	26.11	6.94–12.78	10.56–16.11
Kegging installation	2.22	3.06	3.61	2.22–3.61	NI
Process water	0.83	1.11	2.22	1.11–2.22	NI
Service water	NI	NI	NI	2.22–4.72	NI
Miscellaneous	NI	NI	NI	9.17–12.78	26.39
Total	43.33	53.62	65.55	44.99–67.50	24.44–64.72

([1]) 20 000 to 500 000 hl beer sold/yr.
([2]) 300 000 to 500 000 hl beer sold/yr.
NB: NI = no information provided.
Source: [35, Germany 2002]

Figure 40: Heat consumption for different brewery departments/processes, report [5]

What can be seen from this table is that the brew-house represents half of the total energy use. It is for this reason that the report recommends efficiency measures to be taken within the brew-house to lower the consumption.The European report recommends the use of low-temperature mashing, re-use of steam from wort-boiling as well as CO2-expansion: Åbro uses these three solutions to this day which explains it relative good grade compared to the European standard: The European average electricity needed to produce beer is of 53.62 kWh/hl compared to Åbro's 16 kWh/hl. See figure 45 for comparison with European counterparts.

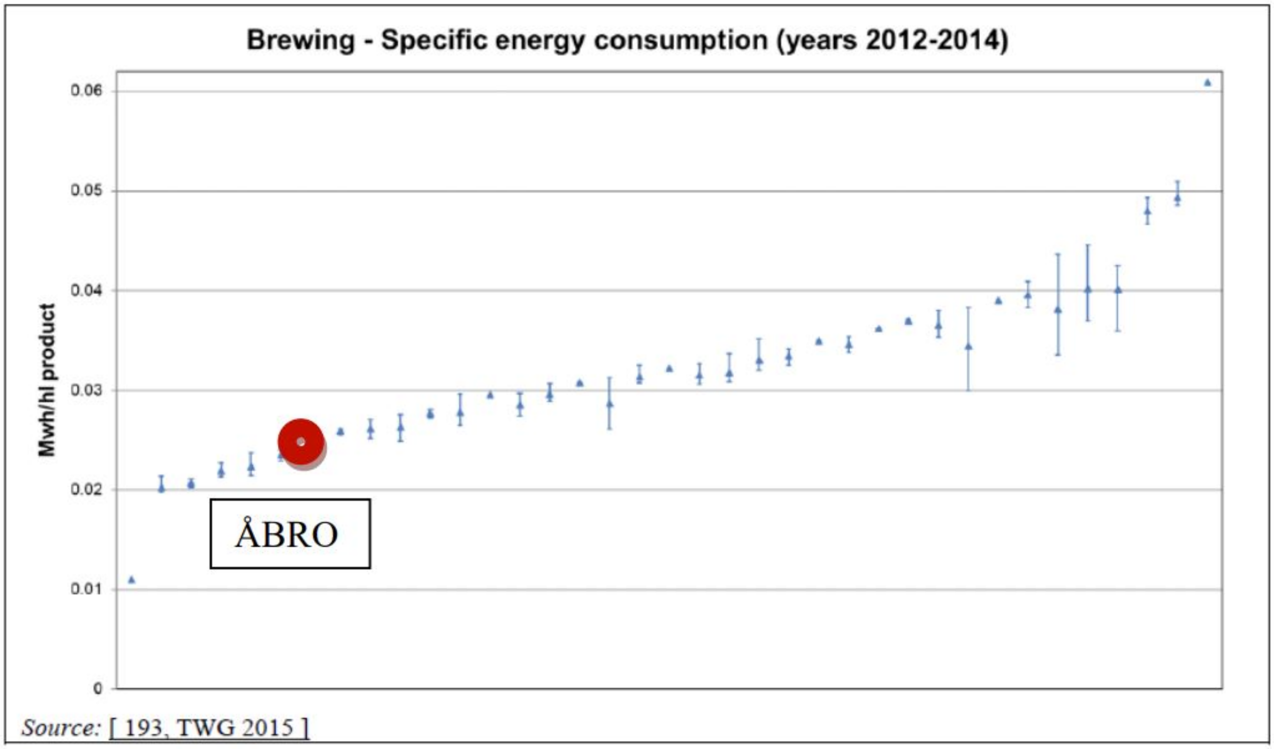


Figure 41: Åbro's specific energy consumption compared to the competition in Europe, study [5]

A measure that could reduce energy consumption is the brewing of a higher concentrate of wort and then adding water later in the process for the final product: this has the potential to save energy according to the report by [5]. Åbro has expressed no interest in using such a method since it would alter their recipe which, according to them (see interview A in annex), assures a higher quality in terms of taste compared to other brands.

The boiler has a system with heat exchangers which allows it to use waste heat, see figure 39. The wort is pre-heated in the so-called "wort-heater" before being moved to the Wort Kettle. This wort-heater is supplied with heat taken from the vapours released from the wort-kettle. Åbro brewery also made the decision to shut down their own oil-boiler and buy steam from the district heating: this required them to have a more stable consumption since the district heating plant requires planning. The consequence is that instead of having 100% of the steam volume supplied under 30min the district heating supplies steams so that 60% of the volume is received after 50min. With a more constant supply of the steam system it has the added benefit of having less load on the system. According to the report from the brewery, this new boiler system and management allows the boiler to save 500 [MWh/year] compared to before the changes.

Another choice that Åbro made to reduce its overall energy consumption is the reduction of steam-use for processes that require "low-quality" heat. This essentially means instead of using steam which is a high-quality it suffices to use hot water from the district heating network to do processes like heating of buildings or cleaning of work area. This has allowed Åbro to reduce the use of the oil-boiler and instead import more heat from Vimmerby Energi which uses biomass to fuel its own boiler. This had the effect of increasing the overall sustainability of the brewery by having more biomass as a source of energy.

The brewery has also made efforts to reduce energy consumption during the christmas break: during which the factory works at minimal levels due to workers being on leave. After remotely shutting-down some systems, a walk in

Measure 2. Improve boiler system Åbro has had a boiler since 2010 which allowed a good degree of waste heat utilization. But in 2015 they changed the system due to maintenance and has the layout as shown in figure 39. The latest data from 2020 shows that the boiler has a steam use of 123 kWh/m3 of beer compared to the old 148 kWh/m3 from 2010.

Measure 3. Implement use of waste heat and cold A list of the heat processes with reuse of waste heat-potential was made. Below is a figure 42 listing these processes.

Heat Source	Included in recovery system? [Y/N]	Energy [MWh/year]	Temperature [C]	Potential for recovery [High/medium/low]
Waste Heat Spent Grain	No	?	75	Low
Vapour at Boiler start-up	Yes	?	100	-
Vapour Condensation Boiler	Yes	303	110	-
Wort Cooling	Yes	1,708	86,2	-
Waste water bottle & keg washer	Yes	285	100	-
Waste water Pasteurizer	Yes	2,314 [kWh/batch]	80	-
Waste heat from air compressor	Yes	250	75	-
Waste heat from boiler flue gas	Yes	994	130	-
Waste heat from discarded water	No	3,350	22	Low
Waste heat condensation from coolers	Yes	307	30	-

Figure 42: Processes within the brew-house with potential for use of waste heat.

Pasteurization can be done in essentially two ways: either in a tunnel pasteurizer or through a heat exchanger. In a tunnel pasteurizer the bottles and cans are sprayed with hot water at 80°C while in a heat exchanger the beer is heated by passing through the heated tubes of the heat exchanger. Åbro uses a pasteurization machine which pasteurizes bottles and cans in batches. The waste water is then recuperated and sent to the heat exchanger. This way, the brewery saves an estimate of 2,314 [kWh/batch]. The same method is used for the cleaning of bottles and kegs: this allows the brewery to save 285 [MWh/month].

The bottling of beer is after the pasteurization and is usually done cold so to prevent foaming: this would limit the temperature of bottling and the speed in the process line. Åbro has implemented hot-bottling in its process to save energy in cooling. In practice, the beer is kept cooled at 5.6 °C instead of 1 °C, this allows the brewery to use the passive cool energy it is recuperating from other processes and not needing to use active energy: the brewery does not use extra energy to cool the beer after pasteurization. The savings are of the order of 120 [MWh/year].

Furthermore, Åbro has a series of condensers which it uses to cool down the beer. From those, an estimate of 1500 [MWh/year] of heat is passed through heat exchangers and is recuperated for the hot water tank.

With these measures implemented Åbro claims that 73% of the waste heat is reused in the process. Below is a figure 43 illustrating the extent of the heat recycling:

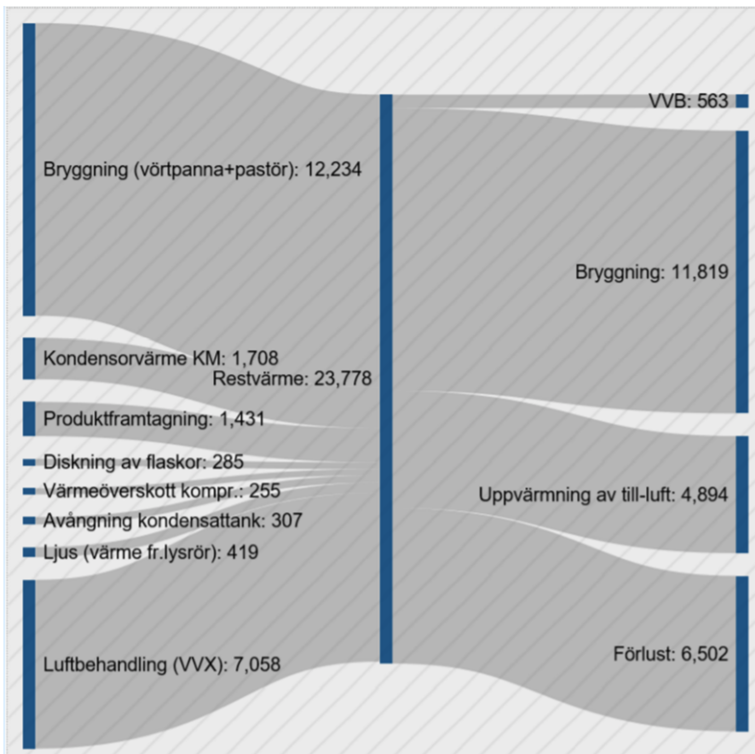


Figure 43: Waste heat distribution to each sector

The same approach has been used to the cooling system. Here the result is even higher with the cold being reused up to 97%. See figure 44 below:

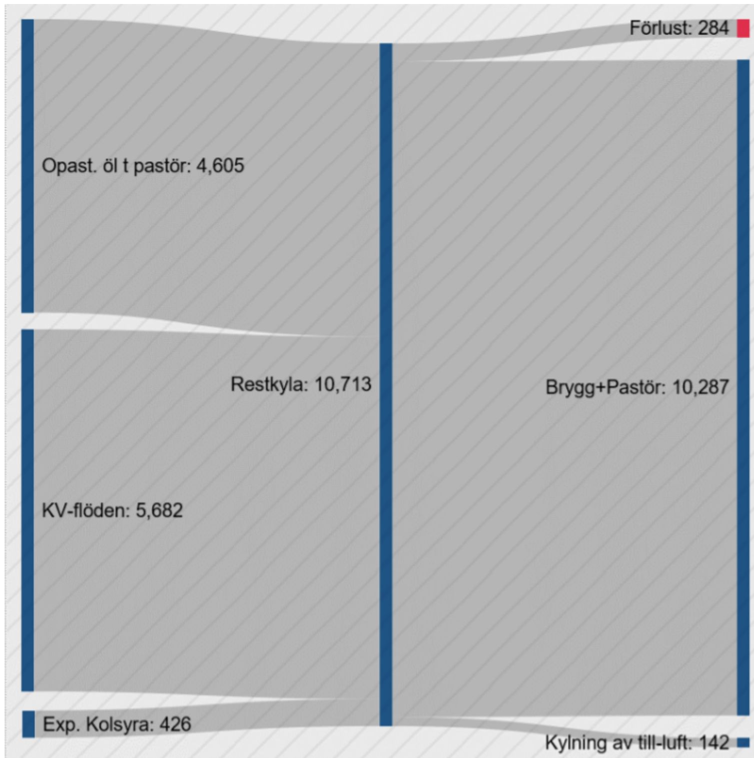


Figure 44: Waste cold distribution to each sector

For the compressors, water is used to cool down the ceramic seals: this means that a lot of heat is released into the cooling water which can then be used for cleaning water for Cleaning-In-Place (CIP).

Measure 4. Automation of processes In regard of electricity Åbro has used several measures to reduce its lighting consumption: Åbro has introduced LED-lighting on a industrial level and has been able to save a substantial amount of electricity: an estimation of 2/3 power-cut.

Furthermore, Åbro has a new set of radar-sensor which allows to monitor levels in tanks as well as liquid flow in pipes.

Measure 5. Water optimization Åbro brewery has access to its own water source which it pumps from the subterranean wells. Åbro has the goal to reduce water consumption in its policy. Below can be seen the specific water usage by Åbro compared to the other breweries in Europe.

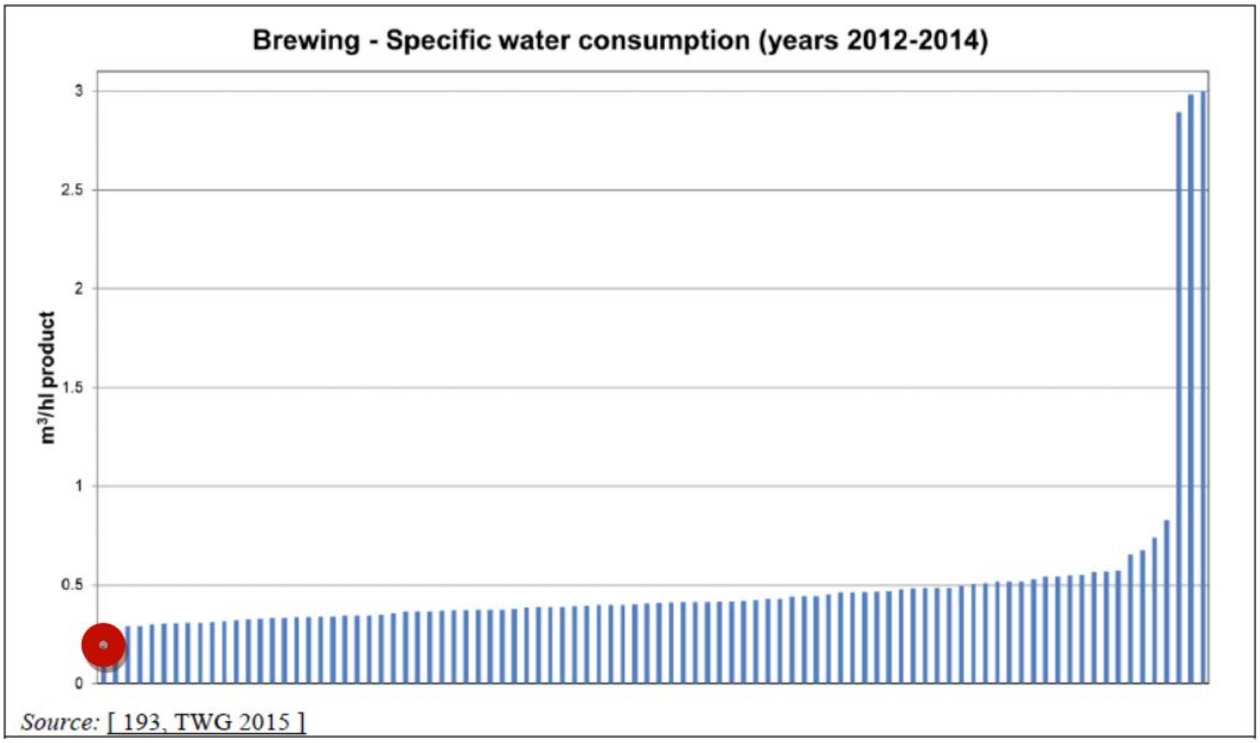


Figure 45: Åbro's specific water consumption compared to the competition in Europe, study [5]

By striving to use less water per batch, Åbro manages to consume less energy from a reduced need for pumping work. A reorganization of the CIP in the bottling area allowed for a reuse of existing water. Furthermore, water is then reused as technical-water, meaning water for the cleaning of surfaces.
The brewery has a set of compressors it uses to move the beer around and pump the hot water. These compressors need to be replaced after a certain time due to the usage of parts. The compressors were replaced in 2018.

