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Economic feasibility of utilizing forest biomass in district energy systems – A review

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ABSTRACT

Recent global protocols and agreements have motivated countries to use biomass for energy generation. However, the barriers in biomass utilization including variations in biomass availability, high moisture content, low bulk density and dispersed distribution of biomass have made investors reluctant to invest in bioenergy projects in some parts of the world. In this paper, in addition to a brief summary of the conversion technologies used for energy generation, a review of the world literature on techno-economic assessment of district energy systems using forest biomass as the primary fuel with references extending over two decades is provided. Although energy generation from forest biomass is found to be expensive in many countries, the review of literature revealed important factors that increased the share of biomass in energy production in other countries. These important factors include using more efficient technologies, providing governmental grants and subsidies, setting new policies in favor of biomass utilization, increasing emission reduction targets, and introducing tradable carbon credits. The feasibility of utilizing forest biomass in district heating systems has been examined in the literature mainly based on the costs, while considering social and environmental profiles of these systems could improve their acceptance. Future research studies on assessing the performance of biomass district energy systems should consider environmental and social impacts of these systems in addition to their costs.

Contents

1. Introduction

Energy consumption in residential and commercial buildings contributes to approximately one third of global greenhouse gas emissions ([1,2]); therefore, a decrease in the use of fossil fuels in these buildings could make a significant contribution in meeting emission reduction targets. One solution to reduce fossil fuel consumption in residential and commercial sectors is to decrease energy demand [3,4] by incorporating energy efficient solutions

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in the design of buildings such as thermal insulation, double and triple glazing, solar shadings, cavity wall, reflecting coating windows, etc. [5]. However, the energy efficient solutions on their own cannot offset the demand for energy in new buildings, and they are costly and time intensive when applied to existing buildings. Therefore, other strategies such as replacing fossil fuels with alternative renewable sources of energy [6] and improving energy conversion efficiency [7] should be applied along with decreasing energy demand to reduce fossil fuel consumption in buildings.

Several authors examined the economic feasibility of using renewable sources of energy for heating and cooling purposes. Esen et al. [8] evaluated the technical feasibility of using renewable biomass, solar, and ground energy and Chau et al. [9] studied the techno-economic viability of woody biomass boilers for heating greenhouses, respectively in Turkey and Canada. In [10], the ground source heat pump (GSHP) system was compared to conventional heating systems in Turkey. The results of this study indicated that GSHP showed economic advantages over conventional heating systems. In [11], two ground source heat pump systems, ground-coupled and air-coupled, were compared for space cooling. Ghafghazi et al. evaluated the energy sources including natural gas, wood pellets, sewer heat, and ground heat for district heating in British Columbia, Canada in [12] and ranked them in [13] using a multi-criteria approach.

District energy is an example of an efficient energy system in which thermal energy conversion takes place at a centralized plant and then a network of underground pipelines distributes the thermal energy to a group of users via hot water or low pressure steam [14]. District energy systems have higher efficiencies than individual energy systems as they minimize energy wastes [15]. In an investigation to choose the best energy system to heat detached homes in Sweden, Gustavsson et al. [16] showed that district heating was a more efficient and less expensive system with less environmental impacts than decentralized and electric heating systems. Difs et al. [17] also showed that converting to district heating in Swedish industries, where the electricity use is extensive, could result in significant reduction in the electricity and fossil fuels consumption. In a survey of literature, Rezaie et al. [18] have reviewed applications and classifications of district energy systems and discussed their technological, environmental, and economical advantages.

One important feature of district energy systems is their flexibility in using a wide variety of energy sources as their feedstock including conventional fossil fuels as well as renewables [19]. Using forest biomass, namely residues from logging activities, primary and secondary mill residues, urban wood wastes, and energy crops [20], in district energy systems provides the opportunity to produce heat and/or power with limited environmental impacts by utilizing renewable source of energy and increasing conversion efficiency simultaneously [19]. In comparison with other renewable sources, forest biomass can be stored for later use [21] and can be converted into solid, liquid, and gaseous fuels [22]. Using forest biomass in district energy systems creates jobs and promotes social and economic development in communities [23]. In comparison with other biomass resources, particularly agricultural biomass, forest biomass has higher bulk density [24] and because it is available throughout the year from various sources, it provides a more reliable feedstock and eliminates the long-term storage issue associated with agricultural residues [25].

Despite the environmental, social, and economic advantage of using forest biomass as fuel, forest biomass supplies are underutilized at the moment. Some barriers that restrict the use of forest biomass for producing energy are seasonal variations in biomass availability [26], limited availability and high production costs of biomass [27], existing technical limitations (e.g. conversion efficiency) and complex and costly fuel supply chain logistics [28], which is because of some physical characteristics of forest biomass. Low bulk density of biomass, which ranges from 50 to 130 kg m^{-3} depending on the biomass type [29], together with high moisture content, and low calorific value increase the logistical requirements of the supply chain including the size of handling system and storage space requirements [30]. Because of the issues discussed above, before investing in forest biomass for district energy, the availability of supplies should be investigated to assure a secure supply. The delivery cost of feedstock and conversion costs should be calculated not only to determine the cost structure but also to measure its competitiveness with alternative energy resources.

Many researchers have assessed the viability of bio-energy generation from forest biomass considering financial feasibility (e.g. [31]) and biomass availability (e.g. [32] and [33]). This paper is an overview of the previous studies that have been carried out to examine the feasibility of using forest biomass for generating heat and electricity in district energy plants and also in combined heat and power (CHP) systems. The purpose of this paper is to provide a review of the previous studies in the field of forest biomass based district energy by summarizing recent developments and highlighting factors that impact the economic viability of using forest biomass. The studies are categorized into three groups based on the indicators of feasibility: (1) studies on forest biomass supply availability, (2) studies focusing on delivered cost of biomass to the gate of district energy systems, and (3) studies that estimated the cost of energy generation from forest biomass, which includes at plant costs as well as the delivered cost of biomass. The reviewed literature in this paper indicates that heat and power production from forest biomass is relatively expensive. In order to increase the share of forest biomass in energy production and to benefit from its environmental advantages policy reforms may be required. Setting new policies and legalization and providing governmental subsidies will promote the economics of district energy from forest biomass.

2. Studies estimated forest biomass supply availability for utilization in district energy systems

Technical and economic viability of forest biomass district energy systems significantly depend on availability of forest biomass supplies since it quantifies the capacity of district energy system in terms of the size and number of plants. The spatial distribution of forest biomass supplies also determines the transportation distances and costs and therefore impacts the selection of the plant location [34]. Angelis-Dimakis et al. [35] have reviewed the literature on estimating biomass availability including forest biomass for energy purposes focusing on the tools and methods for estimating biomass supplies. Several studies have estimated forest biomass supply levels for bio-energy in general [36,37] and particularly for district heat and/or power generation [38,39] with the aid of geographic information system (GIS) and taking into account yield, forest area, and residue ratios.

Using thematic cartography information of soil and forest growth rates, Vasco et al. [38] quantified the annual forest biomass availability and the associated potential of electricity production at a regional level in Mozambique. Taking residue availability, protected forest areas, and transportation infrastructure into account, Vasco et al. [38] located combustion power plants. Viana et al. [39] evaluated the residue availability within the economic distance from a number of existing and in-construction plants in Portugal based on dendrometric data, biomass allometric regression equations (BARE), and biomass expansion factors (BEF). Allometric equations relate the total volume of above-ground biomass as well as various tree components (e.g. stem, top and branches) to