Renewable and Sustainable Energy Reviews 30 (2014) 230–236

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Optimal utilisation of heat demand in district heating system—A case study

Alemayehu Gebremedhin *

Faculty of Technology, Economy and Management, Gjøvik University College, N-2802 Gjøvik, Norway

ARTICLE INFO

Article history:
Received 26 May 2013
Received in revised form
4 September 2013
Accepted 13 October 2013

Keywords:
District heating
CO_2 emissions
Biomass
CHP
Combined cycle

ABSTRACT

Global warming is one of the most important issues to handle in the energy sector, due to the high CO_2 emissions from fossil fuel based power plants. The district heating sector can play a significant role in reducing the emissions. This, however, depends on how efficiently current and future heat demands are used as a heat sink.

This paper presents the results of a model study of a district heating system (DHS). As a case study, a local DHS in a town in Sweden has been modelled using a linear programming method. The electricity generation system in northern Europe is also modelled in simplified way to serve as an input. The purpose of this study and modelling in this way is to answer the questions concerning the choice of technology solutions and fuels from an economic and an environmental point of view where the focus is on the local DHS. The main objective is to study the impact of different levels of biomass prices and emission allowances on the choice of fuels and production technologies (no other taxes, fees or any kind of subsidy are considered). The results show that low biomass prices along with high emission costs promote investment in biomass-based cogeneration. However, this would mean that the market price of existing renewable incentives and CO_2 cost must be higher than the current level. Furthermore, biomass as it is used now in traditional CHP system is not system optimal. In an integrated system, plants with high electrical efficiency provide better economy and lower emissions of global CO_2 than solutions based on traditional biomass CHP. The need for a system solution where the heat demand is used efficiently is seen in facilities with high electrical efficiency.

Contents

1. Introduction

Global warming has put the focus on the issue of CO_2 and that CO_2 emissions must be reduced. Most emissions of CO_2 come from power generation and transport sectors. According to an agreement signed by EU heads of state and government, a number of measures have to be taken to address energy supply security and climate change issues. One of the measures proposed by the EU is to cut green house gas emissions by 20% compared with 1990 levels [1]. Each member state has to reduce its emissions by a certain percentage compared to 2005 [1]. In Sweden, the target is a 17% reduction of CO_2 emissions. Countries that have recently

* Tel.: +47 61 13 51 74; fax: +47 61 13 54 46.
E-mail address: Alemayehu.Gebremedhin@hig.no

1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.10.009

become members are permitted to have an increase in emissions in order to secure their economic growth. In addition to the reduction of greenhouse gases, a target has been set that 20% of final energy consumption in 2020 must come from renewable energy sources [2]. The objective also includes a 10% share of renewable fuel for vehicles. In addition, primary energy use must be 20% lower by 2020 compared with projected level [3].

One of the major policy measures for reducing CO_2 is allowances for emissions. These are limited and connected to a cost and there is a trade mechanism for them. By lowering the amount of allowances, the cost will rise and provide incentives for investments in new CO_2-clean technologies and programmes for reduced consumption of electricity. In Europe, a scheme for emission allowance trading was established by the directive from 2003 [4]. The European emission trading scheme (EU ETS) started in January 2005 and covers many installations in the industrial and energy sectors. The first phase of the EU ETS ran from 2005–2007 and the second phase of the trading scheme that started in 2008 was completed in 2012. The scheme is now in its third period and this will run from 2013 to 2020.

It is a well-known fact that a large proportion of the CO_2 emissions come from electricity production based on fossil fuels. To reduce emissions, it is thus important to reduce the use of electricity as much as possible. Since the world is highly dependent on electricity, it is important to find solutions that reduce emissions while maintaining cost effective production. Different fuels and technologies will contribute differently to emissions of CO_2 depending on electrical efficiency and type of energy source. Natural gas and the combined cycle technology give relatively low emissions while coal condensing steam turbines produce relatively high emissions. The use of biomass as an energy source gives low or no emissions of CO_2. A problem with biomass, however, is that it does not provide the same high electrical efficiency as, for example, conventional fuels.

With this in mind, district heating can play an important role to reach some of the energy and environmental targets. A district heating scheme (DHS) is a system where the product (hot water) is generated centrally. The hot water is then distributed through pipeline to different types of customers that are connected to the network. One of the main benefits of DHS is that it enables the use of combined heat and power production (CHP) and makes the overall system efficient. It allows also the use of biomass and other sources of heat such as industrial waste heat. An overview of district energy system from technical, economic and environmental perspectives is given in [5].

