Energy management of surplus heat from refrigeration

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ABSTRACT

Many industrial processes generate a large amount of surplus heat. For instance, in a refrigeration process there is potential heat sources from the condenser or from the compressor. The challenge has been to find useful use of this heat. In many productions the need for heat and cold is not simultaneous. To utilize this, a solution is to have different companies sharing the surplus heat. In southern part of Norway a dairy, a meat plant, a food company and a greenhouse has cooperation sharing the surplus heat from their production.

This paper will present the form of cooperation, the economical benefits and energy reduction potential. Using an energy planning model the potential reduction of the total energy use and further improvements in the cooperation is shown. The model minimizes total energy system cost of meeting predefined energy demands of electricity, heating and cooling within a geographical area over a given planning horizon. The model uses a detailed network representation of technologies and infrastructure to handle investments decisions down to single components, cables and pipelines. The object function includes investment, operating and environmental costs over a planning horizon of several decades for most relevant energy carriers and conversion between these.

INTRODUCTION

In CREATIV, an ongoing research-based innovation project aiming for improved industry energy efficiency, there is an activity on energy efficiency in industrial parks.

There are several of reports indicating huge benefits from employing surplus heat utilization networks. For example, [1] states that in a large industrial complex, the total energy cost might be reduced by more than 80 %. However, most of these papers discuss large industrial parks and utilization of high-temperature surplus heat. For the industrial plants in the industrial park discussed in this paper, the surplus heat has lower temperature, only about 20–70 °C. We have not found any recently published paper indicating the economic and environmental potential in employing surplus heat utilization networks when the temperature is in this range.

Still, some recently published papers refer to single industrial plants [2] gives an evaluation of different energy saving measures in slaughter and meat processing plants (SMP). Which measures that are most profitable and environmentally interesting, depends on the plant size. The abovementioned paper also mentions that as plant sizes increase, the potential for saving energy increase. It also points out some benefits from establish other food processing plants close to a SMP.

Surplus heat at 20–70 °C is not suitable for generating electricity. On the other hand, a combined heat and power plant (CHP) plant may produce heat enough to meet the total heat demand of an industrial park, and the electric power produced would then be an extra benefit. That might be economically and environmentally interesting [3], but it still does not utilize the surplus heat of 20–70 °C. According to [2], a combined heat, cold and power plant (CCHP) solution might be able to take care of that. The 20–70 °C surplus heat might be used for chilling by an adsorption chiller [2], though the economic and environmental potential of this is uncertain. The surplus heat can also be raised to higher temperatures using a heat pump [4]. Whether this is profitable or not, depends on several factors as plant size and energy prices [3].

Description of the industrial park

Kviamarka industrial park is situated in south-west of Norway. The park is under installation and is expected to be operational within 2011.

The Interacting Companies

The main driving force in this cooperation has been Tine BA. Tine BA is Norway's largest dairy company. They produce milk, cheese and milk products. Their production consists of chilling, heating and evaporation (drying) processes. The other companies are, Jærkylling, a chicken processing plant with refrigeration and heating processes, Cardinal foods (Prima), a food processing plant, producing sandwich spread and canned food, Nortura, a meat plant with refrigeration processes, Miljøgartneriet (MG), a greenhouse plant, and Jæren Fjernvarme, a district heating company. Tine, Jærkylling, Cardinal foods, and Nortura are mainly producers of heat, while Miljøgartneriet (MG) is mainly a user of heat.

Cooperation

A major challenge was to make an cooperation between these companies. Their prime production is not heat, so not to have an conflict with their main production Tine decided to establish a own company dealing with flow of heat and economical considerations. Tine Energisentral, the new company, act as a network administrator, controlling the balance in the network and paying and invoicing the participants.

