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Research paper

Biorefinery site selection using a stepwise biogeophysical and social analysis approach

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ABSTRACT

A key factor in the production of economically viable and environmentally sustainable biofuels is biorefinery site selection. Facility location analysis has traditionally been driven by access to feedstock, proximity to customers, and local incentives. While economic constraints will always be major factors in site selection, incorporating social metrics may further reduce the cost of constructing a biorefinery. A community's disposition toward a biorefinery project may significantly impact implementation success: grassroots support can lower implementation costs while opposition may increase the costs of permitting blockages and other scale-up delays. The proposed biorefinery siting tool improves upon previous research by incorporating site-specific biogeophysical measures and more complete and comprehensive social measures of community innovation and capacity for collective action. A refined biogeophysical analysis assesses pulp mills for their potential as repurposed biorefineries. The social asset components of site selection are greatly improved by enhancing and disaggregating key metrics through the use of multiple indicators of community collective action capacity and propensity for change. The refined measures are integrated into a biorefinery site-selection tool. Pulp mills that rank highly in both the biogeophysical and social asset measures may be considered more suitable candidates for repurpose into a biorefinery. This enriched methodology has been applied to biorefinery siting decisions in the U.S. Pacific Northwest region; however, it is suitable for applications to infrastructure development projects in any region of the U.S.

1. Introduction

In the United States' Pacific Northwest region (PNW), woody biomass residuals from logging operations are proposed as a potential feedstock for conversion into iso-paraffinic kerosene, or sustainable aviation biofuel [1,2]. A key factor in the production of economically viable and environmentally sustainable biofuels is biorefinery site selection. The location of a facility is primarily driven by access to feedstock, proximity to customers, and local incentives [3]. While economic constraints will always be major factors in site selection, incorporating social measures may further reduce the cost of constructing a biorefinery. A community's disposition toward a biorefinery project may impact implementation success: grassroots support can lower implementation costs while opposition can increase the costs of permitting blockages and other scale-up delays [4].

Social measures are rarely incorporated into siting decisions due to the qualitative nature of the data and a lack of experience in applying the metrics. Acknowledging difficulties in adequately measuring social assets, Martinkus et al. [5] were the first to create a single metric to measure community capacity for collective action as an indicator for community support of a biorefinery project. The authors developed a facility siting tool that combined county-level biogeophysical assets with a single social score to identify communities in a region with the highest potential for successful biorefinery implementation. While this tool was the first to identify

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potential sites using biogeophysical *and* social assets, its measurement of communities' capacity for collective action remains incomplete and does not fully capture this important, yet underutilized, resource. Given the demonstrated importance of social assets to economic development and successful environmental policy implementation [6–14], this study provides an improved facility siting tool by incorporating enhanced measures of both social assets and biogeophysical metrics.

Specifically, the goal of this research is to develop a biorefinery siting tool that incorporates both location-specific siting variables and social metrics that indicate a community's ability to implement a biorefinery project. The major objectives are to: (1) refine the biogeophysical analysis by including location-specific siting variables, (2) improve and disaggregate social asset components through multiple indicators of community collective action capacity and propensity for change, and (3) integrate the refined measures into a biorefinery site-selection tool. The improved methodological framework is tested in the PNW states of Oregon, Idaho, and Washington to identify existing pulp mills best suited both biogeophysically and socially for potential biorefinery projects.

Pulp mills are targeted for repurpose as their infrastructure is similar to that of a wood-based biorefinery, and many have closed or been decommissioned in recent years due in part to the "Great Recession" of 2007–2009 [15]. Repurposing pulp mills into wood-based biorefineries may provide a revitalization opportunity for communities traditionally dependent on forest products-based employment. Additionally, existing facilities may offer a trained workforce, feedstock connections, and local support for retaining jobs [16].

2. Literature review

As noted by Hutchins and Sutherland [17], supply chain decisions traditionally focus on the economic measure of sustainability. Environmental considerations have gained strength through life cycle assessments, yet social measurements remain ill-defined [17]. This is evident in biorefinery siting research. While community characteristics and social assets are acknowledged, the inclusion of these assets is often minimal and does not incorporate characteristics that adequately predict success of these projects.

