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# New Potential for Climate Leadership and Rural Revitalization in Maine Forests? Assessments of Ligno-cellulose Nanofiber, Cross-laminated Timber, and Recreation

Mary Ignatiadis
*University of Maine*, mary.ignatiadis@maine.edu

# NEW POTENTIAL FOR CLIMATE LEADERSHIP AND RURAL REVITALIZATION IN MAINE FORESTS? ASSESSMENTS OF LIGNO-CELLULOSE NANOFIBER, CROSS-LAMINATED TIMBER, AND RECREATION

By

Mary Ignatiadis

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A THESIS

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Advisory Committee:

Adam Daigneault, Associate Professor of Forest Policy and Economics, Advisor

Mehdi Tajvidi, Associate Professor of Renewable Nanomaterials, University of Maine

Mindy Crandall, Assistant Professor in Forest Policy, Oregon State University

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Thesis Advisor: Dr. Adam Daigneault

An Abstract of the Thesis Presented
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Maine is poised to meet growing demand for forest ecosystem services from the U.S. construction and recreation industries. Manufacturing sustainable building materials from sustainably-grown Maine wood may help the state to achieve its climate change mitigation and adaptation goals, in addition to revitalizing its rural communities. Managing lands for recreation may have the same effects. This thesis evaluates the financial feasibility of an innovative particle board production line in Chapter 1, and Chapter 2 explores the cultural feasibility of a recreation-based economy in the historic center of Maine's forest industry.

The selective design analysis (+/- 30% accuracy) in Chapter 1 identifies the capital requirements for the commercial-scale manufacturing of both ligno-cellulose nanofiber (LCNF) and particle board (PB) with an LCNF adhesive. The novel application of LCNF as PB adhesive is developed and tested at the University of Maine. The modeled PB process can use either: an 85/15 mix of LCNF from old corrugated cardboard and CNF from untreated wood pulp, or LCNF alone. In the first stage of the analysis, five (L)CNF- only production scenarios yield 50 t/ day (dry). Capital requirements vary based on whether (L)CNF production is co-located with pulp and/or repurposed an existing facility. The second stage of the analysis models (L)CNF costs at 170 t/ day (dry), to support 250,000 m3/ year of PB production. Capital requirements for the six PB scenarios vary based on whether PB production is co-located with (L)CNF production, and whether (L)CNF production occurs in a repurposed facility. We found that the cost

savings from using a repurposed facility were more than double the cost savings from using LCNF over the LCNF/ CNF mix. Minimum product selling price (MPSP) in the first analysis stage ranged from \$477/ dry ton to \$1,534/ dry ton, while MPSP in the second stage ranged from \$453/ m^3 to \$870 / m^3. Scaling (L)CNF production for PB manufacturing resulted in significant reductions to (L)CNF MPSP, as did sourcing electricity for (L)CNF production from the PB co-generation facility. This study shows that (L)CNF production is commercially viable, but that (L)CNF-bound PB requires significant technological advances to reduce MPSP. This study provides financial analysis for policy-makers and investors hoping to advance (L)CNF and engineered wood products at a time of high demand for natural building products.

Chapter 2 investigates possible opportunities for consensus-building using survey data from the Katahdin Region, Maine. The region is primarily known for its abundance in forest-based manufacturing and recreation opportunities and is undergoing a major transition in its regional economy. We do this by applying the Sense of Place (SOP) framework to test the utility of SOP for understanding the development priorities. We identify the key similarities and differences in SOP between and within demographic groups that might lead to conflicts. Our results can be used to target outreach and facilitation activities to effectively build regional consensus, particularly with respect to targeting economic development. This approach presents a nuanced, yet intuitive picture of regional socioeconomic concerns with significant utility for development practitioners.

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## 1.1 Introduction

Maine is poised to diversify its forest-based economy by increasing production of wood-based sustainable building materials. Maine already supplies a significant majority of New England's dimensional lumber for construction (Poyry, 2017). Maine did not previously diversify into other construction products because of the dominant presence of the pulp and paper industry (Listo, 2018). This industry consumed the low-grade wood that could otherwise have been used in construction materials like particle board and fiber board. Following decades of decline in pulp and paper demand, Maine's forest industry is beginning to transition to non-lumber wood construction product manufacturing. Projects like GoLogic's new wood cellulose insulation plant are repurposing existing forest industry infrastructure to meet new demand for sustainable and high-performing construction materials (Milliken, 2020).

Federally funded research at the University of Maine is supporting the search for other new and sustainable uses for wood in the construction industry. Of the approximately 600 organizations worldwide researching cellulose nanofiber, the University of Maine is the first to demonstrate the use of less-refined, ligno-cellulose nanofiber (LCNF) as an adhesive in particle board (PB) (Amini thesis, 2019; Turpin and Nelson, 2020). Wood composite panels like PB are ubiquitous in the global furniture and building industries. The U.S. alone consumed approximately 4.5 million $m^3$ of PB in 2018 (Howard and Liang, 2018). PB could be a productive outlet for the sawmill residues and low-quality wood that can no longer be sold to pulp and paper mills in Maine. This study explores the viability of LCNF - bound PB within a selective design techno-economic analysis (TEA). TEA is the standard method for quantifying capital requirements for commercializing piloted production processes (U.S. EPA, 2014; Moran, 2015). This TEA identifies a minimum product selling price that can then be compared to current market prices.

UMaine LCNF-PB research is of national and not just regional importance because it addresses key drawbacks to PB - its toxicity and dependence on fossil fuels. The durability and affordability that make PB so popular come partly from the use of carcinogenic urea formaldehyde (UF) adhesives (Solt et al., 2019). The National Toxicity Report classified formaldehyde as a carcinogen in 2011, and illness due to formaldehyde exposure is well-documented in those who make or work with wood composites ("Formaldehyde", Priha et al., 2004). Public concern over formaldehyde exposure from wood composites led to the passage of the Formaldehyde Standards for Composite Wood Products Act (FSCWPA) in 2010 (40 CFR 770, Frihart et al., 2012). The U.S. EPA issued its final rules for FSCWPA compliance in 2018 (U.S. EPA, 2019). Though individual PB products must now meet EPA standards for formaldehyde emissions, PB is so ubiquitous that formaldehyde off-gassing from PB furniture and trim can reach dangerously high concentrations in living spaces (California Air Resources Board, 2020).

Meeting the new emissions standards increased production costs for many manufacturers; the estimated annual compliance costs for the manufacturing and retail industries are between $38 and $83 million (USD 2013) (U.S. EPA, 2019). Manufacturers must also spend more on low-emission alternative adhesives, which can represent 50 % of their material costs (Solt et al., 2019). Alternative adhesives relying on soy proteins or other compounds often require additives like epichlorohydrin, which likely presents additional health risks (Toxic Air Contaminant Identification List Summaries, 1997). No alternative PB adhesive currently on the market fully produces panels that are both competitive and proven to be completely safe (Solt et al., 2019).

UF adhesives present an additional public health threat by contributing to global climate change, which is also negatively affecting Maine's forest industry. These adhesives are manufactured from ammonia and natural gas, both of which can be potent sources of greenhouse gases (Solt et al., 2019). The 2018 CO2 contribution from UF resins consumed in PB in the U.S. was at least 7,300 MT. UF resins represent 28% of all embodied energy in PB (Wilson, 2008; Table 1.11). Lifecycle emissions from UF resins will continue to grow with the U.S. furniture and construction markets unless more environmentally friendly alternatives replace it. U.S. PB consumption grew ~42% from 2011 to 2018 (Honeyman, 2016). The largest PB plant in North America opened in Michigan in 2019, the first greenfield (i.e., entirely new) PB plant to open in the U.S. since 2001 (Buti, 2019). The U.S. market is currently increasing both imports and production of PB to keep up with rising demand (Honeyman, 2016).

Meeting this demand increase with new PB production with a bio-based alternative adhesive could help to fill this U.S. market gap. New LCNF-PB production in Maine could help to rebuild the state's forest industry, while displacing greenhouse gas emissions from UF in the growing PB market. Options for ultra-low emission formaldehyde (ULEF) composite panels in and around Maine are currently limited (Composite Panel Association). The Columbia Forest Products facility in Presque Isle uses an innovative plywood binding technology developed by the College of Forestry at Oregon State University (Columbia Forest Products). The facility also manufactures low-formaldehyde fiberboard. The nearest ULEF particleboard producers are Tafisa Canada in LacMegantic, QC, and Uniboard in Sayabec, Quebec.

The Laboratory of Renewable Nanomaterials at the University of Maine has found that ligno-cellulose nanofibers (LCNF) from recycled forest products meet the same American National Standard strength requirements as urea formaldehyde adhesives in PB (Amini, 2019). The lab's research was the first in the U.S. to show that cellulose nanofiber (CNF) or LCNF alone can be used as a commercial-grade binding agent (Amini et al., 2017, Sun et al., 2019; Diop et al., 2017). Concurrent research by Kojima et al. (2014) in Japan successfully used LCNF to make medium-density fiberboard, while Kojima et al. (2016) evaluated CNF performance in particle board.

CNF and LCNF are logical binder components for building materials because they are the most basic structural unit in plants. Due to their high surface area and numerous hydroxyl groups, (L)CNF form tight, aggregated bundles that give strength to plant cell walls (Moon et al., 2016). Disaggregated nano-scale cellulose fibrils therefore form strong bonds with wood particles and other appropriately charged materials (Moon et al., 2016, Diop et al., 2017). Nanofibrils, or “fines”, are cellulose strands with at least one nanoscale (< 100 nm) dimension, though other dimensions can be as long as a few microns (Diop et al., 2017). Its binding ability makes CNF a versatile manufacturing input, with potential applications from drug delivery to the moulding of car parts (Moon et al., 2016, Tayeb et al. 2018). However, most existing applications require only small volumes of CNF, creating insufficient demand to support rapid commercialization (Diop et al., 2017).

The process for making CNF is similar to that used in commercial paper manufacturing: wood pulp is chemically or enzymatically treated to remove other plant compounds, like lignin, and then mechanically refined (Kojima et al., 2016). Kojima et al. (2014) and Amini (2019) showed that CNF is still an effective PB adhesive when lignin is not removed from the feedstock, demonstrating a use for large volumes of LCNF and avoiding the high processing and input costs of CNF production. This finding provides a potential pathway forward for the green building economy, and is significant for PB manufacturers in light of the challenges posed by other bio-adhesives.

Federal and state investors in LCNF research at UMaine also hope that this new wood technology could help to revitalize the state’s forest-based communities. The UMaine LCNF process consumes old corrugated cardboard (OCC) already recycled at two plants in Maine, using a process similar to that used in Maine’s pulp mills and for making LCNF. Widespread closures of these mills since 2010 have devastated local communities (Bell et al., 2018). Diversifying Maine’s forest products industry with LCNF could lessen the impacts of commodity boom-and-bust cycles in the future. Making PB from LCNF in Maine would further support the industry by growing the markets for sawmill residues and low-diameter wood. However, no studies have yet assessed the financial viability of commercial LCNF or LCNF - PB production. The high initial capital costs of PB production will deter commercial-scale investment unless those costs can likely be recouped in the short-term (Solt et al., 2019).

Our techno-economic analysis of the LCNF and LCNF/ PB production processes identifies the costs associated with each production step, using them to estimate the minimum product sales price (MPSP) that attains the industry standard rate of return. We adapt the 2018 analysis of CNF production by de Assis et al. to identify key costs and financial outcomes from LCNF production. This CNF analysis offers the best point of comparison for LCNF, as the production processes differ only in the original inputs. The UMaine CNF process modeled by de Assis et al. (2018) is similar to that used by other CNF researchers, and uses the northern bleached softwood kraft (NBSK) pulp common to Maine's mills (Amini, 2017). The difference in inputs between OCC-based LCNF and CNF could significantly impact the relative profitability of each production process - NBSK pulp prices are 10-15x higher than recent OCC prices (St. Louis Fed CPI), and de Assis et al. (2018) found that the price of pulp was a major determinant of whether CNF production was cost effective. Following de Assis et al. (2018), our techno-economic analysis shows how MPSP changes with input costs, output volume, and the required internal rate of return.

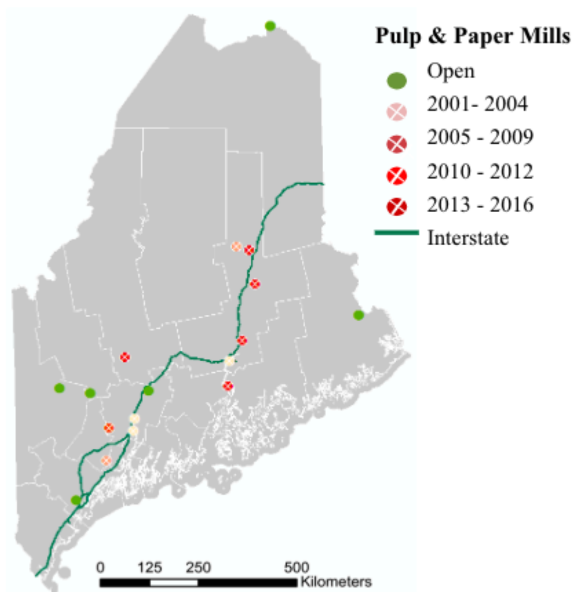
We also test whether manufacturing LCNF and PB together makes more economic sense than producing either one alone. Demand for LCNF could be too low without local or conjoint PB production, or PB capital investment could be prohibitively expensive unless producers are making their own adhesive. LCNF - PB could also command a price premium as a safer and more sustainable product than traditional PB.

### 1.1.1 Maine's Forest Industry

Maine dominated both domestic and international pulp and paper production from the late 19th to late 20th centuries, such that the state's economy and culture grew around that forest industry subsector (Smith, 1970). Forest-based activity unrelated to pulp and paper benefited from the infrastructure and wood residues market that the subsector created (Meister Consulting Group, 2017). This lack of diversification left the state's forest industry vulnerable in the face of increasing foreign competition, declining paper use, and lack of innovation in the state's mills (Listo, 2018). Widespread mill closures began in 1980 and peaked after the 2008 - 2009 global financial crisis (Fig. 1, Listo, 2018). Employment in Maine's pulp and paper industry dropped 66.7% from 2001 to 2016, decreasing from 10,208 to 3,399 jobs (Listo, 2018). During that same time period, the value added by the forest industry to the national economy declined by more than a third (Lebedys and Li, 2014).

Maine's forest industry today accounts for 4 - 6% of Maine's GDP and is slowly diversifying, with the state's first cross-laminated timber mill opening in a former paper town (Crandall et al., 2017). The Forest Opportunity Roadmap developed by state stakeholders seeks to grow the industry's annual economic contribution from $8 billion in 2016 to $12 billion in 2025 ("Forest Opportunity Roadmap/ Maine"). Meeting this ambitious goal requires that Maine firms transition to new, higher value-added products that are competitive in a rapidly changing global market (Wang et al., 2015). Maine's abundance of hydroelectric and wind energy could power new manufacturing without increasing greenhouse gas emissions (Marchs, 2016). Using renewable energy in an average US PB manufacturing facility would reduce fossil fuel emissions by ~88%, to ~43 kg/m3 (Puettman, 2013). Maine's forest products industry would therefore have an advantage over the largest PB-producing region in the U.S., the fossil fuel-dependent South, if national and international policies favor renewable over fossil-fuel based energy (Honeyman, 2016).

Analyses by Daigneault and Listo (2017) show that Maine's forests can sustainably support increased biomass demand due to new forest products manufacturing in the state. Their highest-demand scenarios predict a harvest increase of only 7.4 - 10.4 % over 2018 levels, well below historic harvest volumes. Forest area would also increase by up to 0.9 % to meet timber demand (Daigneault and Listo, 2017). Higher demand would also mean higher returns to forested land (Favero et al. 2020), and would likely prevent or delay forest conversion in rapidly developing southern Maine (Balukas et al., 2019). The prevalence of working conservation lands (Zhao et al., 2020) and certified forest ownership in the state (~50 %) provide additional assurance that increased harvesting would follow best sustainability practices ("Maine Forest Industry at a Glance").




### 1.1.2 Manufacturing LCNF and CNF

The process for manufacturing LCNF (or CNF) is simple compared to processes for manufacturing other adhesives. There are two primary steps: OCC (or bleached Kraft pulp) is mixed with water in a hydropulper to obtain a 3 - 4 % solids slurry, then fibrillated in a disk refiner (Bilodeau and Paradis, 2015). Fibrillation breaks down the ligno-cellulose solids until the slurry contains the desired percentage of nanoscale ligno-cellulose fibers (“fines”). According to the pulping equipment manufacturer GL&V, OCC and bleached Kraft pulp require different disk refiners (David Cowles, personal communication).

Amini (2019) found that the adhesive properties of LCNF and CNF in PB do not increase significantly at fines levels higher than 70%, and do not increase at all at levels higher than 80%. In contrast, the amount of energy required to refine slurries at or above these thresholds increases drastically: refining LCNF or CNF to 90% fines from 80% fines requires an increase of ~69% in disk refiner energy use. Alternative methods of fibrillation for CNF that have been tested for LCNF include microfluidization and ultrasonication, (de Assis et al., 2016; Espinosa et al., 2019) but these processes are much more energy-intensive and are limited in scale.. Much of the existing research on LCNF and CNF manufacturing uses chemical pre-treatments to reduce fibrillation time and energy requirements, but may detract from the binding ability and safety of LCNF and CNF in PB (Bian et al., 2017).

A mix of CNF and LCNF slurries ((L)CNF) is likely a stronger adhesive than an LCNF slurry alone (Amini, personal communication). Based on the results of Amini (2019) there is likely no significant improvement in PB panel strength for LCNF/ CNF mixes exceeding a ratio of 85:15. The only study to hybridize the LCNF and CNF binders (Horseman et al., 2017) did not evaluate binding properties.

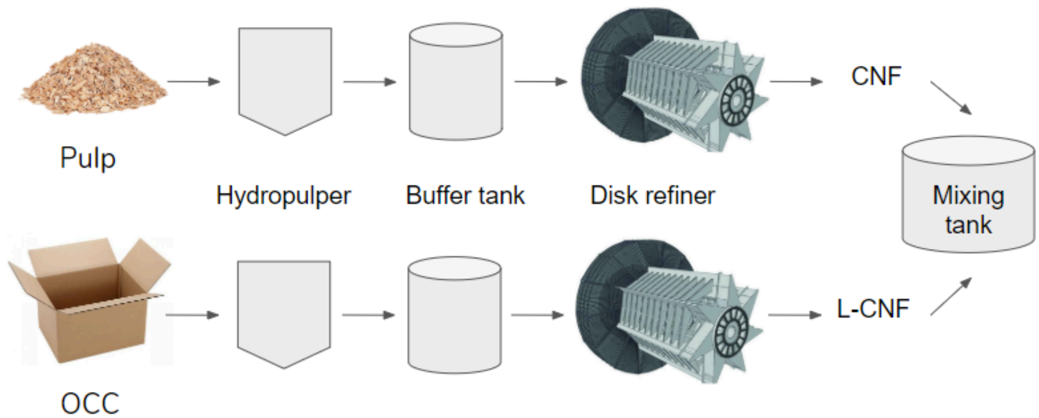



Figure 2. A simplified schematic of the UMaine CNF and LCNF manufacturing processes. CNF and LCNF are combined in ratios ranging from 20/80 to 0/100 to achieve the desired adhesive strength.

### 1.1.3 Manufacturing PB with (L)CNF

The theoretical commercial PB process based on Amini (2019) begins with mixing pre-sifted wood particles and the 3.5% solids (L)CNF slurry for 1 - 5 minutes. Nanofibers attach preferentially to wood particles during mixing, releasing the hydrogen bonds that adsorb the water molecules to the cellulosic surface (Amini et al., 2019). Amini et al. (2019) term this phenomenon 'contact dewatering', and show that contact dewatering significantly lowers the amount of time required to mold a panel through cold pressing (a mechanical dewatering process). This commercial line uses vacuum-assisted cold pressing to lower the dewatering time even further. Collected wastewater is filtered and reused, reducing environmental compliance costs associated with wastewater discharge. The molded, condensed panel travels by conveyor belt to a hydraulic heat press at 4.8 MPa and 180 °C. The hot press induces evaporative dewatering in the panel, and requisite emissions control systems capture the released steam and volatile organic compounds. The panels are then cooled prior to sanding and trimming.

The final panel from Amini et al. (2019) measured 3 ft. x 3 ft. x 0.5 in. and approximated the average US panel density of 746 kg/ m3 at ~700 kg / m3 (Wilson, 2008).[1] The commercialized panels would likely be made to the standard 4 ft. x 8 ft., or as a continuous piece ~8 ft. in width ("Feasibility Assessment"). Scaling up the panel size is unlikely to change either the performance or the 'press factor' - the number of seconds required to cure 1 mm (Solt, 2019). The press factor will likely determine the financial success in the Amini (2019) PB process because it is the largest determinant of processing time (Solt et al., 2019). Producers require low processing times to achieve the economic efficiencies of high-volume output.

A low press factor is therefore critical to making LCNF/ CNF PB production competitive with PB production from low-formaldehyde alternatives. Many of these alternatives are also lignin-based, but rely on small amounts of UF, or on formaldehyde-based adhesives other than UF (Solt et al., 2019). Press factors for commercially produced, low-formaldehyde PB panels range from 15 to 35 s/mm at temperatures greater than 180 ℃ (Solt et al., 2019). In contrast, the panel press factor from Amini et al. (2019) was much higher at ~150 s/mm.[2]

The processing time in the UMaine LCNF-PB process can be shortened in several ways to achieve a production volume similar in scale to the national average (347,690 m3, from Wilson, 2008; avg. density 746 kg/m3). While the 3' x 3' test panel needed 35 minutes to dry completely, compared to the five minutes or less required when using UF adhesives, The press factor could be reduced by increasing the hot press temperature; the panels could be removed from the hot press prior to reaching the desired moisture content, to finish drying on cooling racks. The expected press factor when using these measures is ~50 s/mm to ~80 s/mm.

