ENERGY- AND CARBON FOOTPRINT REDUCTION IN INDUSTRIAL PRODUCTION OF HOT WATER IN ABATTOIR BY USE OF SURPLUS HEAT AND HEAT PUMP SYSTEMS.

Kristina N. Widell[(a)], Erlend Indergård[(a)], Sarah Laselle[(b)]

(a) SINTEF Energy Research, Kolbjørn Hejes v. 1D, 7465 Trondheim, Norway
Kristina.widell@sintef.no
(b) Norwegian University of Science and Technology…

ABSTRACT

Industrial food production plants often use steam both for production processes and for hot water production. The hot water is further used for tap water and for cleaning. These systems have in addition often waste heat from the refrigeration system, which includes heat from the compressors and from the condensers.

In this paper, the use of energy for hot water in an abattoir was analyzed. This system was recently extended with extra piping and heat exchangers for utilizing the heat from the ammonia compressors for hot water heating. A heat pump that uses refrigeration condenser heat was also installed.

The measurements and the calculations have shown a reduction in energy consumption for hot water. The production varies over the year, so monthly consumption for different years has been done. The results show…

The carbon footprint has also been calculated. The steam, which was used before for hot water production, was produced in a combination steam boiler, heated with electricity and with oil. Oil is now used only seldomly at the abbatoir.

1 INTRODUCTION

Energy consumption and its associated environmental impacts are an important issue in the food production industry. This is especially true of meat production, which requires energy both in the production line and for refrigeration. On-site, low grade energy recovery is an attractive option for industries requiring hot water, because the waste heat can replace heating processes which would otherwise consume electricity or fuels. Additionally, waste heat is abundant in refrigeration processes. In the UK, for example, it is estimated that 11.4 TWh of recoverable heat goes to waste each year, which could replace fossil-fuel based energy (Law, Harvey, Reau, 2012). The most efficient use of low-grade heat, especially at temperatures below 60°C, is within the process or in a process nearby. The temperature can be increased with a heat pump, which gives a broader range of utilization. The installation cost is often paid back within a few years.

Fritzson and Berntsson (2006) used process integration methods to investigate a slaughter and meat processing plant. This plant had already a fairly modern heat recovery system, so there was low potential for extended heat recovery. However, they suggest that it would be fairly easy to save 30% of the external heat demand at a less modern plant. They also suggest installing an additional heat pump in the existing system, which could result in no external energy use for the heat demand, except for the process steam.

In April 2012, a Norwegian industrial abbatoir implemented a system to recover waste heat from the refrigeration system. The waste heat is used for heating of tap water, both directly and indirectly in a heat pump. This system has been analyzed and the results are presented in this paper. The energy use and the carbon footprint before and after the installation have been calculated.

2 SYSTEM DESCRIPTION

The abbatoir that has been analysed in this paper is situated in the southwestern part of Norway. It is the largest private owned abattoir in Norway and it butches pork, beef and lamb. The beef and the lamb are cut at this plant, but the pork is transported to another abattoir in the same company.

2.1 Refrigeration system and surplus heat

The refrigeration system is an ammonia (NH_3) two stage system. The refrigerant in the low pressure stage, at approximately -33°C, is used directly in freezing store evaporators and in quick chiller evaporators for pork meat. Refrigerant from a middle pressure, at approximately -10°C, is both used directly in cold store evaporators and in an ice water system. The ice water is circulated in several cold store heat exchangers. The condensers are effectively cooled by water from a nearby lake.

The refrigeration system has surplus heat from the compressor and the condenser. The temperature in the oil cooling systems of the high pressure compressors are about 40-50°C. The temperature of the warm gas of the high pressure compressors is about 80°C. The cooling capacity for the high stage compressors is 1430 kW and 584 kW for the low stage compressors. The condensers work normally at about 9.7 bar, which corresponds to 24°C. The total capacity in the condensers is 1900 kW.

2.2 Tap water heating

When the incoming tap water first enters the factory, its temperature is between 5 and 13°C (average 10°C), depending on the time of year. It is first heated to approximately 18°C in a heat exchanger which recovers heat from the ventilation system. Secondly, it is further heated to about 40°C in the "40°C-loop". 20% of the tap water is used in the hand washing stations and the rest is heated further in the "60°C-loop". The out coming water is about 67°C and it is used for production and cleaning.