Measure 6. Optimization of air ventilation and compressed air The ventilation and compressed air is also a position in a factory which utilises a substantial amount of electricity. At Åbro they made the decision to reduce the power consumption by coupling the cooling system with the preheating of hot water.

The specific energy use of the compressors has dropped throughout the years even thought the need for compressed air has increased. This was explained by a new smart system and a PLC code that optimizes the compressor by ensuring they are being used in their ideal cycle.

Measure 7. Energy use from by-products In the study by S. Głowacki et al. [6] the authors analyzed the embedded energy within the brewer's spent grain and estimated the energy that could be harvested. They estimated that 17 MJ are stored in the heat combustion per kilogram of dried grain. Knowing that Åbro produces around 1,000,000 of hectoliters of beer per year on average it is possible to estimate the amount of energy that could be harvested by the burning of spent grain in a boiler. See figure 46 below for calculations.

Potential Energy from Spent Grain	
Spent Grain	143 [kg/m3] *(S. Glowacki et al.)*
Amount of Beer	100,000 [m3/year]
Amount of Spent Grain (wet)	14,300,000 [kg/year]
Amount of Spent Grain (dry)	5,005,000 [kg/year]
Energy of Combustion	85,085,000 [MJ/year]
Energy from Boiler (90% efficiency)	76,577 [GJ/year] 21,273 [MWh/year]

Figure 46: Potential energy that would be delivered by using the spent grain as a biomass for a boiler

Åbro has considered to use the spent grain and the waste water as a source for biogas. This biogas can be used as fuel for heating or power production or used as a fuel for vehicles. A private company had done a study to assess the cost of building such a infrastructure: it amounted to 54 million Swedish crowns. The brewery writes the following in their report: (Translated from Swedish) *However, the cost of using biogas as a fuel is 3 to 5 times higher than if it is used for co-generation. Market value of biogas used as fuel for heavy-duty vehicles only increases by a factor of 2 compared to if the gas is used for co-generation. The costs for small biogas plants without access to a local market for heavy-duty vehicles are generally too expensive to be proportionate to the benefit to society. There is therefore no reason to include in these plants a specific upgrading to fuel.* Thus, even if the biogas were to be used as a fuel for the trucks run by Åbro, the advantage would not be in parity with the investment that the company would have to do.

Thus, after careful study of the consumption of Åbro, there seems to be no major savings to be made to their heat and electricity consumption. Therefore the heat and electricity demands that will serve as a basis for the next part of the sustainability report are the following figures:

Heat demand [kWh/year]	
District heating	3,040,581
Steam	8,193,760
Oil	1,417,766
Sum	**12,652,107**

Electricity demand [kWh/year]	
Brewing	2,893,512
Ventilation and cooling	2,242,689
Lighting	1,046,921
others	447,815
Sum	6,630,937

5.2.3 Section 3: description, potential & integration of renewable energy

The electricity consumption of 6,630,937 [kWh/year] will need to be met with renewable energy sources. There are a few possible renewable energy sources available for Åbro brewery to use: wind power, solar power and solar heating.

Wind power is a possibility for Åbro brewery. The on-site visit and meetings with the representatives of the brewery were helpful in this matter. Below is the location of the brewery in relation to the surroundings (figure 47 and a picture of the site where the wind turbines could be built: these lands are owned already by Åbro Bryggeri AB (figure 48).

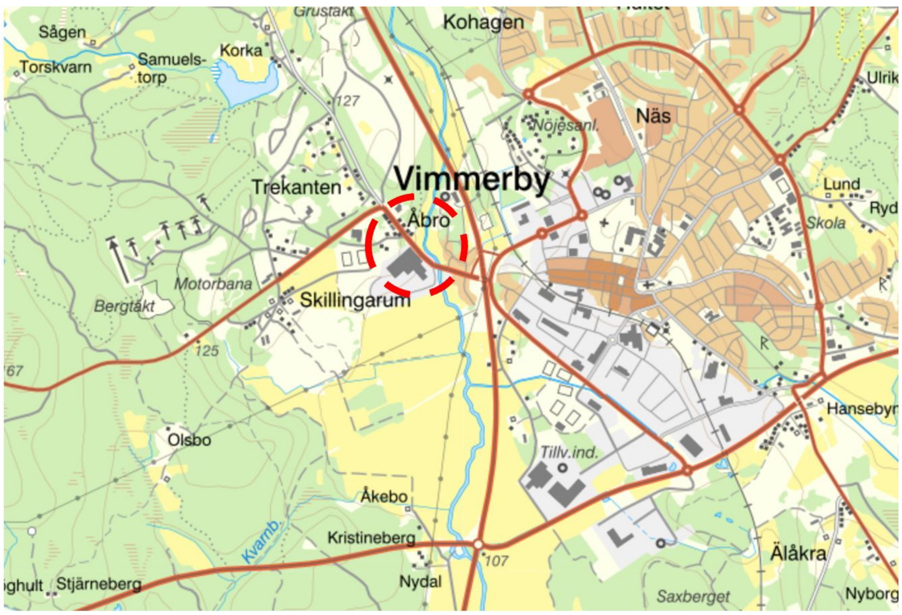


Figure 47: Location of Åbro brewery in relation to Vimmerby and surroundings. Image taken from Lantmäteriet.se and adapted.

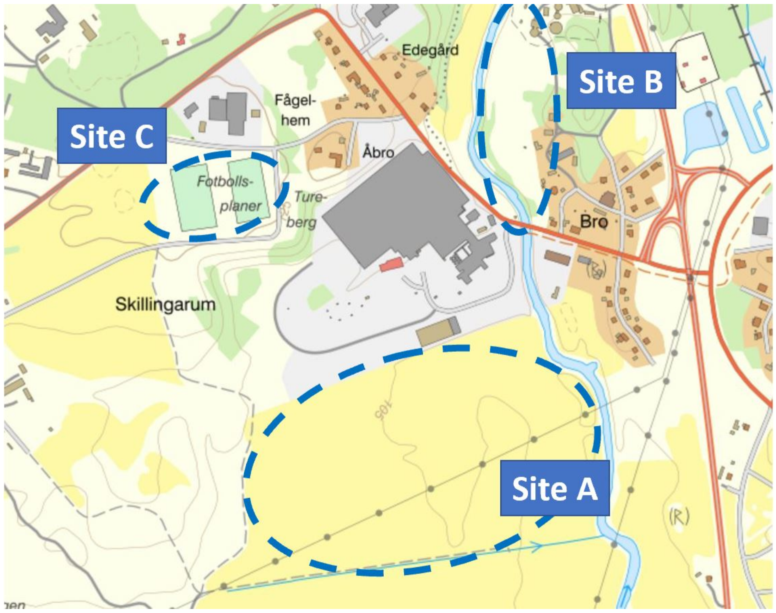


Figure 48: Location of the sites where the wind turbines could be set up. Image taken from Lantmäteriet.se and adapted

In regard of the parameters 1 to 6 on page 40, the three sites available are owned by Åbro and are wide enough which makes them potential candidates to house a wind turbine. The wind turbines would be close enough to the grid of the town and Åbro which minimizes the use of wires. The access to the roads also facilitates the construction. A few issues are to be considered however: looking at figure 48 it is obvious that site B and C are less than 100m from the road which makes them unsuitable. Site A is also close to the road but has an area that is at a safe distance from the road. In regard of parameter 7 a few points can be made by looking at figure 49 and 50. Land beyond the sites are covered in forest and hills this topography is not ideal for the prospect of a wind turbine farm. A land that is open and flat is to be desired. Site A is East of a large hill, proper space in between the hill and the turbine would be required for it to properly function and capitalize on the wind resource.

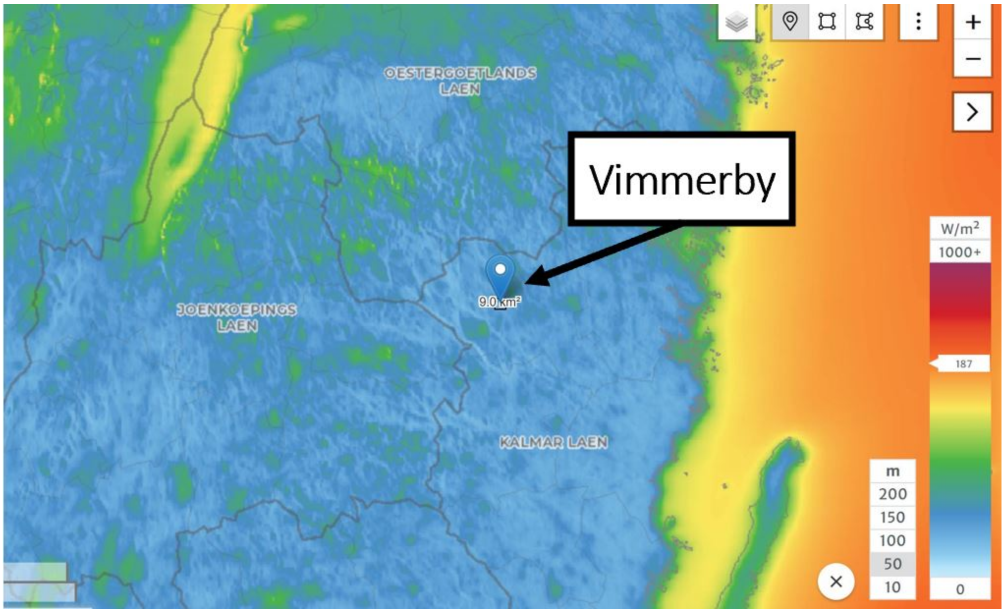


Figure 49: Map of the mean power density of central Sweden, showing as well the location of Vimmerby.

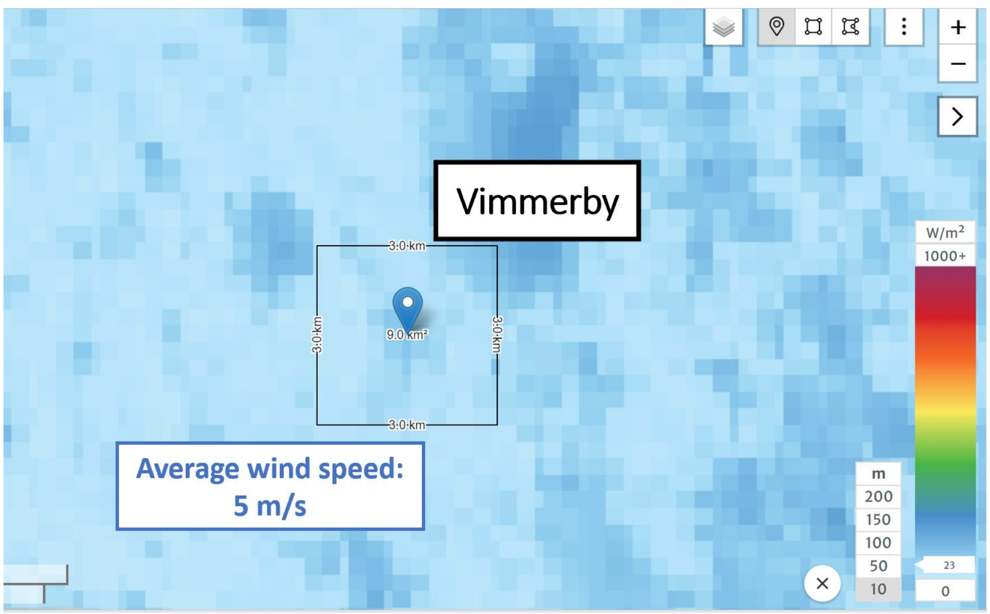


Figure 50: Map of the power density at the scale of Vimmerby: noting that the average wind speed at Vimmerby is of 5m/s on average

A quick calculation with the help of the power curve, see figure 31, shown in Section 4.4.1, shows the potential output of the Wind turbine:

$$W_{yearly} = P \cdot h_{year} \cdot C_f$$
$$W_{yearly} = 30.4 \cdot 8766 \cdot 0.25 = 66.62 MWh/year$$

Where W is the yearly output, P is the rated power at a specific wind speed, h the amount of hours per year and C is the capacity factor. In this calculation the factor was assumed to be 25%.