[1] commercial panel production could meet target densities of 0.60 kg/ m3 - 1.0 kg/ m3 to meet ANSI standards for low, medium, or high-density particleboard
[2] 12.7 mm, ~1800 s of curing time

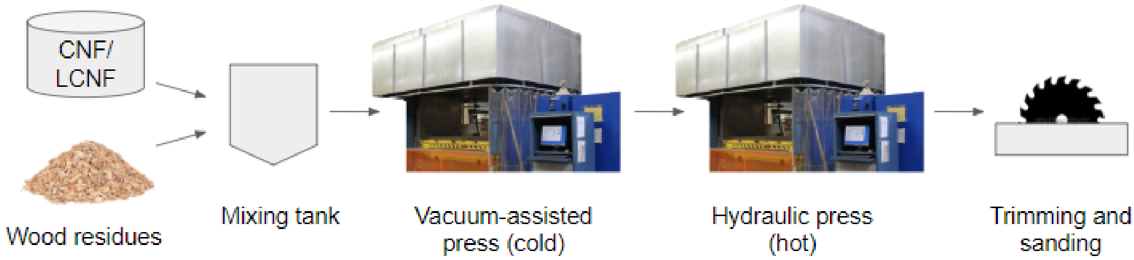



Figure 3. A simplified schematic of the UMaine (L)CNF- PB manufacturing process.

One major advantage of manufacturing PB with LCNF is that the wood residues used for PB do not need to be dry, eliminating several energy- and capital-intensive steps from a conventional production line. A conventional PB manufacturing line starts by sifting, hammer milling (size reduction), and drying wood residues before they are mixed with UF resin. Residues for conventional PB  must be dried from an average moisture content of 26% (oven-dry weight) to 3 - 5%, requiring an industrial dryer, energy, control devices for volatile organic compound emissions, and fire risk reduction systems (Wilson, 2008; “Feasibility Assessment”). Drying equipment and fire risk reduction systems would still be necessary for the wood residues used to power co-generation.

On-site wood energy generation is critical to lowering the financial and environmental costs of producing compressed panels (Wilson, 2008). The UMaine process energy needs will likely approximate those of an average North American PB production line: 0.164 MWh of electricity and 1730 MJ (equivalent to 0.481 MWh) of thermal energy per $m^3$. Projected electricity use for a possible MDF facility in neighboring NH was 88,000 MWh/ yr, all of which can be provided by a co-generation facility (“Feasibility Assessment”). Existing manufacturers rely on natural gas boilers or wood co-generation to meet these extraordinary energy demands (Wilson, 2008). However, extending natural gas lines in rural New England is expensive and in opposition to states’ climate change mitigation strategies (“Feasibility

Assessment”, Maine Climate Council). Recent steep decreases in the cost of natural gas are also likely to be countered by increased regulation of fossil fuels. In contrast, wood co-generation provides an economically efficient outlet for PB trimmings and other wood fiber waste. The New Hampshire Feasibility Assessment concludes that wood energy co-generation is the only financially viable option for a rural New England sheet good plant.

Overall cost-savings from using an 85/15% (L)CNF adhesive in PB are expected to come from: reduced electricity requirements over a 100% CNF adhesive; reduced input costs from using OCC instead of NBSK; replacing (L)CNF energy sources with co-generation when (L)CNF and PB manufacturing are coupled. Additional cost savings could be achieved in the 100% LCNF scenarios by increasing hydropulper and disk refiner capacity and omitting the smaller and less efficient CNF-only machines.

## 1.2 Methods

I use a techno-economic analysis to find the minimum product selling price (MPSP) possible using the input parameters from the University of Maine (L)CNF and PB manufacturing processes. I structure my analysis using de Assis et al.’s CNF TEA Microsoft Excel template, solving for the MPSP required for the facility to have a net present value of 0. I expand and alter template parameters and assumptions to represent 11 (L)CNF and PB scenarios. All scenarios assume a 3.5% aqueous (L)CNF solution and a PB density of 700 kg/m$^3$. Additional technological assumptions are described in Table 1. Following de Assis et al., (2018) I assume that production occurs in or near existing mill infrastructure in the Penobscot River valley. While much of de Assis et al.’s template refers to Peters, Timmerhaus, and West (2003), I adhere to cost estimation methods recommended in more recent literature (Towler and Sinnott, 2013; Moran, 2015) where de A et al.’s methods diverge. The resulting analysis is a preliminary, AACE International Class 4 estimate with an expected cost accuracy of +/- 30% (Towler and Sinnott, 2013,

p. 311). The following section explains scenario development, determination of capital requirements, and sensitivity analysis in this study.

Table 1. Main technological assumptions for all scenarios, after de Assis et al (2018). Electricity consumption estimates for Dieffenbacher particle board equipment used in the analysis cannot be disclosed.

| Process input | Value | Units |
|---|---|---|
| (L)CNF production, (L)CNF-only scenarios | 50 | Dry tons |
| (LCNF) production, (L)CNF – Particle board scenarios | 170 | Dry tons |
| Particle board production | 250,000 | $m^3$ / year |
| (L)CNF solids content | 3.5 | % |
| Particle board final moisture content | 8 | % |
| Overall equipment efficiency | 93 | % |
| Electricity consumption, hydropulper | 333 | kWh/ dry ton pulp or cardboard |
| Electricity consumption, disk refiner (CNF) | 3, 433 | kWh/ dry ton pulp |
| Electricity consumption, disk refiner (LCNF) | 882 | kWh/ dry ton cardboard |
| Electricity cost | 60 | USD/ MWh (Emera Maine) |
| NBSK pulp cost | 1,128 | USD/ dry ton (Brian McCay & Associés, 2019) |
| Old corrugated cardboard cost | 60 | USD/ dry ton (Resource Recycling) |
| Freight cost | 50 | USD/ dry ton (Whalley et al., 2017) |
| Tap water cost | 0.60 | USD / ton (Old Town Water District) |
| Wood residues cost | 30 | USD/ green ton (Sherman and Pelkki, 2019) |

### 1.2.1 Scenario development

Scenarios differ by binder suspension composition (85% LCNF/ 15% CNF or LCNF only), the level of development required at manufacturing sites (repurposed, co-location, or greenfield), and the presence or absence of PB production (Table 1). I use one of the development categories used by de Jong et al. (repurposed) and two used by de Assis et al. (2018) (co-located, greenfield) to capture manufacturers' siting choices. "Repurposed" in this context refers to a new (L)CNF production line inside an existing mill, while "co-located (with pulp production)" describes the manufacturing of CNF from adjacently manufactured pulp. "Co-located (with PB production)" describes the joint manufacturing of (L)CNF adhesive and PB, likely in separate buildings. Finding a use for abandoned or underutilized mill infrastructure was a primary motivation for funding (L)CNF research at the state and federal levels. The repurposed and co-located production scenarios test whether (L)CNF or (L)CNF-PB production is an efficient way to utilize this infrastructure. The greenfield scenarios of ground-up construction provide useful comparisons for decision-makers.

Co-location differs from repurposing in that freight costs for the co-located input are omitted, and installed and operational capital costs are lowered by the existing physical and human capital. Co-location and repurposing can also be additive; in scenario 1a, I assume that co-location with pulp production also entails re-purposing of some pulping equipment (i.e., hydropulpers) for (L)CNF production (Table 1). In contrast, scenario 1b tests a repurposed production site that sources pulp from nearby mills in the absence of co-located pulp production. Repurposing of mill infrastructure is also possible when pulp is not an input (scenarios 1d and 1e).

The PB manufacturing scenarios (2a - 2f) represent the use of (L)CNF from the repurposed-facility and greenfield scenarios. Co-production of PB and (L)CNF occurs only when pulp is produced elsewhere. PB production co-located with pulp production would require a larger-than-average mill (likely > 600,000 sq. ft.), significant safety measures, and extraordinary initial capital investments.[3] For example, scenario 1c does not require pulp co-production, allowing co-production of LCNF and PB for scenarios 2a and 2d. Scenarios 2e and 2f test the viability of LCNF-PB production without LCNF co-production. Readers should note that the processing time and capital expenditure parameters used for PB equipment assume that the pressing time for (L)CNF-bound PB can be reduced to 36 s/mm . This strong assumption was necessary to use recent equipment price estimates.

The target production volume for the (L)CNF-only scenarios is 50 short tons (dry weight basis) per day, following de Assis et al. The PB scenarios are all evaluated at a target production of 250,000 $m^3$/yr, requiring 170 short tons (dry weight basis) of (L)CNF binder. This PB volume is realistic for a three-shift-per-day facility, encompasses the minimum volume needed for a plant to be competitive, and is slightly less than the average U.S. PB plant capacity ("Feasibility assessment"; Wilson, 2008, Expert Opinion). (L)CNF-bound PB requires more than three times the (L)CNF production assessed by de Assis et al. (2018) when assuming a binder content of 30% (dry basis). I model the scaled-up (L)CNF production alongside PB production. In the (L)CNF-PB co-production scenarios 2a and 2d, I assume that there are economies of scale, that there are no freight costs for (L)CNF, and that all electricity for (L)CNF production is provided by the co-generation capacity belonging to the PB process.

[3] Likely sufficient size determined by adding the required square footage for the proposed New Hampshire MDF plant of comparable production volume (~500,000 sq. ft.) and an approximation of a typical Maine pulp mill square footage (~100,000 sq. ft.). I add an additional 50,000 sq. ft. to account for the fact that the equipment must likely be divided among several buildings for safety reasons. These estimates include warehouse space.

Table 1. Factors differentiating scenarios in the (L)CNF (stage one) and PB (stage two) manufacturing processes.

<table>
<tr><td colspan="7">Letters a - f represent likely combinations of potential producer choices to: use (L)CNF or LCNF; combine or separate production processes; repurpose existing infrastructure or build from bare ground. Relative infrastructure intensity is represented in the model by low and high levels of factors - the amounts by which bare equipment costs are multiplied in selective design analysis to infer indirect capital costs (after PTW (2003) and T and S (2015)).</td></tr>
<tr><th>Stage</th><th>Product</th><th>Scenario</th><th>Description</th><th>Pulp Purchased</th><th>Existing Pulp Equipment and Facilities Repurposed for (L)CNF</th><th>Direct & Indirect Cost Factor Level</th></tr>
<tr><td rowspan="5">1</td><td rowspan="3">(L)CNF mix</td><td>1a</td><td>Repurposed and Co-located (with pulp)</td><td>No</td><td>Yes</td><td>Low</td></tr>
<tr><td>1b</td><td>Repurposed</td><td>Yes</td><td>Yes</td><td>Low</td></tr>
<tr><td>1c</td><td>Greenfield</td><td>Yes</td><td>No</td><td>High</td></tr>
<tr><td rowspan="2">LCNF only</td><td>1d</td><td>Repurposed</td><td>N/A</td><td>Yes</td><td>Low</td></tr>
<tr><td>1e</td><td>Greenfield</td><td>N/A</td><td>No</td><td>High</td></tr>
<tr><th>Stage</th><th>Product</th><th>Scenario</th><th>Description</th><th>(L)CNF Purchased</th><th>Existing Pulp Equipment and Facilities Repurposed for (L)CNF</th><th>Direct & Indirect Cost Factor Level, PB Only</th></tr>
<tr><td rowspan="6">2</td><td>PB, (L)CNF</td><td>2a</td><td>Co-located (with (L)CNF)</td><td>No</td><td>Yes</td><td>Low</td></tr>
<tr><td>PB, (L)CNF</td><td>2b</td><td>Greenfield</td><td>Yes</td><td>Yes</td><td>High</td></tr>
<tr><td>PB, (L)CNF</td><td>2c</td><td>Greenfield</td><td>Yes</td><td>No</td><td>High</td></tr>
<tr><td>PB, LCNF</td><td>2d</td><td>Co-located (with (L)CNF)</td><td>No</td><td>Yes</td><td>Low</td></tr>
<tr><td>PB, LCNF</td><td>2e</td><td>Greenfield</td><td>Yes</td><td>Yes</td><td>High</td></tr>
<tr><td>PB, LCNF</td><td>2f</td><td>Greenfield</td><td>Yes</td><td>No</td><td>High</td></tr>
</table>

### 1.2.2 Determination of Capital Requirements

#### *1.2.2.1 Fixed Capital*

Peters, Timmerhaus, and West (2003) emphasize that fixed capital expenditures "can exceed 80% of the total plant cost," such that assumptions about fixed capital costs significantly influence the results of plant cost models. They define fixed capital as "all tangible infrastructure and its direct and indirect installation costs" (Peters, Timmerhaus, and West 2003). The engineering literature also categorizes these as "Inside Battery Limits" and "Outside Battery Limits" costs (Towler and Sinnott, 2012). I find fixed capital costs using the standard Lang (1948) factor method, in which each fixed cost item is the multiple of the bare equipment cost and a specified factor (Peters, Timmerhaus, and West, 2003). Recent factor estimates in plant cost estimation literature reflect relative costs in currently operating plants (Towler and Sinnott, 2012; Moran, 2015).

I account for the same standard direct and indirect costs and factors as de Assis et al. (2018). Also following de Assis et al. (2018), I primarily use the factors provided in Peters, Timmerhaus, and West (2003) for solid-fluid plants. De Assis et al. cite Peters, Timmerhaus, and West (2003) for the factors used to calculate indirect fixed costs as a percentage of direct costs. However, their resulting indirect fixed cost estimates are far below the factors recommended in most literature (Peters, Timmerhaus, and West, 2003; Towler and Sinnott, 2012; Ereev and Patel, 2015). Instead, de Assis et al.'s indirect cost estimates approximate those from Woods (2008). This discrepancy between the Woods (2008) and Peters, Timmerhaus, and West (2003) factors is partly offset by other fixed costs added elsewhere in their analysis. Ereev and Patel (2015) recommend using Peters, Timmerhaus, and West's (2003) factors over Woods' (2008) for most indirect fixed costs. Using higher indirect cost factors is especially important when assessing a new type of plant (Towler and Sinnott, 2012). I therefore use the range of factors from

Peters, Timmerhaus, and West (2003) and Towler and Sinnott (2012) for all direct and indirect fixed costs. [4]

Following de Assis et al., I use low and high factor levels to correspond to co-located/ repurposed and greenfield facilities. The low/ high factor levels are lower/ high than the factors recommended for new facilities. I also use a medium factor level with an average of the new-facility factors from the literature to evaluate (L)CNF-only greenfield facilities. The resulting cost estimates therefore capture a wide range of potential capital costs.

Also following de Assis et al. (2018), I use low, medium, and high factor levels to reflect the increasing amount of infrastructure development required for the co-located & repurposed, repurposed, and greenfield scenarios.

I find bare equipment costs using equipment capacity and price estimates provided by representatives from GL&V (for (L)CNF) and Dieffenbacher (PB). I adjust the equipment price estimates according to Williams' (1947) scale factor method (eq. 1), which is still the standard in modern cost analysis for assuming the most efficient machine size in cost modeling. I use the recommended scaling factor for new facilities, s = 0.6 (Towler and Sinnott, 2012).

$$Cost_{Equip} = Price_{Equip} \times \frac{Capacity, Used}{Capacity, Total}^{S}$$

Equation 1. Equipment cost derived from bare equipment price

In addition to basing bare equipment costs on the (L)CNF and PB equipment described in Sections 1.2 and 1.3, I follow the NH MDF Feasibility Assessment by including wood-based energy generation (without natural gas) as an equipment cost for PB scenarios.

[4] Piping and equipment installation factors are absent from the Peters, Timmerhaus, and West (2003) factor tables available to me at the time of writing. However, as de A et al. include these direct cost items and they are not explicitly included in the other PTW (2003) factors, I used piping and equipment installation factors from Towler and Sinnott (2012). Van Amsterdam (2018) asserts that the factors calculated for off-site costs have increased since the publication of PTW (2003).

The internal rate of return (IRR), or discount rate, required for the project to be cost-neutral is the minimum interest rate required to pay loans on capital investment. The interest rate paid on capital investment loans depends on the overall cost of capital, “the weighted average of the cost of debt and the cost of equity [expected shareholder return]” (Towler and Sinnott, 2012). The cost of debt will be specific to each company, as will the relative amounts of debt and equity financing. The usual ranges for the costs of debt and equity are 5-10% and 25 - 30%, respectively. The costs of debt and equity include inflation effects. I follow Towler and Sinnott (2012) and de Assis et al. in using a 16% overall cost of capital. Additional financial assumptions are stated in Table 2.

Table 2. Main financial assumptions for all scenarios, after de Assis et al (2018).

| Input | Value | Units |
|---|---|---|
| Project start | 2019 | year |
| Financial evaluation horizon | 10 | Years from year 0 |
| Production in year 0 (2021) | 80 | % of plant capacity |
| Production in year 1 | 100 | % of plant capacity |
| % of CAPEX spent in year -2 (2019) | 50 | % of investment |
| % of CAPEX spent in year -1 | 50 | % of investment |
| Depreciation schedule, straight line | 10 | years |
| Working capital | 10 | % of year +1 sales |
| Hurdle rate<br><br>Tax rate on EBIT | 16<br><br>21 | %<br><br>% |
| Terminal value in year 10 | 5 | Multiple of EBITDA |
| Operating days | 340 | days/ year |
| Maintenance costs | 2 | % of RAV[5] |
| Capital reinvestment | 1 | % of RAV |
| Overhead costs | 3 | % of sales |
| Other fixed costs (insurance, property taxes, and emissions control) | 1.5 | % of RAV |

#### *1.2.2.2 Working Capital*

[5] Replacement Asset Value

Working capital requirements for (L)CNF and (L)CNF-PB encompass both direct and indirect working costs. Direct workings costs include raw materials (NBSK pulp, OCC, wood residues). Indirect costs include labor, utilities (electricity, thermal energy, and water), maintenance, environmental controls, taxes, insurance - any other variable cost necessary for plant function. I follow de Assis et al.'s assumptions about working capital requirements, with the exceptions of pulp costs, utility rates, and labor requirements.

De Assis et al. use both a probabilistic and deterministic assessment of their pulp production co-location scenario. I account for market pulp price fluctuation in the sensitivity analysis in place of a deterministic assessment. (L)CNF scenarios in which pulp is made off-site (1b, 1c, 2b, 2c) assume freight costs of $50/ ton (dry weight basis) (after Whalley et al., 2017, and de Assis et al., 2018). PB scenarios in which (L)CNF is made off-site (2b, 2c, 2e, 2f) also assume freight costs of $50/ dry ton. I also approximate monthly North American NBSK prices from annual averages for 2015 - 2019, reprinted by the Canadian Government from Brian McCay & Associés (2019).

I differ from de Assis et al. in using 2015 - 2019 industrial electricity rates from the Emera Maine Bangor Hydro District that serves Old Town. I also use local industrial water rates.

I estimate plant energy needs from equipment energy estimates provided by GL&V and Dieffenbacher representatives, and I assume that wood co-generation covers all co-produced (L)CNF and PB plant energy needs in scenarios 2a and 2d. I assume that wood co-generation requires 2100 dry tons/ MW of capacity of a local hardwood/ softwood wood chip mix each year (Feasibility Assessment). I estimate dry tons to be half the mass of green tons.

I adapt the assumed labor requirements from de Assis et al. for (L)CNF production, and scale those estimated by Dieffenbacher for PB production. De Assis et al. (2018) include pulp workers in their labor costs for their co-location scenario. As no other pulp production costs are included in the co-location scenarios, I assume that all pulp production costs, including labor, are separate. I use salary estimates that are approximately $20,000 greater than the Maine average, assuming that any new plants are part of the state's upward trend in forest industry employment and wage competition (and that the new plant prioritizes paying their workers living wages). This is a departure from De Assis, whose estimates for worker salaries are up to twice the U.S. and Maine average salaries for the various plant employment positions (BLS, 2019).

#### 1.2.3 Sensitivity Analysis

The sensitivity analysis reflects the ± 30% accuracy associated with Class 4 plant cost estimates (see above). The 30% error margin is designed to further capture "process, financial, and political risks" (Moran, 2015) not captured in the capital contingency estimate. I iteratively alter all physical inputs by at least 30%; I alter OCC prices by 50% to reflect historic trends. I test the tax rate on EBIT at 16% and 31%, the number of working days at 320 and 360, and the internal rate of return at 10% and 20%.

I also scale the stand-alone (L)CNF production scenarios, 1b and 1e, that correspond to the (L)CNF-PB co-production scenarios (2a and 2d). I then compare the (L)CNF production costs between 1b, 1b (scaled), and 2a and between 1e, 1e (scaled), and 2d. I use the results to differentiate the cost savings from scaling production and those from sourcing electricity from co-generation rather than from the grid.

### 1.3 Results

#### 1.3.1 (L)CNF

The minimum product selling price (MPSP) per dry ton for (L)CNF ranged from $704 (1d) to $1,543 (1c - high) (Table 3). These scenarios had the lowest and highest fixed capital investments, respectively (Table 3). LCNF production in the repurposed setting (1d) was $276 (28%) less than (L)CNF production in the same setting (1b). Co-locating (L)CNF production with pulp production in the repurposed setting (1a) resulted in a savings of $27 (3%) per dry ton compared to not co-locating with pulp production (1b). This savings did not lower the MPSP from 1a to within the margin of error (30%) of the MPSP from the LCNF-only scenario in the same repurposed setting (1d). The MPSP from the repurposed and co-located scenario (1a) was slightly less than the MPSP of the greenfield LCNF-only scenario (1e) when medium factors were used to calculate non-equipment capital costs. The (L)CNF greenfield scenario (1c) MPSP was higher than that from the LCNF greenfield scenario (1e) regardless of the factor level used for both capital calculations.

