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A cost-effective evaluation of biomass district heating in rural communities

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HIGHLIGHTS

- Develop a cost-effective model using secondary data examining delivering heat through Biomass District Heating (BDH).
- Eight of ten rural villages studied could cost-effectively deliver heat through BDH below the 2013 price of heating oil.
- 80% of the annual cost of BDH was attributable to capital expenses.
- Erratic fuel oil prices substantially impact future feasibility.
- Village level feasibility is highly-influenced by the presence of large heat demanders.

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ABSTRACT

The economic feasibility of Biomass District Heating (BDH) networks in rural villages is largely unknown. A cost-effective evaluation tool is developed to examine the feasibility of BDH in rural communities using secondary data sources. The approach is unique in that it accounts for all the major capital expenses: energy center, distribution network, and energy transfer stations, as well as biomass procurement. BDH would deliver heat below #2 fuel oil in eight of the ten rural study villages examined, saving nearly $500,000 per year in heating expenses while demanding less than 5% of the forest residues sustainably available regionally. Capital costs comprised over 80% of total costs, illuminating the importance of reaching a sufficient heat density. Reducing capital costs by 1% lowers total cost by $93,000 per year. Extending capital payment period length five years or lowering interest rates has the next highest influence decreasing delivered heat price 0.49% and 0.35% for each 1% change, respectively. This highlights that specific building heat is a strong determinant of feasibility given the relative influence of high-demanding users on the overall village heat-density. Finally, we use a stochastic analysis projecting future #2 fuel oil prices, incorporating historical variability, to determine the probability of future BDH feasibility. Although future oil prices drop below the BDH feasibility threshold, the villages retain a 22–53% probability of feasibility after 20 years as a result of high #2 fuel oil price variability.

1. Introduction

Recently, there has been a renewed interest in biomass (i.e., wood chips) as energy source, resulting largely from its potential to address several of the numerous challenges faced by the U.S. including dependence on foreign oil imports [1,2] and national energy independence [2,3]. Biomass in the form of wood is the second largest source of renewable energy available in the U.S. [4]. It is also an important tool in reducing atmospheric CO_2 levels by reducing and sequestering carbon and offsetting emissions from alternative fossil fuel sources [1,2,5].

Using biomass to meet local heating needs can provide several economic benefits that aid in developing rural communities, such as: establishing new markets, providing a stable-priced heating fuel, and closing regional economic leakages [5–7]. Biomass has a lower energy density than competing fossil fuels[1] and therefore rarely has the economic potential to be transported over 80 km,[2] making it a characteristically local resource for rural communities [9–11]. Using forest residues to produce heat would also expand

[1] For example, wood chips have an energy content of approximately 11.5 MJ/kg, 40% moisture content on a wet basis, mixed hardwood-softwood; whereas, heating oil has an energy content of 43.8 MJ/kg [8].

[2] A notable exception is wood pellets, which are frequently distributed on the global scale, resulting from an increased energy density and relatively low costs of ocean transport.

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Nomenclature

BDH	Biomass District Heating
CBECS	Commercial Building Energy Consumption Survey
EIA	Energy Information Administration
ETS	Energy Transfer Station
HDD	Heating Degree Days
RECS	Residential Energy Consumption Survey
H_p	total yearly HDD attributable to the coldest day (%)
D_p	the average hourly heat demand for the peak day (GJ/h)
L_{spec}	the specific building pipe length (m)
d_a	the pipe diameter (m)
C_d	the distribution capital cost ($/GJ)

the market for low-grade wood in rural regions, promoting better silvicultural practices and ultimately increasing both the quantity and quality of wood available from these oft-times high-graded forests [12]. In the Northeast, biomass is also an economically stable fuel source having exhibited a real price increase of less than 1% per year historically [13]. In contrast, #2 fuel oil has displayed erratic price trends and escalated more than 3% per year [14]. Ultimately, with an estimated $0.78 for every $1.00 spent on fuel oil leaving regional economies in New York State (NYS), approximately $9.3 million dollars of the $11.9 million annual heating expenditures are exported out of the local economies of the ten study villages (Fig. 1) [15]. Closing these relatively large economic leakages can recycle annual heating expenditures through the local economy and thereby serve as a significant catalyst for economic development.