In regard of the yearly distribution of the wind speed, it was seen that the winter half of the year offers higher wind speeds, see figure 51. Furthermore, the wind speeds seem to pick up during the morning and the evening and is at its lowest during the peak sun hours, see figure 52

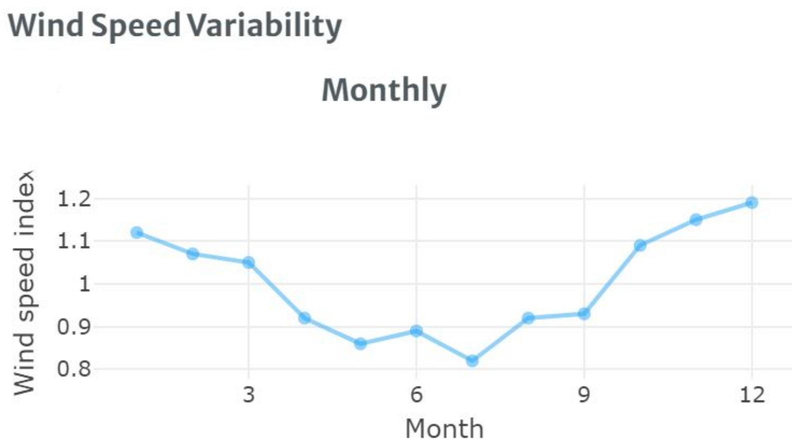


Figure 51: Wind index showing the annual distribution across the months

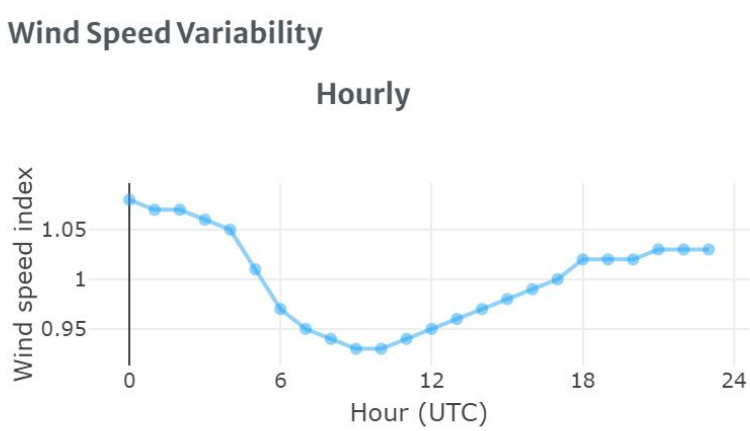


Figure 52: Wind index showing the daily wind resource across the day

$$W_{winter,month} = 30.4 \cdot 8,766 \cdot 0.30 = 79.95 MWh/year$$

$$W_{summer,month} = 30.4 \cdot 8,766 \cdot 0.20 = 53.3 MWh/year$$

A production of 79.95 MWh/month for the winter months and 53.3 MWh/month for the summer months represents respectively 11.5% and 8% of the monthly electricity demand. Should the Åbro Bryggeri have access to more land in the foreseeable future a construction of a wind park with a few 600kW turbines could help the brewery becoming more energy independent. Although this could be done it was deemed unlikely that the construction of wind turbines in the area of Vimmerby can be done. Therefore, wind power was excluded from the final energy balance for the brewery.

Below on figure 53 is a map of the solar irradiation of southern Sweden.

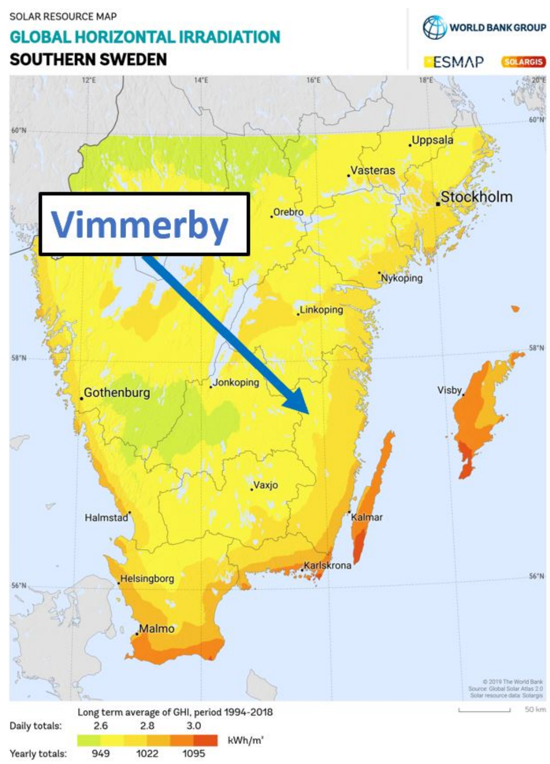
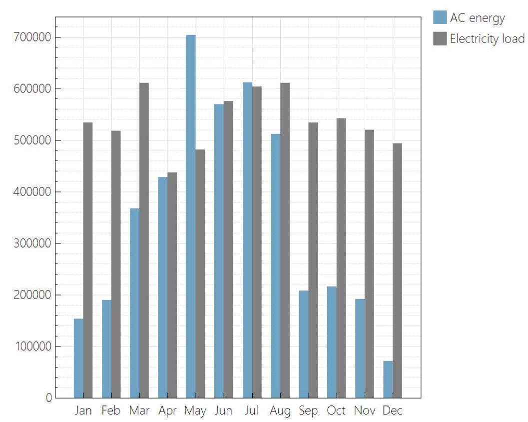


Figure 53: Map of Sweden with its irradiation. The data is from SOLARGIS. The yearly average irradiation is calculated with satellite images and taking into account the cloud coverage.

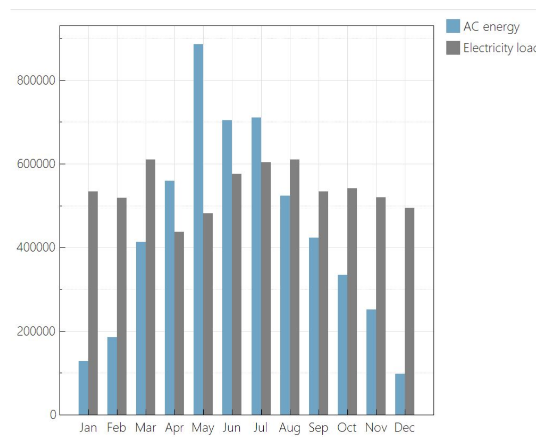
By using the SOLARGIS tool (available on their website) the irradiation of Vimmerby can be considered at 980 kWh/m2, which can be compared to the maximum Swedish irradiation of 1100 kWh/m2 on Gotland. With a modest irradiation, Åbro has the ability to utilize solar PV-cells.

By knowing the electricity demand throughout the year, we know that Åbro has a yearly consumption of 8,286 [MWh/year]. The demand throughout the year does not fluctuate since during the winter season the brewery stocks up on beer for the summer months where the demand for beer increases. The monthly demand was estimated with the help of historical values for year 2020 and by subtracting the wind turbine output that can be supplied during winter and summer.

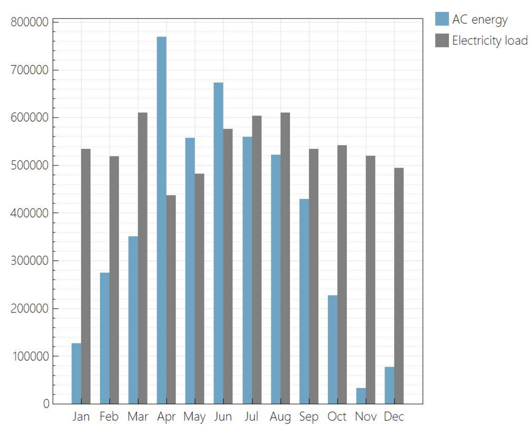
With the use of the software tool SAM, it is possible to estimate the size of the solar park needed to supply the brewery with enough solar energy to cover the demand for the summer months. Below is the figure **??** which shows the result of a simulation. The weather data for Vimmerby was downloaded from The National Solar Radiation Database (NSRDB). The the PV-cell module chosen was the SunPower SPR-300E-WHT with an output of 300W. The inverter used was a ABB-Trio-20-480[V]. The system was divided in 1,557 strings with 12 modules per strings amounting to 18,684 modules. The amount of inverters was chosen to be 230 so to be undersized for the size of the system: this is done because the PV-cells seldom produces at maximum output. A rule of thumb is that there should be a ratio of 1.3 DC to AC to correctly size the inverter.



(a) SAM simulation of the improved 2020 electricity demand plotted against the PV-production for model year of 2017



(b) SAM simulation of the improved 2020 electricity demand plotted against the PV-production for model year of 2018



(c) SAM simulation of the improved 2020 electricity demand plotted against the PV-production for model year of 2019

Considering the studies [13] [18] the size of the solar park of 5,6MW should pose no threat to the power network of Vimmerby.

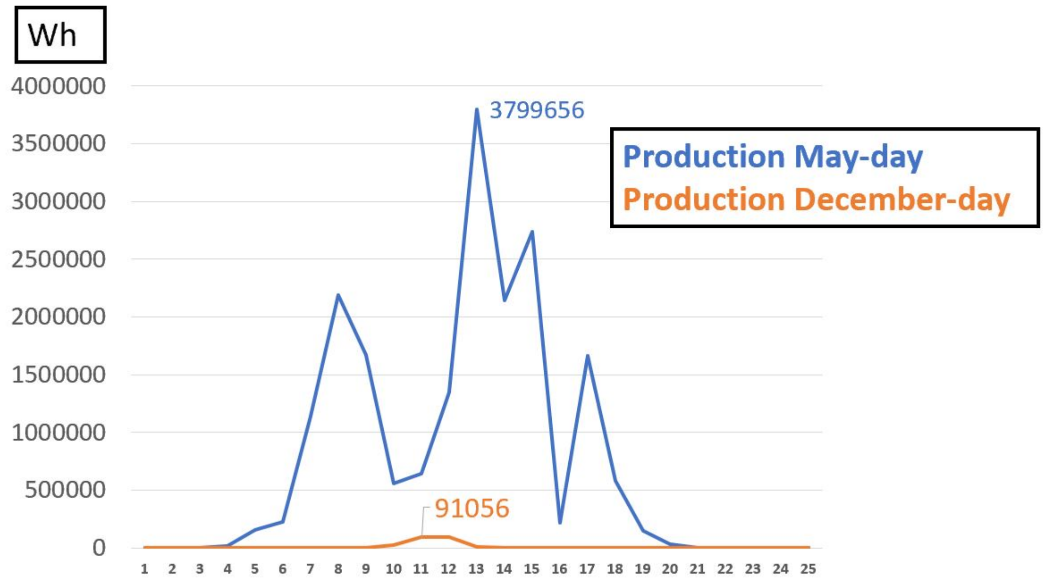


Figure 55: Results from the PVGIS tool with a hourly timestep for the production of the 5.6 MWp park

The heat consumption of 12,652,107 [MWh/year] is today met by district heating and a oil boiler. Åbro utilises district heating supplied by the company Vimmerby Energi. This company supplies heat as well steam to the brewing process. The source of energy is mostly biomass: wood chips and other by-products of the forestry. There is an ongoing debate whether or not biomass can be considered as a renewable or just a sustainable energy source. Renewable energy sources are to be preferred over sustainable ones. Policy-makers in the future might re-classify biomass from forestry from a renewable energy source and start to tax it more heavily. For the purpose of the thesis the supply from the district heating will be reasonably lowered and partly replaced by solar heating.

Solar heating requires the location of the solar collectors as-close as possible to the brewery. Åbro has space outside of the brewery but on the roof as well. The location of the solar collectors can be placed as is shown on figure 85 in the Annex. Considering a field area of 3000 m2, the area could be covered with the Absolicon Solar Collector T160. The company has had experience before in supplying breweries and other industries using low-quality heat, see figure 84 in Annex. This collector can supply steam at temperatures up to 160°C. By supplying to the hot water tank, a temperature of 85°C is enough to charge the hot water tank with heat (considering the pasteurization needing heat at 80°C). According to the Absolicon Simulation tool, the 3000 m2 size of the solar collector park would supply 971 kWh/h (during solar peak hours during the day: 4h at the location of Vimmerby). This would amount to 461 MWh/year.

With the use of solar heating the brewery would save up to 46.6 tons/year of oil equivalents savings/year. This means that during the lifetime of the solar collector park (considering 25 years) the CO2 savings would be of 3674 tons/year. These numbers are calculated from the simulation tool by Absolicon.

In regard of the electricity, the PV-cell park would supply 4,599,940 kWh per year according to the SAM simulation. Considering that the brewery is using a Nordic electricity mix which usually considers 20g CO2 per kWh or 20 kg of CO2 per MWh this would amount to 91,999 kg of CO2-equivalent saved each year.

Considering the mass balance showed before in background in section 1 (shown also below 56, a new mass balance can be obtained with the CO2 savings, see figure 57:

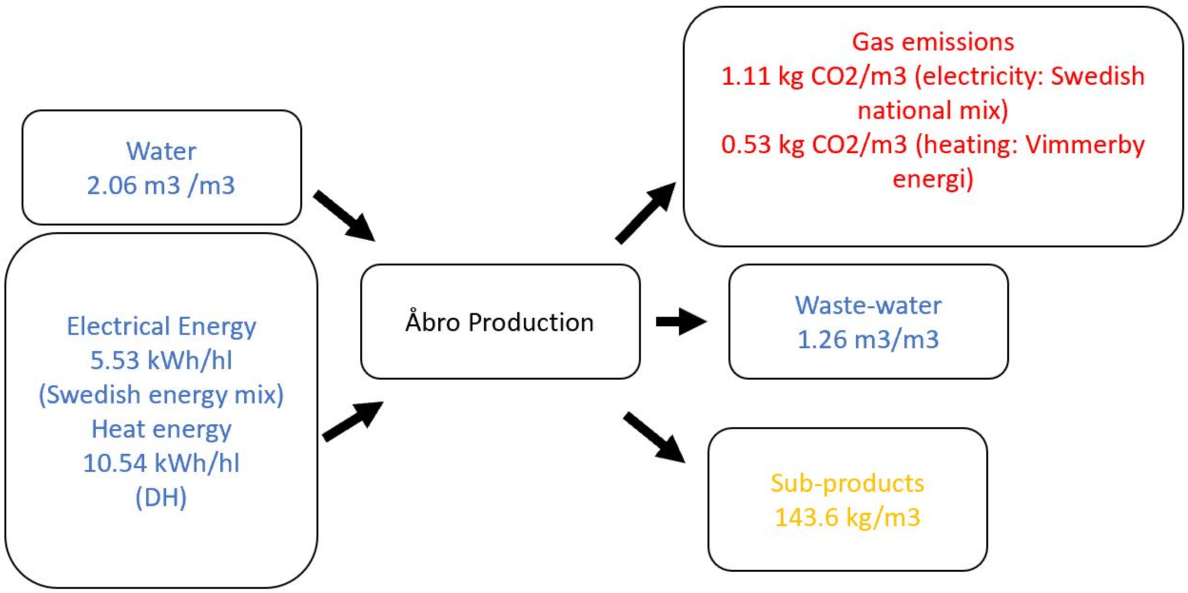


Figure 56: Old energy and mass balance of the production of beer at Åbro

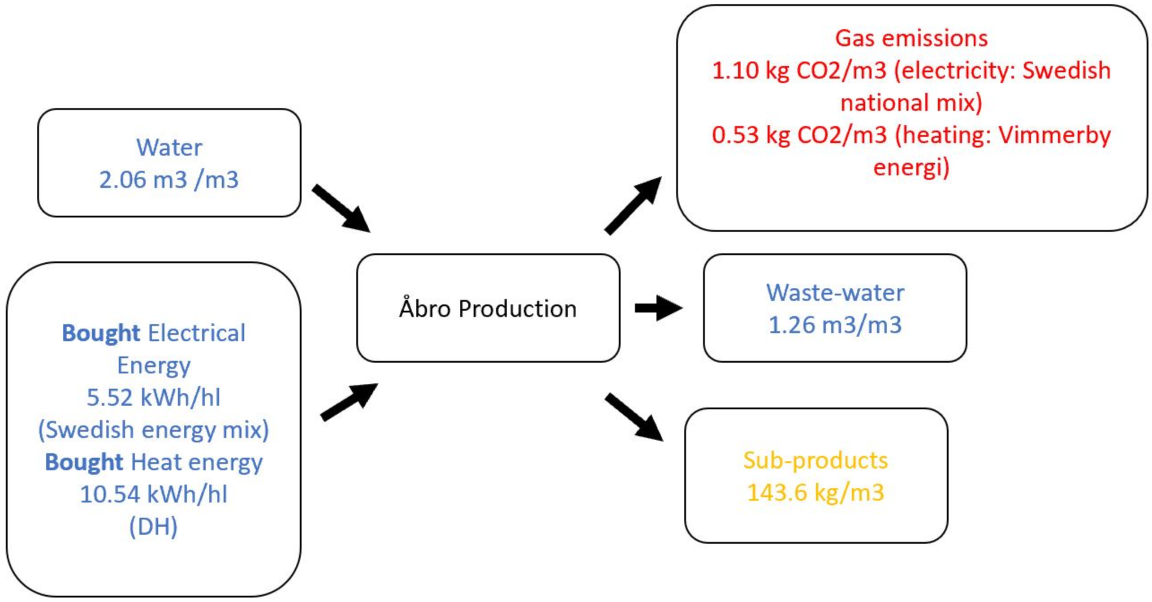


Figure 57: New energy and mass balance of the production of beer at Åbro

6 Results: Sustainable Fishery

6.1 Background: Pico island

Pico island is located in the Atlantic ocean in the Azores archipelago. Even though the Azores islands are located some 2,000km away from the European cost, these islands are considered by Portugal as national territory. Therefore, they receive a substantial amount of subsidies and other aids from the Portuguese Government as well as the European Union. Pico island has little under 14,000 inhabitants of which the main activities are fishing, cattle and ´dairy farms and tourism. Fishing is one of the main activities of the primary sector, namely the capture of tuna for the canning industry. Historically, Pico was a central island for the whaling industry which represented a substantial revenue for the inhabitants. For the sake of the thesis, a visit was done on Pico island and interviews were issued (see annex for interviews and pictures). The data and benchmark values were taken from these interviews. The fishery is planned to be set up in the town of São Roque on the northern coast of Pico Island.