Table 3. (L)CNF production requirements for all (L)CNF scenarios in year 0. The greenfield scenarios (1c and 1e) are run with both medium and high factor levels.

| Scenario | MPSP ($/ dry ton) | % FCI from direct costs | Total FCI ($ Mil) | Total operating costs ($ Mil) | Total capital costs (Mil $) |
| --- | --- | --- | --- | --- | --- |

| | | | | | |
|---|---|---|---|---|---|
| 1a | 953 | 79 | 31.93 | 11.48 | 30.28 |
| 1b | 980 | 78 | 33.4 | 11.78 | 31.65 |
| 1c- high | 1,534 | 73 | 77.85 | 17.96 | 73.55 |
| 1c - med | 1,270 | 72 | 56.81 | 15.01 | 53.19 |
| 1d | 704 | 79 | 27.46 | 8.46 | 25.85 |
| 1e - high | 1,138 | 75 | 62.06 | 13.25 | 57.69 |
| 1e - med | 975 | 68 | 49.09 | 11.49 | 45.76 |

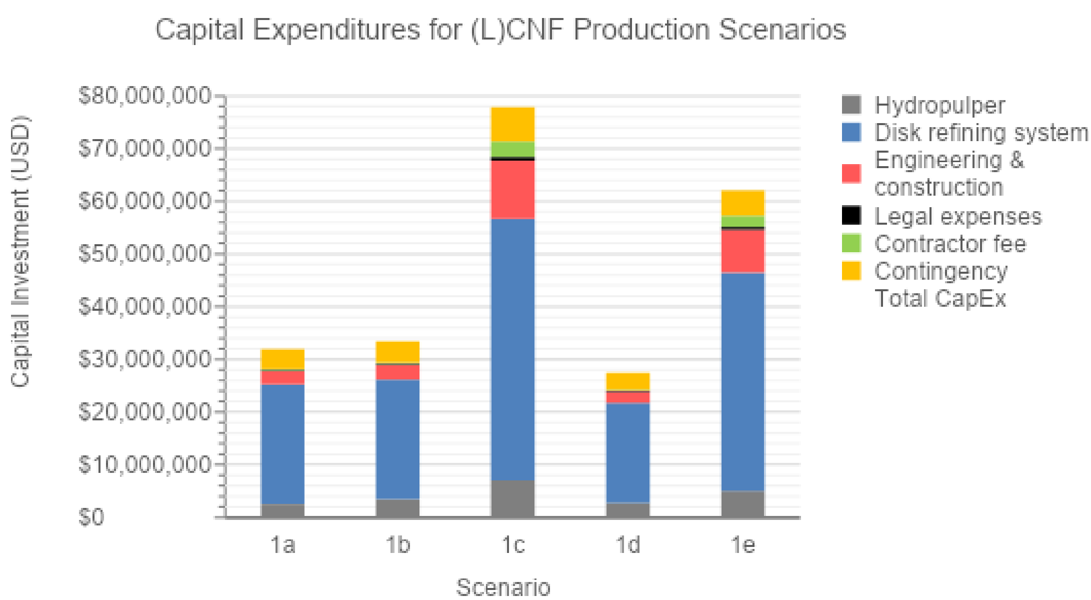



Figure 4. Capital Expenditures for (L)CNF Production Scenarios

Greater capital, tax, and indirect working costs drove production costs in greenfield scenarios (1c, 1e) to be ~ 1.5x those in the repurposed scenarios (1a, 1b, 1d) (Fig. 4, Fig. 5). Indirect working costs make up the majority of costs across all scenarios. Depreciation contributed more to indirect cost increases in greenfield scenarios than did labor, overheads, or maintenance (Fig. 6). Indirect working costs had the largest impact on overall costs when pulp inputs were removed and capital factors were assumed to be low (Fig. 5, 1d).

Direct working costs such as labor were constant among the (L)CNF (1a – 1b) and among the LCNF (1d , 1e) scenarios (Fig. 6). Labor for (L)CNF included 70 employees, +/- 3 in the differing scenarios. The cost savings from omitting NBSK in scenario 1e were insufficient to offset the increased depreciation costs in the greenfield scenario (Fig. 6). The reduced electricity costs from omitting NBSK in scenarios 1d and 1e did offset slight increases in OCC expenditures.

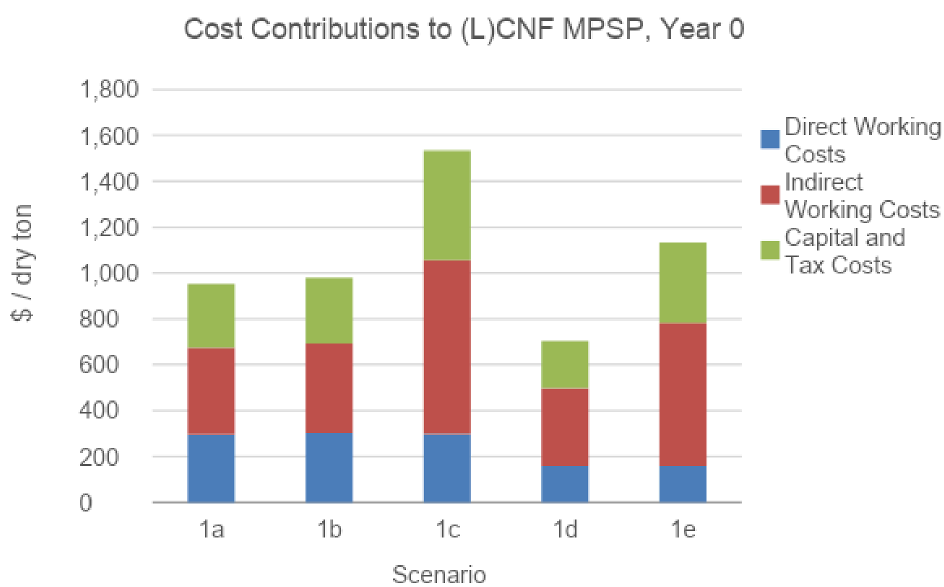



Figure 5. The relative magnitudes of capital and tax costs, indirect working costs, and direct working costs changes between the repurposed (1a, 1b, 1d) and the greenfield (1c, 1e) scenarios.

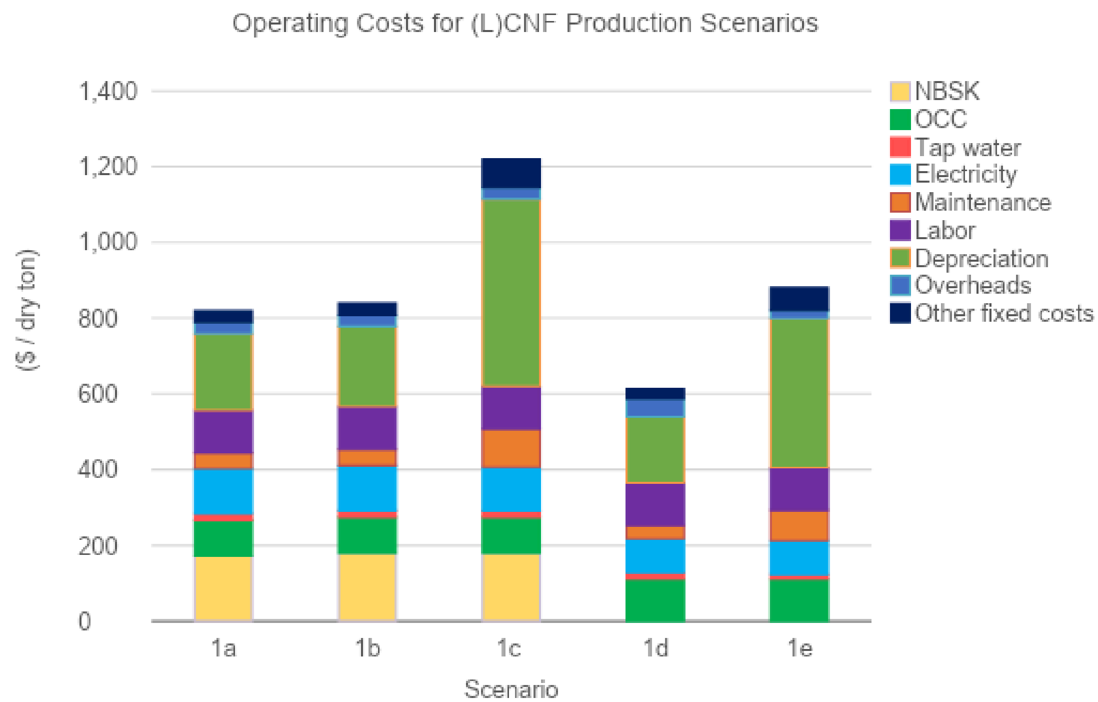
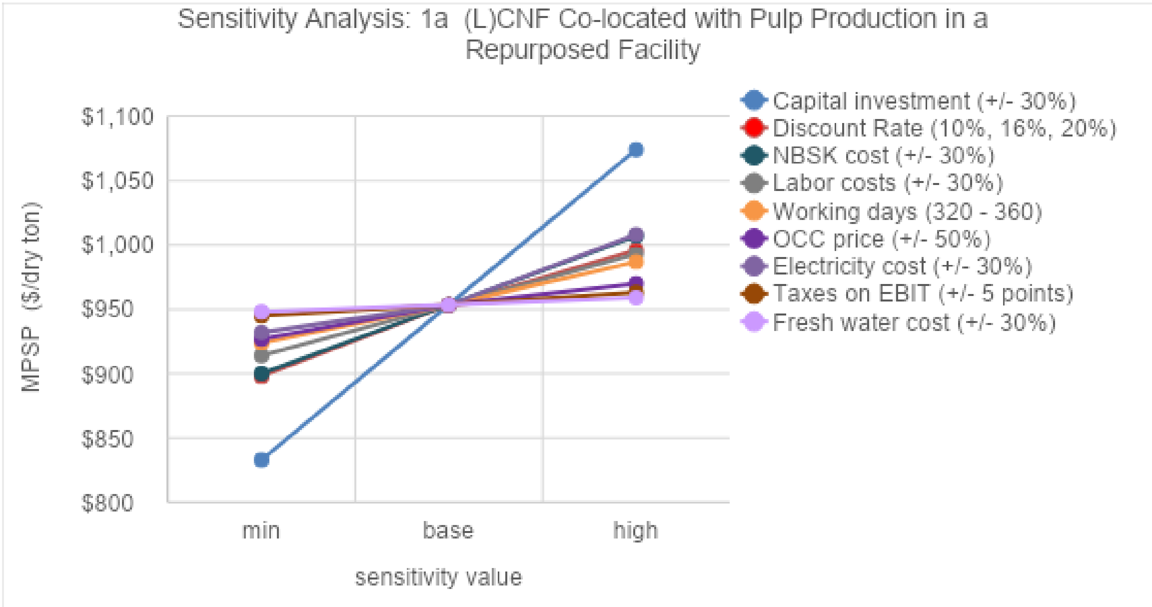



Figure 6. Operating costs for (L)CNF production scenarios. Increases in depreciation contribute the most to manufacturing cost differences between repurposed (1a, 1b, 1d) and greenfield (1c, 1e) scenarios.

### *1.3.1.1 Sensitivity Analyses - (L)CNF Production*

(L)CNF price was at least twice as sensitive to a 30% change in capital investment as to a 30% change in any other cost, across all scenarios (Figure 6). The change in MPSP from this cost item was \$197 (1c) for the (L)CNF scenarios, and \$157 (1e) for the LCNF scenarios. Electricity cost (± 30%), NBSK cost (± 30%), and discount rate (10%, 20%) were the next-most important items for determining MPSP. Graphs and values from the sensitivity analyses for all scenarios are in Appendix A.



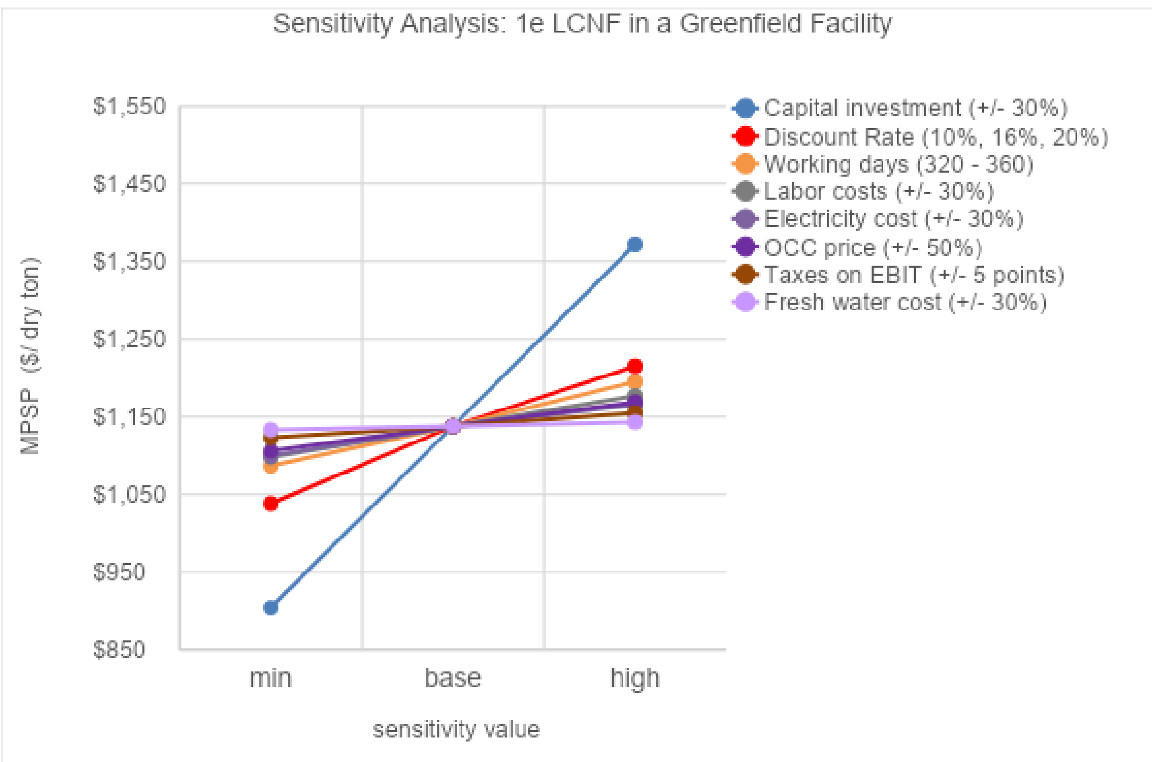



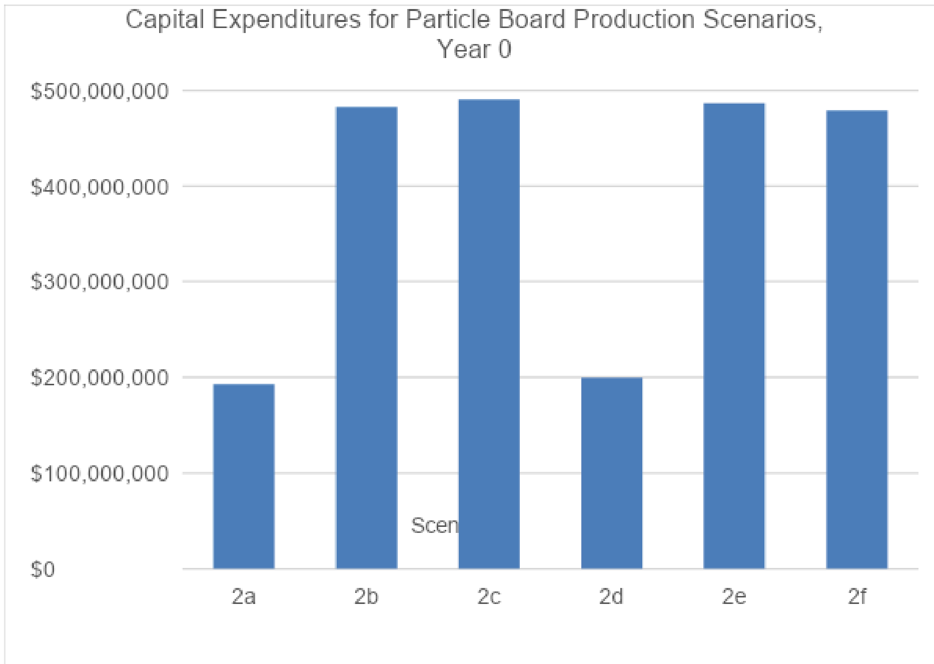

Figure 7. Graphs of (L)CNF sensitivity analyses for scenarios 1a (top) and 1e (bottom) show how (L)CNF MPSP could change with changes in cost items under the most different scenario assumptions.

### 1.3.2 (L)CNF-bound particle board

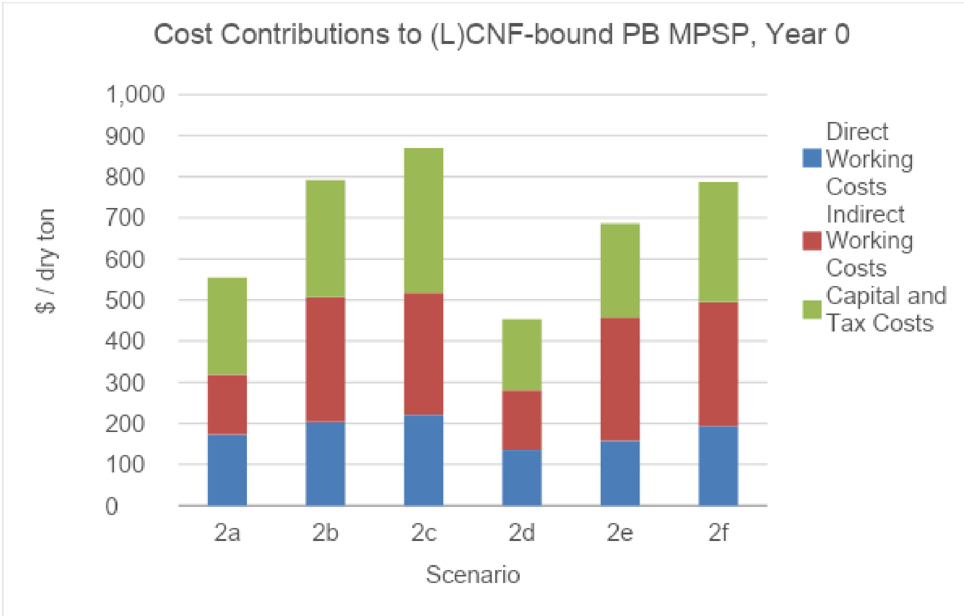
The minimum product selling price (MPSP) for (L)CNF-bound PB ranged from $453/ m^3 (2d) to $870/ m^3 (2c) (Table 4). The capital investment required in 2c was more than twice that required in 2d (Table 4, Fig. 8), while the operating costs were slightly less than twice as great in 2c as in 2d (Table 4, Fig. 9 and Fig. 10). Co-locating stage one and two production in a repurposed setting resulted in more savings than using LCNF over (L)CNF as an adhesive. LCNF-PB production in which stages one and two were in separate greenfield locations (2f) was $83 (10%) less than (L)CNF-PB production in the same setting (2c). Co-locating PB production with (L)CNF production in the repurposed setting (2a) resulted in a savings of $258 (32%) compared to not co-locating with (L)CNF production in that setting (2b).

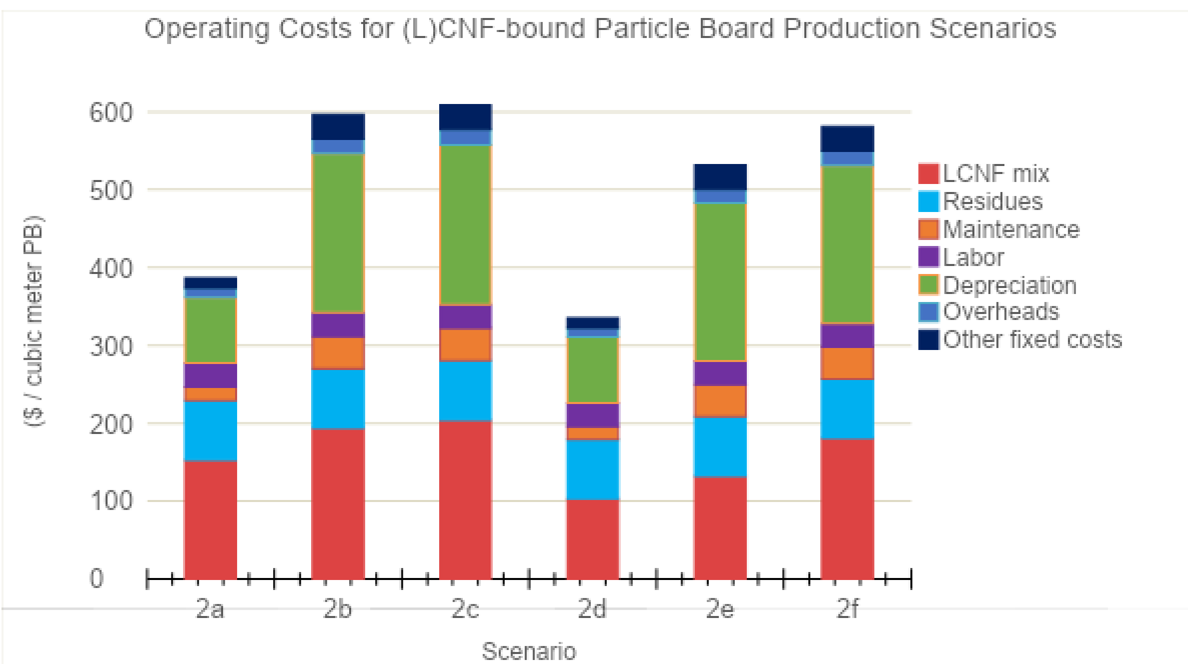
Table 5. Production requirements for all (L)CNF-bound PB scenarios in year 0.

| Scenario | Product | Capital Factor Level | MPSP ($/ dry ton) ($/ m^3) | $ / 1.219 m x 2.428 m x 12 mm (4' x 8' x 0.5") board | Total operating costs (Million $) | Total capital employed (Million $) |
|---|---|---|---|---|---|---|
| 2a | (L)CNF | Low | 663 | 21 | 29.6 | 65.1 |
| | PB | Low | 555 | | 79.6 | 189.5 |
| 2b | (L)CNF | Low | 791 | 31 | 29.0 | 65.0 |
| | PB | High | 813 | | 125.0 | 449.5 |
| 2c | (L)CNF | High | 912 | 33 | 36.9 | 117.0 |
| | PB | High | 870 | | 132.5 | 451.3 |
| 2d | LCNF | Low | 447 | 17 | 22.2 | 52.8 |
| | PB | Low | 453 | | 70.0 | 188.3 |
| 2e | LCNF | Low | 525 | 26 | 22.3 | 52.7 |
| | PB | High | 686 | | 114.6 | 445.1 |
| 2f | LCNF | High | 746 | 30 | 30.0 | 123.9 |
| | PB | High | 787 | | 111.2 | 446.4 |



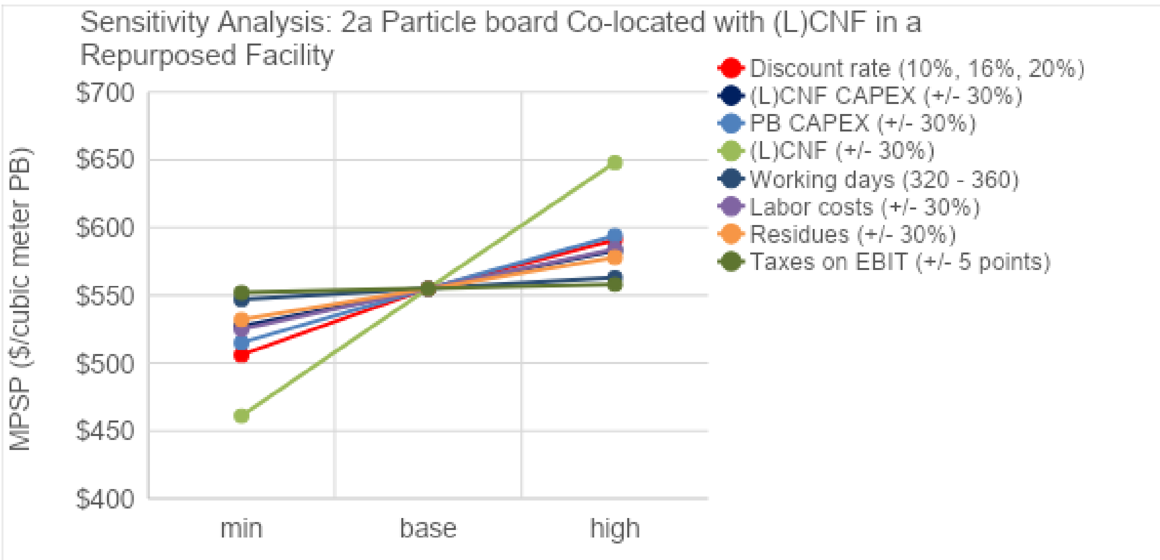

Co-located production of (L)CNF and PB decreased the share of indirect costs relative to capital and tax and direct costs. Indirect working costs were similar in magnitude among the co-located and repurposed scenarios (2a, 2d), and among the greenfield scenarios (2b, 2c, 2e, 2f). Capital and tax costs were the greatest cost components in 2a, 2c, and 2d (Fig. 9). Depreciation contributed more to indirect cost increases in greenfield scenarios than in the co-located and repurposed scenarios, in which depreciation costs were greater than those from labor, overheads, and maintenance combined (Fig. 10). PB manufacturing at 250,000 $m^3$ per day required100 employees, +/- 5 in the differing scenarios.