1.1. Challenges of biomass heating

The low fuel costs associated with biomass in comparison to #2 fuel oil are contrasted typically by high capital costs for the boiler [11,16,17]. Biomass also has a significantly lower energy density and mass density than fossil fuels [18]. As a result, associated transportation costs and necessary storage volumes are higher compared to conventional fuel sources [19]. The combination of these two problems often hinder the implementation of biomass heating at a residential or small business scale [20,21]. Wood pellets attempt to address these concerns through densification, which increases energy density by reducing volume, thus decreasing transportation and storage costs [22]. However, in the study region the pellet distribution structure is nascent, the expenditures would leave the region, and the raw energy cost ($/GJ) is roughly four times that of wood chips, thereby neutralizing many of the economic benefits of biomass heating.

1.2. Biomass District Heating (BDH)

BDH utilizes the benefits of biomass heating by aggregating individual buildings with low heat demands and dispersing the high capital costs, while keeping the yearly heat expenditures within the regional economy by using wood chips harvested locally [11,23]. Although district heating has been used throughout the United States for over 150 years in densely populated area, rural villages pose new problems that result from low heat densities and dispersed communities [9,24,25]. Little work has been done to identify the potential for BDH in rural villages [5,9].

1.3. Purpose and scope

The purpose of this study is to determine if BDH can be a tool for rural communities to use abundant, local forest resources to produce heat. This study is unique in that it assesses the feasibility of BDH in rural communities in a replicable way in terms of the four major costs: the energy center, distribution network, Energy Transfer Station (ETS), and biomass using secondary data. Specifically, this paper will:

- Establish a method for determining the cost of heat-only BDH in rural communities in a clear and replicable manner using secondary data sources by examining 10 rural villages within the Tug Hill region of NYS.
- Determine the regional biomass demand associated with implementing a BDH considering wood chips derived only from locally sustainably harvested logging residues [26].
- Estimate break-even cost for delivered heat from each village BDH system to compare its competitiveness with the local alternative, #2 fuel oil.

2. Study region: The Tug Hill

Nine towns and one school district were identified by the Tug Hill Commission initially as those without access to natural gas. Towns in New York are highly dispersed areas sometimes containing multiple villages; therefore, the original list was narrowed down to 12 villages contained within the nine towns. Of the 12 villages, two did not have the necessary GIS village level tax parcel data to obtain an annual village heat demand, thus leaving ten villages to be examined (Fig. 1, Table 1).

Traditionally rural, the roughly 544 thousand hectares of the Tug Hill are inhabited by roughly 100,000 residents [27]. The majority of the population resides in the villages on the edge of the forested plateau (54% of the Tug Hill region is covered by forests) [27]. The region has a high demand for heat with the annual Heating Degree Days (HDD) ranging from 6977 to 7681, approximately 1000 HDD more than the state average [28–30]. The economic impacts of the high annual heating demands are exacerbated in the region which has 15.6% of its population living in poverty [31].

3. Methods

The methodology used to determine annual village heat demands followed [33], relying on data from The Residential Energy Consumption Survey (RECS) and Commercial Building Energy Consumption Survey (CBECS) from the U.S. Energy Information Administration (EIA). However, the study conducted by [33] was based upon estimates for heat demand at the census region level.[3] This study estimated specific heat demands at the village level by multiplying the estimates for annual fuel consumption by principal building activity (GJ/thousand ft^2) with the average building floorspace (thousand ft^2/building) by principal building activity for the Northeast Region. This region most closely resembled the heating demands of the Tug Hill. The principal building activity and number for each of the ten study villages was derived from GIS-tax parcel data which then paired with the specific building heat

[3] CBECS and RECS establish 11 census regions based upon geographic groupings of U.S. states.