Applied Energy 104 (2013) 623–632

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

Integrated biomass-based production of district heat, electricity, motor fuels and pellets of different scales

Nguyen Le Truong *, Leif Gustavsson

Linnaeus University, SE-35195 Växjö, Sweden

HIGHLIGHTS

- ▶ District heat from integrated production options are cost and primary energy efficient.
- ▶ Coproducing of bioelectricity is more cost-efficient than coproducing biomotor fuels.
- ▶ There is great potential to polygenerate biopellets in district heat production systems.
- ▶ Composition and cost of district heat production depend on the scale of the system.

ARTICLE INFO

Article history:
Received 12 April 2012
Received in revised form 16 November 2012
Accepted 18 November 2012

Keywords:
Coproduction
District heating system
Biomotor fuels
Biopellets
Minimum cost

ABSTRACT

Woody biomass can be used in different ways to contribute to sustainable development. In this paper, we analyze biomass-based production of district heat, electricity, pellets and motor fuels. We calculate production cost and biomass use of products from standalone production and from different district heat production options, including only heat production and various co/polygeneration options. We optimize the different district heat production systems considering the value of co/polygenerated products, other than district heat, as equal to those produced in minimum-cost standalone plants. Also, we investigate how the scale of district heating systems influences the minimum-cost composition of production units and district heat production costs. We find that co/polygenerated district heat is more cost and fuel efficient than that from heat-only production. Also, coproduction of electricity is more efficient than of motor fuels except for dimethyl-ether production in large district heat production systems. However, the cost difference is minor between coproduction of dimethyl-ether or electricity in such systems. Integrated biopellet production increases the production of electricity or motor fuel and reduces the production cost. District heat production cost depends on fuel price, however, its dependence is reduced if district heat production system is cost-minimized and based on co/polygenerated units. Also, the optimal composition and cost of district heat production depend on the scale of the system. The demand for biopellets may limit the potential integrated production of such a product.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Energy security and the environmental impact of energy use are of increasing global concern. Various countries have adopted strategies to reduce their dependency on fossil fuels and environmental impacts, including the promotion of renewable and low-carbon fuels and more efficient energy-conversion technologies. Biomass, the most important global renewable energy source [1], is considered a key resource in mitigating greenhouse gas emissions and a substitute for fossil fuels. In Sweden, biomass has the potential to provide half of the current Swedish final energy use [2,3]. This can help to reduce oil dependence and mitigate greenhouse gas emissions. Several researches have analyzed and suggested how biomass could be efficiently used to achieve specific targets [4–6]. In all these studies, using biomass for heat production has been considered an option to reduce both oil use and CO_2 emissions.

District heating is common in Sweden, Finland, Denmark, the Baltic countries and Eastern Europe [7]. In Sweden, district heating systems supply more than 10% of total primary energy use and about 14% of final energy use [8]. A common district heat production system (DHS) consists of different production units. Mostly, low-investment heat-only boilers are used to cover peak-load demand due to short annual utilization time (U_f). Combined heat and power (CHP) plants are usually used as the base-load units with a longer U_f to take advantage of high initial investment cost

* Corresponding author. Address: School of Engineering, Linnaeus University, SE-35195 Växjö, Sweden. Tel.: +46 47 076 7593; fax: +46 47 076 8540.
E-mail addresses: nguyen.truong@lnu.se (N.L. Truong), leif.gustavsson@lnu.se (L. Gustavsson).

0306-2619/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apenergy.2012.11.041

but low operation costs [9,10]. However, the base-load CHP units do not always operate at full load due to the variation of heat demand, especially during summer periods.

District heating systems can play an important role in increasing the use of renewable energy and in reducing primary energy use [7]. In Sweden, district heat production has shifted from fossil fuels to mainly biomass during the last three decades [11]. The use of biomass has increased more than fivefold since 1990 [12]. Currently, biomass supplied more than 46% of the total energy input for district heat production in 2009 [8,12]. However, the present net effective electricity-to-heat ratio of the Swedish district heating systems is only 0.13 [13]. That is low compared to their actual potential [14]. That share is expected to increase with the application of CHP plants [15]. In minimum-cost DHSs, biomass can compete with fossil fuels and supply more than 97% of the district heat production with an overall electricity-to-heat ratio of up to 0.8, depending on fuel prices, taxation mechanism and the type of conversion technology used [9,10].