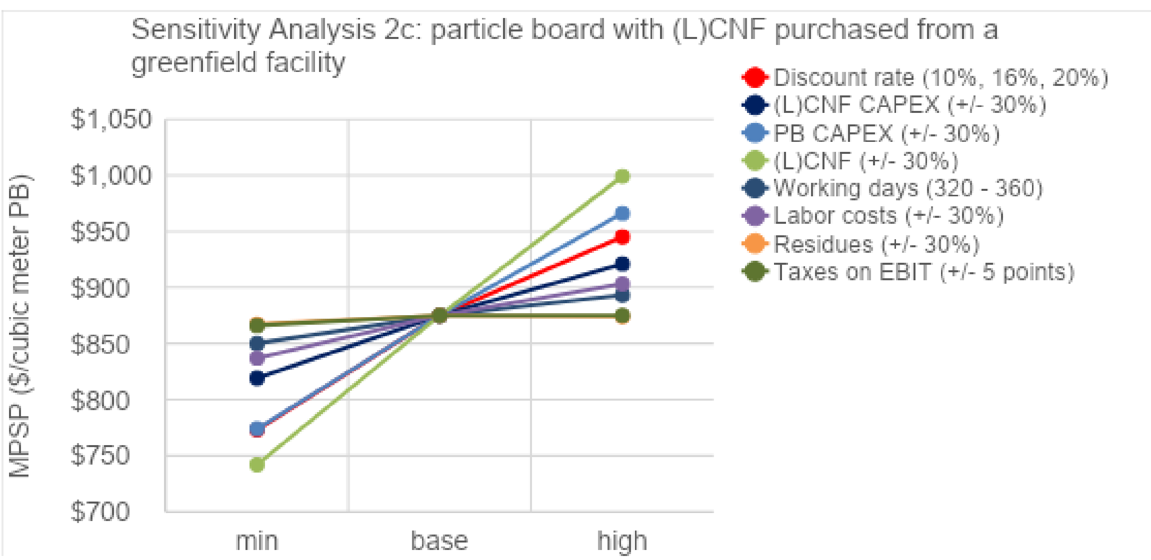



*1.3.2.1 Sensitivity Analyses - (L)CNF-bound Particle Board Production*

Changes in (L)CNF prices (± 30%), PB capital expenditures (± 30%), and discount rate (10%, 20%), had the largest impacts on PB prices (Fig. 11). Changes in the number of working days (320, 360) and taxes of EBIT (16%, 26%) had the least effect, with a five-point percentage change in taxes on EBIT affecting PB $/m$^3$ by $3 - $5. The largest change in MPSP from any factor was -$133 ((L)CNF price, 2c) for the (L)CNF scenarios, and -$140 (LCNF price, 2d) for the LCNF scenarios. Graphs and values from the sensitivity analyses for all scenarios are in Appendix A.



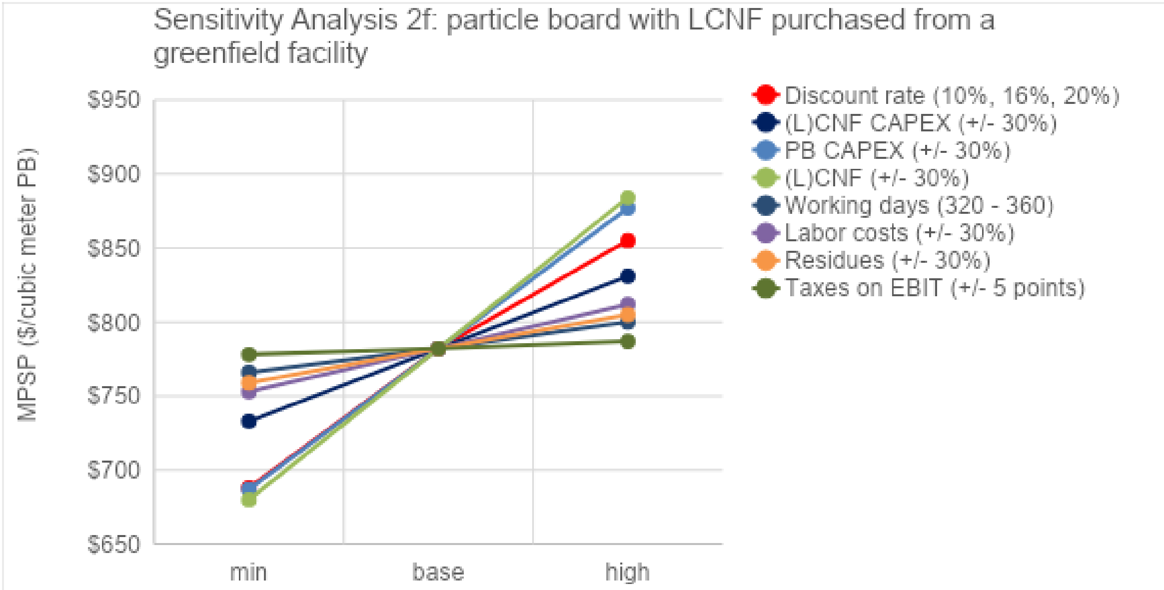



Figure 11. Sensitivity analysis graphs for scenarios 2a, 2c, and 2f show the range of sensitivities of (L)CNF-bound particle board minimum product selling prices to cost items.

## 1.4 Discussion

This selective design techno-economic analysis identified key constraints on the commercialization of (L)CNF and (L)CNF-bound PB in Maine. Analyzing (L)CNF and (L)CNF-PB production as discrete and sequential processes revealed how key constraints on (L)CNF production was scaled for use in PB, and when production was co-located with PB. Lowering the fixed capital costs for both products lowered MPSP more than any producer choice modeled. As in de Assis et al. (2018), these reductions in fixed capital costs came from using repurposed facilities, from co-locating (L)CNF with pulp production (in stage one), and from co-locating (L)CNF with PB production (in stage two). Scaling (L)CNF production to meet PB production requirements enhanced savings from reduced fixed capital costs. However, these and other decreases in (L)CNF costs could not make (L)CNF-bound PB cost-competitive. Further technological advancement in (L)CNF-bound PB could make this product competitive in the future. In the present, (L)CNF could be successfully commercialized for non-PB applications, especially in markets where it can be substituted for CNF products.

### 1.4.1 (L)CNF

The (L)CNF process studied here is likely cost-competitive with the dry and colloidal lignocellulose commercially available today. Though (L)CNF suspension manufacturing have been widely studied for use in over 500 industrial applications, commercial-scale production of (L)CNF is relatively new and under-studied (de Assis et al., 2018; Turpin and Nelson, 2020). Growing demand for (L)CNF from a variety of industries will likely continue to change the minimum product selling price for cost-competitive production. Regardless of market changes, the price of (L)CNF will always be significantly less than that for CNF, barring the unlikely event that pulp prices sink lower than those for old corrugated cardboard. The TEA of CNF from wood pulp by de Assis et al. (2018) found MPSPs of $1,893/ dry ton for their lowest-capital intensity scenario and $2,440 for their greenfield (highest capital intensity) scenario. The MPSPs identified here ranged from $704/ dry ton to $1534/ dry ton, even though key assumptions were the same between the two studies (Table 3).

Eliminating 85% of the pulp input per unit of production makes (L)CNF prices less sensitive to pulp costs and pulp co-production (Fig. 7), relative to the prices identified for similar products. De Assis et al.'s results were more sensitive to a 30% change in pulp costs than to a similar change in capital intensity costs. This study found just the opposite for the (L)CNF-only scenarios. Similarly, a TEA of colloidal lignin by Ashok et al. (2018) estimated an MPSP of $1,070 / ton when this material was co-produced with wood pulp, and $1,714/ ton when produced separately. This study finds only a small change (the cost of freight) between the co-production (1a) and non-coproduction (1b) scenarios that both take place in repurposed facilities.

Whether the (L)CNF is made in a repurposed or a greenfield facility is a greater determinant of its cost than its composition (85/15 LCNF/CNF or LCNF). This is true even if the cost of NBSK varies (Appendix B, 1a, 1b, and 1c), and is especially noticeable when (L)CNF production is scaled for PB manufacturing (Fig. 11).

### 1.4.2 (L)CNF-bound particle board

In contrast to (L)CNF, global and regional markets for PB are well-established and highly competitive, due to the low cost of formaldehyde-based PB adhesives. Worsening construction materials shortages and new U.S. EPA formaldehyde regulations may create an opening for PB with alternative adhesives. (L)CNF-bound PB could successfully enter the current market with an MPSP of \$402/ $m^3$ or less (Fig. 11; Trott, 2020). The lowest MPSP found in this study was \$453, in scenario 2d (Fig. 12). While the estimated capital costs for this scenario were ~\$55 million less than those in the New Hampshire PB feasibility assessment (2001), the cost of the LCNF adhesive likely drove higher overall costs. The cost of LCNF was greater even than that of the residues used to power the facility and make the boards.

The sensitivity analysis for this co-located and repurposed scenario (2d) showed that reducing the price of LCNF by 30% would put the PB MPSP at \$313/ $m^3$, almost \$100 less than the required MPSP for price parity. Further sensitivity analysis revealed that the minimum reduction in LCNF price reach price parity to be 25%. The LCNF-only sensitivity analysis for the repurposed setting (1d) showed no one change in any input large enough to reduce LCNF MPSP by 25%. LCNF cost reductions would therefore have to come from reductions in multiple input prices. However, the 2d scenario already assumes zero electricity costs for LCNF production (which is powered by the co-generation facility included in PB capital costs). The 2d scenario also assumes low capital costs for LCNF. Reducing LCNF costs by the requisite amount could therefore be difficult.

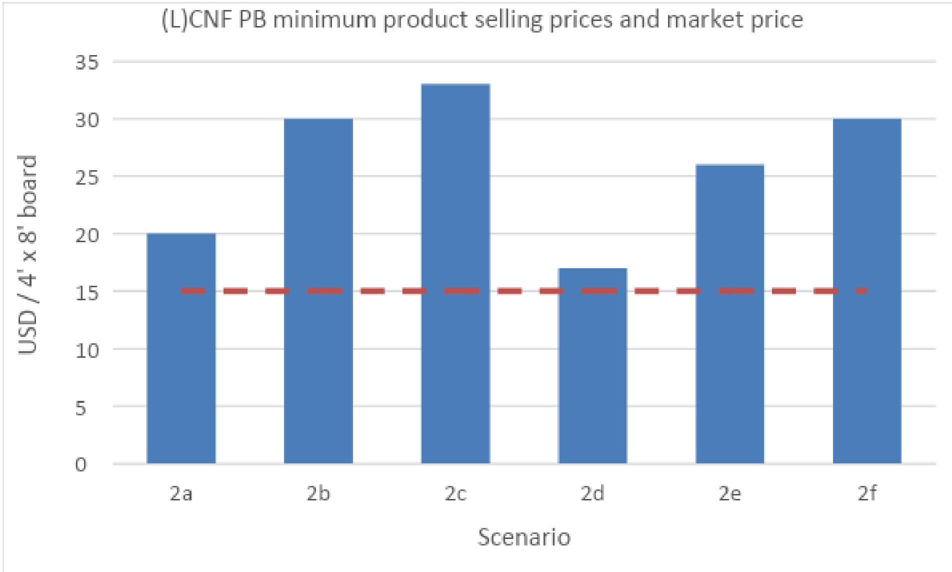



Figure 12. (L)CNF PB minimum product selling prices all exceed the current market price of $15 (demarcated with the orange dotted line).

A production line tailored to (L)CNF-PB manufacturing incur fewer costs than the production line modeled here, which was built for conventional PB manufacturing. Overall equipment costs may be lowered in an (L)CNF-PB line due to fewer toxic emissions management requirements. Additionally, panel presses optimized for (L)CNF instead of formaldehyde- or soy-based binders would likely be more efficient than the panel presses modeled here. This study indicates the need for further modeling of optimized (L)CNF-PB production processes with specialized equipment.

### 1.4.3 Comparing (L)CNF and (L)CNF-bound particle board results

The overall costs calculated for both production processes should fall within the ± 30% uncertainty margin characteristic of this kind of TEA. However, the (L)CNF model outputs are likely more accurate than those from the PB. The (L)CNF process is relatively simple, requiring only a few machines. The TEA could draw on existing data from (L)CNF manufacturing on pilot-scale machines. The TEA could not draw on such data for PB manufacturing, since the modeled PB process used different technical specification from pilot-scale (L)CNF-PB production. The scaling of equipment cost and production estimates for PB assumed a more-than three-fold decrease in the PB press factor, an extremely strong but necessary assumption to model this kind of PB on existing PB equipment.

The two-stage (L)CNF-bound PB analysis revealed (L)CNF production efficiencies from scale and co-generation that are not considered in much of the literature. Figure 13 shows the results from comparing the (L)CNF sensitivity analysis (described in 2. ) to the (L)CNF costs in the (L)CNF-PB scenarios. Increasing the capital costs of (L)CNF by 200% to include a co-generation facility saved more than $100/ dry ton, as pulp refining increased overall energy consumption relative to OCC refining. Cost savings from co-generation were only $1/ dry ton in the OCC-only scenario. The negative projected savings from co-generation installation are small compared to the positive savings from scaling production from 50 dry tons/ day to 170 dry tons/ day, for both (L)CNF and LCNF.

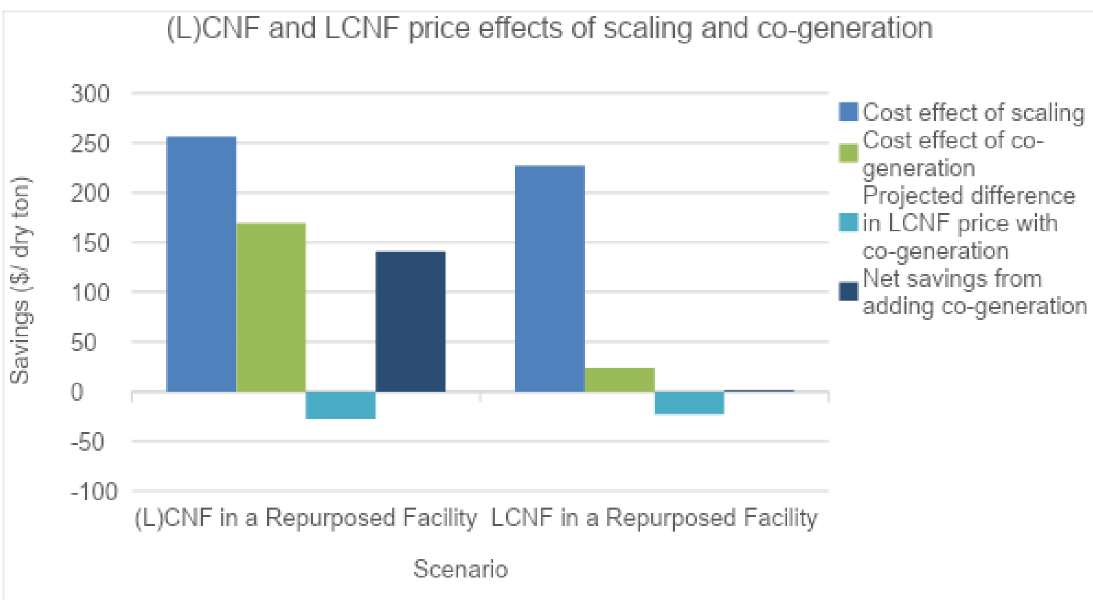



Figure 13. Differences in (L)CNF minimum product selling price with and without coupling with PB production, when produced at the scale required for PB.

## 1.5 Conclusion

In conclusion, (L)CNF and (L)CNF-bound PB could both contribute to Maine's forest industry in the future. Commercial-scale production of (L)CNF is promising and should be explored further, perhaps with a more detailed TEA comparing different commercial machinery for defibrillating OCC. Getting (L)CNF-PB to price parity will require significant reduction in press times, something that University of Maine researchers are already working to achieve. Direct cooperation between researchers and industry engineers could also result in tailored equipment that makes the PB process more efficient. The construction industry is unlikely to accept higher prices for environmentally-friendly PB, as consumers chose PB over other composite panels for its low cost (Trott, 2020).

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## CHAPTER 2 : OPERATIONALIZING SENSE OF PLACE TO EVALUATE POTENTIAL CONFLICTS IN NATURAL RESOURCE-DEPENDENT RURAL ECONOMIES

### 1.1 Introduction

Globalization and climate change are exacerbating the devastating effects of natural resource commodity boom and bust cycles in rural economies, which are overwhelmingly dependent on natural resource extraction. Even in developed countries like the U.S., rural communities are struggling to adapt by diversifying their economies. From 2007 to 2016, the number of people living in an economically distressed rural area increased by one million, with little-to-no in-migration (Economic Innovation Group, 2018). The result is the devastating and well-described decline of rural communities (Flora, Flora, and Gasteyer, 2018). Several of these communities have historically had a strong dependence on natural resources to support a mix of extractive-, manufacturing-, and/or amenity-based local economies (Winkler et al. 2012). However, not all natural resource-dependent rural communities in the U.S. are in decline. The few areas with positive economic indicators are almost all located in counties with strong outdoor recreation and conservation industries (Lawson, 2019). However, transitioning to a recreation- and conservation-based economy from natural resource extraction requires large shifts in land use and public resource management (Masterson, 2017). Such a transition also increases the number of outsiders, who may differ from community members in physical appearance, mannerisms, and beliefs (Winkler et al., 2012; Flora and Flora, 1996). These significant changes offer hope to some communities and community members while feeling threatening to others, creating opportunities for conflicts that stymie diversification and growth (Flora, Flora, and Gasteyer, 2018). The outcomes of these and similar conflicts will shape communities and the U.S. natural resource base for decades to come.

A number of natural-resource-dependent communities in northern New England have recently faced economic shocks that have challenged their resilience and identity (Dillon, 2011; Colocousis, 2013; Duncan, 2014). The Katahdin Region (KR) of Maine, United States (Fig. 25), is one such rural area whose future depends on the outcome of resource use conflicts stemming from economic change. The decades-long decline in the U.S. paper industry and the 2015 closure of the Great Northern Paper Company left the region's most populous town, Millinocket, without its creator and largest employer (Pérez-Peña, 2016). The lack of internet access, the lack of access to regional commercial hubs, and a paucity of physical infrastructure for tourism all contribute to the KR's difficulty in adapting to its new economic reality. However, efforts to diversify the KR's economy away from the paper industry have also been derailed by conflicts (Wald, 1986; Pérez-Peña, 2016). These conflicts centered on the reallocation, or perceived threat of reallocation, of regional resources such as infrastructure funding, land access, local decision-making capacity, and jobs. Understanding how residents relate to these resources could help stakeholders to predict and avoid conflicts in the future.