Energy system

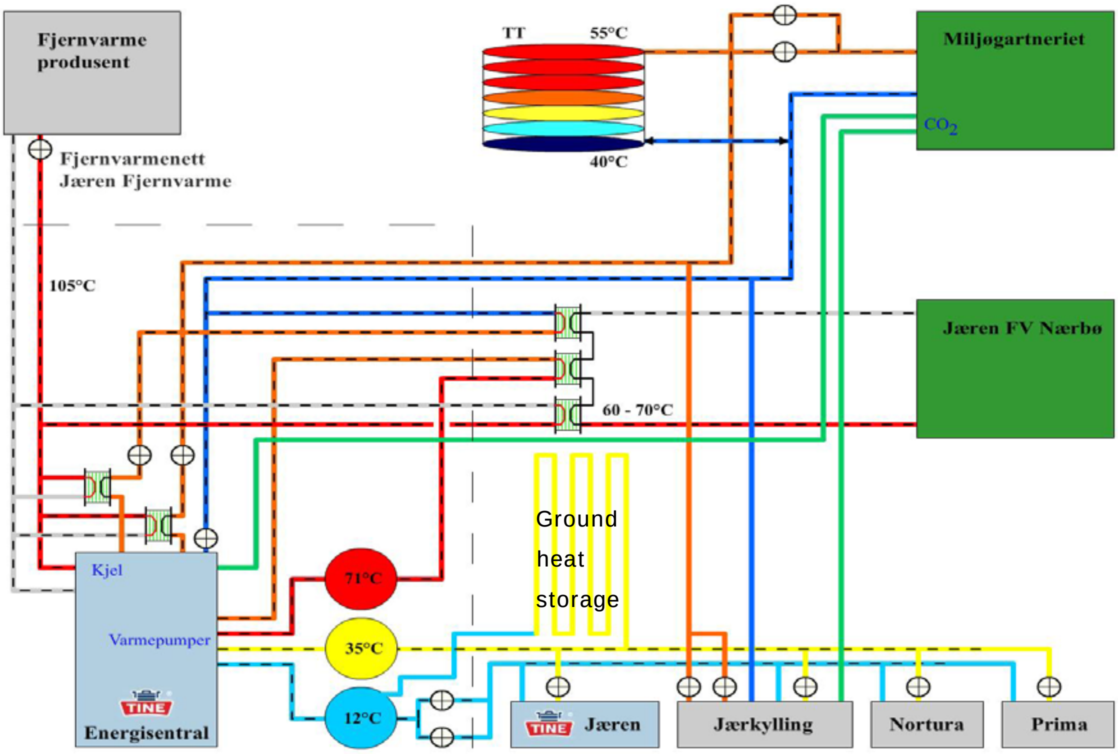

Figure 1: Overview of heat flow

Figure 1 shows an overview of the heat flow among the companies.

Tine BA, Jærkylling, Nortura and Prima will deliver heat at 35 ºC from their refrigeration plants, mainly coming from the condensers and compressors. In return they get water at 12 ºC, thereby enabling a low condenser pressure. This line is also connected to a ground heat storage system which acts a heat sink when production is high. The heat at 35 ºC is delivered to Tine Energisentral (TE) which uses high pressure ammonia heat pumps to increase the temperature to 71 ºC at the hot side and decrease it to 12 ºC at the cold side. This "cold" water is used to get heat from the condensers and with that lower the energy use.

TE also operates a direct-fired boiler which can deliver heat at 105 ºC to the district heating system.

MG is the main user of heat. They can receive heat at 71ºC and 105 ºC which they accumulate in a water tank. This tank delivers heat to the greenhouse at 55 ºC to 40 ºC. In addition MG receives CO2 from Jærkylling and Tine BA.

E-transport – The model to be used

This industrial park is under construction. As a part of the cooperation with the Creativ project this site will be modelled in e-Transport, an energy expansion planning tool. The aim is to develop the model for low temperature heat sources and at the same time serve as a tool for the management of the industrial park.