2.3 Old solution for heating water

Figure 1~~Figure 1~~ illustrates how the system was assembled before the heat recovery system was installed. The "40°C-loop" received heat from an R134a heat pump and the steam boiler. This heat pump worked between 3 and 15 bars, which correspond to 0°C and 50°C, respectively. The evaporator heat was received from a closed loop heated by the hot gas of the compressors. The boiler used both electricity and fuel oil to produce steam. This steam was used for the 40°C-loop in situations (typically wintertime) when the heat pump did not provide enough heating.

The "60°C-loop" received all necessary heat from the steam boiler. Norwegian Food Safety Authority requires that the carcass saw is cleaned with 80°C water, which is heated separately in an electrical boiler.

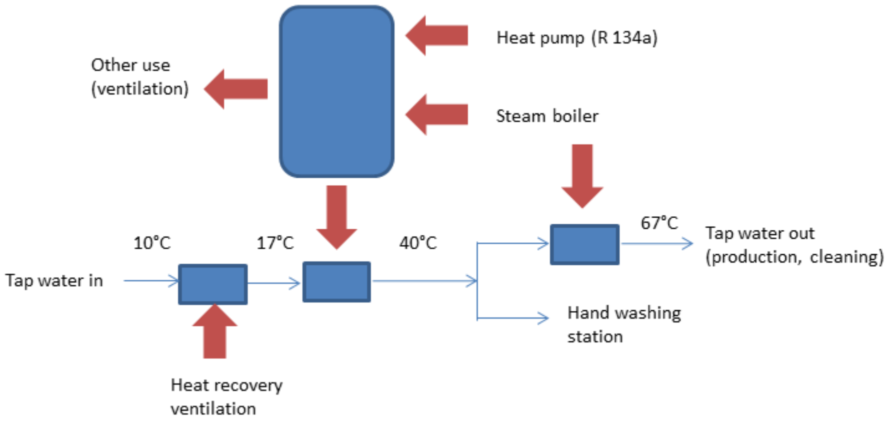

Figure 1. Illustration of old solution for heating tap water.

2.4 New solution for heating water

The new system consists of additions to the old system. The heat recovery from the ventilation system for initial warming of tap water is still in place and the "40°C-loop" still receives heat from the R134a heat pump. The heat pump evaporator now receives the heat from the refrigeration condenser cooling water. A new heat recovery tank has also been installed, which provides heat to the tap water between the ventilation heat exchanger and the "40°C-loop"-heat exchanger. This tank is heated with heat from the high pressure compressors; the warm gas and the oil cooling system.

An ammonia heat pump was installed to heat the "60°C-loop", as an alternative to the steam boiler. It is installed on top of the refrigeration system and the compressor works between 10 bar and 35 bar.

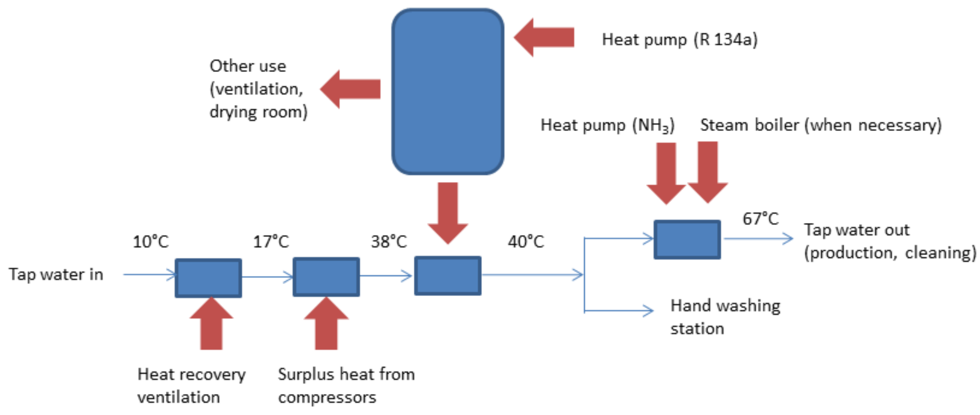

Figure 2. Illustration of new solution for heating tap water.

