Biomass and Bioenergy 95 (2016) 244–256

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Modeling and analysis of renewable heat integration into non-domestic buildings - The case of biomass boilers: A whole life asset-supply chain management approach

Fuzhan Nasiri [a,*], Fereshteh Mafakheri [b], Dotun Adebanjo [c], Fariborz Haghighat [a]

[a] Department of Building, Civil, and Environmental Engineering, Concordia University, Montreal, QC, Canada
[b] Concordia Institute for Information Systems Engineering, Concordia University, Montreal, QC, Canada
[c] Department of Systems Management and Strategy, Business School, University of Greenwich, London, UK

ARTICLE INFO

Article history:
Received 17 March 2016
Received in revised form
1 October 2016
Accepted 31 October 2016

Keywords:
Renewable heat incentive
Biomass boilers
Non-domestic buildings
System dynamics
Supply chain management
Asset management

ABSTRACT

This study proposes a whole life asset-supply chain optimization model for integration of biomass boilers into non-domestic (non-residential) buildings, under a renewable heat incentive scheme in the UK. The proposed model aims at identifying the optimal energy generation capacities and schedules for biomass and backup boilers, along with the optimal levels of biomass ordering and storage. The sensitivity of these decisions are then analyzed subject to changes in source, types and pricing of biomass materials as well as the choice of technologies and their cost and operational performance criteria. The proposed model is validated by applying it to a case study scenario in the UK. The results indicate that a Renewable Heat Incentive scheme could incentivize the adoption of biomass boilers, with a 3 to 1 ratio for biomass and backup boilers' utilization. As such, the findings from this study will be useful for industry managers, tasked with the decision of which biomass boiler system to utilize, considering the support from RHI. On the other hand, it is shown that RHI does not provide encouragement for efficiency when it comes to the choice of biomass technologies and fuels. This presents itself as a major implication for the success and sustainability of the UK government's renewable heat incentive scheme.

1. Introduction

Energy from renewable sources not only plays a critical role in cutting carbon emissions, but also reduces dependency on fossil fuels, promoting energy security. Increasing the share of renewable energy is a major component of many national and regional energy directives across the globe, such as feed-in-tariff and renewable portfolio standard policies, which are mostly directed towards creating a surge in renewable electricity generation capacities [1]. Globally, however, heating is associated with about half of final energy use, compared to about 30% and 20% share for electricity and transport [2,3]. This clearly highlights the importance and impact of increasing the share of renewable energy sources for heat generation. Further, it should be mentioned that space heating and hot water in domestic (residential) and non-domestic (non-residential) buildings account for over half of the global energy needs for heating purposes [2,3].

This study is based in the UK and it develops and presents a model that is applicable to making optimized decisions regarding the choice of 'building-integrated' biomass boilers under the renewable heat incentive scheme of the UK government. In the UK, when it comes to the use of renewable sources, electricity generation accounts for 75% of all installed renewable energy capacities, followed by heat and transport with a share of 15% and 10% [4]. This lack of investment in the use of renewable energy for heat generation runs contrary to the fact that heating accounts for over 40% of energy consumption in the UK [5]. In the particular case of non-domestic buildings, about half of the energy consumption is attributable to heating [6]. Based on this realization, integration of renewable heat technologies into non-domestic buildings has become an integral part of the UK Government's agenda for the building sector through the introduction of Renewable Heat Incentive (RHI) program in 2011 [7]. It is the world's first support program that directly pays and incentivizes the non-domestic building participants generating and using renewable energy (from certain eligible technologies) to heat their buildings [8].

For managers who wish to participate in this scheme and take

* Corresponding author.
E-mail address: fuzhan.nasiri@concordia.ca (F. Nasiri).

http://dx.doi.org/10.1016/j.biombioe.2016.10.018
0961-9534/

advantage of the incentives from the government, there are several important decisions to be made regarding, for example, the capacity of the biomass boiler and the type of biomass boiler. It is important that the right combination of decisions is made in order to maximize the incentives received and to avoid a loss-making investment. It is also important for the success and sustainability of the UK government's policy that a win-win scenario is generated such that the buildings that invest in biomass boilers are not financially disadvantaged. Being a pioneering scheme, there is currently no model that can be applied to support and direct the integration of biomass boilers in buildings under RHI.

Recognizing such a gap, in the following sections, we first present a literature review, then turn to a methodology section exploring the rationale behind developing our proposed model, its elements including the objective function, decision variables, and constraints. We further elaborate on the adopted optimization framework, followed by a case study and results analysis to implement the model, interpret the findings and report on sensitivity of a number of targeted parameters. The paper concludes with a research summary as well as recommendations for future research.