The use of district heating may increase [16,17], and various studies have suggested different ways to improve its performance. Knutsson et al. [16] analyzed the potential expansion of CHP generation in district heating systems. Gustavsson et al. [9] showed the potential of electricity generation from district heating systems if a biomass integrated gasification combined-cycle CHP is used. Wetterlund and Söderström [18] and Difs et al. [19] showed that the introduction of biomass gasification to produce biomotor fuels in district heat production provides economic and CO_2 benefits due to the ability to increase the production of high-value products. Marbe and Harvey [20] suggested the integration of biofuel gasifiers in natural gas CHP plants. The coproduction of district heat and motor fuels can be a suitable combination, as in the production of motor fuels, a certain amount of low temperature heat can be used as district heat [21]. This may lead to an overall cost-efficient system [22] with a high biomotor fuel-to-heat ratio [10]. The production of biopellets requires a significant amount of heat for drying [21]. Therefore, the integration of biomotor fuel and biopellet production with district heat production can be a multi-benefit solution due to (i) the longer process utilization time of district heat production units, (ii) the improvement of the system efficiency and (iii) the diversification of the generated products. However, selection of technologies and capacity for a minimum-cost DHS may depend on biomass price and the scale of district heating system.

In this study, we analyzed production cost and biomass use of biomass-based DHSs. We considered standalone production and integrated production of district heat, bioelectricity or biomotor fuels without or with biopellet production. We evaluated the performance of a minimum-cost DHS and showed how an integrated DHS change the district heat production costs and primary energy use. Also, we showed how a minimum-cost DHS improve the performance of base-load unit with integrated production option. Furthermore, we investigated how the scale of district heating systems influences the selection of different district heat production units and district heat production costs.

2. Method and assumption

Our analysis was based on a district heating system equal to that for the main district heating system in Östersund, Sweden with an annual measured heat load from May 1st, 2008 to April 30th, 2009 as showed in Fig. 1. The heat load is arranged in descending order and the total heat load is 612 GWh with a peak demand of 160 MW.

We considered three types of biomass-based district heat production system: (i) heat-only district heat production; (ii) district heat and electricity production without and with pellet production; and (iii) district heat and motor fuel production without and with pellet production. For each type of system, we designed a minimum-cost DHS that meets the district heat demand following the heat load duration curve (Fig. 1). The value of co/polygenerated products was assumed to equal those from minimum-cost standalone plants. Fig. 2 summarizes the approach of our analysis.

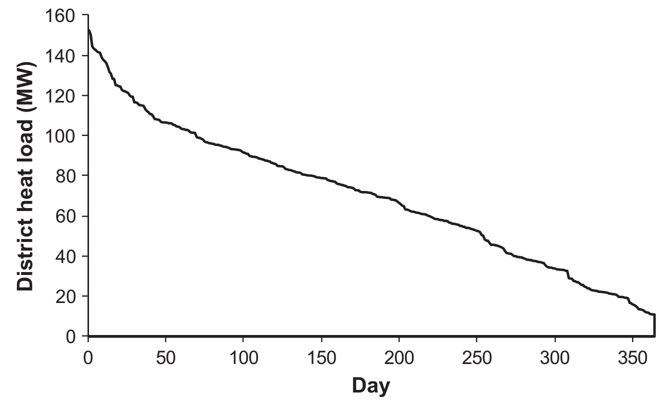

Fig. 1. Heat load duration curve.

In the system with biomotor fuel production, we considered the production of biomethane, dimethyl-ether (DME), methanol or ethanol, which correspond to various fossil motor fuels. Biomethane is compatible as a replacement for fossil gas in compressed natural gas vehicle systems [23], DME is an excellent diesel substitute [24,25] and methanol is purported to blend with gasoline. Ethanol can be blended with diesel and gasoline and is widely used in gasoline-engine vehicles. The production of the first three biomotor fuels is usually based on the thermochemical process (gasification-based conversion) of biomass [21,24,26,27], whereas for ethanol production, the production can be based either on the thermochemical or the biochemical (hydrolysis and distillation) processes [21,28–31]. In this study, we considered ethanol production based on the biochemical process, as ethanol production from the thermochemical process is less developed [32,33]. All calculations and presented data were based on the lower heating value (LHV) of fuels.

Data of the considered production units in district heat production are presented in Table 1. We considered biomotor fuel production processes that emitted excess heat that could be recovered as district heat. An ethanol production unit can be designed to minimize the internal use of solid residue (which remains unconverted through the hydrolysis process) or to maximize the production of electricity and low-temperature heat (which suits a district heating system). We considered only the alternative with internal use of solid residues for heat and electricity production, as this alternative is typically more economically favorable [34].

Investment costs of the production units were scaled according to their given scales (Table 1) using the following formula:

$$\frac{C}{C_{ref}} = \left(\frac{S}{S_{ref}}\right)^{R} \qquad (1)$$

where S is the considered size of a production unit (MW), S_{ref} is the reference size of a production unit (MW), C is the investment cost of a production unit at a considered size (€), C_{ref} is the investment cost of the reference production unit at the reference size (€), and R is the scale factor of a production unit.

The production costs of bioelectricity, biomotor fuels, biopellets or wood powder from standalone production plants were calculated using the following equation:

Download English Version:

https://daneshyari.com/en/article/6693597

Download Persian Version:

https://daneshyari.com/article/6693597

Daneshyari.com