2.5 Additional heating

Another recent change in the factory is that the "40°C-loop" will also be used to heat the drying room where "pinnekjøtt" (a Norwegian specialty of lamb ribs) is prepared. This will be a seasonal activity, typically from autumn to Christmas.

Heating of the ventilation system is also provided by the "40°C-loop". Before the new heat recovery installations, there was sometimes lack of heat for this system, but this no longer seems to pose a problem.

3 MEASUREMENTS AND CALCULATIONS

3.1 Logging system and measurement data

The majority of the information and data regarding the new and old system was provided by the slaughterhouse's own system for measuring, which is accessible on the internet. Energy use, water flows and production mass are logged in an online system. High grade energy (electricity and fuel oil) is given as well as internal low grade energy flows. Electricity consumed by the combination boiler, the boiler's feed water tank, and the three main switch boards, named H1, H4, and H5, are also available. There is not a clear structure for which equipment that is connected to which board, but most of the refrigeration and heat pump systems are connected to switch board H5. Only this board is therefore included in the calculation of the total energy usage. This was divided by the production amount (in tonnes) to give the specific energy use. Temperatures in the refrigeration and heating system were recorded and visualized in another system, which was only available at the slaughterhouse.

Information regarding material needs of the new system was obtained through correspondence with the manufacturer of the system. Data for the weight and material of the system's new components were found in industry product catalogues. Information regarding the carbon footprint of energy sources, materials, and processes were obtained from the Ecoinvent database.

3.2 Energy to heat tap water

Energy for heating of the tap water was calculated separately. Before the new heat recovery installations, the heat came from the "40°C-loop" and from the steam boiler. Heat from the "40°C-loop" to the tap water was given in the logging system. Explicit values for the heat to the tap water from the steam boiler were not given, so these were calculated from assumed temperatures and logged mass flows. Water density of 1000 kg/m3 and specific heat capacity of water of 4.1845 kJ/kgK were used in these calculations. Neither the heat from the ventilation recovery system nor the temperature of the tap water into the system was logged, so this part of the system was excluded from the calculations. The external energy used for this heat was electricity to the R134a heat pump, electricity to the steam boiler and oil to the steam boiler. It was assumed that all of the heat from the"40°C-loop" was covered by the R134a heat pump. External energy divided by total energy for tap water heating gave the resulting values.

After the new installations, all of the energy flows that was necessary for these calculations are logged in the system. Heat flows to the tap water were from the "40°C-loop", surplus heat from compressors and from the new heat pump (NH_3). No electricity or oil was used in the steam boiler for heating of the tap water.

Electricity that was used by the heat pumps was not logged and a COP had therefore to be assumed. The COP for the R134a heat pump was set to 3.9 and for the NH_3 heat pump was 4.4. These numbers were based on the temperature levels for the heat pumps and an assumed compressor efficiency of 0.7.

3.3 Carbon footprint calculations

To model the carbon footprint of the energy use in the system, the carbon footprint of a kWh hour of electricity and fuel oil were calculated using SimaPro software (The Swiss Centre for Life Cycle Assessment). The carbon footprint for electricity produced at the plant was calculated twice, once assuming the European electricity mix (EUR) and once assuming the northern European electricity mix (NORDEL). The carbon footprint of burning the light fuel was determined by using the modified Ecoinvent process for burning light fuel oil in a furnace. The heat from the combination boiler using electricity was modeled by assuming that all electricity was converted to heat and that this heat required the same boiler infrastructure, the Ecoinvent process for burning light fuel oil in a furnace. The carbon footprint, kg CO_2 equivalents/kWh energy, is shown in Table 1~~Table 1~~.

