Resources, Conservation & Recycling 128 (2018) 90–97

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

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

Full length article

Geospatial assessment of regional scale bioenergy production potential on marginal and degraded land

Mithun Saha[a], Matthew J. Eckelman[b,*]

[a] Research and Modeling, AIR Worldwide,131 Dartmouth Street, Boston, MA 02116, United States
[b] Department of Civil & Environmental Engineering, Northeastern University,360 Huntington Avenue, Boston, MA 02115, United States

ARTICLE INFO

Keywords:
Bioenergy
Urban energy
Geospatial analysis
Energy resilience

ABSTRACT

This study presents a GIS-based model developed for urban site-specific bioenergy production potential on marginal land parcels. The model is applied on a metropolitan region level, encompassing 101 cities and towns surrounding Boston in the northeastern United States. The 'marginal' land use category includes vacant and abandoned lands, portions of public and private lots, and degraded lands, with poor soil quality. Four different energy crops—miscanthus, switchgrass, poplar, and willow—were considered as biomass feedstocks for bioenergy production. A total marginal land area of 71,200 ha (712 km^2) was identified that can be suitably used for bioenergy production, representing 20% of the total land area of the region. Spatial analysis revealed greatest marginal land densities close to the urban core. Statistical analysis found a weak positive correlation between population density and marginal land availability. Short-rotation hybrid poplar was identified as the highest yielding bioenergy crop for this region. Bioenergy potential calculations revealed that poplar can potentially yield up to 22 PJ (HHV) of yearly primary energy for this region that can be used for heat, conversion to transportation fuels, and/or electricity production. This is equivalent to > 50% of current biomass primary energy use in Massachusetts and could potentially fulfill all of the core city of Boston's heating demand. Hauling of biomass from the periphery to the urban core would add an estimated maximum of $7.20 per ton delivered. While the results reflect a maximum utilization scenario for marginal land, several logistical and social considerations are discussed that would impact practical implementation.

1. Introduction

The precise definition of marginal land may vary depending on prior uses and geographical considerations such as location and scale (Saha and Eckelman, 2015; Zhao et al., 2014). While several land use categories could be considered as marginal, in general, marginal lands can be broadly categorized as "lands that are not suitable for food-based agriculture and have limited economic potential for fulfilling other ecosystem services" (Kraxner et al., 2016). Their unsuitability can be attributed to poor physical and chemical soil properties, aridity, and/or susceptibility to erosion (Kang et al., 2013). Past studies have claimed that using marginal lands to produce bioenergy on a global scale is unfeasible due to lack of economic incentives and threats to biodiversity and conservation areas (Bryngelsson and Lindgren, 2013; Field et al., 2008). However, global analysis masks strong geographic heterogeneity, as marginal production levels may be viable when considered on the local and regional level, with certain regions having high land and/or biomass availability, suitable growing conditions, existing infrastructure, and suitable population densities (Lewis and Kelly, 2014).

A number of methods exist for identification of marginal land parcels, with suitability generally depending on desired scale and resolution (Lewis and Kelly, 2014). At the local level, many municipalities maintain datasets that detail parcel-specific data, usually associated with tax assessment but also often with biophysical data that can be used for identification of marginal or degraded lands (Boston DIT, 2015). Parcel characteristics can be further combined remote sensing data to screen parcels for above-ground features and improvements, tree canopy, or ease of access (McClintock et al., 2013). At larger scales, there are national datasets that classify land as marginal in terms of soil quality and/or economic potential (USDA NRCS, 2014), as well as inventories of marginal land types (such as landfills) that can be aggregated together. For example, a national assessment for the United States identified approximately 120 million ha of marginal land area not in active use, including federally designated brownfields, closed landfills, and degraded or abandoned lands (Niblick and Landis, 2016). Approximately 67% of this land area is within the administrative boundary of urban metropolitan regions.

As centers of energy demand, cities can be made more energy

* Corresponding author.
E-mail addresses: m.eckelman@northeastern.edu, m.eckelman@neu.edu (M.J. Eckelman).

http://dx.doi.org/10.1016/j.resconrec.2017.09.008
Received 2 June 2017; Received in revised form 18 August 2017; Accepted 6 September 2017