6.2 The Sustainable industry report

6.2.1 Section 1: key figures

The fishery to be built on Pico will process mainly Blue-Fin Atlantic tuna during the higher season of the fishery. These fish can weigh up to 400kg. The high season is March-September and the volume can reach up to 500 tons of tuna per week. The yearly production would be of 20,000 tons/year.

A benchmark setup for the freezing solution was chosen with the help of a retailer within the refrigeration industry, namely ColdEnergy. The parameters required to properly design the size of a freezing machine and its cold storage is the volume of fish to be processed per day as well as the turn-over for the storage. For the purpose of the thesis a turn-over of 4 weeks was chosen. Furthermore the choice of having two cold rooms for storage is due to the fact of being able store during the low-season and use different temperatures for different periods for supply (fish that will be consumed long into the low-season period are frozen at lower temperatures while fish that will be consumed fairly soon can be stored a warmer temperature). Moreover, having two cold rooms allows the fishery to shut down one room and to use the other cold room at a higher efficiency rate.

The setup is illustrated below in figure 58. To the left are the freezing machines represented by light blue ellipses while the the cold rooms are represented by light blue squares to the right. The center dark blue squares are the refrigeration systems. The total consumption for each system with its freezing/cooling machine coupled to the refrigeration is illustrated.

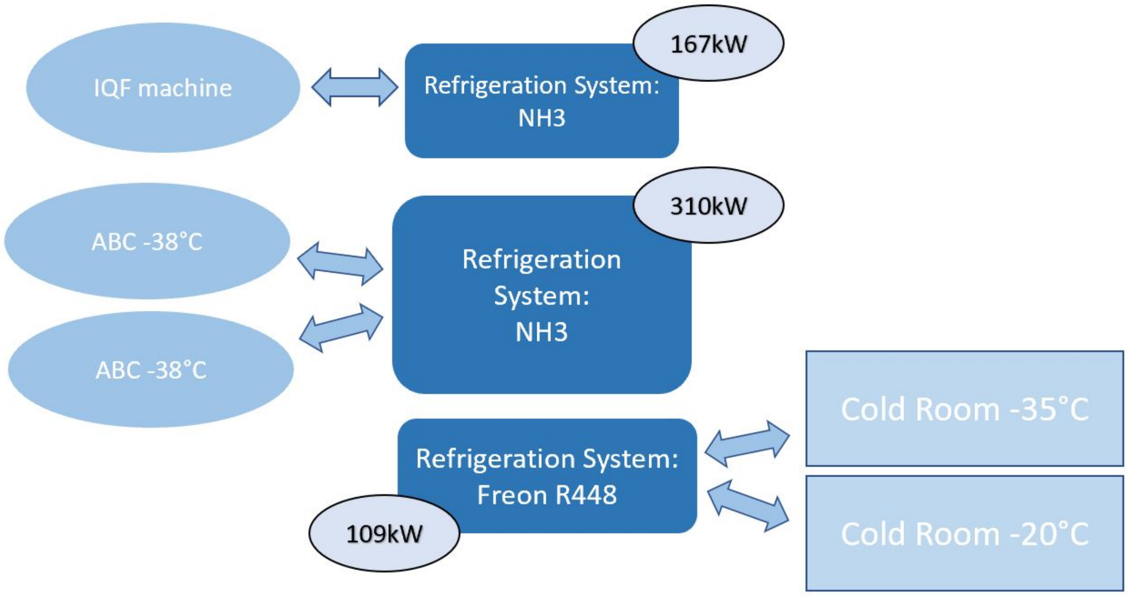


Figure 58: Setup recommended by company Cold Energy.

After the fish has been caught, brought to shore and processed the fish is separated in two different product-lines: one being fillets, to be frozen in the IQF, and another being entire blocks of tuna. The blocks of tunas cannot be frozen in a IQF and are therefore supposed to be frozen in the ABC to reach -20 °C and then moved to the cold rooms where the tuna is stored and can reach lower temperature over some time. The interview with Cold Energy established that the ABC consume more power due to the larger fans and therefore the tunas should finish their "freezing" to -35°C in a cold room.

With the freezing system established an estimation of the other consumption of the factory had to be made: this other consumption is mainly the processing (gutting, filleting etc.), water treatment, ventilation, lighting and the production of ice for the chill baths on the boats when the fisherman are carrying the catch back to shore. To estimate the power usage for the processing, data was taken from the American study from the FAO [24]. What is worth noting in the table (shown below in figure 59) is that the freezing and packaging accounts for 60% of the consumption (if the thawing is excluded). Thus improvements in the freezing method would have considerable effect on the overall consumption of the fishery.

Process element	Water (m^3 per tonne)	Energy (kWh per tonne)	Waste (kg/tonne)	Output (kg/tonne)
Thawing (frozen fish)	5	0	20	980–1 000
De-icing washing and grading	1	0.8–1.2	0–10	980–1 000
Grading	0.3–0.4	0.1–0.3	0–20	980–1 000
Scaling	10–15	0.1–0.3	20–40	960–980
Deheading	1	0.3–0.8	270–320	680–730
Filleting (whitefish)	1–3	1.8	200–300	700–800
Filleting (oily fish)	1–2	0.7–2.2	~440	550
Skinning (whitefish)	0.2–0.6	0.4–0.9	140	950
Skinning (oily fish)	0.2–0.9	0.2–0.4	140	960
Trimming and cutting	0.1	0.3–3	240–340	660–760
Packaging freezing, storage	0.2	10–14	0	1 000
Average for total process		20		

Figure 59: Output and energy costs for fresh fish processing. Data from the Danish Environmental Protection Agency shared in the FAO report [24]

For the estimation of the ice-production, the same study [24] offers benchmark values on the electricity consumption for ice, see table in figure 60.

Type of ice	Temperate			Tropical		
	kWh per tonne ice produced	Ice use per tonne fish	Energy cost USD per tonne fish	kWh per tonne ice produced	Ice use per tonne fish	Energy cost USD per tonne fish
Flake	50–60	1.3	9.8–11.7	70–85	1.7	17.9–21.7
Plate	45–55	1.3	8.8–10.7	60–75	1.7	15.3–19.1
Tube	45–55	1.4	9.5–11.6	60–75	1.9	17.1–21.4
Block	40–50	1.5	6.75	55–70	2.0	16.5–21.0

Figure 60: Energy consumption and costs for manufacture and use of ice [25]. Based on ideal-use conditions with energy costs of 0.15$ per kWh

Water treatment and ventilation are also substantial tasks in the fishery which consumes electricity. Pumps are needed to move this water around which is used to clean working spaces but also is a by-product from working with fish and fans are needed to properly ventilate the working stations. An estimation was done from the study by FAO. The authors said the following about the energy distribution: *For fish processing units, freezing (45%), cold storage (12%) and ice making (11%) were also the most significant users of energy. Cooling water*

(2%), air conditioning (7%), lighting, hot water, water supply (3% each), wastewater (4%) and other uses (10%) accounted for the remainder (from study[24]).

Considering that the fishery on Pico handles 100 tonnes of tuna per day during high season (figure 61) and 20 tonnes of fish per day on low season (figure 62), the following energy consumption can be estimated:

High Season, 100 tonnes fish per day				
Equipment	**Rated Power [kW]**	**Usage [h/month]**	**Consumption [kWh/month]**	**Fraction [%]**
IQF + refrig.	167	160	26,720	10
ABC + refrig.	310	160	49,600	19
Cold room 1	97	730	70,810	27
Cold room 2	12	730	8,760	3
Gutting, Fil.	8 [kWh/tonne fish]	160	16,000	6
Lighting	1	160	8,000	3
Waste water	-	160	10,000	4
Ice prod.	50 [kWh/tonne fish]	-	100,000	38
Ventilation	-	730	18,000	7
Hot water	-	160	7,000	3
Other	-	-	20,000	8
Total	-	-	263,170	100

Figure 61: Energy consumption for the high season

Low Season, 20 tonnes fish per day				
Equipment	**Rated Power [kW]**	**Usage [h/month]**	**Consumption [kWh/month]**	**Fraction [%]**
IQF + refrig.	167	120	20,040	15
ABC + refrig.	310	120	37,200	27
Cold room 1	97	600	58,200	43
Cold room 2	12	0	-	0
Gutting, Fil.	8 [kWh/tonne fish]	120	2,400	2
Lighting	1	160	8,000	6
Waste water	-	160	10,000	7
Ice prod.	50 [kWh/tonne fish]	-	20,000	15
Ventilation	-	730	18,000	13
Hot water	-	120	5,000	4
Other	-	-	12,000	9
Total	-	-	135,800	100

Figure 62: Energy consumption for the low season

An interesting note can be made in regard of the distribution of energy consumption in figure 61 62 versus the distribution given by the quote by FAO on the page before. The freezing tasks represents much more in % of the overall consumption in the fishery than in the benchmark fishery on Pico: one possible reason is due to the use of IQF which is a state-of-the-art freezing method. For this reason the consumption of the cold rooms represents a higher share in %.

6.2.2 Section 2: optimization & recovery

Implementing the 10 measures mentioned in section 2.3.3 on page 22 would allow the fishery to make substantial savings in regard in emissions (both CO2 and CH4).

Measure 1. Refrigeration system management What can be understood from the comparison in-between the freezing methods, the IQF has the lowest consumption, see Table 3 in section 2.3.2 Although the possibility of selling entire tunas is lucrative and there is a market for it, a streamlining of the factory would benefit from only processing fillets of fish and therefore only using a IQF machine for the freezing. Therefore, a new layout of the machines was designed excluding the ABF, see below figure 63.

Measure 2: automation. By using automation for the proper timely switching on and off of the machines some power could be saved. Furthermore, the use of LED-lights would lower the consumption compared to previous technology in lighting. To estimate this difference an assumption of 5% was considered.

Measure 3. Energy generation from food waste. Proper handling of the waste from the handling of fish is a critical step to prevent the accumulation of food waste in landfills. The study by [10] said the following: *it has been realized that some of the seafood meant for consumption does not serve its purpose, but rather is wasted along its life cycle (Love et al., 2015; Gunders, 2017). This indicates that there is a loss of not only the valuable food, but also the water and energy that were used in production.*

Using the food waste from the gutting of fish could assist in creating biogas. With a share of 30% of the original waste the amount of fish waste would amount to ?%. Applying the method mentioned in [26] this would amount to biofuel of ?% per ton of fish.

Measure 4. Water optimization. A hot water tank will be necessary in order to clean the work places. Having the condensers releasing heat could be a source to pre-heat the technical water destined for cleaning. The COP from the provided system by ColdEnergy is of 1.21: this means that heat is released from the condenser which can be utilized through a heat exchanger. The product sheet provided by ColdEnergy suggests that the condenser temperature is at +36°C, evaporation temperature at -43 °C and the cooling power of 124.6kW. Knowing these it is possible to calculate the heat released by the condenser.

The maximum theoretical efficiency (or Carnot efficiency) is given by:

$$\frac{Q_H}{T_H} + \frac{Q_C}{T_C} = 0$$

Rewritten so that we solve for the heat flow we obtain the following:

$$Q_H = -Q_C \frac{T_H}{T_C}$$

Thus, considering the values mentioned above we have a heat flow of 167,39 kW. Considering that the heat exchanger has an efficiency of 95% and 5% losses from the refrigeration system it was estimated that 151 kW of heat can be transfered to a hot water tank (per compressor). On a daily and monthly basis this can be estimated to 1,208 kWh respectively 30,200 kWh.

Measure 5. Improving compressor work One aspect mentioned by [34] is the choice of a screw compressor. These with an ammonia system are the most common in the industry. The author mentions the importance of properly matching the screw compressor built-in volume ratio with the system's pressure ratio: if not there will be nonproductive work and loss, which would result to over or under-compression. This can be remedied with a use of a side valve to make sure to have the compressor operating at ideal speed, or instead of having two compressors operating: shutting off one and only using one at higher speed. The use of an economizer is also to be preferred. The author managed to reach an improvement of 6.1% of the COP with an optimized compressor system. Thus, it is estimated that with a slide-valve, the compressor system of the fishery would save roughly 6% of its power consumption.

Measure 6. Improving fan operation. The author K.N. Widell wrote another study looking specifically into the fan operation in a ABF chamber(can be found in [34]) and found that a proper speed control of fan operation could save up to 25% of the power consumption while retaining the same freezing time. Thus, for the thesis an improvement of the fan operation of 20% was assumed for the cold chambers.

Measure 7. Reducing heat loads. As shown in figure 24, the heat loads are distributed between the products, fans and pull-down (when the machine has been off). Proper use of the doors and adequate insulation is required to keep the consumption of fans to a minimum.

Measure 8. Integration with a heating system. Since the compressors uses lubricant and oil to seal the parts and reduce friction these get hot and often need to be cooled before being reintroduced into the compressor. If this exergy can be used to preheat the building it would reduce the energy load of the fishery. This is a probable measure but since the heat is of low-quality it is difficult to make calculations. Therefore, for the thesis, this measure was not considered for the calculation of the streamlined fishery.