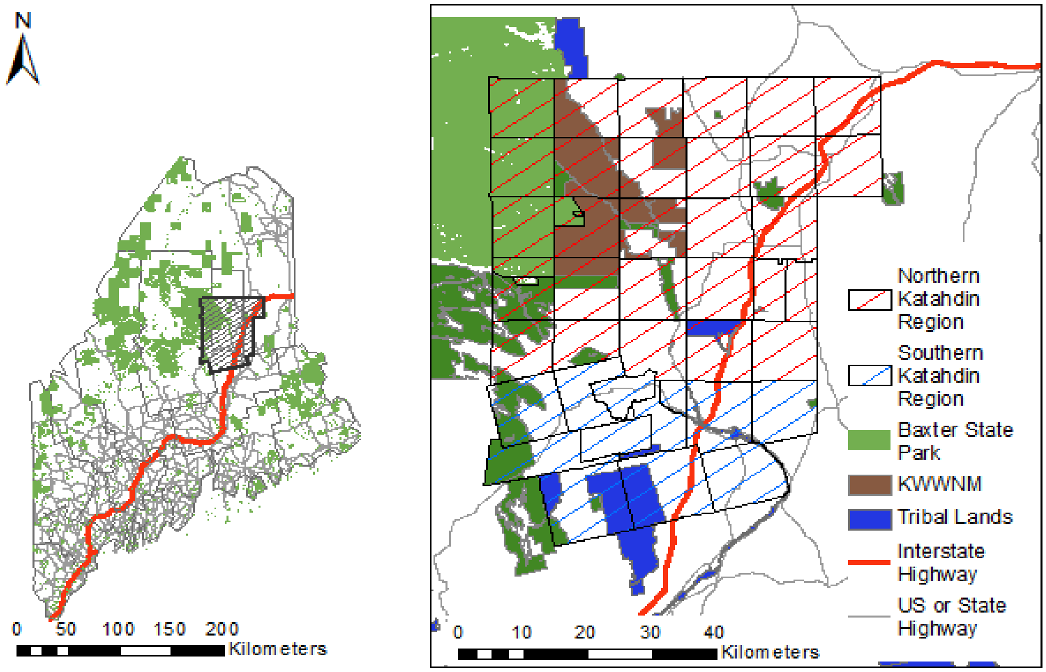


Figure 14. The Katahdin Region, Maine, USA. "KWWNM" designates Katahdin Woods and Waters National Monument.

### 1.1.1 Understanding Conflict through Sense of Place

Development practitioners navigating resistance in transitioning economies can use the sense of place (SOP) framework from environmental psychology to understand the root causes of development conflicts (Schmuck & Schultz, 2002). This framework describes individuals' modes of understanding and connecting to a specific geographic location, including tangible (economic dependence) and intangible (emotional, cognitive) modes of attachment (Tuan, 1977; Hammitt et al., 2009; Masterson et al., 2017; Eaton et al., 2019a). Two broad, commonly-accepted SOP components are place dependence and place identity. Place dependence is the belief that a place directly or indirectly satisfies certain physical or psychological needs (Dwyer et al., 2019), while place identity is the notion that places serve various functions in identity development that promote a sense of belongingness"

(Davenport & Anderson, 2005). However, social context – i.e., feelings of belongingness or membership to a group of people, as well as the emotional connections based on shared history, interests or concerns (Raymond et al., 2010)– can be a greater determinant of place significance than other components of SOP (Raymond et al., 2010; Amsden et al., 2011).

Because individuals are more willing to accept change if it does not threaten their primary means of constructing SOP, understanding SOP is key for identifying - and avoiding - potential change-related conflicts (e.g., Cantrill & Senecah, 2001; Stedman, 2008; Eaton et al., 2019a; Masterson et al., 2017). Development-related conflict can occur when a change further threatens SOP for one group of stakeholders while positively impacting SOP components for others. Clearly defining and understanding SOP is especially important in communities where economic crises are already eroding residents' SOP (Garau-Vadell et al., 2018; Bergstén & Keskitalo, 2019). However, research highlighting the potential of SOP frameworks for guiding resource development questions also highlights the need for better-defining SOP dimensions (Woo et al., 2015).

SOP may be especially complex in rural communities because of their dependence on natural areas or working lands for income, recreation, and/or cultural meaning (Trentelman, 2009; Cross et al., 2011; Lequieu, 2017). Our conceptualization of sense of place incorporates Eaton et al.'s (2019a) finding that place dependence alone is an unreliable SOP component in working landscapes (Fig. 26). We follow their recommendation that future SOP research more thoroughly explore[s] the empirical and theoretical viability of an economic/livelihood dimension as a distinct component of SOP (Eaton et al., 2019b) by breaking place dependence into economic dependence and dependence for physical/ day-to-day needs (i.e. food, shelter, transportation, etc.). We further operationalize the concept of physical/ day-to-day dependence for development planning applications by specifically considering the public resources (financial assistance, land access for food gathering, etc.) available to meet those needs.

We specify the place identity component as personal identity dependence on place, linking the psychological and emotional modes of building identity with those of building place dependence. We therefore capture the overall intangible meaning of place to individuals in a way that can inform development planning. We operationalize social context SOP components from the literature by specifying them as the formal and informal social institutions within a place.

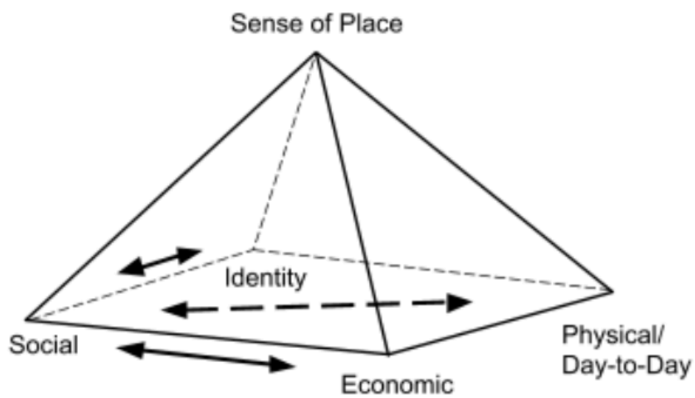


Figure 15. A visualization of common constructions of Sense of Place (SOP) from social sciences literature, showing cross relationships between SOP components (Dwyer et al., 2019).

Beginning with McAndrews (1998), social scientists have identified SOP dimensions using Principal Component Analysis (PCA) of survey questions about a place (Stedman et al., 2006). PCA is a type of confirmatory factor analysis that is widely used to reduce survey data into underlying constructs (Vyas & Kumaranayake, 2006), and has consistently revealed similar SOP components in the literature. However, the relative influence of each component on an individual's SOP varies between individuals and communities (Jorgensen & Stedman, 2006).

### 1.1.2 Sense of Place and Conflict in the Katahdin Region

The name “Katahdin” means “The Greatest Mountain” in the language of the local Abenaki tribes, who have continuously called the region home for thousands of years (Sargent, 2017). The late 18th and early 19th centuries saw increasing populations of European settlers turn the KR into an historic American ideal, deriving economic prosperity, adventure, and spiritual renewal from the landscape (Reilly & Renski, 2008). Vast privately owned working forests and internationally competitive paper mills co-existed with multiple forms of recreation for much of the 19th and 20th centuries (Lilieholm, 2007). Even as local mills employed thousands of workers, writings by conservation leaders like Thoreau spread the KR’s reputation as an iconic American wilderness. The founding of the 84,782 ha Baxter State Park in 1931 and the designation of Maine’s highest mountain, Katahdin, as the northern terminus of the Appalachian Trail solidified this legacy (Lilieholm, 2007). Visitors owed their experience of the KR as an accessible and continuous forested landscape to a unique tradition of open (public) land use on the private lands surrounding the Park (Kay, 2017). This tradition has given the KR some of the largest networks of hunting areas and snowmobiling trails in the United States (Hathaway et al., 2019).

The KR today embodies Maine’s multiple identities as a center of forestry and forest products manufacturing, recreation tourism, and conservation. Agriculture is also prevalent in the northern half of the region. KR residents embedded in this complex history are likely to construct SOP in complex ways, resulting in a range of perceptions of economic change. Residents’ SOP in the southern KR’s mill towns is likely shaped by their “resource-extractive, company community past” (Lequieu, 2017, p. 209), in which the paper companies created and dominated the mill towns. Beckly (1998) found that the paper company in nearby Rumford, Maine, purposefully limited unrelated economic development to remain indispensable to the town. This dependence on the mills can create strong SOP’s that lead some residents to prioritize unstable industries over economic growth in other sectors, even after the demise of the mills. In the former company towns studied in the literature, identity is created through industry interactions and jobs, social interactions take place in industry settings, physical sustenance is acquired in industry-owned commercial centers, and economic dependence is handed down through mill jobs for generations (Colocousis, 2013). KR mill workers explained their dependence on the mills in public interviews during a 1986 conflict with recreationalists and conservationists, whose activities appeared to (but did not directly) threaten the mill's growth (Wald, 1986). Vertical integration in the pulp and paper industry meant that northern KR towns sending timber to the mills were similarly dependent on the mills for SOP.

The KR's decades-long economic decline and resulting out-migration are therefore likely to have negatively influenced SOP (Bell et al., 2018; Bergstén and Keskitalo, 2018). The year-round population has decreased over 11% since 2000 and 30% since 1970 (Daigneault, 2018). About 68% of the current population of 10,680 people in the KR is concentrated in the southern towns of Medway, East Millinocket, and Millinocket. Over 500 of these residents, or about 7% of the population in Millinocket and East Millinocket, lost their jobs following the 2008 global financial crisis, when Great Northern Paper's mills there finally closed after three decades of downsizing (EDAT, 2017). The KR's northern towns of Sherman, Stacyville, Patten, Mt. Chase, and Island Falls had supported the mills through forestry activities. These towns have experienced a nearly 4% population decrease since 2000. The median annual household income of $35,265 for the entire KR is now significantly less than state and national averages (Daigneault, 2018).

In addition to decreasing economic opportunity, the mill closures have also initiated changes in mill-owned or forest industry lands. These "familiar, industrial landscapes" (Lequieu, 2017, p. 203) of mill towns, timberlands, and farms, likely contributed significantly to SOP throughout the KR (Colocousis, 2013). The divestiture of KR forest lands by timber companies and the acquisition of these lands by outsiders may threaten, or appear to threaten, the open land use tradition and residents' SOP (Perez-Peña, 2016). Some of the 4-fold statewide increase in conserved areas since 2000 occurred in the KR, instilling fear that timber harvests (Fig. 2, "Economic"), firewood collection ("Physical/ Day-to-day"), snowmobiling ("Economic", "Social"), and hunting ("Physical/ Day-to-day") may be limited or banned on these lands (Cottle & Howard, 2012). The forest industry jobs that remain are among the highest-paying in the area (Lilieholm, 2007), and snowmobiling alone draws over 32,000 people every year (Hathaway et al., 2019). However, there were about 100,000 visits to conservation areas (i.e., Debsconeag Lakes Wilderness Area, the Katahdin Woods and Waters National Monument (KWWNM), and Baxter State Park, Fig. 1) in 2018 (Tim Hudson, Personal Communication). Placing timberland under conservation is an alternative to placing timberlands in the hands of individuals who face less public pressure to adhere to the open land use tradition, and who are more likely to contribute to landscape fragmentation that threatens all public uses.

Easy access to this both industrial and "wild" landscape attracts over 1,200 seasonal residents, whose constructions of SOP for the KR likely differ from those of year-round residents solely dependent on the region's physical and social landscapes (Maine Land Use Regulation Commission, 2012). Residents have recently disagreed on: the acceptability of a large commercial development (Lilieholm, 2007); the designation of the 35,200 ha Katahdin Woods and Waters National Monument (KWWNM) (Perez-Peña, 2016); and changes to zoning laws designed to make Millinocket a regional commercial hub (Brooks, 2019). State and Federal government intervention, land use restrictions, and land accessibility are significant sources of potential disagreement within the KR (Cottle and Howard, 2012; Brooks, 2019).

Successful development strategies for the KR should incorporate shared components of SOP (Chapin et al., 2012; Masterson et al., 2017). SOP research is relatively new to the KR.

Cottle and Howard (2012) interviewed 15 residents about recent conservation acquisitions around the KR, but did not evaluate demographic drivers of stakeholder attitudes. A 2017 report from a federal Economic Development Assistance Team (EDAT) included state subject experts and identified growth strategies for the Region's forestry industry but did not include resident perspectives on development and highlighted the need for more resident surveys (EDAT, 2017). Our work attempts to fill this research void in the KR, while adding to the understanding of SOP in the context of rural development and presenting the application of the Potential for Conflict Index 2 ($PCI_2$) for economic planning.

## 1.2 Methods

### 1.2.1 Survey Data

This study utilizes responses from a survey administered to residents of the Katahdin Region during the summer of 2018. The questionnaire contained 115 Likert-like scale questions ranging from -2 to +2 ("strongly disagree" to "strongly agree") in addition to 23 open-ended and demographic questions. Responses were collected using a mixed sampling approach that included convenience and random sampling. This approach was primarily used due to budget constraints and desire for community development groups to assist with survey distribution, with the understanding that the sample may not truly be reflective of the total regional population (Dillman et al, 2014). First, we directly mailed a survey card to all 3,662 households in the Katahdin Region with mailing addresses, directing the head of the household to an online questionnaire that was administered via Qualtrics[6]. The card also provided a phone number where residents could request a paper copy of the survey so that it did not exclude anyone without internet access. Second, regional economic development organizations recruited participants by posting the link to the questionnaire on their social media platforms. Third, respondents were intercepted at regional community meetings and asked to complete the survey in person. To

[6] Budget constraints limited our study to just one mailing, which may introduce sample response bias.

reduce response bias, the survey prompt included a statement that the questionnaire should be taken only once per respondent, and that it should ideally be limited to one person in each household. These survey methods were approved by the University of Maine Institutional Review Board.

Our mixed sampling approach has the potential to introduce some response bias. However, soliciting survey responses from a wide distribution of households is a potential improvement over most of the existing scholarship on community resilience that typically relies on only a few in-depth interviews to represent the views of entire regions (Cottle & Howard, 2012; Lequieu, 2017). Furthermore, distributing the survey through community organizations improves the chance of reaching residents with the time, resources, and motivation to already be engaged with the community. As these residents are more likely to make their opinions heard during the development process, they also determine which development strategies are contentious.

We received 227 completed surveys, for a response rate of 6.2%. The response rate was calculated based on the number of cards sent to KR households through the U.S. Postal Service. The questionnaire took a median time of 20.5 minutes to complete. Table 1 compares demographics of survey responses to the KR population, and indicates that some of our respondent demographics are not completely aligned with regional population estimates (US Census Bureau, 2018). This difference is to be expected because of the mixed methods approach we used to solicit responses. In our study, 51% of the respondents were female, and 77% lived in the southern part of the region, which are both close to the regional population estimates. Respondents had a median age of 60 years old and earned a median income of $50,000 per year, which are both higher than the general population. About 49% of respondents reported having at least a four-year college degree, which is four times greater than the general population. We attempt to control for the difference in demographics for our study through statistical analysis and note some potential biases of our findings in the discussion.

Table 5. Summary of demographic data of Katahdin Region survey respondents (n=227)

| Demographic | Survey Respondents (n=227) | Katahdin Region (n =3,662) |
|---|---|---|
| Median Age (years) | 60 | 53 |
| Population Female (%) | 51% | 53% |
| Population living in South Katahdin (%) | 77% | 69% |
| Education: high school graduate or higher (%) | 99% | 88% |
| Education: bachelor's degree or higher (%) | 49% | 11% |
| Median household income ($) | $50,000 | $35,501 |
| Labor Force Participation Rate (%) | 57% | 47% |
| Unemployment Rate *(%)* | 6% | 8% |
| Length of residence in region (years) | 39 | n/a |
| Business Owner (%) | 18% | n/a |

### 1.2.2 PCA and Index Creation

We use PCA to test for four SOP components previously identified in relevant survey-based studies: personal identity, social resources, economic resources, and public resources meeting daily needs, such as common infrastructure (Bergstén and Keskitalo, 2018; Eaton et al., 2019a; Verbrugge et al., 2019). Modeling after Hammitt et al. (2009) we begin with a subset of survey questions ("variables", Table 2) assessing individuals' perceptions of infrastructure, government, and social relationships at the town and regional levels. We test for a significant and separate economic component of SOP after Eaton et al. (2019b) by including variables asking about the importance and compatibility of traditional industries (i.e. timber and manufacturing) relative to the outdoor recreation industry.

We use Varimax rotation to identify linear combinations of survey questions with similar patterns of individual response variation. The resulting uncorrelated factors explain unique portions of data variance (Vyas & Kumaranayake, 2006). We keep only factors explaining more variance than the average variable and delete missing data listwise. Following Hammitt et al. (2009), we then iteratively eliminate variables with rotated, rescaled factor loadings less than 0.4. The loadings are estimates of the correlation between the variable and the factor. We then rerun the PCA according to the above criteria until the percentage of variance cumulatively explained by the identified factors plateaus, and calculate a Cronbach's alpha for each factor as a measure of index reliability (Van Berkel et al., 2018).

We create mean indices for each of the four SOP components from the resulting PCA factors, excluding variables that decrease the factor's Cronbach's alpha. While creating indices from means eliminates individual-level response variance, the variation-dependent $PCI_2$ will still accurately reflect disagreement potential if the internal consistency of the index is sufficiently high. Calculated indices range from -2 to 2. The statistical analysis was conducted using SPSS V25.0.

Table 6. Survey questions used as variables in Principal Component Analysis, grouped by the previously researched SOP components to which they best correspond.

| SOP Components & Survey Question |
|---|
| *Social Institutions* |
| I trust how decisions are made in my town. |
| People in my town have the ability to solve their own problems. |
| The leaders of my town are working hard to make positive changes. |
| My town has effective leaders. |
| The opinions of residents are valued when creating an economic plan for my town. |
| People in my town trust public officials. |
| The departure of friends and family members due to job loss has impacted relations in my town. |
| *Economic Dependence* |
| The Katahdin Woods and Waters National Monument is important to the Katahdin Region. |
| Recreational opportunities associated with conservation land will bring new people and jobs to my town. |
| In the future, the economic importance of outdoor recreation and tourism will exceed that of the forest products sector in the Katahdin Region. |
| Conservation land ventures and the forest products industry are compatible activities that can both thrive in the Katahdin Region. |
| Outdoor recreation and tourism is important to the economic future of my town. |
| My town has the motivation to attract new business |
| My town is positively contributing to the economy of the Katahdin Region. |
| *Personal Identity* |
| I am optimistic about the future of my town. |
| I feel a sense of belonging to my town. |
| I am proud to live in my town. |
| I will always call the Katahdin Region my home. |
| My family or household is self-sufficient. |
| *Public Resources* |
| My town has the financial resources it needs to resolve town problems. |
| My town has the resources to attract new business. |
| My town has sufficient infrastructure. |

| Table 6. Continued |
| --- |
| I can purchase most of what I need in my town. |
| There are adequate technical and mechanical skills available in my town. |

### 1.2.3 Potential for Conflict Index$_2$ (PCI$_2$)

In this paper, the Potential for Conflict Index$_2$ (PCI$_2$) developed by Vaske et al. (2010) represents a relative measure of how likely residents are to disagree on fundamental aspects of community development. Similar to other survey response indices, PCI$_2$ interprets the distribution of differences, or distances, between survey respondents. However, PCI$_2$ is a uniquely efficient method for analyzing and communicating Likert-scale survey data to detect disagreement. Other existing indices for conveying residents' attitudes either do not adequately include social science theory around conflict (Tastle & Wierman, 2005), do not reflect all relevant distribution characteristics (Van der Eijk, 2001), or are difficult to use in practice (Fasth et al., 2018). The PCI$_2$ statistic captures the multiple characteristics of survey response distributions that conflict theory uses to predict conflict likelihood (Bennett et al., 2017; Manfredo et al., 2017). Furthermore, PCI$_2$ provides an intuitive interpretation of the interactions between the predictive distribution characteristics when graphed against the survey scale (Fig. 27.). Peer-reviewed uses of PCI$_2$ explore human-wildlife conflicts in domestic and international parks and preserves, and include publications by U.S. federal agencies (Heeseman et al., 2010; Gangaas et al., 2013; Roemer & Vaske, 2014; Sakurai et al., 2014; Alazaizeh et al., 2015; Sponarski et al., 2015; Larson et al., 2016; Heneghan & Morse, 2019). To our knowledge, PCI$_2$ has never been applied previously to inform resource-based economic development.

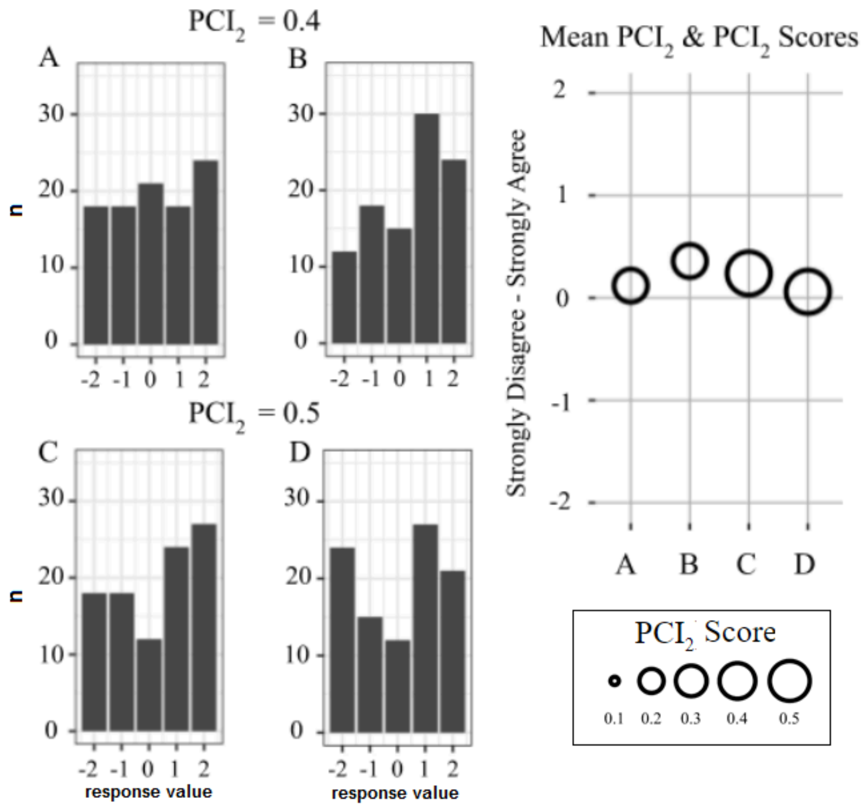


Figure 16. Example response distributions for populations with Potential for Conflict Index ($PCI_2$) scores of 0.4 (A and B) and 0.5 (C and D), shown with mean response and $PCI_2$ scores plotted after Vaske et al. (2010).

The $PCI_2$ value ranges from 0 to 1. The larger the $PCI_2$ value is, the greater the differences in opinion between sub-groups (i.e. lower consensus). The smaller the $PCI_2$ value, the greater the similarities in opinion between groups, a prerequisite for coalition-building. Development practitioners should use local knowledge to determine the level at which $PCI_2$ indicates sufficient disagreement to cause conflict. Even in the absence of significant disagreement, $PCI_2$ can identify differences in how specific factors affect SOP construction for different segments of the population. Appendix A provides a more detailed explanation of the $PCI_2$ statistic, as well as a comparison of $PCI_2$ to other conflict indices.

