Atmospheric Environment 161 (2017) 191–199

Contents lists available at ScienceDirect

Atmospheric Environment

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

Impact assessment of biomass-based district heating systems in densely populated communities. Part II: Would the replacement of fossil fuels improve ambient air quality and human health?

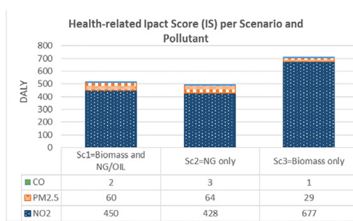
Olga Petrov [a, b], Xiaotao Bi [a, *], Anthony Lau [a]

[a] University of British Columbia, Vancouver, British Columbia, Canada
[b] British Columbia Institute of Technology, Burnaby, British Columbia, Canada

HIGHLIGHTS

- Locally-distinct conditions and 5 operational scenarios are considered.
- $PM_{2.5}$ emissions from biomass gasification lower than from natural gas combustion.
- Uncontrolled NO_2 emissions from biomass plant exceeded provincial objective.
- Health impacts highest for NO_2 (677 DALY) when energy supplied solely by biomass.
- Location and emission control are pivotal in community energy system configuration.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 December 2016
Received in revised form
27 April 2017
Accepted 1 May 2017
Available online 4 May 2017

Keywords:
Fuel consumption
Air quality dispersion modeling
Intake fraction
Disability adjusted life years
Health-related impact score

ABSTRACT

To determine if replacing fossil fuel combustion with biomass gasification would impact air quality, we evaluated the impact of a small-scale biomass gasification plant (BRDF) at a university campus over 5 scenarios. The overall incremental contribution of fine particles ($PM_{2.5}$) is found to be at least one order of magnitude lower than the provincial air quality objectives. The maximum $PM_{2.5}$ emission from the natural gas fueled power house (PH) could adversely add to the already high background concentration levels. Nitrogen dioxide (NO_2) emissions from the BRDF with no engineered pollution controls for NOx in place exceeded the provincial objective in all seasons except during summer. The impact score, IS, was the highest for NO_2 (677 Disability Adjusted Life Years, DALY) when biomass entirely replaced fossil fuels, and the highest for $PM_{2.5}$ (64 DALY) and CO (3 DALY) if all energy was produced by natural gas at PH. Complete replacement of fossil fuels by one biomass plant can result in almost 28% higher health impacts (708 DALY) compared to 513 DALY when both the current BRDF and the PH are operational mostly due to uncontrolled NO_2 emissions. Observations from this study inform academic community, city planners, policy makers and technology developers on the impacts of community district heating systems and possible mitigation strategies: a) community energy demand could be met either by splitting emissions into more than one source at different locations and different fuel types or by a single source with the least-impact-based location selection criteria with biomass as a fuel; b) advanced high-efficiency pollution control devices are essential to lower emissions for emission sources located in a densely populated community; c) a spatial and temporal impact assessment should be performed in developing bioenergy-based district heating systems, in which the capital and operational costs should be balanced

* Corresponding author. 411-2360 East Mall, Vancouver, British Columbia, V6T 1Z3, Canada.
E-mail address: xbi@chbe.ubc.ca (X. Bi).

http://dx.doi.org/10.1016/j.atmosenv.2017.05.001
1352-2310/

with not only the benefit to greenhouse gas emission reduction but also the health impact to the local community.

1. Introduction

Ecosystem deterioration in both local and global scales due to the use of fossil fuels has been well documented over the past few decades. Natural gas is widely used for heat and electricity production in Canada. Although natural gas is a relatively clean-burning fossil fuel, its combustion contributes to greenhouse gas emissions and global warming. In addition, many remote off-grid communities across Canada are still using diesel for power generation. In recognizing these issues, the province of British Columbia (BC) has set a suite of policy actions proposing, amongst others, the use of BC's plentiful biomass resources for energy generation. Climate change, energy security and energy diversification are some of the drivers for increased utilization of renewable energy sources such as biomass. Biomass-based district energy systems (DES) (Fiorese et al., 2014), configured as combined heat and power (CHP) or heat only production systems, also known as district heating (DH) are rapidly growing in Canada. There were merely 3 such projects in 2009 but it increased to more than 100 projects in the last few years (Bradley, 2012; CIEEDAC) with a total heating capacity of 121 MW_{th} or 3.4% share of Canadian district energy heating capacity from all energy sources (CIEEDAC). Utilization of bioenergy could be beneficial to Canada's and BC's economy, providing improvements in energy efficiency and reduction in greenhouse gas (GHG) emissions.