Measure 9. Optimizing with cold thermal energy storage (CTES). There is a possibility of using CO2 as a refrigerant coolant (see interview C in annex). This could be a good solution to use excess CO2 from other industries. But the increased power consumption could lead to a less efficient system if the cooling load is too low: a higher load would allow the refrigeration system to run at its ideal regime: this is where a CTES could have its ideal use. Using the eletricity during the night when its cheaper would allow the system to shift the load of the fishery: peak loads during the day can be avoided and power costs decreased. Furthermore, the CTES can be used to produce actual disposable ice for the fishing boats for the early morning before they set off. According to the study by K.N Widell [34] up to 30% of the power consumption of the compressors can be saved with the use of a CTES. For the fishery an assumption of 30% was considered to reduce the power consumption of the compressors.

The new layout of the improved fishery is illustrated below:

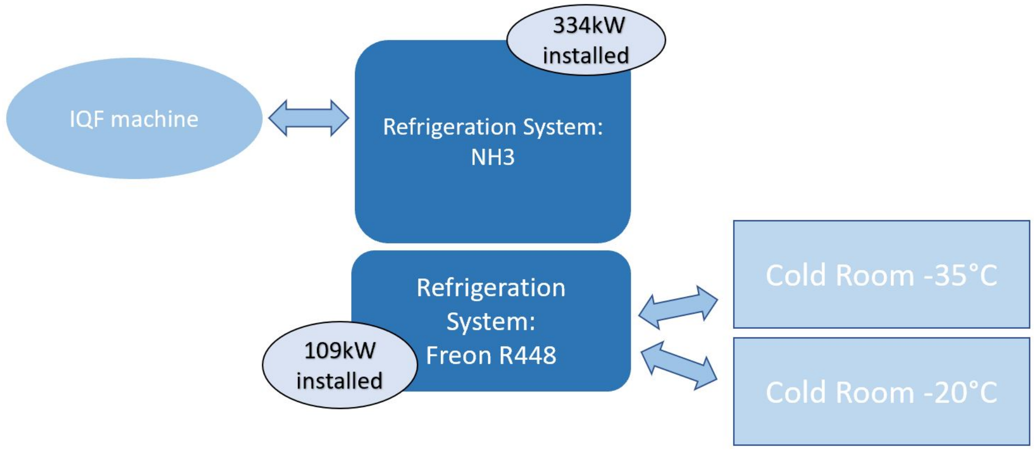


Figure 63: The improved fishery with the suppression of the ABF

The summary of the consumption for high and low season can be stated as below:

High Season Improved, 100 tonnes fish per day				
Equipment	Rated Power [kW]	Usage [h/month]	Consumption [kWh/month]	Fraction [%]
IQF + refrig.	313.96	160	50,234	19
ABC + refrig.	0	0	-	0
Cold room 1	77.6	730	56,648	22
Cold room 2	9.6	730	7,008	3
Gutting, Fil.	8 [kWh/tonne fish]	160	16,000	6
Lighting	1	160	7,600	3
Waste water	-	160	10,000	4
Ice prod.	50 [kWh/tonne fish]	-	100,000	38
Ventilation	-	730	18,000	7
Hot water	-	160	-	0
Other	-	-	20,000	8
Total	-	-	197,256	75

Figure 64: The new consumption during high season with the measures applied

Low Season Improved, 20 tonnes fish per day				
Equipment	Rated Power [kW]	Usage [h/month]	Consumption [kWh/month]	Fraction [%]
IQF + refrig.	334	120	40,080	30
ABC + refrig.	0	0	-	0
Cold room 1	97	600	58,200	43
Cold room 2	12	0	-	0
Gutting, Fil.	8 [kWh/tonne fish]	120	2,400	2
Lighting	1	160	7,600	6
Waste water	-	160	10,000	7
Ice prod.	50 [kWh/tonne fish]	-	20,000	15
Ventilation	-	730	18,000	13
Hot water	-	120	-	0
Other	-	-	12,000	9
Total	-	-	98,200	72

Figure 65: The new consumption during low season with the measures applied

	Consumption[kWh]	difference[%]
high season old	263,170	0
high season new	197,256	25
low season old	135,800	0
low season new	98,200	28

Figure 66: Comparison in-between the old and new consumption

Comparing the state-of-the-art fishery with a traditional one the CO2-equivalent savings can be calculated:

$$E_S = W_{old} - W_{new}$$

$$E_S = 2,139,080 - 1,574,624 = 564,456 kWh/year$$

Where E is the energy saved on a yearly basis, W-old is the traditional benchmark fishery and W-new is the state-of-the-art fishery.

6.2.3 Section 3: description, potential & integration of renewable energy

With a consumption of 197,256 kWh per month for the high season and 98,200 kWh for the low season, renewable energy can be used to cover this need while bearing in mind the challenges mentioned in section 3.4

Wind is an available resource for the production of renewable energy for the fishery. The nearby island of São Jorge has a few wind turbines of 600kW on the plateau. Below is a figure from the study [11] showing the wind energy production from an estimation for the construction of a 5 wind turbines of 2MW each:

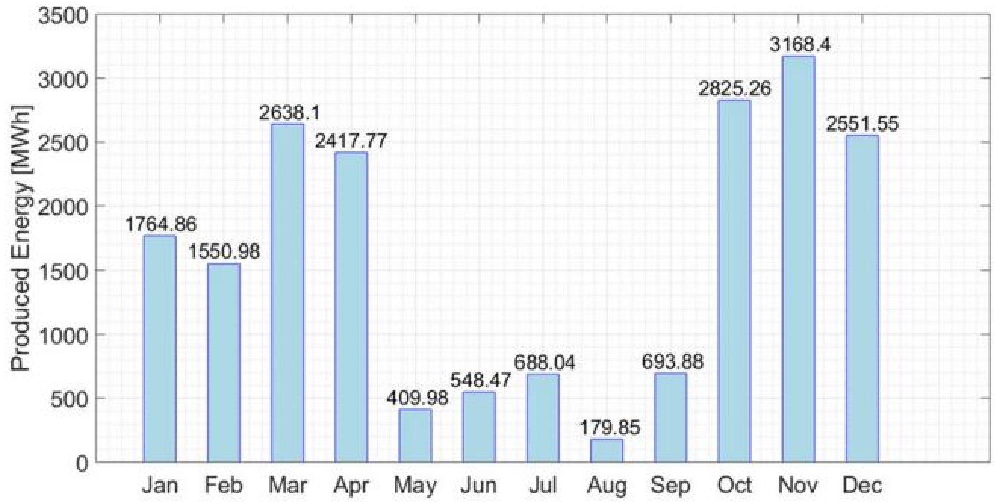


Figure 67: Wind distribution for the estimation done by the authors from study [11]

What is interesting to note here is that the wind production is higher during the winter-half of the year compared to the summer. This was relevant since it makes it a good candidate to complete the PV-production which is higher during the summer when wind is low. The higher energy generation can be explained by the higher wind speeds measured during the winter months. Below are data gathered from Meteoblue.com on the wind speed (figure 68

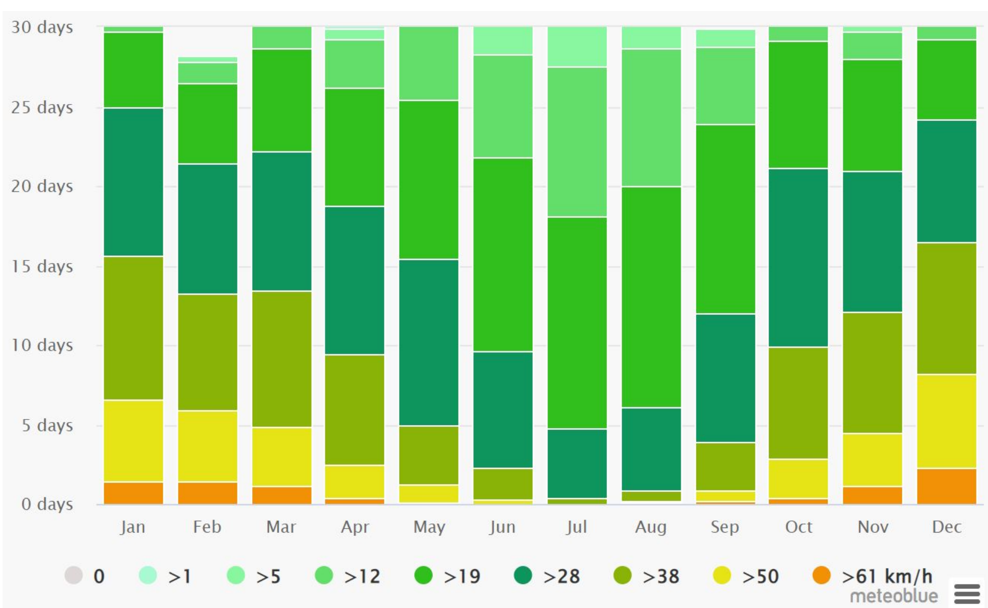


Figure 68

Below are the wind atlas of the island of Pico as well as the location 1 and 2:

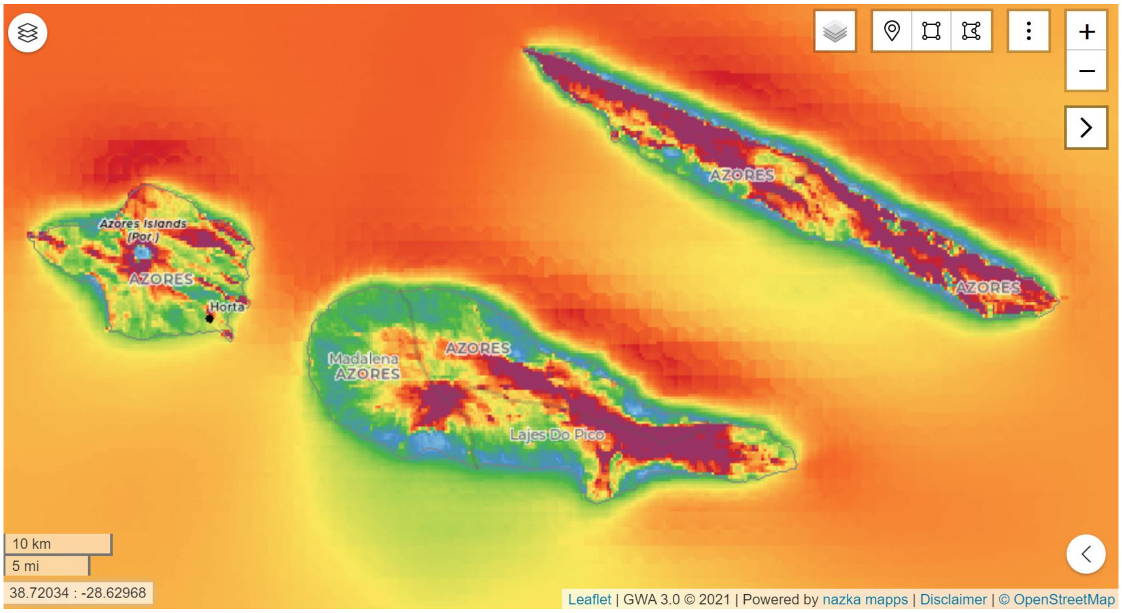


Figure 69: Mean Power density of the area surrounding Pico island from GWA

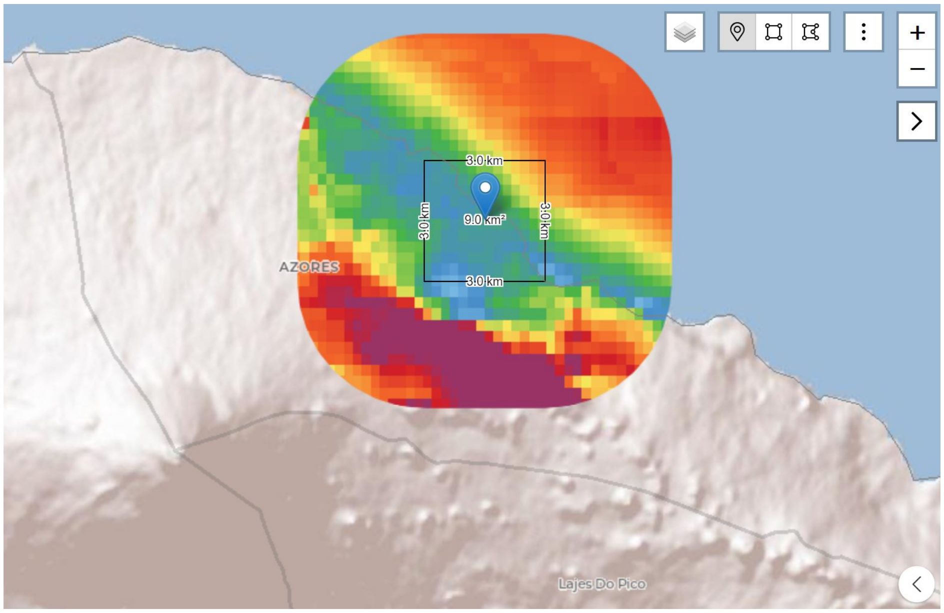


Figure 70: Mean Power density map for location 1 near São Roque from GWA

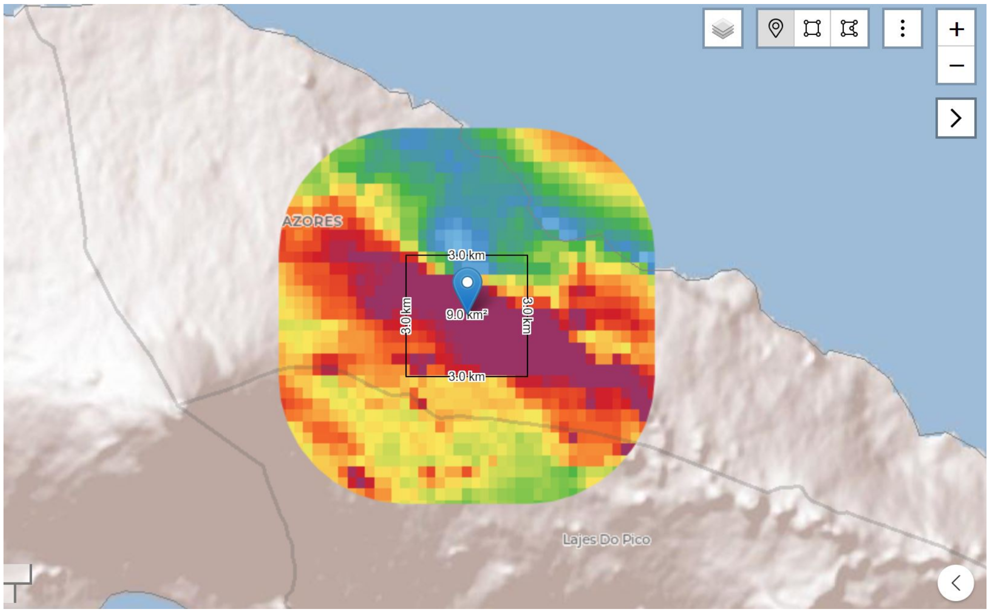


Figure 71: Mean Power density map for location 2 at the bottom of the plateau, from GWA

Considering the parameters to study according to the NREL the following can be said of location 1: The location 1, being on the outskirts of S. Roque is ideal for the close connection to the "load" (being the factory), and allows it to be easily reachable during construction and maintenance. Moreover, as can be seen in figure 70 the wind resource is good. Although the population is accustomed to wind turbines in the Azores, it is unquestionable that the population in the town would prefer having the turbines outside of town. The location is in close vicinity to residential areas as well as a main road used by the inhabitants. It was therefore concluded that location 1 was deemed unsuitable for the construction of a wind turbine.