We calculate the $PCI_2$ statistic for each of the four SOP-related factors from the PCA using the Excel Macro developed by Vaske et al. (2010).[7] Input frequencies for responses were calculated across the population and also separated by demographic subgroups for additional inference. We confirm between-group differences for the effect of demographic characteristics on SOP components and component variables using ANOVA in SPSS v. 25, with Tukey HSD post-hoc tests where the Levene Statistic indicated inhomogeneity of variance. We use a relatively high p-value of 0.15 due to the uncertainty inherent in our small sample size and non-directional test (Vidgen & Yasseri, 2016), and list the statistical test estimates in Appendix B. We then use the $PCI_2$ Workbook to calculate a simulated mean and standard deviation for $PCI_2$'s based on 400 simulations.

We chose to assess disagreement within and between the demographic groups predicted by social theory, previous research, or anecdotal evidence to disagree on the issues composing PCA factors. These subgroupings include:

- *Subregions: North vs. South:* The southern towns of Medway, East Millinocket, and Millinocket far exceed the Region's northern towns in population and access to recreation. Survey respondents did not own businesses or property in the other half of the Region, indicating that residents' experiences shaping SOP are likely concentrated in their area. Residents in these southern towns may have different experiences with the forestry and recreation industries that will result in differing SOP. Furthermore, these differences could result in a sense of competition between the North and Southern halves. Intra-regional conflict in rural economic development has previously been noted by Cox and Mair (1988) and Meyer and Burayidi (1991).

[7] http://welcome.warnercnr.colostate.edu/~jerryv.

- *Employment Status:* The high number of retirees in the KR likely differ in their priorities and perspectives from younger residents who are employed or looking for work (Bell et al., 2018). Survey choices for employment status were retired, unemployed, part-time, full-time.
- *Household Income:* Different income levels may proxy: the different levels of economic security among residents; the different job types present in the KR; and differences in residents' access to resources and social groups (Soini et al., 2012). As discussed in the literature, these proxy characteristics all influence SOP construction, such that different income groups experiencing these characteristics differently likely construct SOP differently. We assess differences between residents from households making < $40,000, $40,000 - $75,000, and > $75,000 annually. Cross et al. (2011) used similar income levels to determine the impact of farm income on farmers' senses of place, showing that income impacts SOP through multiple components in working landscapes. Vaske et al. (2011) also showed that income influenced Colorado residences' SOP as revealed through landscape management preferences.
- *Business Ownership:* Business owners may be more open to new forms of economic activity than non-business owners, especially if they perceive that new activity would add to their existing business or business community. No survey respondent owned a business in a different part of the KR from their hometown.
- *Years in Katahdin Region:* Matarrita-Cascante et al., 2010, Almeida-García et al. (2016), and others have found length of residence to be a significant predictor of components of SOP (Smaldone, 2007, Qin, 2016). We might expect that residents who moved to the Katahdin Region since the decline of the paper mill (within the past 15 years) to be more accepting of recreation-oriented development dependent on conservation; presumably these residents are either younger, and identify less with the legacy of the forest products industry than older residents, or moved to the KR for the conserved landscape and have no attachment to the legacy

of previous industry. We categorized residents as being long-time (> 20 years), established (5 - 20 years), or recent (< 5 years) or seasonal. Following Qin (2016), recent and established residents are separated by the end of an era (i.e., the post-2008 mill closures). Established residents are similarly separated from long-time residents by the beginning of the paper mill decline in the 1980's. We grouped recent and seasonal residents for the $PCI_2$ because both group samples were small, and differ from other residents in their dependence on the KR for SOP components.

## 1.3 Results

### 1.3.1 PCA

The PCA reveals four components, which together explain 63% of response variation within the selected variables (Table 3). Each component is constructed from three to six of the 19 total SOP variables remaining after nine iterations of PCA as described above. We label these components according to the previously identified SOP components with which they align.

Component 1, Social Institutions, consists of questions of trust and participation in town and government. Localities and local governments are key modes through which individuals can interact with regional issues (Flora, Flora, and Gasteyer, 2018). Raymond et al. (2010) found political and social contexts to contribute independently to SOP. However, governance aligned with other social components in this analysis, likely because of its importance as a social institution, and because satisfaction with government is influenced by social factors (McLellan & Barrett, 2016).

Questions about the economic benefits and importance of conservation land, outdoor recreation and tourism, and the forest products sector comprise component 2, Economic Dependence.

The question with the most consistent co-variation with other component variables was about the regional importance of the KWWNM.

Component 3, Personal Identity, are from questions of belonging, pride, and optimism. These feelings indicate emotional investment in a place or place-based community. Other questions include two posited to belong to Economic Development (“My town has the motivation to attract new business”, “My town is positively contributing to the economy of the Katahdin Region”) and one hypothesized to belong to Public Resources (“My town has the resources to attract new business”). Notably, self-sufficiency did not align strongly with Personal Identity, though other research has found that being able to sustain oneself in a landscape engenders belonging, pride, and optimism in rural communities (Cantrill, 2003).

Component 4 contained variables relating to public resources, infrastructure and resources for problem-solving that align with the daily needs dependence factors identified in other studies.

Table 7. Indices from Principal Component Analysis after 9 iterations of culling dissimilar response variables.

| Component and Corresponding Individual Variables | Factor Loadings | | | | Cronbach’s Alpha |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| *Social Institutions (percent of variance: 21.3%)* | | | | | 0.889 |
| S1: I trust how decisions are made in my town. | .864 | | | | |
| S2: The leaders of my town are working hard to make positive changes. | .825 | | | | |
| S3: My town has effective leaders. | .805 | | | | |
| S4: The opinions of residents are valued when creating an economic plan for my town. | .794 | | | | |
| Table 7. Continued | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| S5: People in my town trust public officials. | .673 | | | | |
| *S6/I4: My town has the motivation to attract new business | .547 | | | | |
| *S7/I5 : My town is positively contributing to the economy of the Katahdin Region. | .488 | | | | |
| *Economic Dependence (17.0%)* | | | | | 0.848 |
| E1: The Katahdin Woods and Waters National Monument is important to the Katahdin Region. | | .898 | | | |
| E2: Recreational opportunities associated with conservation land will bring new people and jobs to my town. | | .869 | | | |
| E3: In the future, the economic importance of outdoor recreation and tourism will exceed that of the forest products sector in the Katahdin Region. | | .757 | | | |
| E4: Conservation land ventures and the forest products industry are compatible activities that can both thrive in the Katahdin Region. | | .726 | | | |
| E5: Outdoor recreation and tourism is important to the economic future of my town. | | .657 | | | |
| *Personal Identity (15.2%)* | | | | | 0.806 |
| I1: I am optimistic about the future of my town. | | | .822 | | |
| I2: I feel a sense of belonging to my town. | | | .728 | | |
| I3: I am proud to live in my town. | | | .643 | | |
| *I4/ S6 My town has the motivation to attract new business | | | .606 | | |
| I5: My town has the resources to attract new business. | | | .535 | | |
| *I6/ S7: My town is positively contributing to the economy of the Katahdin Region. | | | .485 | | |
| *Public Resources (9.2%)* | | | | | 0.636 |
| PR1: My town has the financial resources it needs to resolve town problems. | | | | .817 | |
| PR2: People in my town have the ability to solve their own problems. | | | | .706 | |
| PR3: My town has sufficient infrastructure. | | | | .517 | |

Notes: *: Variable appears twice. Rotation Method: Varimax with Kaiser Normalization; Rotation converged in 5 iterations

### 1.3.2 $PCI_2$

The $PCI_2$ s for each of the four SOP mean indices are shown in Figure 28. To interpret these graphs, the bubbles in the figure are centered on the survey response mean (n = 227), while the bubble diameters correspond to the individual $PCI_2$ value. A larger bubble diameter indicates a higher conflict potential, with a minimum $PCI_2$ equal to 0 and the maximum equal to 1. On average, residents in the KR are neutral regarding their local government (S1-S6) but agree slightly with the economic direction posited in the survey (E1-E5), with almost everyone believing that outdoor recreation is important to the Region's economic future, as indicated by the E5 $PCI_2$ score of 0.05. However, residents were less in agreement about the economic importance of the new Katahdin Woods and Waters National Monument to the Region (E1), which was reflected with a $PC1_2$ of 0.42, the highest of all the 115 Likert-scale questions in the entire study.

Most residents feel somewhat positive about their role in their towns and the towns themselves (i.e., mean agreement scores > 0). A $PCI_2$ score of 0.1 for I5 indicates that residents are almost unanimous in their pride in their towns. In contrast, a $PCI_2$ score of 0.4 for I3 highlights that residents are most likely to disagree on local motivation for economic diversification. Residents feel slightly negatively about the availability of public resources (PR), as individual mean agreement scores for that component range from -0.8 to 0.2. A slight belief in the townspeople's abilities to solve their own problems with the resources already available to them (PR2) is outweighed by disbelief in the sufficiency of regional towns' financial resources (PR1) and infrastructure (PR3).

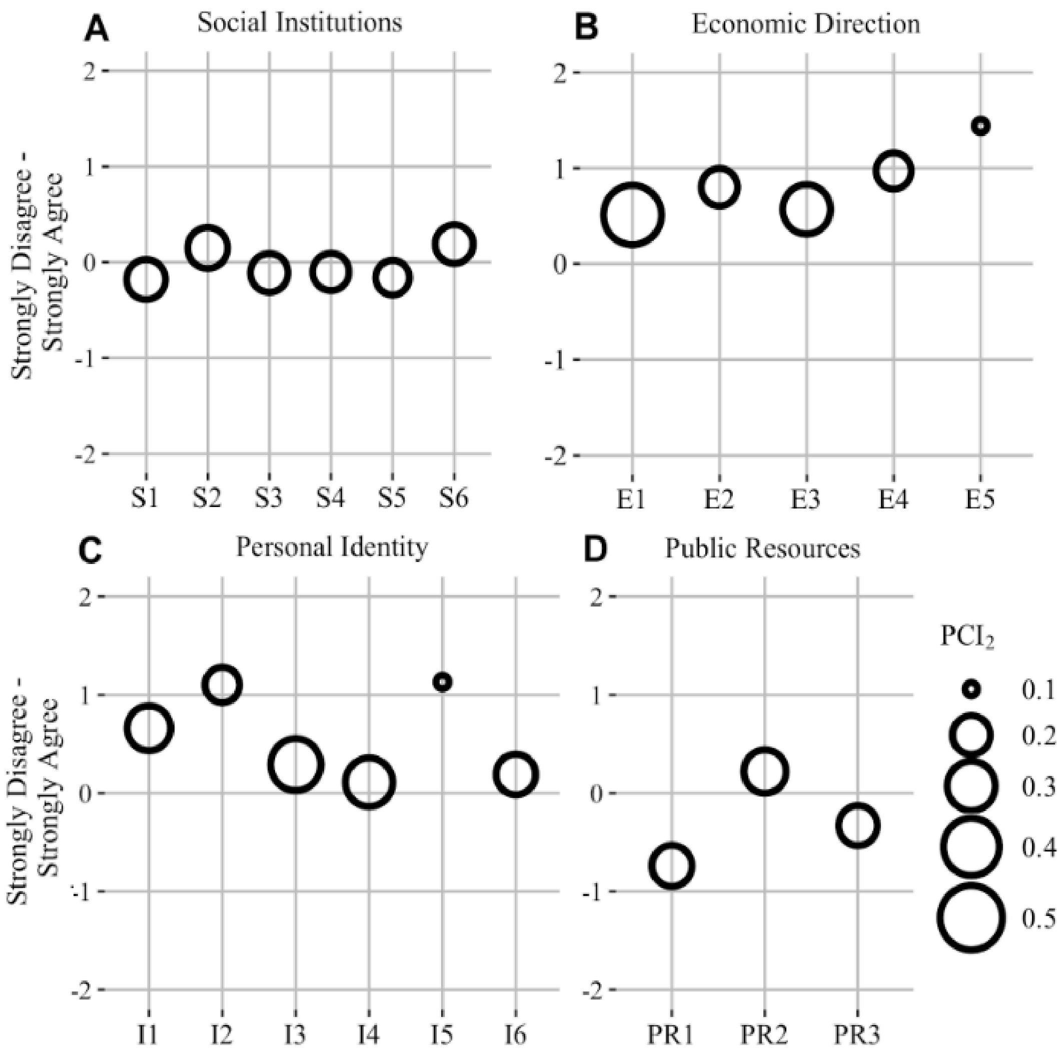


Figure 17. Mean scores and Potential for Conflict Indices ($PCI_2$) scores for sense of place component variables (A – D) from a survey of the Katahdin Region. Notes: Center of each circle represents mean score. Diameter of each circle represents $PCI_2$ score, where larger diameters indicate greater disagreement. Component variable labels along X-axes correspond to the variables in Table 3.

Plotted means for the selected demographic subgroups follow those of the whole survey population, though significant differences between subgroups exist in at least one component for all demographic characteristics except income (Fig. 18). Mean subgroup differences are most often statistically significant for the economic and identity components. We find no relationship between $PCI_2$

and explanatory power for either the component variables (Fig. 29) or the components (Fig. 29). Both the components and the variables of each component in figure 28 are in order of decreasing explanatory power. The component $PCI_2$'s resemble $PCI_2$'s from the variables with high explanatory power more than variables with low explanatory power. This partly explains how the $PCI_2$'s for Personal Identity and Public Resources (Figure 29, A) are almost zero, even though disagreement exists within sub-groups regarding those components (as shown by the large bubble circumferences on the identity component in Figure 29, B - F).

$PCI_2$'s for both the components and component variables for demographic subgroups are independent of sample size (Figure 29, Appendix B). For example, the populous southern half of the Region score a small $PCI_2$ for the identity component (0.05) but a large $PCI_2$ for the economic component (0.2), while the opposite is true in the less populous northern half (Fig. 18, B). Relatively large $PCI_2$ estimates for subgroups often co-occur with significant differences in sub-group means ($p < 0.15$), indicating that issues that divide sub-groups are also divisive within sub-groups. Disagreement within subgroups is relatively larger than disagreement within the population as a whole (Fig. 18, A) for employment status, years in the Katahdin Region, and income (Fig. 18, C, E, & F), as shown by the larger $PCI_2$ scores. The difference in SOP for length of time of that residents have lived in the Region was statistically significant for the economic and identity components, with established residents having lower $PCI_2$ scores than those who have not lived as long in the KR. Interestingly, there was no significant difference in SOP indicator scores across income brackets.

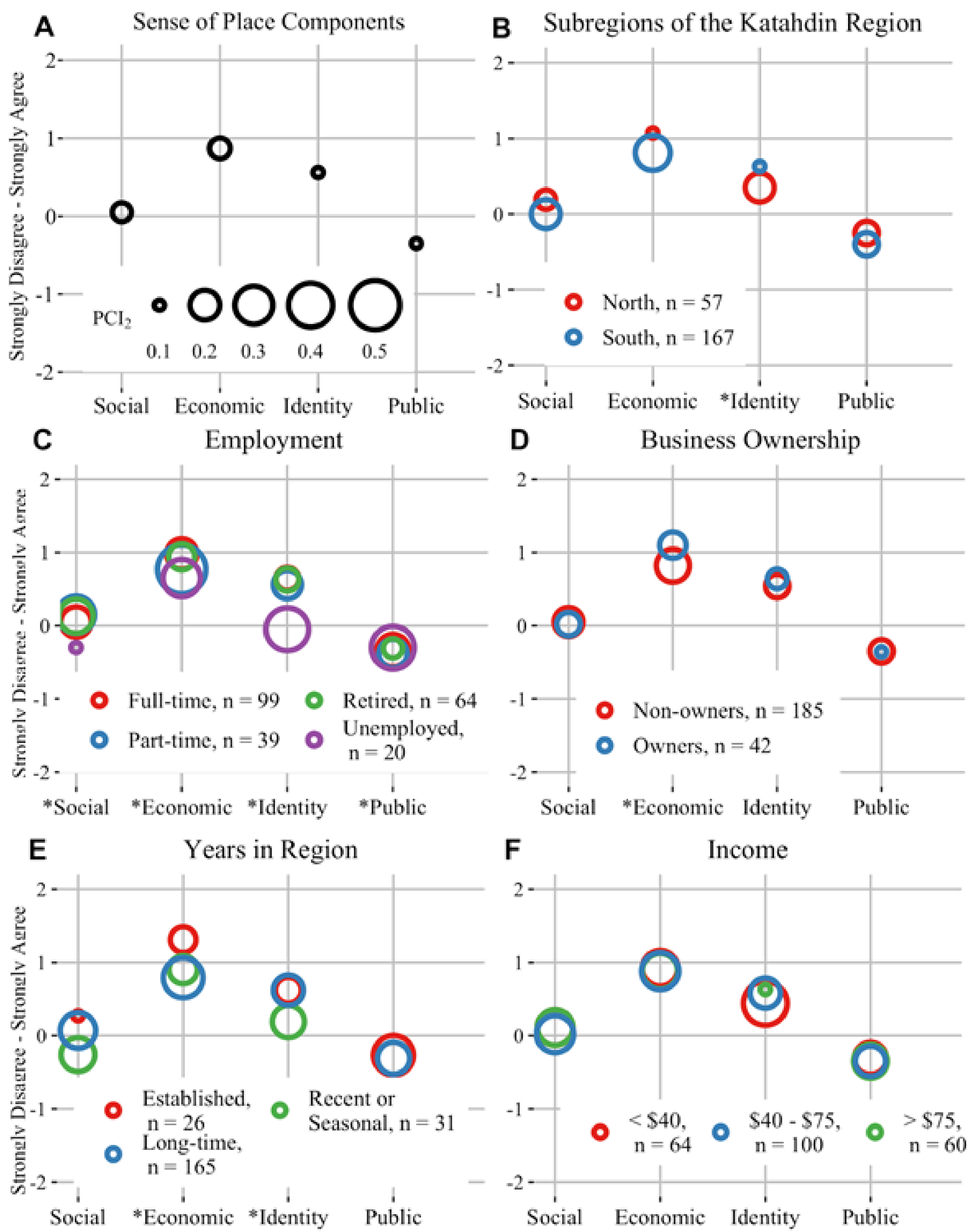


Figure 18. Means and $PCI_2$ scores for Sense of Place (SOP) components, overall (A) and by five categories of demographic subgroups (B-F). Income brackets (F) are in thousands of dollars. *statistically significant difference across subgroup means ($p < 0.15$)

## 1.4 Discussion

The $PCI_2$ graphs of PCA components and component variables (Figure 28 and Figure 29) clearly indicate how a transition to a diversified, recreation-based economy will affect SOP construction. Differences in subgroup PCA mean scores (indicating negative or positive SOP contribution) and in subgroup PCI scores (indicating disagreement) are not large enough to portend significant conflict over the proposed economic changes. However, this analysis shows that subgroups do use the physical and social landscapes differently from other subgroups to construct SOP. Economic planners can use this understanding to predict how changes to the physical and social landscapes resulting from economic transition will affect specific demographics. We discuss key potential impacts on subgroups that KR planners should consider to improve community outcomes.

As the strongest PCA component, even small levels of disagreement over Social Institutions could be greater sources of conflict than high levels of disagreement over other SOP components. The overall population means for Social Institutions (Fig. 29, A) and for the index variables vary tightly around zero (Fig. 28, A), indicating overall indifference towards towns' leaders and towns' leadership in the KR. Recent or seasonal residents are less likely to feel positively about their towns' primary social institutions than those who have been there slightly longer, but only the established residents are united in their slight approval of Social Institutions. This is the greatest difference in opinion for this SOP component by the most people. However, the difference itself is small, with an average opinion of "neither agree nor disagree". This difference is notable chiefly because town governments approved of by established residents are likely supportive of economic changes that positively affect established residents' other SOP components, and established residents differ from other residents in both economic dependence and personal identity.

The lack of strong and trusted leadership in the eight towns of the KR could impede consensus-building efforts. Residents' varied perceptions of individual leaders belies their uniform distrust of town officials, regardless of town (Fig. 17, S5). Residents' disagreement on whom to trust is the largest source of disagreement in the social component (Fig. 28, S2), and distrust of town officials contributes negatively to Social Institutions. Establishing trust in local governments may be an important step in economic diversification in the KR. Masterson et al. (2017) describe how trust in local governments is an important factor in both SOP and economic development. However, rural SOP research elsewhere in the U.S. find that rural residents are unlikely to trust any level of government to change land use and land access, despite the fact that these changes can both preserve the natural resource base and support economic transition (Cantrill, 2003). State land use planners facing push-back from KR residents over new zoning laws could use this study to target outreach to groups of residents with SOP's threatened by the changes.

Overall differences in how residents perceive their economic dependence on the KR are small, indicated by the low (~0.2) $PCI_2$ score for the Economic Dependence component for all residents (Fig. 29, A). Views on the relative importance of traditional and new forms of economic activity vary differently, though slightly, across sub-groups. $PCI_2$ analyses of component variables (not shown) show that northern residents have already accepted economic diversification, but are less inclined to support outdoor recreation requiring additional conservation. The idea of outdoor recreation and tourism eclipsing other industries with or without additional conservation is divisive in the southern part of the KR, increasing the population-wide $PCI_2$ score (Fig. 29, B; Fig. 28, E3). Southern KR residents at least agree that outdoor recreation is important, even if they disagree about its specific role in the economy. Part-time workers disagree more about economic direction than any other employment category, but agree on identity. This difference could be due to seasonal workers already in the region's tourism industry who do not see seasonal tourism work as enough to sustain year-round economic growth. Surprisingly, business owners are only slightly more positive than the general population about the proposed economic direction (i.e., tourism and recreation). We might expect that business owners outside of traditional economic sectors would be more in favor of diversification and increased visitor traffic than business owners in the traditional forestry, manufacturing, and agriculture industries.

The most consistently co-varying question in the Economic Dependence index regarded the importance of KWWNM to the KR's economic future. This question was also the greatest source of disagreement across the entire population, with subgroups differing on this question that agreed on social and personal dependence questions. This finding suggests that the significant conflict over the founding of KWWNM was primarily driven by economic concerns, rather than concerns about changes in social institutions (e.g., increased Federal government presence) or changes in personal identity construction (e.g., inability to access personally significant areas). If this finding is accurate, conflict could have avoided by increasing the economic component of planning for KWWNM. This finding could be corroborated and expanded upon using in-depth interviews or other social research techniques.