Table 1 Carbon footprint of energy carriers

Energy type	Carbon footprint (kg CO_2 equivalents/kWh energy)
Electricity (NORD)	0.190338
Electricity (EUR)	0.561587
Fuel oil	0.327474

In order to compare the new and old system, the carbon footprint from the new system was defined as the carbon footprint embedded in the material requirements of the new, as well as the carbon footprint of the electricity and fuel oil use in the combination boiler, and the electricity use in switch board H5. The carbon footprint of the old system was defined as the carbon footprint of the electricity and fuel use in the combination boiler and the electricity use in switch board H5 before the installation of the new water heating solution.

The material requirements of the new system include the machinery and piping necessary for heat recovery. The manufacture, transportation, and installation of these materials, transporting, have an embedded carbon footprint. Only the material requirements of the new system were included in the carbon footprint calculations, since the new system consists of material additions to the old system.

All energy consumption and material needs were normalized per tonne of production to ensure that no apparent increase in energy consumption would be due to increased production.

There is always a risk of excluding some of the materials when building an inventory. However, the material inventory of the new system is fairly robust due to the detailed information from the manufacturer. Worst case, doubling the material requirements and best case scenario, the calculated material requirements were also compared, with negligible differences in the results.

4 RESULTS AND DISCUSSION

The results have been calculated from logged data from the measuring system at the abattoir. MS Excel was used for all of the calculations. It was clear that the logged data in some situations did not give a correct values for some of the internal low grade energy flows. Aggregated flows of the high grade energy were thus used for the calculations.

4.1 Energy use for heating and refrigeration system

The specific energy use is shown in Figure 3~~Figure 3~~. It was calculated from fuel oil and electricity to the steam boiler and electricity to main switch board H5 divided by the production amount. The specific energy for the last year is lower than for the other two years, except for in September, where it is higher. This is unexpected, because more use of internal heat would naturally lead to less external energy usage.

In the search for an explanation, the number of days with production was found for each month. There is no production during weekends, but there is still energy consumption on these days. September 2010 and 2011 had 22 days of production, but September 2012 had only 20. This could account for some of the increase in specific energy use, but not all.

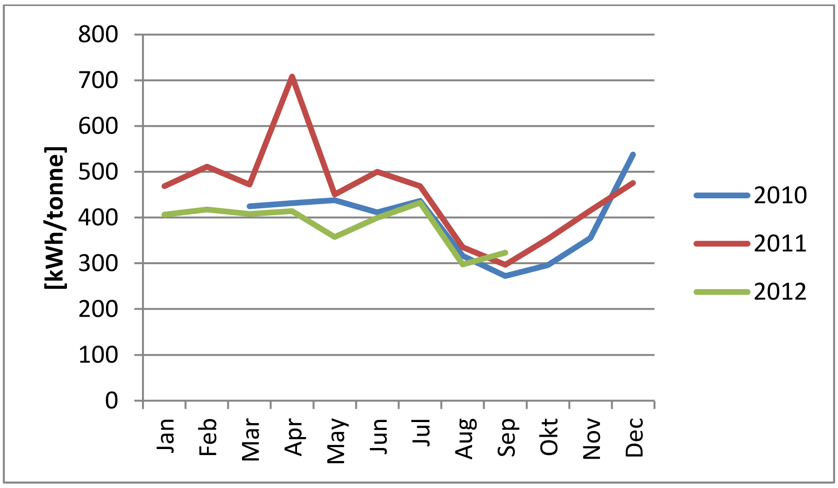

Figure 3 Specific energy use (electricity + fuel oil)

The specific energy use for the complete plant (including all of the main switch boards) has also been calculated, and an average of 617 kWh/tonne was found for 2011. The lowest and highest values calculated as an average per month were 412 and 955 kWh/tonne, respectively. Enova () has registered specific energy use for some similar meat production industries for 2011. These have an average of 560 kWh/tonne, where the lowest is 290 kWh/tonne and the highest is 1300 kWh/tonne.

The processing plant has had a shift towards less use of fuel oil from 2010 until today. Figure 4~~Figure 4~~ shows how the distribution of energy use has developed. These numbers are in percent of total energy use to the complete system. Even though it has varied over the years, the trend is towards no use of fuel oil and less use of electricity in the steam boiler. In July-Sept 2012, 85% of the input energy went to the switch board H5, which includes most of the refrigeration system. The rest was electricity to the steam boiler. Fuel oil was less than 0.5%.