Considering the parameters to study according to the NREL the following can be said of location 2: Very good wind resource, far from residential areas: the area is mainly owned by local farmers who either uses the land for forestry or for cattle. Being far from roads as well as tourist paths the location seems like a good candidate for the prospect of wind power production. Furthermore, the wind turbine would be just 2 km away from the CHP-natural gas plant thus allowing it to be easily connected to the grid.

As can be seen below, on figure 72, 76, the wind speed is the strongest during the winter half of the year on the annual scale. Moreover, at the scale of a day, the wind is usually stronger during the early morning and late evening. This is interesting since it mirrors the output of a PV-cell: high production during summer half of the year and during the peak sun hours of the day.

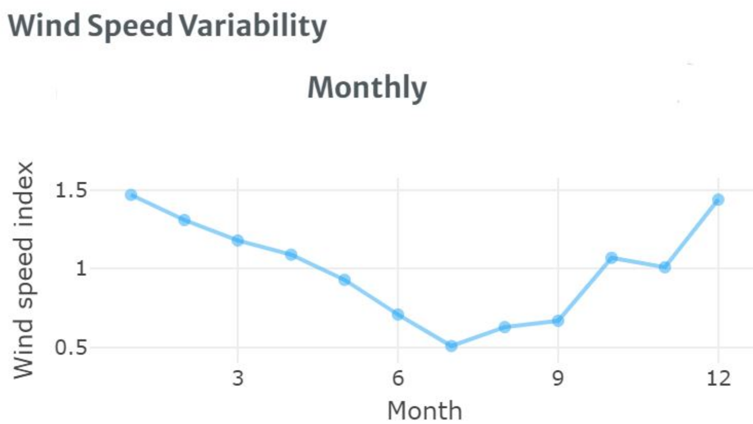


Figure 72: Monthly mean wind speed from GWA

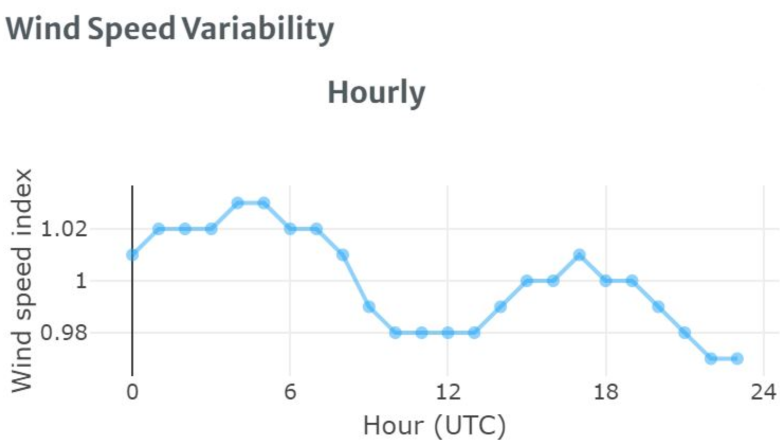


Figure 73: Hourly mean wind speed from GWA

Thus, it was considered for the fishery to have a wind energy and solar power production working simultaneously as a tandem: having the wind turbine producing during the winter and during the night while the PV-cells would provide the power during the summer and at noon.

Below can be seen the output generated by a Vestas 44 turbine with a rated power of 600KW. The capacity factor for the yearly estimation was at 30% while the capacity factor for the winter months was at 60% for the summer months.

	Yearly output for a 600kW - Vestas		
	mean wind speed [m/s]	power density [W/m2]	output [kWh/year]
Location 1	6.92	602	355,023.00
Location 2	10.11	2353	975,655.80

Figure 74: yearly output of a 600kW turbine located at location 1 and 2

	Monthly (winter) output for a 600kW - Vestas		
	mean wind speed [m/s]	power density [W/m2]	output [kWh/year]
Location 1	6.92	602	59,130.00
Location 2	10.11	2353	162,498.00

Figure 75: monthly output of a 600kW turbine located at location 1 and 2 for the winter part of the year

Since a consumption of 98,000 kWh per "winter"-month was considered a 600kW would supply the fishery if placed at a location with a yearly mean speed between 7 and 10 m/s.

For the summer months the following production was considered for the 600kW, a capacity factor of 20% was considered.

	Monthly (summer) output for a 600kW - Vestas		
	mean wind speed [m/s]	power density [W/m2]	output [kWh/year]
Location 1	6.92	602	19,710.00
Location 2	10.11	2353	54,166.00

Figure 76: monthly output of a 600kW turbine located at location 1 and 2 for the winter part of the year

Therefore, for the summer months, the initial consumption of 197,256 kWh can be partly covered by the summer production of the 600kW. If an assumption of 30,000 kWh was made this means that the PV-cell park need to cover 167,256 kWh per month.

The irridiation on Pico island, as can be seen in figure 77 is better than the case shown in Sweden. The map shows that the irridiation is higher on the coast compared to inland: one explanation given by the locals was because of the high altitude of the volcano which catches the clouds and humidity and creates a mist during wet seasons. Thus, the ideal location for a PV park would be close to the sea. Comparing with the islands surrounding the irradiation is similar and choosing Pico.

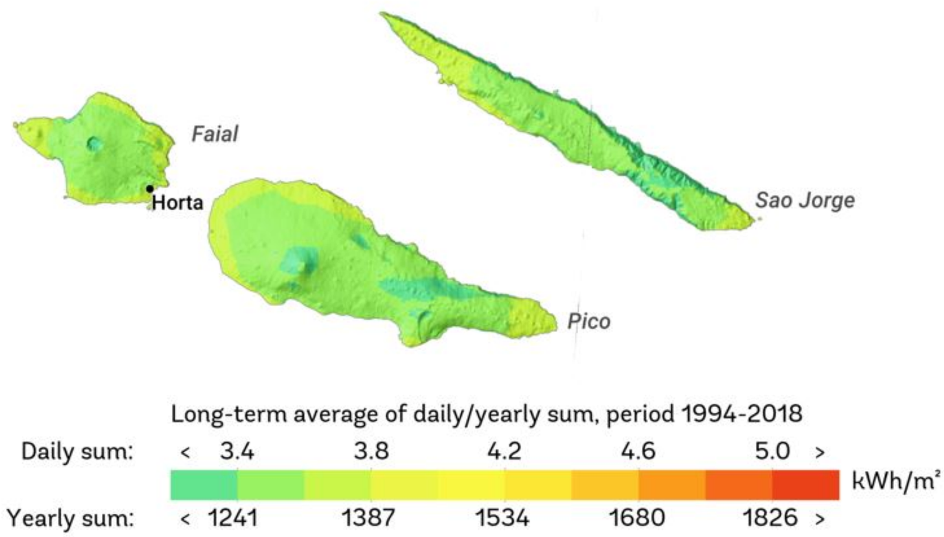


Figure 77: Yearly solar irridiation from the resource Solargis

Having the value of 167,256 kWh as mentioned above as a starting point, a PV-park was designed according to the following shown in 78. The solar park comprises of the same hardware as in the åbro study case. The park was designed to be sized up to 1.15 MWp.

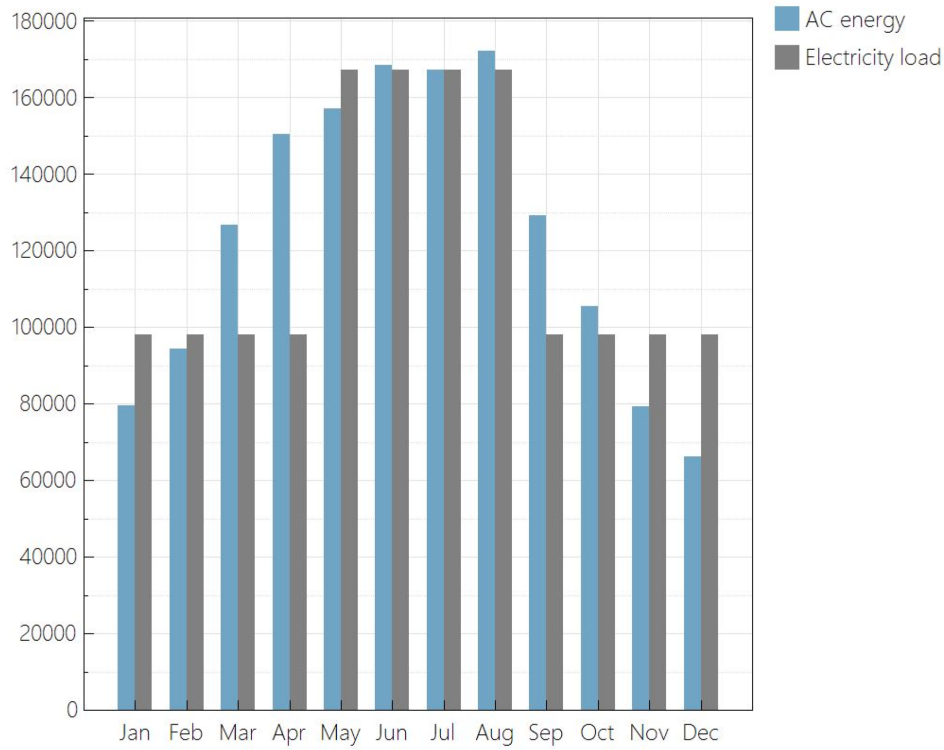


Figure 78: Monthly consumption of the fishery (load) plotted against the PV production of a 1.15 MWp park. The 30,000kWh were deducted for the summer months while the winter months were kept at 98,000kWh for the simulation

Below is the daily PV-production for a July and a December day, see figure 79.

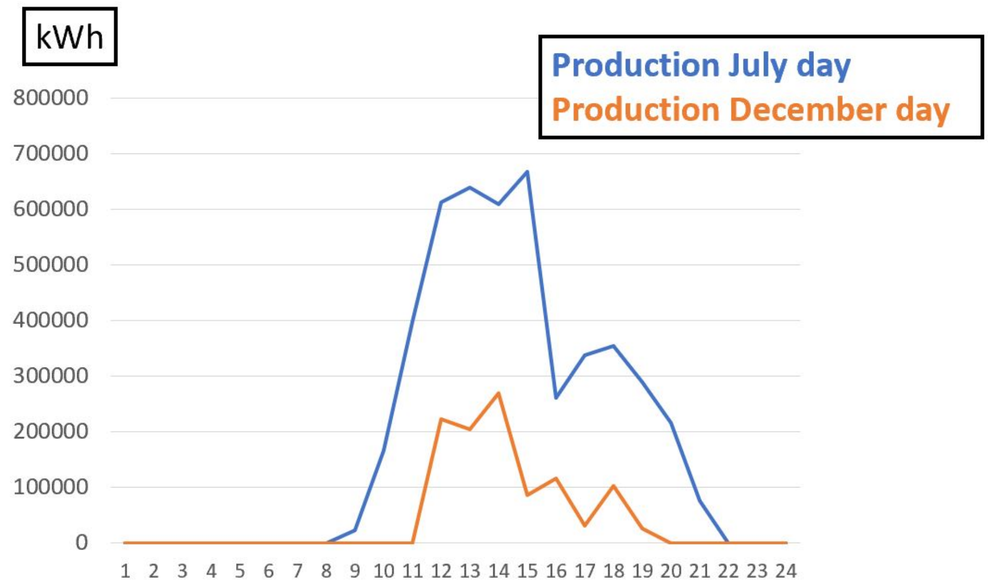


Figure 79: PVGIS simulation of the 1.15 MWp PV-cell park supplying the fishery

With the use of wind energy and PV-cells the fisheries demand can be entirely covered with a considerable amount of overproduction (from the wind turbine).

	Demand [kWh]	Wind Energy [kWh]	PV power [kWh]	New demand [kWh]
jan	98200	100000	79438.1	-81238.1
feb	98200	100000	94314.9	-96114.9
mar	98200	100000	126807	-128607
apr	98200	100000	150432	-152232
may	98200	100000	157129	-158929
jun	197256	30000	168408	-1152
jul	197256	30000	167274	-18
aug	197256	30000	172250	-4994
sep	98200	100000	129316	-131116
oct	98200	100000	105603	-107403
nov	98200	100000	79403	-81203
dec	98200	100000	66163.2	-67963.2

Figure 80: sum of the demand from the fishery and the production from wind and PV on a monthly basis

Estimating the CO2 emissions saved was done from knowing that Pico's electricity grid is supplied by 85% from study [11], and that it is from the burning of natural gas. Assuming that the natural-gas plant has a 60% it can be assumed that the burning of the natural gas emits 0.33 kg CO2-equivalent per kWh-electricity. Thus, multiplying that value with the yearly consumption of the fishery gives the following:

$$CO2_{equivalent,total} = 0.33[kWh/kg] \cdot 1,574,624[kWh/year] = 519,626[kg]$$

7 Discussion

7.1 Analysis

The research questions were answered with the help of the results obtained in section 5 and 6.

RQ1: Is the method proposed suitable to be used in evaluating the energy system of a certain industry?
The method could successfully map the energy flows in both the brewery and the fishery. For the brewery this was facilitated with the energy report provided by the company, as well as several meetings with the operator in charge of the factory. Mapping the energy flows was previously done by the company thus only a few estimations needed to be made.
For the fishery, a lot more estimations were needed to be done since the fishery is yet to be built. Assumptions were made with the help of benchmarks numbers provided from amongst other the FAO. The estimations made allowed the fishery to have initially standard values that put it close to an average fishery: although fisheries around the world vary considerably. Efforts were made to have numbers taken from fisheries from Europe to have some consistency.

RQ2: Is the method able to propose an applied energy transition plan to a certain industry?
For the brewery, the method offered alternative energy sources than the ones used today. Although the brewery used district heating which uses biomass to power its CHP-plant, an assumption was made that it is desirable to move away from a dependency on a district heating plant to a more independent energy regime. The brewery still utilized oil has an energy source up until recently: a boiler operating on a resistance as a heating coil was considered by the company to step-away completely from fossil fuel. Solar heating has a benefit of being able to supply directly the hot-water tank and therefore storing energy produced during sun peak hours. The brewery has the goal to reduce its carbon footprint to a minimum. To this day, the brewery can be considered as low CO2-emitting activity compared to the transporting: this is the last piece of the puzzle for the brewery to be truly carbon-neutral. Transportation was outside of the scope of the thesis as well as not included in the method. For the brewery, an amount of 3766 tons of CO2-equivalent/year was able to be removed from the factory with the help of solar heating and solar power from PV-cells.
For the fishery, an imaginary scenario was created where the fishery would be a state-of-the-art factory relying mainly on renewable energy sources. It is hard to conceive a factory operating completely independently on renewable energy sources: there would be days with no sun nor wind forcing then the factory from drawing energy from the grid. The azores islands rely heavily on natural gas as its source of heating and power: a fast ramp-up of the gas-plant would be able to offset the intermittent production of the renewables. Perhaps a battery solution would have been ideal for the fishery: in this way the fishery could operate independently without relying on the grid during peak consumption hours and then draw energy during the night when consumption on the island is low. The same goes to the brewery: except that the brewery has a higher share of heating needs, this is a challenge to produce in high quantity with wind and solar power. An amount of 519,626 kg of CO2-equivalent was managed to be removed compared to a traditional fishery solely relying on the gas-plant from the island.