Many facility siting studies have examined the impact of biogeophysical variables on site selection in the ethanol industry. Major siting factors were found to include: feedstock availability, access to biofuel and coproduct markets, utility costs and availability, government incentives, and absence of operating ethanol plants [18–20]. Additionally, access to multi-modal transportation, product markets, and producer credit can provide a comparative advantage in attracting ethanol plants [20]. Facility siting analyses using the aforementioned siting criteria have been performed using a combination of geographic information system (GIS) software and/or optimization routines to identify ideal locations for biorefinery siting [3,21–24]. Other studies incorporated environmental constraints into facility siting analyses through measuring greenhouse gasses emitted along the supply chain [25,26], or measuring soil erosion, nutrient loss, runoff, or pesticide movement off-site [27,28]. All studies assume a Greenfield biorefinery will be constructed at the location identified as ideal.

Some used imprecise measures to either quantitatively or qualitatively assess social metrics in facility siting analyses. Van Dael et al. [29] developed bioenergy facility siting criteria and weights with the assumption that early stakeholder buy-in would result in increased acceptance of the final decision. They defined a society criterion as the willingness of communities to accept the project in their area. However, their measurement of this criterion included variables such as community acknowledgement of the local Kyoto protocol, total number of unemployed job seekers, and total free industrial area. Sultana and Kumar [30] assumed that social acceptability of establishing a plant was contingent on proper consideration for man-made, natural, and environmental elements. Fortenbery et al. [31] modeled biodiesel siting decisions through examining several biogeophysical resources, political resources, and socioeconomic variables, including proxies of market measures and community acceptance. They used percentage of houses owner-occupied and education level as indicators of potential opposition to the construction of a biodiesel refinery. Few facility siting analyses incorporate economic, environmental, and social criteria through quantifiable means. You et al. [32] and Perimenis et al. [33] approach facility siting differently, yet both incorporate quantifiable economic, environmental, and social measures through minimizing feedstock costs, measuring greenhouse gas emissions along the supply chain, and estimating the total number of jobs created through an installed biorefinery, respectively. Both also assume the communities surrounding the final location will be accepting of a new biorefinery. Using metrics such as the total number of jobs created, education-levels, or owner-occupied housing offers very poor proxies of the indicators needed to predict success of the biorefinery installation.

Martinkus et al. [5] developed the first biorefinery siting tool to incorporate social assets through quantitative measures for prediction of biorefinery implementation success. Their tool used a step-wise approach, first identifying and ranking suitable communities for a biorefinery through a city- and county-level assessment of biogeophysical siting measures. Next, county-level social assets (*social capital, creative leadership*, and *public health status)* were combined into a single score and applied to the ranked county list to identify communities with the highest potential for biorefinery investment success. However, there are several limitations of this first biorefinery site selection tool, including incomplete measures of social assets and a lack of site-specific biogeophysical measures. Specifically, social capital measures excluded key indicators such as the number of non-profit organizations and associational groups; the creative leadership construct did not fully capture community adaptability and creativity; and, the human health measure relied on self-assessments of health rather than objective measures of community health. Additionally, the biogeophysical assessment was performed at the community level with the assumption that a valid biorefinery location could be found, rather than considering existing industrial sites for repurpose (Table 1). Pulp mills hold great potential as repurposed wood-based biorefineries due to their scale, infrastructure compatibility, and feedstock logistics [34–37], and may provide significant reductions in biorefinery capital expenditures. Using operational cost-based metrics in a facility siting analysis allows for identification of locations that provide reduced annual expenses. Together, consideration for capital and operational costs in a siting analysis may allow for production of a more competitively priced biofuel, which is highly important in this nascent industry. Our proposed model improves site-selection decision making and enhances the likelihood of success for these important biofuel infrastructure projects.

3. Methodology

The Community Capitals Framework, developed by Emory and Flora [38], models community capacity using seven "capitals" that combine various resources, such as social, biogeophysical and financial assets (Fig. 1). The decision tool presented in this paper incorporates six of the seven capitals in a step-wise process. First, a biogeophysical assessment is performed on selected pulp mills,