2. Literature review

RHI is designed to bridge the gap between the cost of fossil fuel heat and that of renewable heat technologies, thus, encouraging private investments in decentralized heating [9]. In addition to carbon saving benefits, decentralized heat generation in cities from renewable sources (instead of heating from centrally supplied electricity or natural gas) helps reduce the pressure on urban energy supply infrastructure [10], increasing their resilience, longevity and reliability. Under the RHI scheme, the eligible technologies are solar thermal collectors, biomass boilers, ground-source and air-to-water heat pumps, and biogas waste digesters [7]. The amount of the incentive is calculated based on three criteria of "type of technology", "generation capacity", and "actual renewable energy use". Table 1 presents the renewable heat incentive structure for non-domestic applications. The leading technologies are solar thermal and biomass boilers that could receive an incentive up to 9.2 and 8.6 pence per each KWh of renewable heat energy generated, respectively [7,11]. The incentive payments are spread over 20 years and paid on a quarterly basis.

Biomass is the most utilized type of renewable energy in the UK that comprises a 70.7% share of renewable energy uses for electricity and heat generation (followed by wind at 20.8% and solar at 5.4%) [4]. It has a 2.3% share in electricity generation and 1% in heat generation [5]. The UK Bioenergy Strategy for 2020 targets an increase of biomass share to 5–11% in power generation and 6% in heating [12]. As a result, some researchers have investigated the factors that could influence the growth of biomass energy sector for heating and power in the UK [13,14]. Biomass, in this context, refers to solid biomaterials (in form of woodchips, pellets, etc.) produced from agricultural residues, waste wood, and municipal solid waste.

With support from the RHI scheme, the installation and use of biomass boilers is becoming a leading choice (for renewable heating) in non-domestic buildings in the UK [15]. There are many reasons to back such a transition. First, RHI provides a high level of support for small scale (less than 200 KW) biomass boilers, second only to solar energy [7]. Also, the levelized capital cost (cost per KWh) of biomass boilers is considerably lower that solar thermal collectors [8]. Moreover, the energy conversion performance of biomass boilers (KWh output per unit cost) is higher than alternative renewable heating technologies [15]. In addition, there exists a higher level of standardization in manufacturing of biomass boilers, while the alternative technologies are project-based with high dependency on characteristics of each specific site. This also creates the advantage of flexibility in terms of generation capacity when it comes to biomass boilers. Last but not least is the fact that biomass is a fuel-based source of energy with benefits for various stakeholders across its supply chain, contributing to its promotion [16]. The promise of biomass applies to society at large by reducing dependence on fossil fuels and transferring some of the weight to more sustainable and environmentally friendly biomass fuels. There are also implications for the reduction of fossil fuel distribution through expensive centralized piping systems. These are in addition to the commercial advantages to the supply chain partners including biomass fuel suppliers, boiler manufacturers and transportation companies.

Investigating and understanding the potentials and challenges of mass utilization of building-integrated small size biomass boilers for space heating and hot water is an emerging area. Kranzl et al. [19] have developed a simulation model to forecast the 2030 fuel-mix for space heating purposes in the EU countries, taking into account future scenarios of demand for space heating, potentials for renewable support policies and incentives, and expected energy (and fuels) prices. They have identified the integration of "small-scale biomass boilers" as one of the core drivers for future growth in renewable heating. Saidur et al. [20] provided a review of biomass boilers including common technologies, suitable fuels, and their advantages and disadvantages with respect to cost, requirements, operational performance and environmental impacts. As a result of the potential advantages of economies of scale [21], supplying renewable heat to buildings through utilization of biomass boilers for district heating is also receiving growing attention [22,23]. McManus [24] provided an environmental assessment framework to quantify the emission levels from a number of case study small size biomass boilers in the UK. Numerical models and computer simulations were also suggested to monitor and control the operation of small size biomass boilers with the aim of increasing the energy efficiency and/or reducing NOx and CO emissions [25,26]. Further, operational performance optimization frameworks were proposed to identify the optimal of mix of biomass fuels [27] and the optimal size of thermal storage for biomass boilers [28].

As the promotion of renewable heat technologies under the RHI scheme is a recent phenomenon, there has been very little research reported on the supply chain and asset management performance of the building-integrated biomass boilers (from cost, reliability, and environmental perspectives) with the existence of such an incentive [15,29].

Despite the recognized advantages of installing localized biomass boilers, there are also inherent risk factors. If not properly installed, the indoor air quality may deteriorate due to NOx, CO and other air pollutants from biomass burning [30,31]. Biomass boilers operate with a lower energy conversion performance compared to natural gas boilers, requiring a considerable space for biomass storage. More importantly, as biomass is a seasonal (and mostly

Table 1
Renewable heat incentive structure for non-domestic applications.

Technology	Capacity (KW)	Use (Hours)	Incentive (GBP/KWh)
Biomass Boilers	<200	<1314	0.086
		>1314	0.022
	200≪1000	<1314	0.05
		>1314	0.021
	>1000	–	0.01
Heat Pumps	<100	–	0.048
	>100	–	0.035
Solar	–	–	0.092
Biogas	–	–	0.073