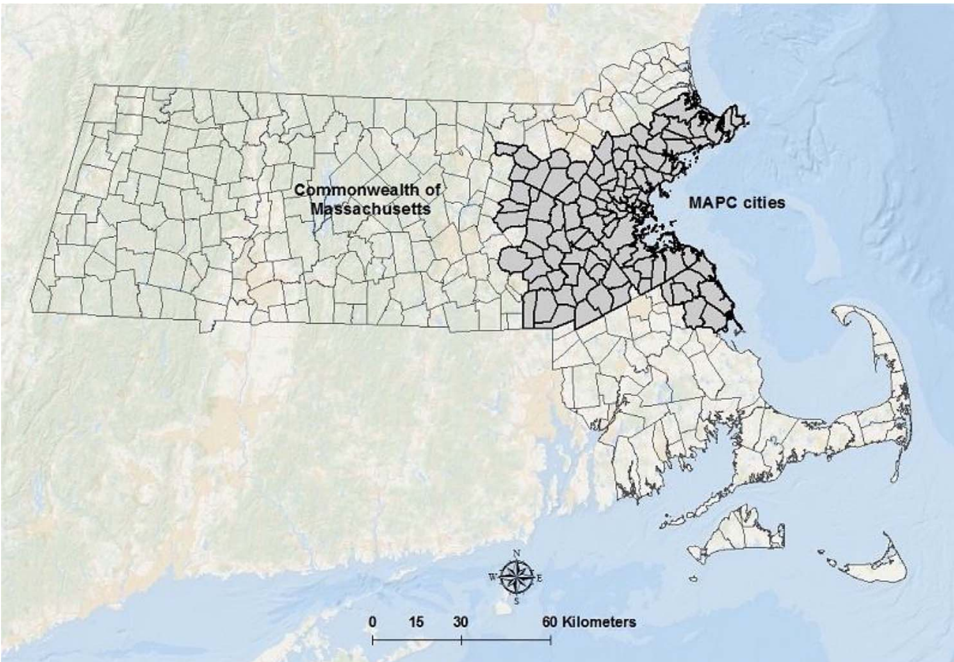

Fig. 1. Study area (MAPC region shaded grey).

resilient and sustainable by improving energy efficiency and investing in decentralized sources of renewable energy (Kammen and Sunter, 2016). A typical urban community's reliance on conventional fossil energy is both carbon intensive and also vulnerable to supply disruptions due to natural hazards, economic, or geo-political factors, particularly for liquid fuels (Grubler et al., 2012). To reduce supply-related uncertainty and increase energy resilience, many cities have started to focus on sourcing a portion of their energy from local renewable energy resources, including biomass (Springer, 2012). Past research suggests that growing energy crops on marginal or degraded land in or around a metropolitan area could be a viable energy strategy in terms of biophysical potential (Niblick et al., 2013; Saha and Eckelman, 2015). Some prospective bioenergy crops are more robust than others and can grow successfully on marginal or contaminated lands and under changing climatic conditions (Smith et al., 2013; Xue et al., 2016).

However, established cities are often densely populated with limited land resources suitable for large-scale renewable energy production and many competing uses for vacant lots. More likely, then, are regional approaches wherein bioenergy can be supplied from the surrounding metropolitan area, which still serves to reduce vulnerabilities associated with long transportation distances and distant energy infrastructure (Keirstead and Shah, 2013). In such a scenario, suitable suburban or exurban marginal land without many competing uses can be repurposed to grow high yield bioenergy crops. Regional scale studies can evaluate the specific goals and plans set out by cities or planning regions, while still being feasible performing high-resolution, parcel-by-parcel geospatial analysis of land use, access, imperviousness, and soil quality to precisely identify areas suitable for a specific bioenergy crop type.

In previous work, we developed a geospatial screening model to identify urban marginal land that could potentially be used for growing bioenergy crops (Saha and Eckelman, 2015). Even though Boston's potential marginal land was found to be approximately one quarter of its total land area, due to high land prices, competition with other current or potential economic activities, and other access and logistical factors, it is unlikely that many of these land parcels will practically be used for cultivation. But bioenergy crops grown outside the city can still be used to fulfill urban energy demand as the transportation requirement and costs are low, an opportunity that has been explored by the Massachusetts Department of Energy Resources (Bowman and Pagano, 2001).

This study expands the geographical scope of our geospatial model to assess the entire region surrounding Boston for marginal land availability and potential bioenergy crop production. Specifically, total potential marginal land availability and bioenergy potential for 101 cities and towns surrounding Boston were assessed. Massachusetts currently uses bioenergy (mostly wood) for both electricity generation and home heating (Timmons et al., 2008); some of this wood is imported from other regions in the U.S. and Canada, despite an abundance of local forested lands. This research tests the hypothesis that outlying municipalities could in theory supply bioenergy for the dense urban areas within the larger metropolitan region without requiring long hauling distances.

2. Material and methods

2.1. Marginal land assessment

This study considers bioenergy production on lands extending out to 30 miles (48 km) from the urban center of Boston. More specifically, the geographic area includes 101 cities and towns located in Eastern Massachusetts, which together fall within the planning jurisdiction of the Metropolitan Area Planning Council (MAPC) (Fig. 1), a state agency tasked with regional development planning and coordination. Because of its strategic location, population density, and economic importance, the MAPC region is considered one of the major energy demand centers of the Eastern United States. The total land area of MAPC region is 360 km^2 and includes more than 3 million inhabitants (MAPC, 2014), approximately half of the entire state population. This area has significant overlap with the Boston-Cambridge-Quincy New England City and Town Area (NECTA, analogous to a Metropolitan Statistical Area) as defined by the U.S. Census Bureau in the 2010 census.

Here, the general geospatial modeling framework developed by Saha and Eckelman (2015) for urban parcel identification was used for MAPC marginal land assessment, with modifications detailed below. Marginal land suitable for bioenergy crop cultivation was classified as specific land use types, with marginal soil quality and flat to moderate soil slopes, as summarized below. Unlike previous assessments of urban areas where a single municipal geospatial data set can be used, here a national scale data layer was used to ensure consistency across cities