General description

The area of optimal expansion planning in energy systems with multiple energy carriers is dominated by large scale optimisation tools for regional or global system studies like MARKAL/TIMES, EFOM, MESSAGE and similar models [5-9]. In such large scale energy system studies, the energy system is typically represented with an aggregated type of modelling with one energy balance per energy carrier, and with resources deployed on one side and end use extracted on the other side. Various technologies are modelled with emissions and energy losses. This approach is usually sufficient for system studies on a national or international level. In an improved optimisation approach for expansion planning in local energy supply systems, however, different infrastructures within the geographical area of concern have to be identified. Geography, topology and timing are all key elements in this approach. It is thus not only a question of which resources and which amounts to use, but also where in the system the necessary investments should take place and when they should be carried out. In international literature several approaches have appeared the last years that integrate two or more energy infrastructures in the analysis. Many of these focus on the integrated operation of gas (fuel) and electricity networks for optimal dispatch of units and/or pricing of transmission capacity [10-14] or downstream optimization of electricity and heat demand from cogeneration [15-16]. Some papers attack the optimization of multiple energy carriers more generalised, incorporating electricity, gas, heat and hydrogen on the supply side as well as electricity, heating and cooling on the demand side [17-20]. The German model DEECO (Dynamic Energy Emission and Cost Optimization) is developed to optimise the rational use of energy and utilization of renewable energy in local energy systems [21-23]. None of these approaches, however, consider the issue of expansion/investment planning of such multiple infrastructures.

Thus, the novel expansion planning model "eTransport" is developed for local energy supply systems where investments in different energy technologies and carriers are considered simultaneously [24-25]. The model gives the user an overview of a given energy system with respect to costs, environmental consequences and use of local energy resources. The model uses a detailed representation of technologies and infrastructure to enable identification of single components, cables or pipelines. The current version can optimize the expansion of infrastructure for most relevant energy carriers and conversion between these. It is not limited to continuous transport like lines, cables and pipelines, but can also include discrete transport by ship, road or rail. The main task of the model is to optimize investments in infrastructure over a planning horizon of 10 to 30 years to bring energy to the end user in such quantities and in such forms that the end users' demands are satisfied in the economically and environmentally best way possible.

The model is separated into an operational model (energy system model) and an investment model; see Figure 2.