RQ3: What are the steps necessary to achieve an industry with 100% renewable energy for the two cases analyzed?
For the fishery, the wind turbine over-produces for the fishery activity. However, for the winter months, as can be seen in figure 79 the PV-cells cannot supply enough power on a monthly

basis. Therefore, having a wind turbine to operate during the winter months allows the fishery to use the renewable source when it is the most favourable. While in theory and on a monthly basis the wind turbine and PV-park covers the need, on a daily basis it is more challenging due to the intermittent nature of the energy sources: a battery would help to guarantee a more independent activity. Although this could only last for a couple of hours (considering a reasonably sized battery which are very expensive) it would be a step towards a fishery using 100% renewable energy. Otherwise, in an ideal meteorological scenario, the fishery with the proposed energy plan in section 6 could very well operate on 100% renewable energy during some periods of time.

Åbro bryggeri has had large successes in its streamlining of its factory: reusing heat as well as limiting consumption. Although PV-cells are a solution to the carbon-neutral brewing (just the brewhouse) it does not suffice just itself: due to the low irridiation solar power and heat cannot cover the brewery needs, also due to the fact that the brewery is operating during the night. If the brewery was located near an optimal site for wind power generation, a much higher share could be covered by renewable energy sources. As mentioned above, the main challenge though to this day for the company to be CO2-neutral is the transport of all the beer: Åbro delivers all its beer mainly through trucks and by boat to the United-Kingdom. The lack of technology today is the main hurdle for CO2-free transportation although the use of trains could have a considerable impact but this requires a more developed infrastructure compared to today.

RQ4: What could the impact (in terms of emission reduction and fuel savings) of this method in the whole sector?

By knowing the CO2 savings achieved by Åbro Bryggeri from their previous measures and with the use of PV-cells as shown in section 5 it is possible to scale-up this improvement to the entirety of Sweden as an estimation of potential impact.

Considering that Åbro uses below half of the energy used by the European mean (16 kWh/hl versus 53.62 kWh/hl) we can estimate the European yearly expenditure: if in the EU 397 billions of hl are brewed each year (see [19]) this would mean that approximately 15,000 GWh could be saved each year. If considering that the mean CO2 emission in Europe is 334 g CO2-equivalent per kWh (see source [1] it would sum up to almost 5 million tonnes of CO2-equivalent that could be saved by adopting the technology used at Åbro Bryggeri (as well as the Swedish power mix).

For the case of the fishery an estimation can be misleading since fisheries are very diverse and handle very different produce: some freeze while other fisheries only processes fresh fish. Furthermore the Pico weather conditions (solar irridiation and wind speed) is different compared to mainland Europe and within Europe the conditions vary a lot. But an estimation was attempted for the sake of the thesis: According to the European Commission (see source [23]) 5.2 billion tonnes of live weight fish was caught and produced (in aquaculture) for European consumption, if multiplied by the 25 kWh/tonne processed as shown in figure 21 this would amount to 130 GWh/year. With the 334g CO2-equivalent per kWh as used in the brewery up-scaling this would amount to 43,420 tonnes of CO2 equivalent per year in Europe.

RQ5: Will the method be able to be implemented in other industries? In the fishery cases, the ammonia-system for the cooling or freezing is by far the better way. But in poorer countries like India or Africa it is Freon-systems that would be seen due to the fact that its cheaper to buy, but it is expensive to operate and a leakage is economically disastrous.

Åbro bryggeri can be considered as one of the most modern breweries in Europe. They have already implemented several measure to increase the efficiency of the brewing process as well as utilizing waste heat. Furthermore, to monitor the production line, Åbro has chosen to follow the OEE-model to seek a reduction of energy use. OEE (Overall Equipment Effectiveness) is a "best practices" metric that identifies the percentage of planned production time that is truly productive. They have been consistently able to shave consumption throughout the years which explains why no obvious and impact-full efficiency measures were found from the method.

Financial aspect plays an equally important role: if the measures does not provide a substantial change in operational costs it is hard to motivate that the change is for the benefit of the company. It is a challenge to find the nexus where the sustainability measure benefits the company as much as society and the environment.

Even though the cost of energy for Åbro is low, under two percent according to their report, the issue around sustainability is a core aspect in their company culture. The report shared by them as well as the work in this thesis shows that achieving a higher degree a sustainability and use of renewable sources is a cheaper and safer journey into the future for the brewery.

7.2 Limitations

The brewery in itself has already achieved a high sustainability with the use of technology and efficient measures. The transportation remains as the main polluter for the company. In this thesis, the transportation was disregarded due to the fact that it would require a study of its own to analyze possible improvements. Furthermore, the energy of producing the packaging like the aluminium cans or plastic consumes a lot of energy and material: this has a substantial CO2 footprint. Åbro Bryggeri does not produce the cans at the brewery, they buy sheets of aluminium and have machines that forms the cans.

For the fishery, a large share of the energy use comes from the fishing boats. Considering the fuel consumption, 50 million m3 of oil is used by the fishing fleet (1.2% of worldwide oil-use): this amounts to 134 million of kg of CO2 annually ([25]). If more efficient and sustainable fuels could be used for the boats, immense progress could be made for the whole fishery industry. Unfortunately, since the industry is very broad and unequal, the use of modern bio-fuels is very limited and would not be able to be scaled-up on a global level.

Both for the brewery and the fishery a battery system would have been interesting to have studied. Having a battery would allow to shift the energy supply from the peak sun hours during the day to the evening and even the night. This was regarded as outside of the scope of the thesis since it requires a deeper study and more analysis.

The cost of the measures were not taken into account, nor the cost of the material and construction of the PV-park and Wind Turbines. Were the brewery prospecting for such project the financial aspect would have been the decisive factor. For the sake of the thesis, to be able to evaluate different energy source options, the money aspect was disregarded.

8 Conclusion

The method used to produce the sustainability report for the brewery was successful. Although no efficiency measures were found, a higher degree of sustainability is achieved with the incorporation of PV-energy and solar heating. In regard of the fishery, the method allowed the implementation of efficiency measures inspired from studies to create a state-of-the-art low energy consuming fishery. The addition of renewable energy was successfully studied for both cases and the improvement quantified. The method showed the possibility of including renewable sources and its benefits.

9 Suggestions for further research

In order to make substantial improvement on the CO2 emissions, new ways of transporting beer as well as lowering the fuel consumption of fishing boats would dramatically drop the emissions. Further research could investigate how beer could be transported from the brewery to the consumer without using fossil fuels or limiting the use of trucks running on petrol or diesel: perhaps trucks could run on bio-fuel or hydrogen instead. In regard of fisheries, further investigation should be made on whether the same efficiency measures can be taken for the aquaculture sector. The aspect of battery integration should also be studied to see if it could help the two factories to be more energy independent from the grid and have a more robust energy regime.

10 Output

The work from this thesis allowed the authors to present several public presentations: in Portugal for the company Bitcliq: an IT company working with the digitalization of fisheries, as well as for the company MG Sustainable AB. The work from the thesis was also the groundwork for applications to European and Swedish investment calls, namely Vinnova, Energimyndigheten and European Horizon-program.

Appendices

A Interviews

Due to the issue of confidentiality the real names of the people have been altered.

Interview A, Åbro bryggeri: Johan

Johan (male, age: 40s) is working at the brewery plant in Vimmerby. He is involved in the technical aspect of the brewery and the plant. The interview was conducted over the phone.

Q: How important is sustainability for Åbro Brewery?
A: It's in our core values, everything we work on is based on that. This is what we strive for: a 100 % sustainable business.

Q: Do you think that fossil energy is necessary for your business?
A: Absolutely not. In the long run, I'm sure we'll be able to achieve that.

Q: How much would you have saved on costs if you had eliminated all fossil energy?
A: The raw material price for oil and gas varies a lot. Compared to before the pandemic, we managed to halve the cost when we went from heating oil to wood chips.

Q: How many years do you think it will take before Åbro is completely fossil-free?
A: All electricity should be covered by the solar cells from our new solar park. It's the heat that still needs to be produced in an environmentally friendly way.

Q: What are the biggest challenges for Åbro to become completely fossil-free?
A: What we lack is the innovative solution. If we had it, we could move away from fossil energy completely and use only renewable energy.

Q: Does the customer value sustainably produced beer? A: Absolutely. There is a much greater awareness on the part of the customer. When it comes to the packaging and everything that is behind the brewing.

Q: Would they pay more for it?
A: They would definitely pay a little more. Although not a too high price.

Q: Is the use of concentrated wort extract something that Åbro could consider in the future?
A: This would alter our recipe significantly and quality is a priority for us which distinguishes us from other brands.

Interview B, OctoFrost: Alex

Alex (male, age: late 50s) is involved in sales at OctoFrost for the international market. The interview was performed over an online meeting.

Q: If small fillets are to be frozen, which is the best method to use?
A: Best method by far is individual quick freezing. The quality preserved with IQF cannot be compared with old methods like freezing chambers

Q: How does it compare to IQF with cryogenics?
A: IQF with cryogenics uses the same method except that it uses liquid gas like CO_2 which raises the operational costs substantially. Also, these systems are very complex and you need proper training in order to be allowed to use it. The companies supplying the gas usually rents out the storage system to the clients, so you would need to pay an additional monthly fee to the bought gas.

Q: What are your thoughts on CAS (the ultra-sound assisted freezing)?
A: We actually performed tests in-house with our technology. We concluded that using ultra-sound assisted technology in addition to our IQF technology did not do any difference. We believe it is because the IQF freezes the fish already at a significant short rate of time that the ultra-sound is not able shorten the time even more. It is therefore not our recommendation to use it with our freezing technology and any IQF.

Interview C, Cold Energy: Phillip

Phillip (male, age: early 40s) is involved in sales at Cold Energy for the international market. Interview was done by mail and over online meetings.

Q: What would it mean to freeze to -30°C entire tuna fish of 400kg in terms of refrigeration power?
A: Unfortunately for a 400Kg tuna it is not possible to reach -30°C at the core of the product.It is not a matter of how high the airflow is or how low the air temperature is from the heath exchanger. The bottle neck in this case would be the size of the fish. To reach that temperature it would require 7 days according to our calculations. Said so, a blast freezing tunnel would be totally useless because you would have enormous energy consumption and my suggestion would be "just put the tuna in a -35°C cold store and wait until it freezes up to -30°C". If we were talking of small tunas (60-70 kg at max) this would have not represented a big deal, but 400kg and -30°C at the core in less than 7 days is something that we (just like all refrigeration companies) cannot provide. Again , this if you are forced to reach the -30°C at the core of the product. With -20°C is something feasible. Freezing 400 kg tuna it is not unreasonable , i have seen myself plenty of warehouse that deals with it. The thing is that in 24 hours you can reach -20°c and not less than that due to physical and thermodynamics reasons. If you must stick with the -30°C at the core then yes , it would be possible to freeze a 60/70 kg tuna in 24 hours.

Q: Which coolant is to be preferred? CO_2, ammonia or Freon?
Co_2 vs NH_3, same COP, same refrigeration power, same energy consumption. To condense NH_3, 4 different phases are needed (compression, condensation, valves, evaporator) same for CO_2 except for the condensation. Evaporative condenser is possible with NH_3 (basically a fan with sprayed water), this helps to cool down and turn it into liquid. For CO_2, this method of cooling is not possible: with a similar evaporator with water (to the NH_3 system) it would not be able to effectively cool the CO_2. This means a medium with more refrigerant cooling power than water is needed. Cost of installation of the extra coolant results usually in 30% higher cost compared to the regular NH_3 variant. Operating a CO_2 system requires skilled staff in warehouse, high pressure in valves. By the end of the day energy consumption is the same. Who uses CO_2? The people who are really "concerned" about the environment, at least on paper. The main positive aspect of using CO_2 is that a leakage is not harmful. NH_3 is actually also present in atmosphere like CO_2 but is produced in a lab. CO_2 cannot hurt people, unless they are in a closed room: then CO_2 can lead to asphyxiation. NH_3 on the other hand will harm people if it comes into contact with a person. This is a small issue because we provide a good system that detects leakages and effectively retrieves the NH_3 that leaked. End if the day because NH_3 is more sound. Same COP, same refrigeration power. NH_3 is the most used since 1950.
Regarding Freon it'd be crazy, Freon is possible end of the day, the cost of using Freon is very costly. 1kg of Freon cost 60€, NH_3 is 7€. 30,000 euro vs 300,000euro leakage. Freon pumping are obsolete, partners are dismissing compressors for Freon and focus only on NH_3 and CO_2. Cost of refrigeration system lower for Freon than NH_3: cheaper usually because for IQF equipment needs CO_2 or ammonia pumped directly into the IQF. Direct expansion for Freon, does not liquid separator (less equipment).

Q: How different would the system be with a CO2 system? A: Completely different , and you would need very very good skilled and experienced personnel to run the plant

Q :"How many extra kW would that mean? How big is the price difference?
A : 30% extra consumption and almost 50% more for the investment.But those are just A ROUGH estimate

Interview E, Meeting with local fisherman: Gabriel

Gabriel (male, age: early 40s) has been a fisherman since his childhood, already helping out his father at the age of 7 on the boat. He is a known figure in the fishing scene on Faial. Interview was done in person on Faial island, Portugal.

Q: Which fish do you catch?
A: Tuna and Goraz (Red Sea Bream). Goraz is the highest value fish in terms of €/kg. I worked in this industry now for 30 years. Now there's less than 10% than when I started. The size of the fish is also reduced.

Q: Why is the stock level so low?
A: I believe it's because we over-fish during vulnerable months when the fish needs to be left alone.

Q: How is the fish caught here?
A: We have artisanal fishing but we have some trawlers in the area. They would indiscriminately fish everything they catch. Then when the net is pulled into the boat the fish is dead. This is very different from fishing with pole and line, since if the fish caught is too small it can always be released back to the sea and survive

Q: How is the catch volume of tuna?
A: It changes from year to year. Depends on the migration routes they choose. From Madeira, we would hear when the tuna is on it's way to migrate up north. So we have a good idea where and when the tuna will be in the vicinity of the islands

Q: How do you catch Tunas?
A: We use mainly pole-and-line. We catch them one by one and pile them up on the deck

Q: Freezing conditions on deck?
A: It's usually small boats. There's not really possibility for freezing on-board, except chilling in ice-bath. We would store the fish under deck at ambient temperature. We would be gone for 2 days at sea so when we reach shore the tuna wouldn't't be in optimal condition

Q: How is the fish sold?
A: The quality is usually only fit for canning. But if the tuna is good enough it is sold to brokers (usually Spanish) and frozen and shipped to Europe. 90% by boat and 10% by plane.
Q: How is the freezing done?
A: It's frozen either on Faial or Pico depending on capacity. It's usually frozen down to -20C in chambers.