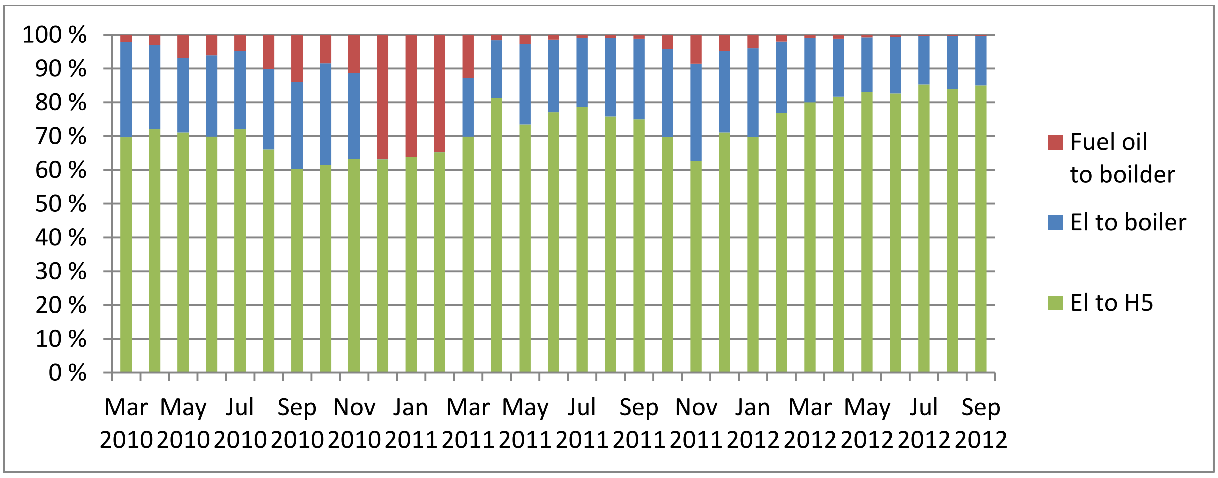

Figure 4. Per cent of energy input to steam boiler and to switch board H5

4.2 Energy to heat tap water

Energy data from the logging system has been used to find the heat and the electricity that is necessary to heat the tap water, excluding other energy flows. The results are shown in Figure 5~~Figure 5~~. It shows how large part of the necessary heat that was covered with electricity or oil. The average before the heat recovery installations was about 55% when it was stable. Some of the months get 100%, which probably can be explained by measurement fault. Another possibility is that the R134a heat pump has been turned off for a longer time, but this has not been reported. There are no logged temperatures from 2010 and 2011, only from 2012, so temperatures had to be assumed. Temperatures are varying, but when looking at the average values these are quite stable. The error of assuming temperatures is probably small.

After the heat recovery installations were made, the average value for how much electricity and oil that was used for heating the tap water was reduced to about 13%. This is because more of the heat within the plant is recovered and less external energy (electricity and oil) is necessary.

The heat from the ventilation recovery system was not logged and therefore not included. If it had been included, it would decrease the the values in Figure 5~~Figure 5~~, mostly for the months before the heat recovery installations.