Garau-Vedell et al. (2018) attribute divergent perceptions of economic development among residents with similar regional identities to residents' perceptions of the relative costs of economic development. They find that residents' support for tourism in a large Spanish tourism destination was significantly greater six years after the 2008 recession than it was two years before the economic crisis. As the closure of the Great Northern Paper mill fades farther into the past, the perceived costs of economic development relative to a no-growth alternative may decrease for all residents.

The Personal Identity component measures the dependence of personal identity construction on place. The unexpected appearance of questions about public resources ("My town has the resources to attract new business") and Economic Development ("My town has the motivation to attract new business", "My town is positively contributing to the economy of the Katahdin Region") alongside questions of pride and belonging indicates the extent to which residents have internalized the town's success. Identifying with the KR's social and physical landscapes is more likely to have a positive impact on SOP for southern residents (Fig. 18, B), who are united in their positivity. While the difference in $PCI_2$ scores between the subregions could be due to the smaller northern resident sample size, the $PCI_2$ is designed to be robust to sample size (Appendix A).

Unemployment and low-income status do not affect uniformly affect identity (Fig. 18, C and F). However, decreased mean identity is consistent between the small sample size of unemployed residents ($n = 20$, between-group difference statistically significant) and the larger sample size of low-income residents ($n = 64$, not statistically significant). These groups lacking identity attachment to the region as it is now are less likely to need support as economic changes alter the region's physical and social characteristics. Economic planners should keep in mind that differences in mean opinion between unemployed and other residents are small, however, relative to the component scale.

We find "Years in Region" to be the most significant predictor of the identity components for all types of residents. Established and long-time residents who score significantly differently on Economic Dependence still construct identity similarly, with noticeably (though slightly) more positivity than recent/seasonal residents (Fig. 18, E). This difference could be attributed to longer-term residents' experiences of their towns' company pasts, experiences found to be significant by Lequieu (2017), Beckley (1998), and Colocousis (2013). Qin (2016) notes that the original context in which in-migrants encounter the Region is important. Recent residents arriving at the time of the mill closure and ensuing KWWNM controversy have less positive senses of place overall, as do seasonal residents who may not feel integrated into the community. Our finding contradicts research by Jorgenson and Stedman (2006), who found that length of residence was not a significant predictor of SOP. Our finding instead builds on findings from Matarrita-Cascante et al. (2010) and Almeida-García et al., (2016) that new-comers to a popular tourist destination were more supportive of further development than long-time residents.

Similar levels of dissatisfaction with infrastructure throughout the KR could be a key starting point for consensus-building. Subgroups means are the most similar for the Public Resources component (Fig. 18). The agreement shown by income-based subgroups indicates that public resource access is not a class issue. Recent and seasonal residents are the subgroup most in agreement on the insufficiency of regional infrastructure, perhaps because they have more recently experienced other places with better infrastructure. Additional interview-based research could identify whether subtle differences in component mean scores (e.g., between northern and southern KR residents, Fig. 18, B) represent significant differences in resource accessibility for those subgroups.

While our study produced some interesting and insightful results, we note that there are some limitations that need to be considered when interpreting our study findings. In particular, survey participants were recruited by means of convenience sampling and thus may not have been fully inclusive and introduced some non-response biases that are not atypical to rural household surveys (Coon et al., 2019). The generalizability of the survey findings to the total populations of the KR is therefore unclear. In addition, our assessment was conducted at only point in time (the summer of 2018) and thus findings may not hold as the region continues to adjust to recent economic shocks. As a result, that important trends in resident attitudes identified by PCA and $PCI_2$ only reflect attitudes captured by the survey data, which had a sample that was not completely aligned with the demographics of the Region's general population (e.g., higher median income and educational attainment). Despite this potential response bias, soliciting survey responses from a wide distribution of households is an important addition to the few in-depth interviews captured in other regional studies (Cottle & Howard, 2012; EDAT, 2017). This study further demonstrates how survey-based studies of rural place-making can inform development efforts despite the significant challenges of rural survey distribution.

While we were unable to compare SOP constructions between respondents and non-respondents through a follow-up survey and analysis, development practitioners can consider whose opinions are not represented, and what barriers or reasons prevented their participation. The SOP constructions that drive responses to development opportunities may not be the same as the SOP constructions of marginalized peoples (Masterson et al., 2017). Development practitioners have a responsibility to reach out to marginalized groups to avoid perpetuating social injustices and resource use conflicts with exclusionary economic planning. In the case of the KR, future outreach should directly involve the government of the Penobscot Nation, whose traditional home encompasses the entire region, whose trust lands are located within and around the region, and whose cultural survival is directly affected by the health of the Penobscot River (Fig. 14).

## 1.5 Conclusion

We demonstrate that combining PCA and $PCI_2$ to analyze survey data from a rural, natural resource-dependent region can uniquely inform economic development efforts there. This method elicits the SOP impacts of different types of economic growth on different groups within the Region and its towns, identifying important considerations for economic planners. Overall, we find that potential for conflict arises from impacts to specific SOP components, and that differences in SOP construction exist both between and within demographic sub-groups.

The greatest differences in SOP components came from questions on how the Region's economy should transition, while nearly all residents were in agreement about having pride in their community. Interestingly, our analysis found that there were often higher levels of disagreement across demographic subgroups than among the population as a whole. This finding highlights how conducting a more detailed analysis of SOP components can direct efforts to find common ground in support of development initiatives.

This results of this study would be more meaningful combined with a greater understanding of residents' modes of interaction with their communities and community decision-makers. For example, follow-up interviews of non-respondents may have revealed that those most opposed to community changes were unwilling to take the survey. The PCI scores found here may actually be biased upwards if strong opposition to community changes is more common than this survey captured. By contrast, some may have chosen not to take the survey because they have already accepted community changes, and see further discussion about those changes as irrelevant. This attitude among non-respondents, if common, may have also biased PCI scores upwards. A follow-up survey of SOP in the KR in 5 – 10 years could explore how much changes in SOP are driven by temporal distance from the industry past, relative to other factors.

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## APPENDIX A: SENSITIVITY ANALYSES FOR (L)CNF AND (L)CNF-BOUND PB PRODUCTION

Table A. 1  Scenario 1a sensitivity analysis

| Scenario 1a: (L)CNF in a co-located and repurposed facility | Minimum selling price | | |
|---|---|---|---|
| | min | base | high |
| | -30% | 0 | 30% |
| Capital investment (+/- 30%) | $833 | 953 | $1,074 |
| NBSK cost (+/- 30%) | $900 | 953 | $1,007 |
| OCC price (+/- 50%) | $927 | 953 | $970 |
| Fresh water cost (+/- 30%) | $948 | 953 | $959 |
| Electricity cost (+/- 30%) | $932 | 953 | $1,008 |
| Working days (320 - 360) | $924 | 953 | $987 |
| Labor costs (+/- 30%) | $914 | 953 | $993 |
| Taxes on EBIT (+/- 5 points) | $945 | 953 | $963 |

| | | | |
|---|---|---|---|
| Discount Rate (10%, 16%, 20%) | $898 | 953 | $996 |
| min | $833 | 953 | $959 |
| max | $948 | 953 | $1,074 |

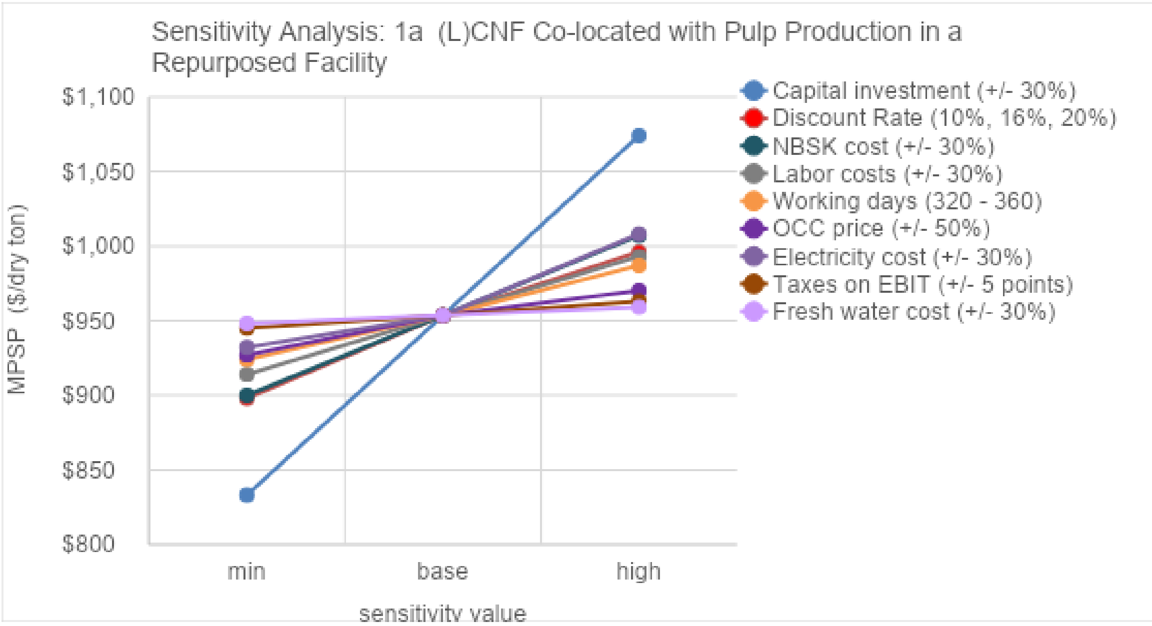


Figure A. 1 Scenario 1a sensitivity analysis

Table A. 2 Scenario 1b sensitivity analysis

| Scenario 1b: (L)CNF in a repurposed facility | Minimum selling price | | |
|---|---|---|---|
| | min | base | high |
| | -30% | 0 | 30% |
| Capital investment (+/- 30%) | $854 | 980 | $1,106 |
| NBSK cost (+/- 30%) | $926 | 980 | $1,034 |
| OCC price (+/- 50%) | $953 | 980 | $1,007 |
| Fresh water cost (+/- 30%) | $972 | 980 | $988 |
| Electricity cost (+/- 30%) | $943 | 980 | $1,017 |
| Working days (320 - 360) | $949 | 980 | $1,014 |
| Labor costs (+/- 30%) | $940 | 980 | $1,020 |
| Taxes on EBIT (+/- 5 points) | $971 | 980 | $990 |
| Discount Rate (10%, 16%, 20%) | $924 | 980 | $1,024 |

| | | | |
|---|---|---|---|
| min | $854 | 980 | $988 |
| max | $972 | 980 | $1,106 |

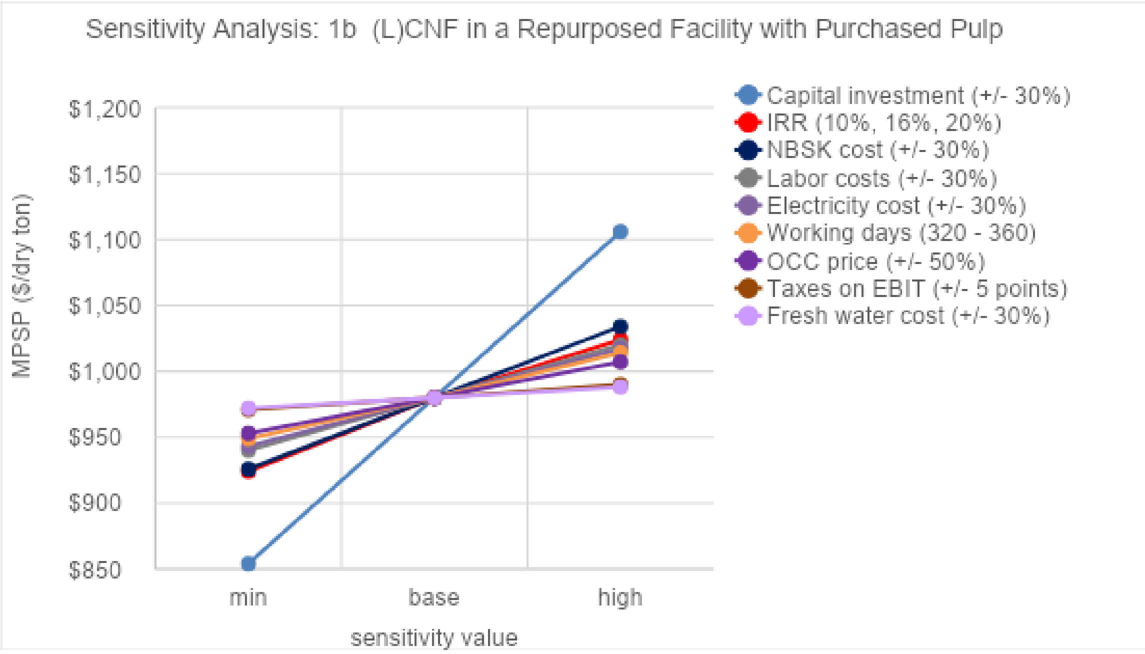


*Figure A. 2 Scenario 1b sensitivity analysis*

*Table A. 3 Scenario 1c sensitivity analysis*

| Scenario 1c: (L)CNF in a greenfield facility | Minimum selling price | | |
|---|---|---|---|
| | min | base | high |
| | -30% | 0 | 30% |
| Capital investment (+/- 30%) | $1,241 | 1534 | $1,827 |
| NBSK cost (+/- 30%) | $1,480 | 1534 | $1,588 |
| OCC price (+/- 50%) | $1,507 | 1534 | $1,561 |
| Fresh water cost (+/- 30%) | $1,526 | 1534 | $1,542 |
| Electricity cost (+/- 30%) | $1,498 | 1534 | $1,570 |
| Working days (320 - 360) | $1,472 | 1534 | $1,603 |
| Labor costs (+/- 30%) | $1,494 | 1534 | $1,573 |
| Taxes on EBIT (+/- 5 points) | $1,515 | 1534 | $1,555 |

| | | | |
|---|---|---|---|
| Discount Rate (10%, 16%, 20%) | $1,408 | 1534 | $1,630 |
| min | $1,241 | 1534 | $1,542 |
| max | $1,526 | 1534 | $1,827 |

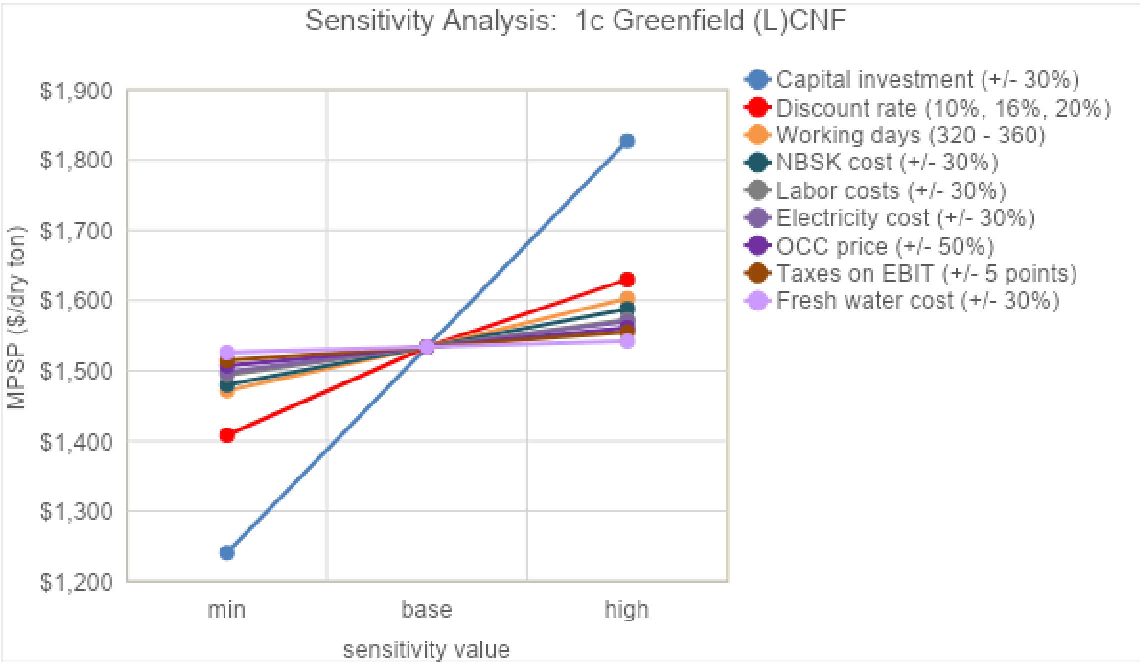


Figure A. 3 Scenario 1c sensitivity analysis

*Table A. 4 Scenario 1d sensitivity analysis*

| Scenario 1d: LCNF in a repurposed facility | Minimum selling price | | |
|---|---|---|---|
| | min | base | high |
| | -30% | 0 | 30% |
| Capital investment (+/- 30%) | $600 | 704 | $807 |
| NBSK cost (+/- 30%) | $672 | 704 | $735 |
| OCC price (+/- 50%) | $698 | 704 | $721 |
| Fresh water cost (+/- 30%) | $676 | 704 | $732 |
| Electricity cost (+/- 30%) | $677 | 704 | $733 |

| | | | |
|---|---|---|---|
| Working days (320 - 360) | $664 | 704 | $743 |
| Labor costs (+/- 30%) | $697 | 704 | $712 |
| Taxes on EBIT (+/- 5 points) | $656 | 704 | $740 |
| Discount Rate (10%, 16%, 20%) | $600 | 704 | $712 |
| min | $698 | 704 | $807 |
| max | $600 | 704 | $807 |

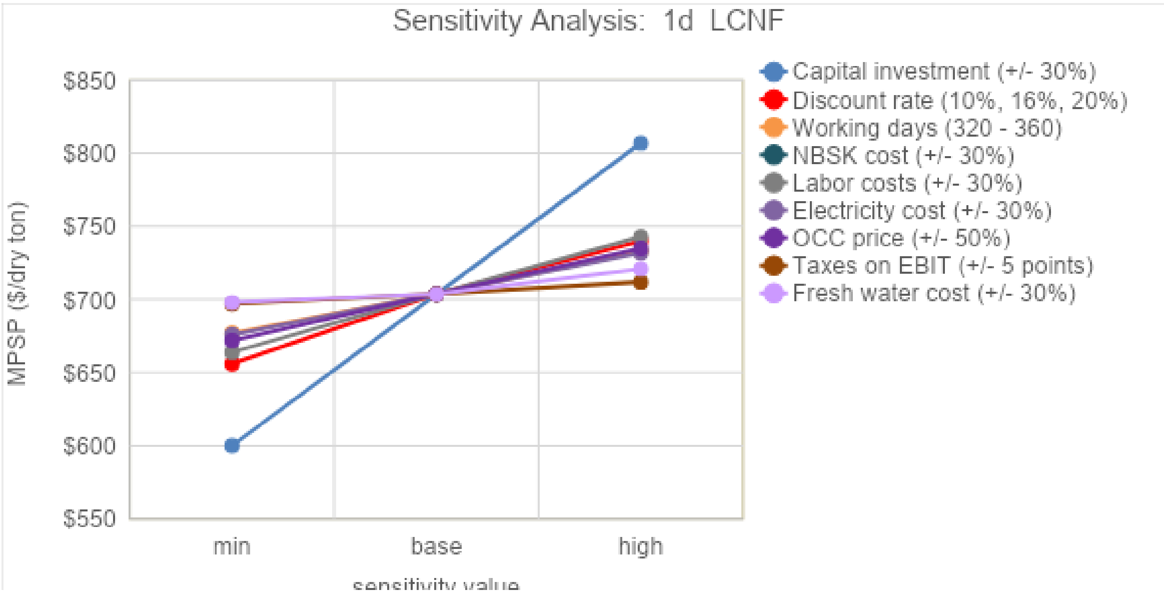


Figure A. 4 Scenario 1d sensitivity analysis

Table A. 5 Scenario 1e sensitivity analysis

| Scenario 1e: LCNF in a greenfield facility | Minimum selling price | | |
|---|---|---|---|
| | min | base | high |
| | -30% | 0 | 30% |
| Capital investment (+/- 30%) | $904 | 1138 | $1,372 |
| NBSK cost (+/- 30%) | $1,106 | 1138 | $1,169 |
| OCC price (+/- 50%) | $1,133 | 1138 | $1,143 |
| Fresh water cost (+/- 30%) | $1,100 | 1138 | $1,166 |
| Electricity cost (+/- 30%) | $1,087 | 1138 | $1,195 |
| Working days (320 - 360) | $1,098 | 1138 | $1,177 |

| | | | |
|---|---|---|---|
| Labor costs (+/- 30%) | $1,123 | 1138 | $1,155 |
| Taxes on EBIT (+/- 5 points) | $1,038 | 1138 | $1,215 |
| Discount Rate (10%, 16%, 20%) | $904 | 1138 | $1,143 |
| min | $1,133 | 1138 | $1,372 |
| max | $904 | 1138 | $1,372 |