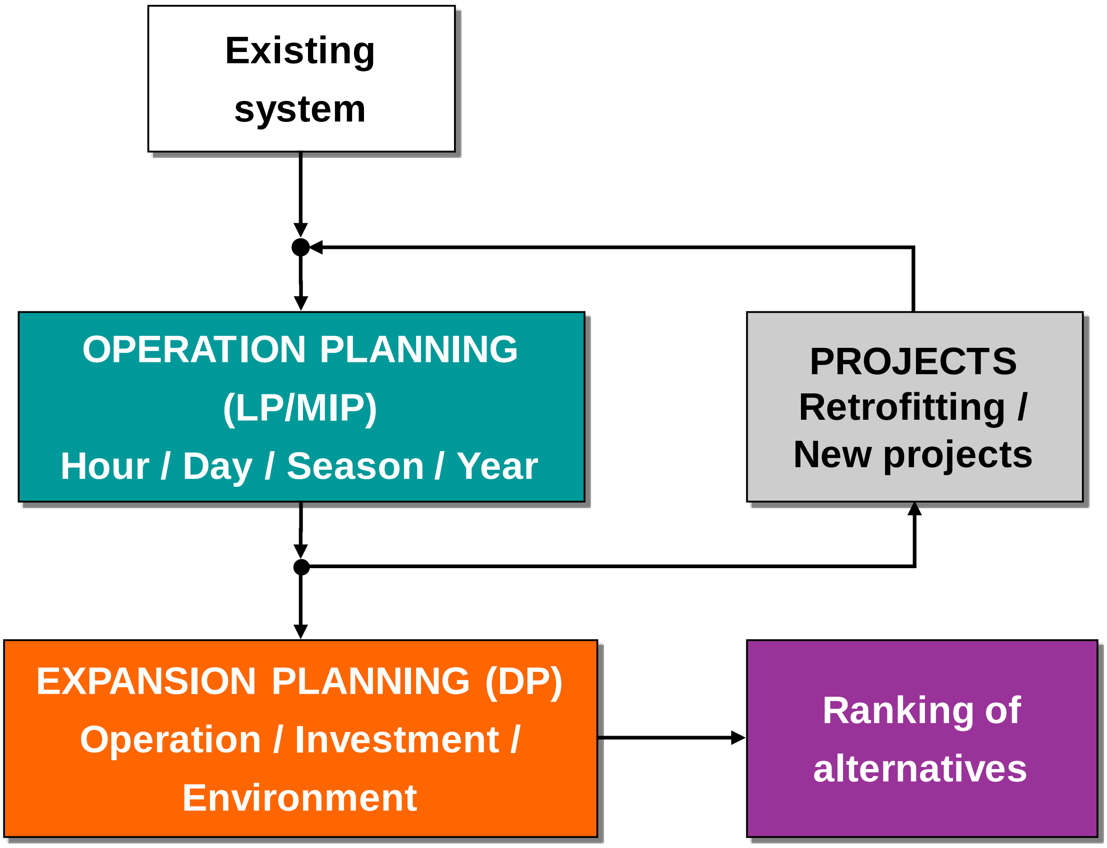

Figure 2: Integration of operation and expansion planning of energy systems.

In the operational model there are component libraries with sub-models for each energy carrier and for conversion components. The operational planning horizon is relatively short (1-3 days) with a typical time-step of one hour. The model finds the cost-minimising diurnal operation for a given infrastructure and for given energy loads. A time-step of one hour is not feasible for investment analysis where the planning period can be 20-30 years. Therefore, the operational analysis is separated from the investment analysis, and annual operating costs for different energy system designs are pre-calculated by solving the operational model repeatedly for different seasons (e.g. peak load, low load, intermediate etc), periods (e.g. 5 year intervals) and relevant system designs. Annual operating and environmental costs for different periods and energy system designs are sent to the investment model that finds the investment plan that minimises the present value of all costs over the planning horizon. Mathematically, the model uses a combination of linear programming (LP) and mixed integer programming (MIP) for the operational model, and dynamic programming (DP) for the investment model as indicated in Figure 2.

The operational model (LP/MIP) is implemented in the AMPL programming language with CPLEX as solver. The investment model (DP) is implemented in C++. A modular design ensures that new modules developed in AMPL for the operational model are automatically included in the investment model. A full-graphical Windows interface is also developed for the model in MS Visio (see Figure 4.). All data for a given case are stored in an Access database.

Modelling of the park

The industrial park has been modelled with electrical energy, natural gas and heat as energy input to the system. As shown in figure 3 it possible to add other energy sources as input to the system. This is planned to be a part of the analysis when construction of the park is finished.

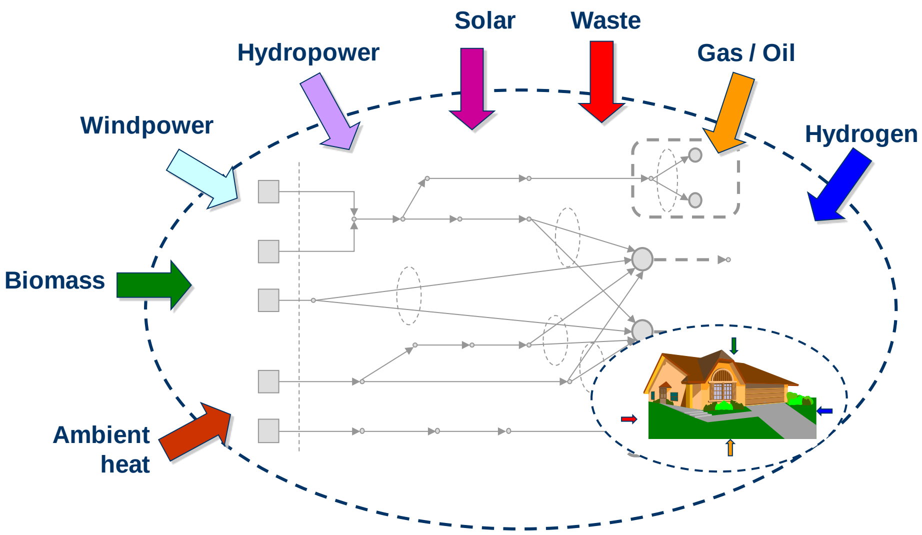

Figure 3: Optimal use of local energy sources.