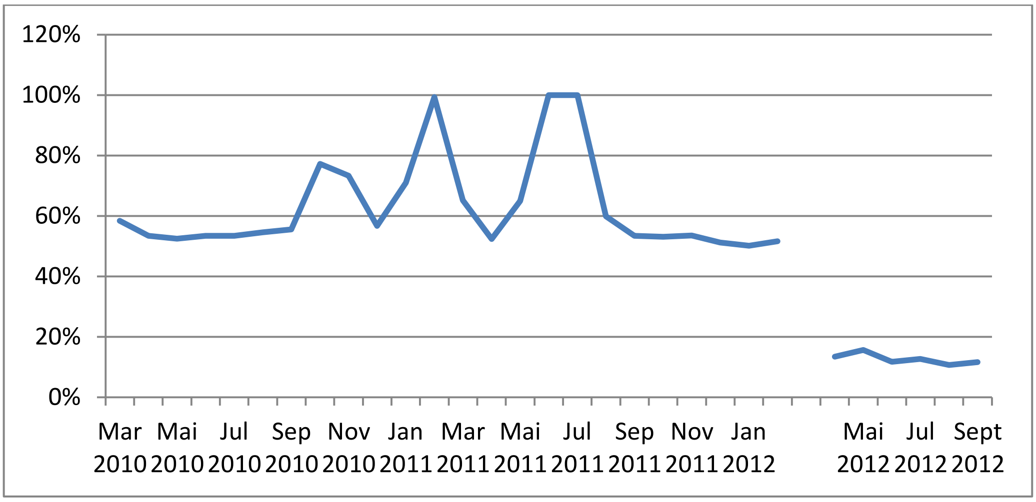

Figure 5. Part of total energy to heating of water from electricity or fuel oil

The results illustrated before were average per month and it can be seen from Figure 5~~Figure 5~~ that the values varied or were also possibly misguiding. Therefore, two months each year (August and September) were selected and day average values were found. These gave more stable results, and average values are shown in Table 2~~Table 2~~. The values are similar to the ones found in Figure 5~~Figure 5~~, 52% before the installations and 12% after. Table 2~~Table 2~~ also gives the CO_2-equivalents, which will be discussed in the following section.

Table 2. Overview of average data for Aug-Sept each year.

	External energy to heat tap water [%]	Total CO_2-equivalents NORD [kg/tonne]	Total CO_2- equivalents EUR [kg/tonne]
Aug-Sept 2010	52 %	10	23
Aug-Sept 2011	52 %	8	24
Aug-Sept 2012	12 %	2	7

4.3 Carbon footprint

The life cycle comparison of the carbon footprint of the new and old systems showed that there was a reduction in carbon footprint per tonne of production for both the Nordic and European electricity mixes.

This is shown in Figure 6~~Figure 6~~. The lesser reduction for the European mix assumption is due to the fact that the European electricity mix has a higher carbon footprint than fuel oil. This is because the European mix electricity mix implies that the sources for some of the consumed electricity mix are more carbon intensive than fuel oil, for example coal. (The Swiss Centre for Life Cycle Assessment) This results in an increased carbon footprint if European electricity mix replaces fuel oil. In the case of the Nordic electricity assumption, electricity has a lesser carbon footprint than fuel oil, meaning that any fuel oil consumption which is replaced by electricity will result in a carbon footprint reduction.

Since Norway imports and exports large portions of the electricity which it produces and consumes respectively, it is an incorrect to assume that the electricity consumed at the factory consist mostly of the Norwegian electricity mix (Jorge, Hawkins, Hertwich, 2012).

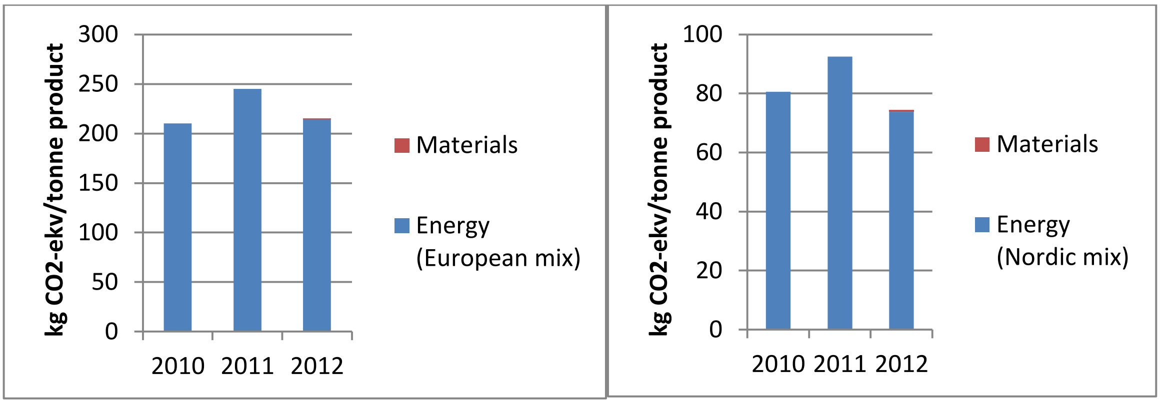

Figure 6. Average CO_2 equivalents per year, for European mix and for Nordic mix of electricity.