B Figures

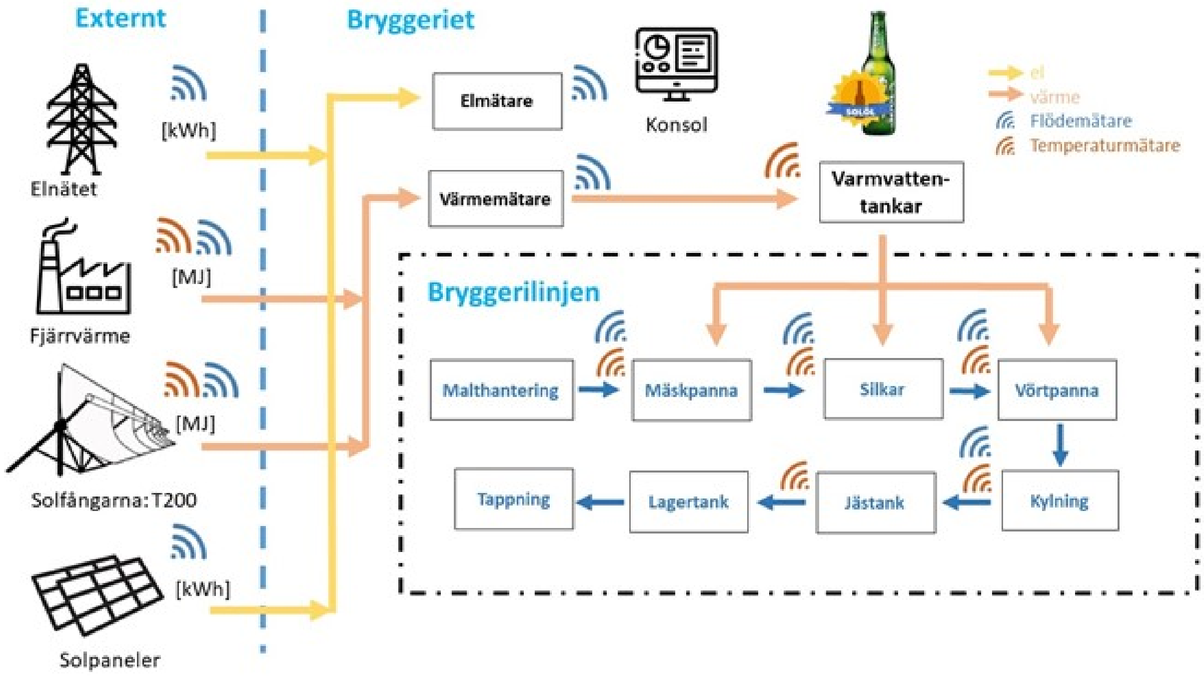


Figure 81: diagram of how solar heat and solar power can be integrated to the brewery

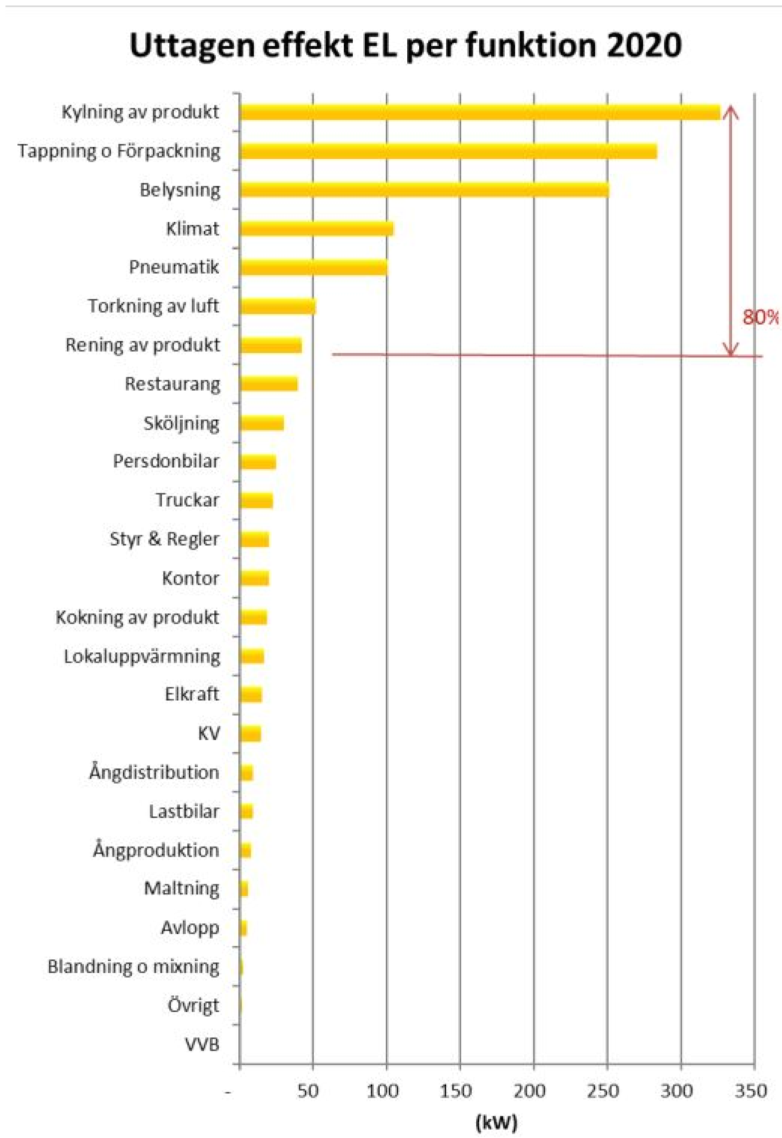


Figure 82: Power consumption by sector

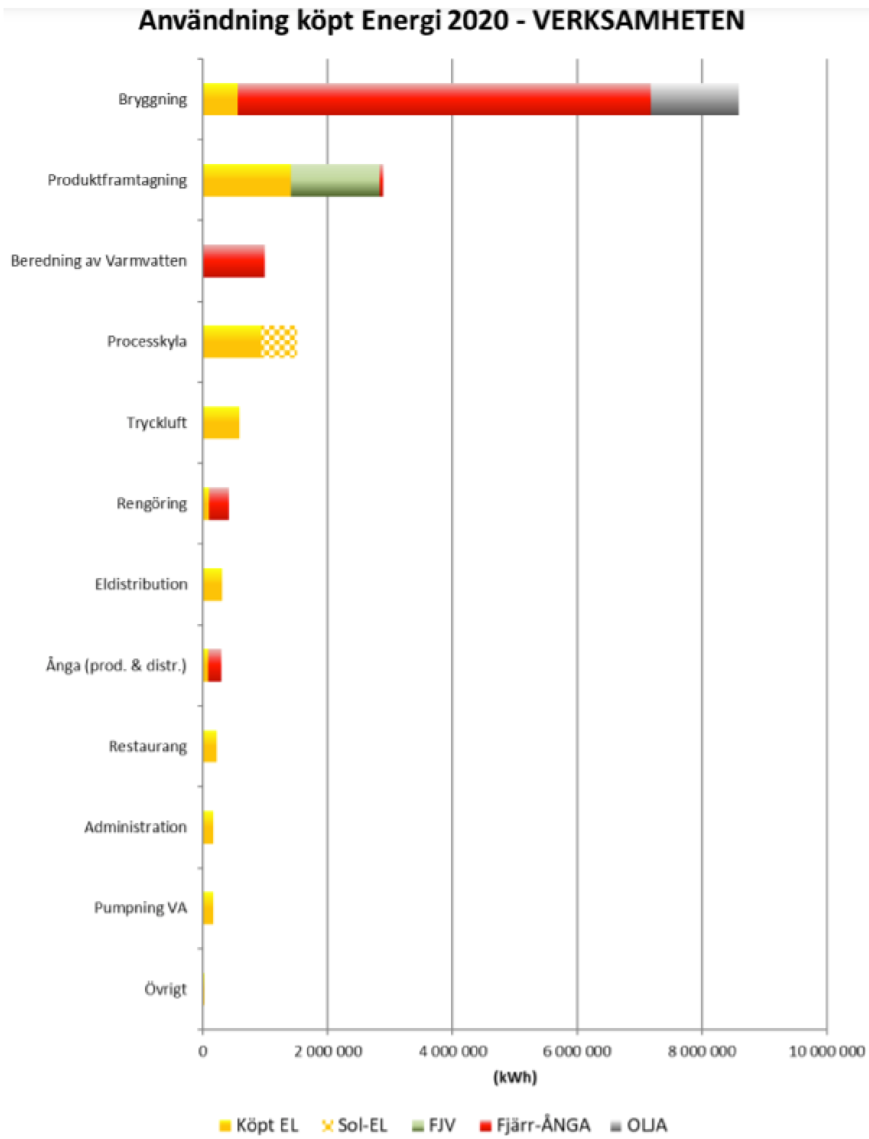


Figure 83: Electricity and heat consumption

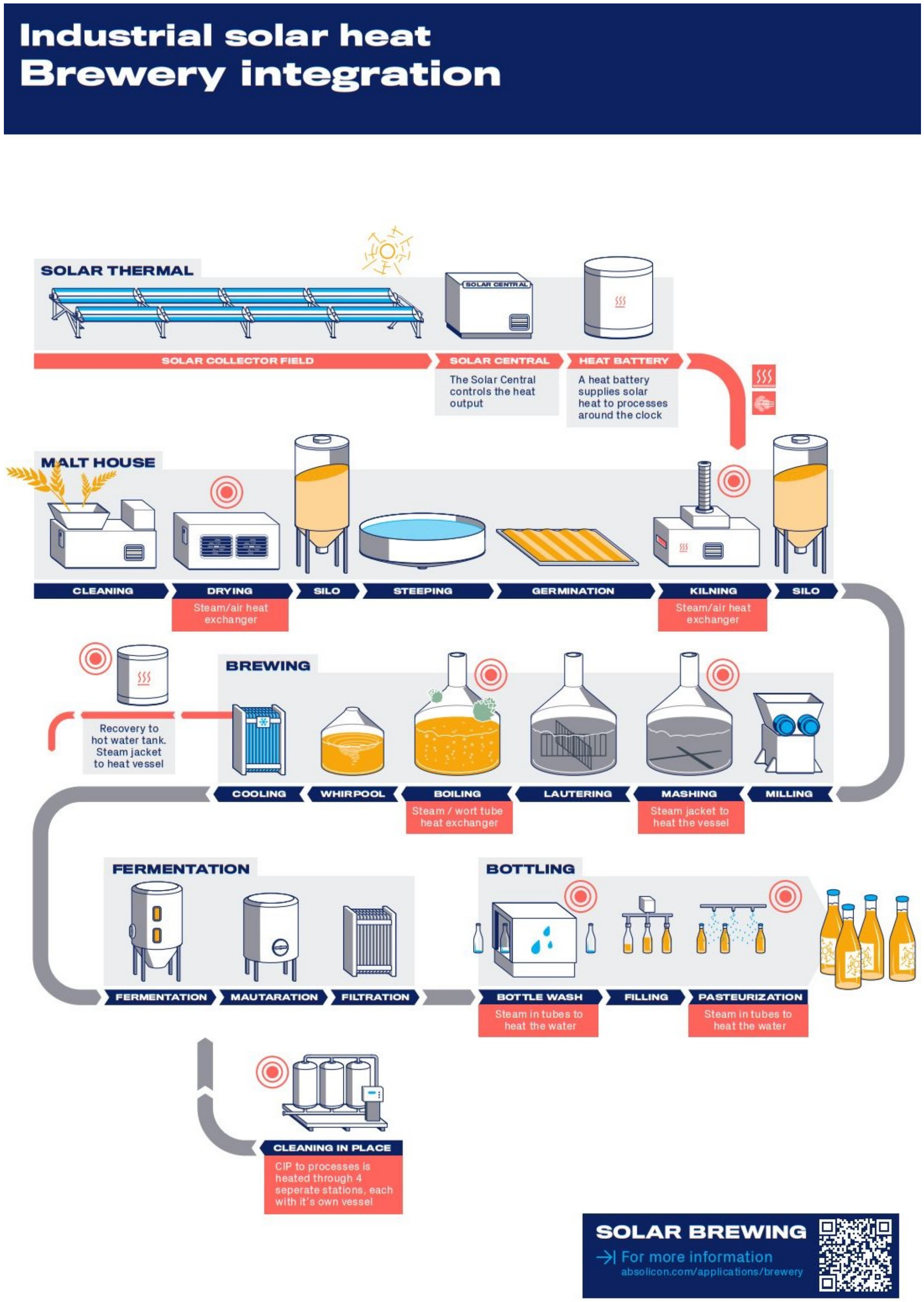


Figure 84: diagram from Absolicon showing the processes in the brewing where solar heat could be integrated

Figure 85: Location of where the solar park could be erected

C Pictures

Figure 86: Picture taken at Åbro factory showing one of the canning lines

Figure 87: Picture taken at Åbro Bryggeri showing the glas-bottle line at the factory

Figure 88: Picture at Åbro Bryggeri showing the author of the thesis to the right with colleagues

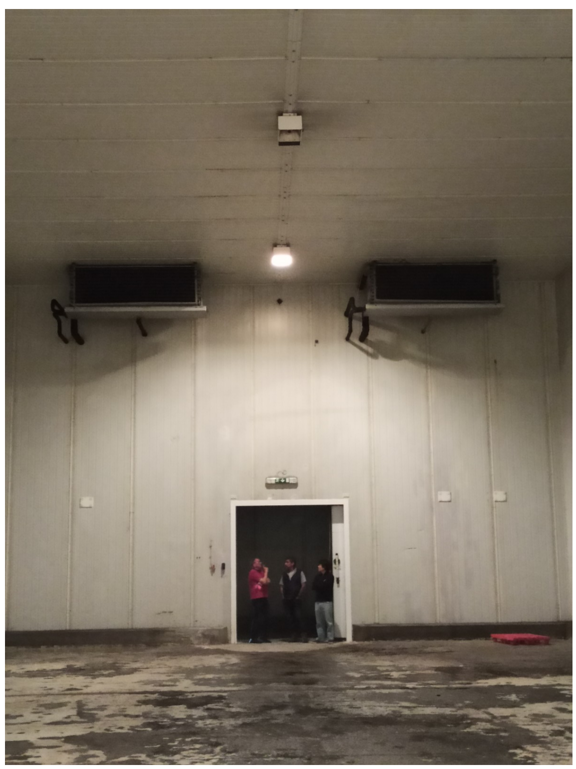


Figure 89: ABC in Madalena, Pico June 2022

Figure 90: ABC in Madalena, Pico June 2022

Figure 91: Tuna fishing boat in harbor of Madalena, Pico June 2022

Figure 92: Refrigerated salt-water baths, Pico June 2022

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