It is part of a future expansion to build a combined heat and power plant run on biomass. This will be a part of future analysis to investigate if is economical and sustainable to add such a plant to the park. The main objective in the first phase is to confirm the environmental and economical benefit of distributing low temperature heat among companies in an industrial park.

“E-Transport” has a windows based graphical interface. Each process (component) is represented with a node that either produce energy (electrical or heat) or consume. The processes are coupled together with basic fixed connection or future connection that should be analysed. Figure 4 shows the graphical interface.

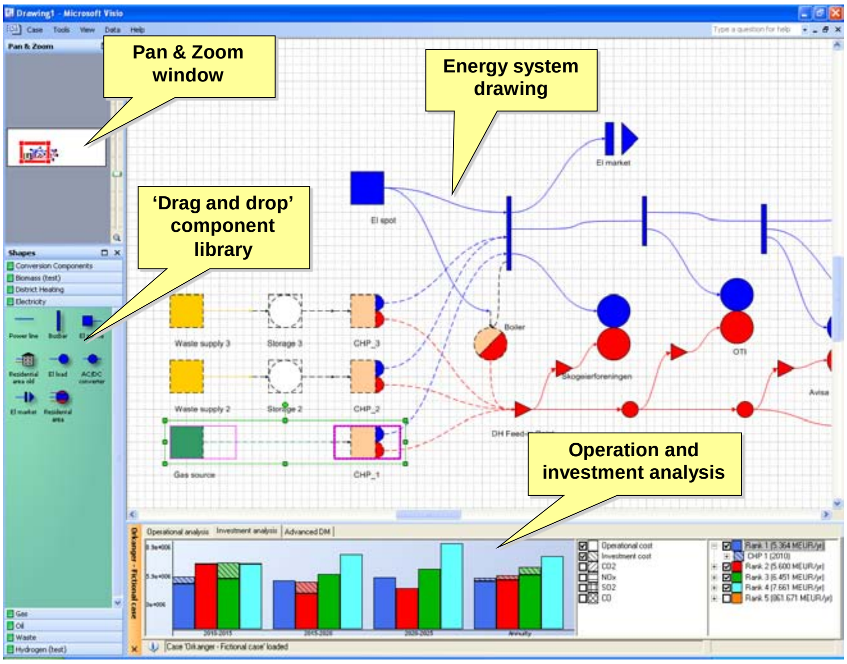

Figure 4: MS Visio graphical interface

In the case of Kviamarka the model are under development to considerate the different companies load profiles. It will be developed a base case that is similar to the actual piping and heat infrastructure of the park. The analysis of this will be adapted to the actual monitored figures of the system. The subsequent cases will be done on planned expansion of the park to foresee the economical and environmental benefits.

Figure 5 shows an example of the results from the analysis. It is possible to see a ranking of different investments regard to either economical or environmental parameters. This will improve the background for the decision makers when they should chose between different alternatives. Hopefully it will also be an tool which can be used to choose between the best environmental friendly alternatives.