As shown in the results from the specific energy use, there is not a definite reduction in carbon dioxide equivalents. Carbon footprint was therefore calculated based on the energy calculations specific for tap water heating and this is given in Figure 7~~Figure 7~~. Before installing the heat recovery system, the average value for CO_2 equivalents was 10 kg/tonne product for Nordic electricity mix and 23 kg/tonne for European electricity mix. After installation of the heat recovery system, the average value for CO_2 equivalents was 4 kg/tonne product for Nordic electricity mix and 9 kg/tonne for European electricity mix. This is a significant reduction.

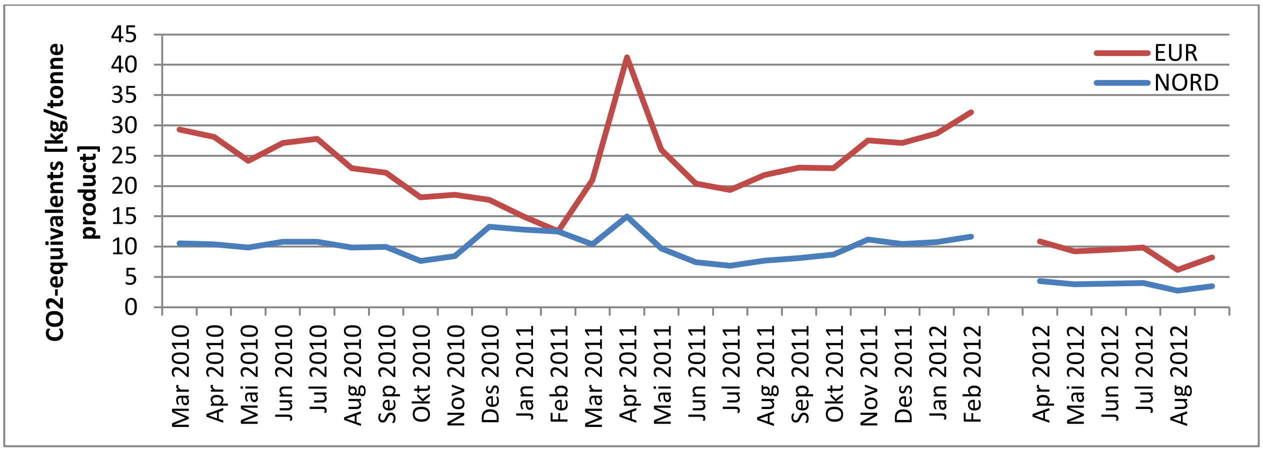

Figure 7. CO2 equivalents per month.

For the European electricity solution, there is a savings of 14 kg CO_2 equivalents per tonne of production. With a yearly production of about 12 000 tonnes, the new system can be expected to reduce the factory's yearly carbon footprint by 168 tonnes CO_2 equivalents per year. This amount corresponds to 1 million person-kilometers in a passenger car. The corresponding number for Nordic electricity mix is 0.4 million person-kilometers.

5 CONCLUSIONS

Analysis of the energy consumption at the factory shows that the new system led to a significant reduction in energy consumption for heating tap water at the abattoir. This shows that the extra electricity needed to run the pumps and the new compressor was less than the energy saved by recovering waste heat.

The results show that, barring any major revelations in the material needs of the new system, the carbon footprint per ton of production is dominated by the energy use. It can therefore be concluded that CO_2 equivalents from the extra material needs of the new system and the energy needs for running the new system, e.g. electricity for the new pumps, are smaller than the savings.

Additionally, comparing the results using Nordic and European electricity mixes illustrates the importance of not only reducing direct fuel usage but also reducing aggregate energy use.

The installation of the heat recovery system and the new heat pump was so successful that the company has decided to build a similar system at one of their other slaughterhouses.

6 ACKNOWLEDGEMENTS

The work in this study has been financed by the EU project Frisbee, Creativ and IPN Optilam (NRC).

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