A number of studies evaluated DES in terms of performance and trade–offs due to integration into urban energy systems (Pantaleo et al., 2014; Kohl et al., 2014), economic feasibility (Akhtari et al., 2014; Panepinto and Genon, 2012; Hannula, 2015; Cleary et al., 2015), benefits to the environment (Ghafghazi et al., 2010; Panepinto et al., 2014; Nguyen et al., 2013), benefit in addressing climate change (Giuntoli et al., 2015; Olsson et al., 2015; Feliciano et al., 2014; Gustavsson et al., 2015) or its impacts over life cycle (Nguyen et al., 2013; Pa et al., 2011; Ghafghazi et al., 2011). Local effects of different technologies used in CHP systems were evaluated in some studies using the Avoided Heat Generation method (Bianchi et al., 2014), Maximum Energy Savings method (Torchio, 2015) or through emission characterization from small-scale natural gas-fueled cogeneration systems (Canova et al., 2008; Mancarella and Chicco, 2009). Nevertheless, local impact assessments of biomass-based systems on air quality and the resulting community exposure are still in its infancy. Very few studies started recognizing the importance of local and urban health impacts of near-by stationary sources. Through systematic literature review we learned that due to either lack of data or project purposes, those studies relied on many assumptions and did not account for dynamic population changes and actual spatial and temporal variations of ambient air quality (Martenies et al., 2015), or selected archetypal environments and emission sources (Humbert et al., 2011).

Conventional furnaces (such as cooking stoves) and open biomass burning (such as forest fires) emit particulate matters (PM) and a wide range of gaseous pollutants such as oxides of sulphur (SOx), oxides of nitrogen (NOx), carbon dioxide (CO_2), carbon monoxide (CO), black carbon, free radicals and various organics (Naeher et al., 2007; Gustafson et al., 2007; US EPA). By comparison, advanced thermochemical conversion systems such as gasifiers are characterized by a reduction in the number of pollutant species and the concentration of PM, CO and volatile organic compounds (VOCs) (Miranda et al., 2010; Sethuraman et al., 2011). In addition, woody biomass is usually a heterogeneous fuel and emissions depend on the tree species and moisture content. Boiler type and operating conditions, as well as the type of biomass affect particulate and gaseous emissions (Boman et al., 2003, 2004; Kocbach Bølling et al., 2009; Kaivosoja et al., 2013). For example, when combusted in high efficiency boilers, wood chips (from forest residues and waste wood) emitted significantly higher fine particles with a diameter less than 2.5 microns ($PM_{2.5}$) and NOx and SO_2 gases due to higher sulphur and nitrogen contents in wood chips. These emissions are higher when compared to the combustion of wood pellets as emissions greatly depend on the fuel type. Sulphur content in wood pellets and wood chips ranges from 63.6 to 175 mg/kg dry weight, which is much lower than sulphur content in fossil fuels (Chandrasekaran et al., 2011), though the emission of gases and particulates is lower than old-type residential boilers (Johansson et al., 2004). On the other hand, while the assumption of carbon neutrality of forest biomass is not correct (Röder et al., 2015; Vanhala et al., 2013; Holtsmark, 2013), fuel derived from woody biomass indeed has lower greenhouse gas (GHG) emissions such as CO_2 and methane (CH_4) when compared to natural gas over the entire life cycle (Pa et al., 2011). Methane could be formed during biomass gasification/pyrolysis in the reducing zone, together with CO and H_2 (Sansaniwal et al., 2017), but is not directly released. Air pollution control devices such as electrostatic precipitators (ESP) and selective catalytic reduction (SCR) need to be in place for the treatment of particulates and NOx, respectively.

In a previous paper, we developed a novel methodology for evaluating the impacts of DH on local ambient air quality and human health (Petrov et al., 2015). We realized the importance of considering spatial and temporal variations of the parameters used to calculate iF, based on the findings that neglecting or even averaging the short-term variation of parameters on a local scale could potentially underestimate iF and the associated health risks by more than 20%. In this study, we applied that new method to evaluate the impacts of emissions from a biomass gasification plant on local ambient air quality and population health which to the best of our knowledge hasn't been reported in the literature.

2. Methods

The Bioenergy Research and Demonstration Facility (BRDF) and the Power House (PH) at the University of British Columbia (UBC) Point Grey campus in Vancouver, BC were selected for this study. Wood waste, a mixture of forest residue and sawmill/planner waste, and natural gas (supplemented by oil as needed) are used as the fuel at the BRDF and PH respectively. Our methodological approach entailed: a) analysis of the UBC campus district heating using fuel characteristics measured at the UBC labs of the fuels currently used and operational data: biomass moisture content, higher heating value, fuel consumption, and thermal conversion efficiency, followed by calculating the required biomass consumption rate should it completely replace fossil fuels for campus heating at the 2012/2013 demand level; b) emission estimates based on pollutant-specific emission factors (EF_{NG} and EF_{OIL} for