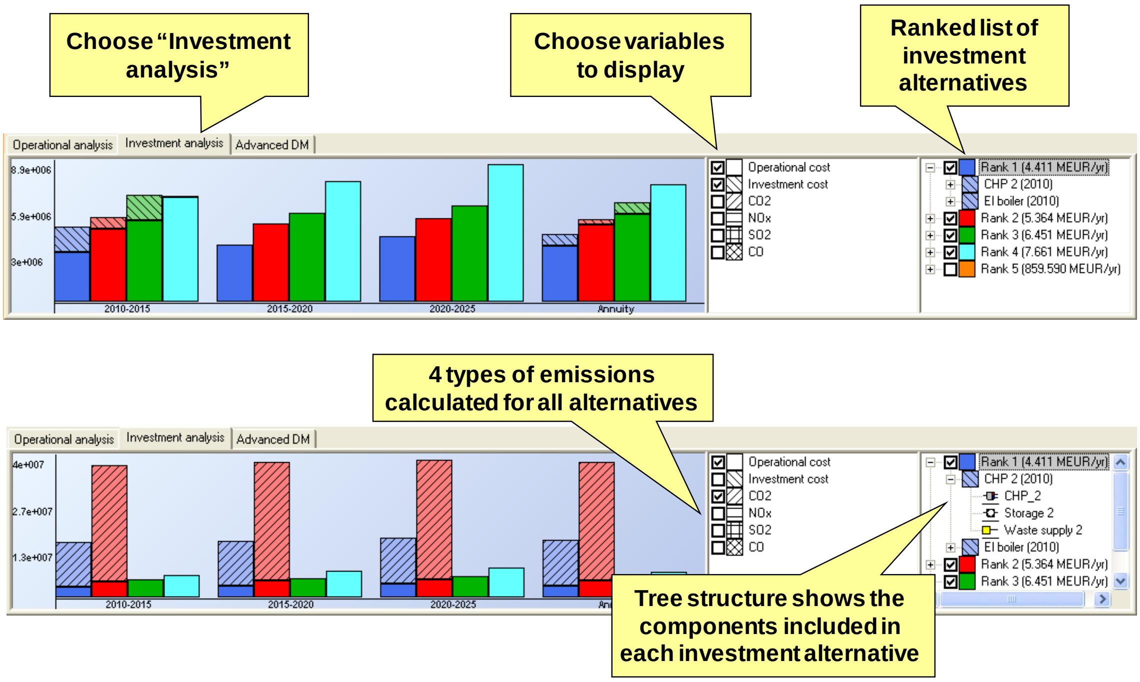

Figure 5: Example of result from the analysis.

CONCLUSION

Many industrial processes generate a large amount of surplus heat. For instance, in the refrigeration process there is potential heat sources from the condenser or from the compressor. The challenge has been to find useful use of this heat. In many productions the need for heat and cold is not simultaneous. One solution to utilize this is to have different plants sharing the surplus heat. In southern part of Norway a dairy, meat plant, food production and a greenhouse has cooperation with the surplus heat from their production. This paper has presented their form of cooperation, and a energy planning model that will be used to analyse future expansions to improve the utilisation of low temperature heat in the most economical and environmental way.

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RESUME

Beaucoup de processus industriels produisent d'une grande quantité de la chaleur en surplus. Par exemple, dans le procédé de réfrigération il y a des sources de chaleur potentielles du condensateur ou du compresseur. Le défi a été de trouver l'utilisation utile de cette chaleur. Dans beaucoup de productions le besoin de chaleur et de froid n'est pas simultané. Pour utiliser ceci, une solution est d'avoir différentes compagnies partager la chaleur en surplus. Dans la région méridionale de la Norvège une laiterie, une installation de viande, une compagnie de nourriture et une serre chaude a la coopération partager la chaleur en surplus de leur production. Cet article présentera leur forme de coopération, des avantages économiques et de potentiel de réduction d'énergie. En utilisant une planification d'énergie modelez la réduction potentielle de toute l'utilisation d'énergie et d'autres améliorations de la coopération est montrées. Le modèle réduit au minimum le coût total de système d'énergie de satisfaire des demandes énergétiques prédéfinies de l'électricité, du chauffage et de refroidir dans un excédent géographique de secteur un horizon de planification donné. Le modèle emploie une représentation détaillée de réseau des technologies et de l'infrastructure pour manipuler des décisions d'investissements vers le bas pour choisir des composants, des câbles et des canalisations. La fonction d'objet inclut l'investissement, le fonctionnement et les coûts environnementaux au-dessus d'un horizon de planification de plusieurs décennies pour la plupart des porteurs d'énergie appropriés et de conversion entre ces derniers.

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