Scandinavia is one of the regions of the world where district heating (DH) has long been established. All major cities and towns in Denmark, Sweden and Finland use DH for domestic heating and its share of the heat market in these countries is significantly high. This is not, however, the case in Norway, which has a rather low share even though the climate conditions are similar to those of its neighbouring Nordic countries. The main reason for this is an abundance of hydropower, which directly or indirectly encourages the use of electricity in the heating sector. Nonetheless, district heating is increasing steadily and the growth potential is higher in Norway than in the rest of Scandinavia.

Although a DHS enables the use of CHP, the degree of utilisation of CHP differs from country to country. In the case of Sweden, the development of CHP was different from some of the Nordic countries. When DH was established in the 1960s, a few CHP plants were also introduced. Originally, various fossil fuels like oil and coal were used, but after the oil crises of the 1970s biomass began to be used based on logging residues from forestry industries. During the 1980s the development of nuclear power in Sweden was completed and this has led to a surplus of electricity and hence low electricity prices. No effort was therefore made to promote electricity generation from CHP plants. On the other hand, there was a continuous expansion of DH based on hot water production from biomass to reduce oil dependency for space heating. This has led to a substantial increase in the share of biomass in the Swedish district heating production. For instance, the share of biomass in the total energy input for district heat production was about 40% in 2011 [6]. Another factor that contributed to increased use of biomass in the last years is the deployment of biomass based CHP. In this case, the introduction of the renewable incentive (see section 2) has played a vital role.

Today, the Swedish DHS has a significant share in the final energy and the system has one of the most diversified fuel mixes in the world. However, district heating seems to have reached its peak in Sweden and the possibility of further expansion is limited. Therefore, the focus is now how to reach other areas where the share is low and to find other application for district heating. Expansion in heat spares areas, energy carrier-switching in industries and poly-generation systems are measures that could lead to efficient DHS. Different studies which highlight these themes can be found in [7–11]. Moreover, there is also a concern regarding low energy buildings which might create difficult condition for the competitiveness of district heating. According to the directive on the energy performance of buildings, all new buildings are expected to have minimum energy requirement [12]. There is therefore a need to effectively utilise existing and future heat demand.

Although district heating is well established in Sweden, the existing district heating demand is still not utilised optimally. This is particularly true regarding CHP. The Swedish DHS still lags far behind leading countries like Denmark and Finland when it comes to the deployment of CHP. For instance, as much as 80% of the district heat supply in Denmark comes from CHP plants [13] and the share of CHP in the total power balance is high [14]. Corresponding value for Sweden is around 40% and CHP has still low share in the total power balance. Moreover, the electricity to heat ratio of the entire system is only 0.14 in 2011 [6]. Efficient use of existing DH demand for CHP generation is efficient energy utilization, which gives low CO_2 emissions.

Several studies have been done, which focus on the Swedish district heating. For instance, the potential for increased CHP generation in the Swedish DHS is studied in Knutsson et al. [15]. The well-established district heating in Sweden and the availability of biomass resources has also triggered other researches that focus on efficient use of biomass in district heating systems. Some studies along this line are: assessment and analysis of biomass gasification alternatives in district heating systems [16,17] and integrated production of heat, electricity and vehicle fuels in district heating systems [11,18].

Surplus of electricity and low electricity prices during the 1980s had been given as one of the many barriers for the slow development of CHP in the Swedish DHS. The situation is now different and the deregulation of the electricity market that took place in Europe and Scandinavia has now led to a common market for electricity in the area. For the Scandinavian countries, Nord Pool is the main marketplace for electricity. Some of the players in this market are also players in the German electricity market and there is a substantial exchange of electric power in northern Europe through both public and private power lines. This in turn has meant that electricity prices tend to become equal in the northern area. However, lack of transmission capacity and other regulations still imply different power prices in the region. There is a directive within the EU to establish a general market for electrical power throughout the EU [19]. Efforts are on-going to expand transmission capacity not only between the Scandinavian countries but also to the continent and within the member states. In the long term, this could mean that the whole of northern Europe will have a common electricity market with a common price. Since electricity price has a large influence on the competiveness of CHP,