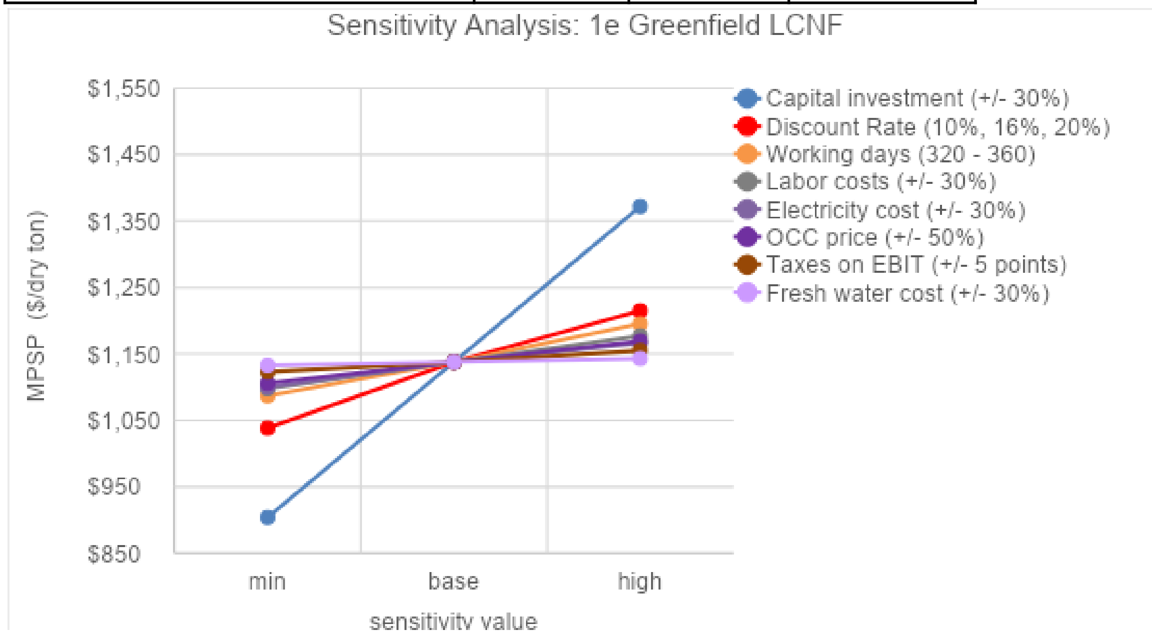


Figure A. 5 Scenario 1e sensitivity analysis

*Table A. 6  Scenario 2a sensitivity analysis*

| Scenario 2a: | Minimum selling price | | |
|---|---|---|---|
| | min | base | high |
| | -30% | 0 | 30% |
| PB CAPEX (+/- 30%) | $515 | 555 | $594 |
| (L)CNF CAPEX (+/- 30%) | $527 | 555 | $583 |
| (L)CNF (+/- 30%) | $461 | 555 | $648 |
| Residues (+/- 30%) | $532 | 555 | $578 |
| Working days (320 - 360) | $547 | 555 | $563 |
| Labor costs (+/- 30%) | $525 | 555 | $584 |

| | | | |
|---|---|---|---|
| Taxes on EBIT (+/- 5 points) | $552 | 555 | $558 |
| Discount rate (10%, 16%, 20%) | $506 | 555 | $591 |
| min | $461 | 555 | $558 |
| max | $552 | 555 | $648 |

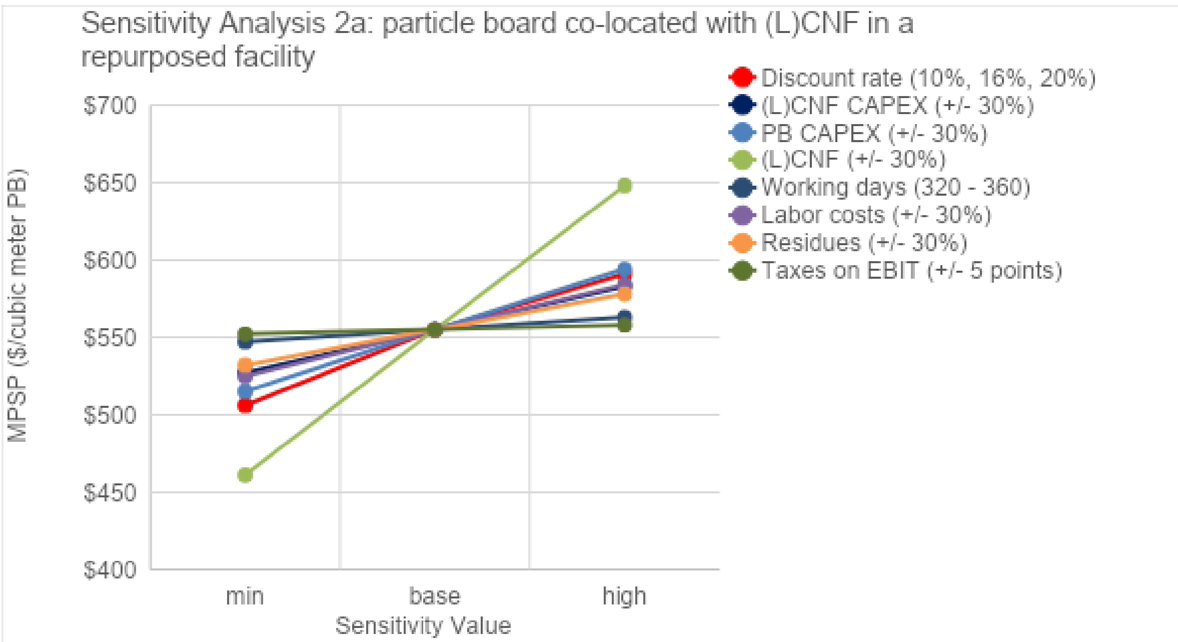


Figure A. 6 Scenario 2a sensitivity analysis

*Table A. 7 Scenario 2b sensitivity analysis*

| Scenario 2b: Particle board with Purchased (L)CNF from a Repurposed Facility | Minimum selling price | | |
|---|---|---|---|
| | min | base | high |
| | -30% | 0 | 30% |
| PB CAPEX (+/- 30%) | $717 | 813 | $909 |
| (L)CNF CAPEX (+/- 30%) | $786 | 813 | $841 |
| (L)CNF (+/- 30%) | $702 | 813 | $924 |
| Residues (+/- 30%) | $810 | 813 | $817 |
| Working days (320 - 360) | $799 | 813 | $829 |

| | | | |
|---|---|---|---|
| Labor costs (+/- 30%) | $780 | 813 | $846 |
| Taxes on EBIT (+/- 5 points) | $809 | 813 | $818 |
| Discount rate (10%, 16%, 20%) | $730 | 813 | $877 |
| min | $702 | 813 | $817 |
| max | $810 | 813 | $924 |

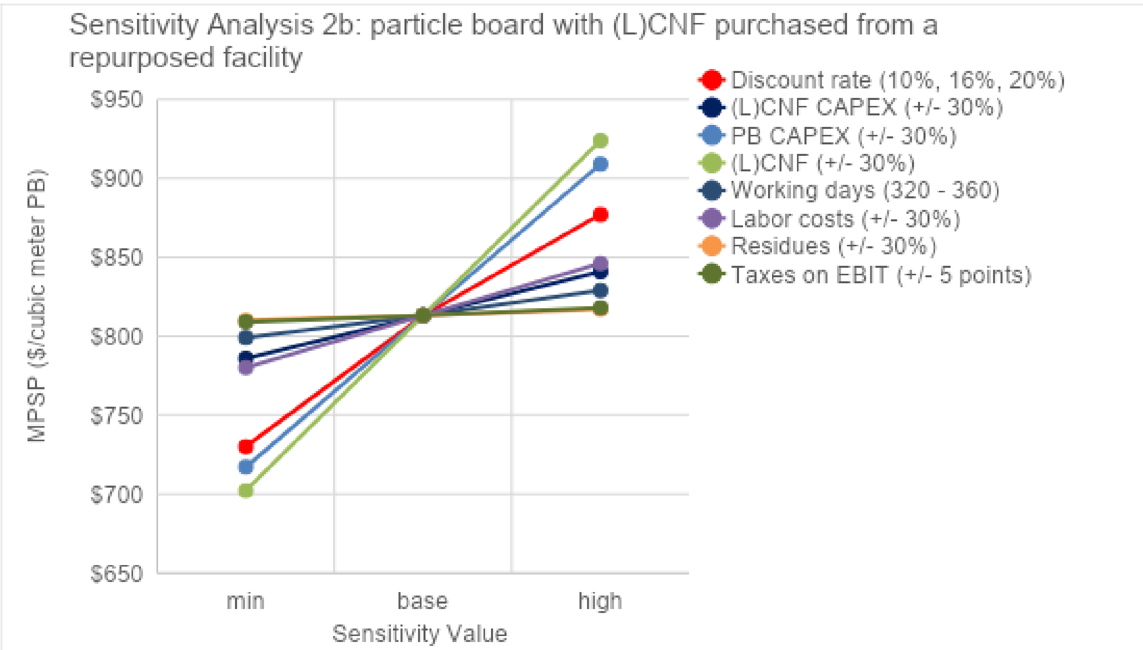


Figure A. 7 Scenario 2b sensitivity analysis

*Table A. 8 Scenario 2c sensitivity analysis*

| Scenario 2c: PB with (L)CNF purchased from a greenfield facility | Minimum selling price | | |
|---|---|---|---|
| | min | base | high |
| | -30% | 0 | 30% |
| PB CAPEX (+/- 30%) | $774 | 875 | $966 |
| (L)CNF CAPEX (+/- 30%) | $819 | 875 | $921 |
| (L)CNF (+/- 30%) | $742 | 875 | $999 |
| Residues (+/- 30%) | $867 | 875 | $874 |

| | | | |
|---|---|---|---|
| Working days (320 - 360) | $850 | 875 | $893 |
| Labor costs (+/- 30%) | $837 | 875 | $903 |
| Taxes on EBIT (+/- 5 points) | $866 | 875 | $875 |
| Discount rate (10%, 16%, 20%) | $773 | 875 | $945 |
| min | $742 | 875 | $874 |
| max | $867 | 875 | $999 |

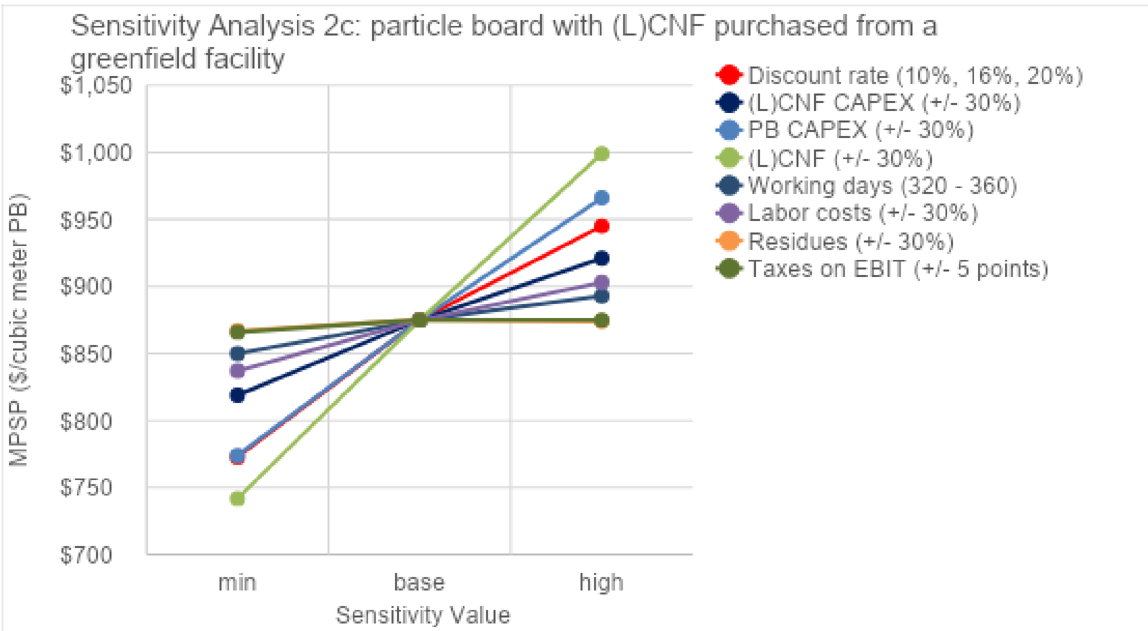

*Table A. 9 Scenario 2d sensitivity analysis*

| Scenario 2d: Particle board Co-located with LCNF | Minimum selling price | | |
|---|---|---|---|
| | min | base | high |
| | -30% | 0 | 30% |
| PB CAPEX (+/- 30%) | $414 | 453 | $493 |
| (L)CNF CAPEX (+/- 30%) | $430 | 453 | $476 |
| (L)CNF (+/- 30%) | $313 | 453 | $581 |
| Residues (+/- 30%) | $430 | 453 | $476 |
| Working days (320 - 360) | $446 | 453 | $461 |
| Labor costs (+/- 30%) | $420 | 453 | $486 |
| Taxes on EBIT (+/- 5 points) | $451 | 453 | $456 |
| Discount rate (10%, 16%, 20%) | $407 | 453 | $488 |
| min | $313 | 453 | $456 |
| max | $451 | 453 | $581 |

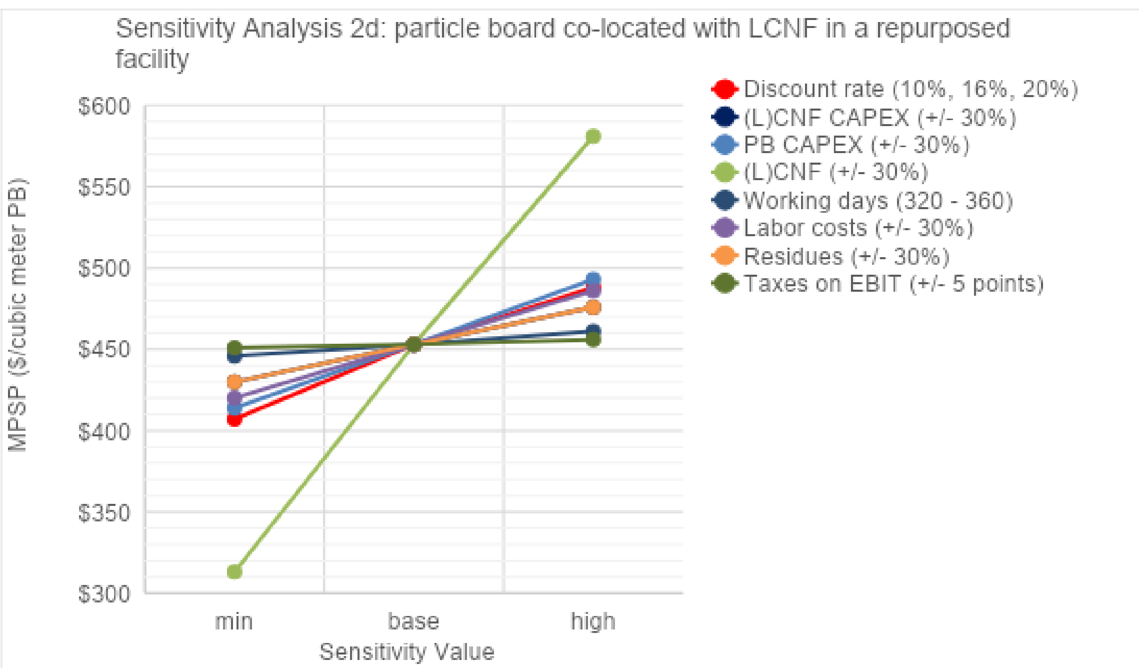


Figure A. 9 Scenario 2d sensitivity analysis

*Table A. 10  Scenario 2e sensitivity analysis*

| Scenario 2e: LCNF purchased from a repurposed facility | Minimum selling price | | |
|---|---|---|---|
| | min | base | high |
| | -30% | 0 | 30% |
| PB CAPEX (+/- 30%) | $591 | 686 | $782 |
| (L)CNF CAPEX (+/- 30%) | $664 | 686 | $709 |
| (L)CNF (+/- 30%) | $613 | 686 | $760 |
| Residues (+/- 30%) | $663 | 686 | $709 |
| Working days (320 - 360) | $673 | 686 | $701 |
| Labor costs (+/- 30%) | $653 | 686 | $719 |
| Taxes on EBIT (+/- 5 points) | $683 | 686 | $690 |
| Discount rate (10%, 16%, 20%) | $607 | 686 | $747 |
| min | $591 | 686 | $690 |
| max | $683 | 686 | $782 |

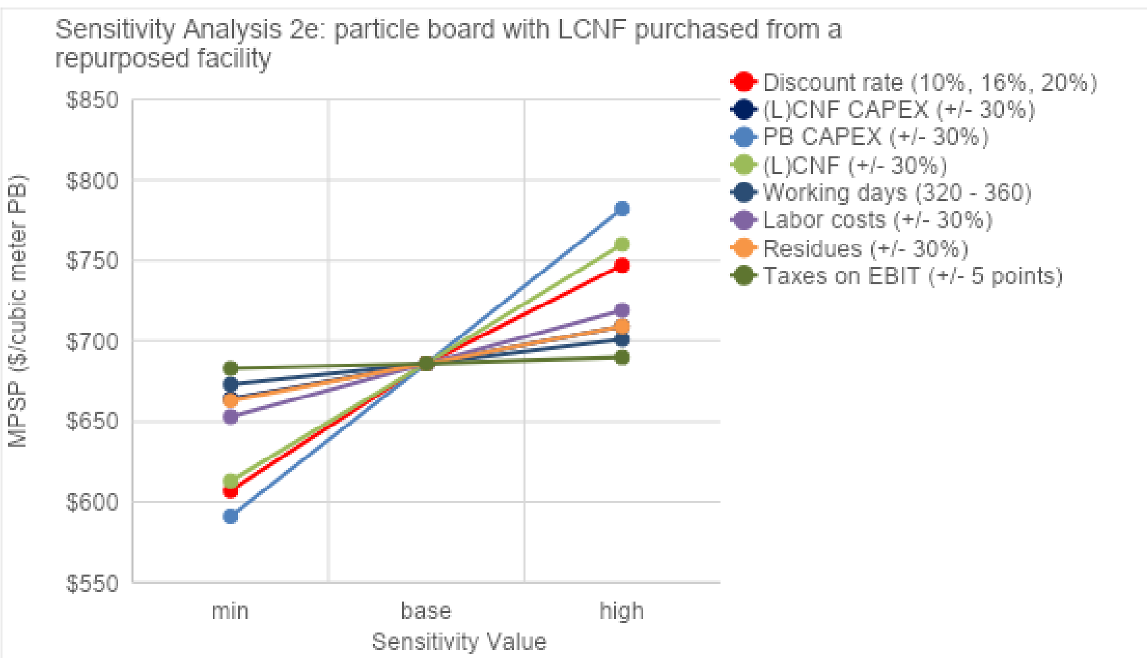


Figure A.  SEQ Figure_A. * ARABIC 10 Scenario 2e sensitivity analysis

*Table A. 11 Scenario 2f sensitivity analysis*

| Scenario 2f: PB with LCNF purchased from a greenfield facility | Minimum selling price | | |
|---|---|---|---|
| | min | base | high |
| | -30% | 0 | 30% |
| PB CAPEX (+/- 30%) | $687 | 782 | $877 |
| (L)CNF CAPEX (+/- 30%) | $733 | 782 | $831 |
| (L)CNF (+/- 30%) | $680 | 782 | $884 |
| Residues (+/- 30%) | $759 | 782 | $805 |
| Working days (320 - 360) | $766 | 782 | $800 |
| Labor costs (+/- 30%) | $753 | 782 | $812 |
| Taxes on EBIT (+/- 5 points) | $778 | 782 | $787 |
| Discount rate (10%, 16%, 20%) | $688 | 782 | $855 |
| min | $680 | 782 | $787 |
| max | $778 | 782 | $884 |

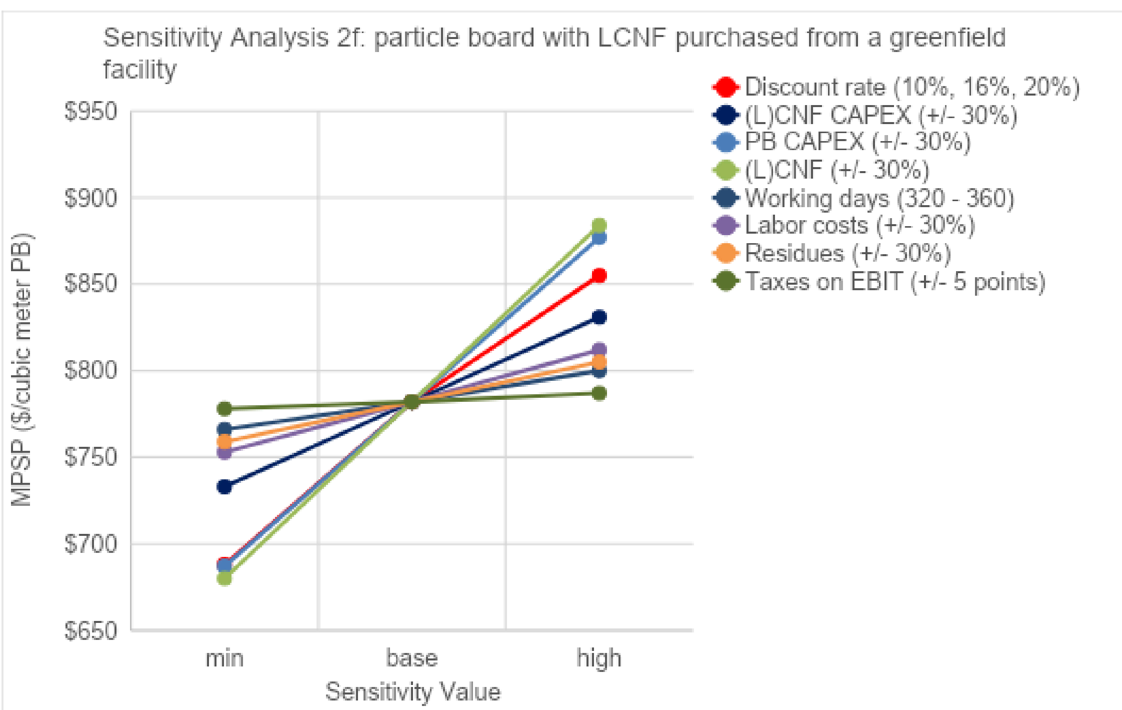


Figure A. 11 Scenario 2f sensitivity analysis

## APPENDIX B: POTENTIAL FOR CONFLICT INDEX 2 ($PCI_2$)

The $PCI_2$ statistic (Vaske et al., 2010) captures the multiple characteristics of a Likert-scale survey response distribution predicted by conflict theory to indicate conflict likelihood. Distribution characteristics commonly used to describe survey results include moments about the sample population mean (variance, skewness, and kurtosis) (Joanes & Gill, 1998) and modality (Manfredo et al., 2003). Neither mean- nor mode-based descriptions alone can adequately predict the extent and strength of potential disagreement between survey respondents. Responses are rarely evenly divided between opposite ends of the response scale or centered around a mean. Furthermore, best-practice tests for multimodality can be unreliable for distributions that indicate high conflict potential, e.g. a distribution with two small modes and large kurtosis (Xu et al., 2014). These density plot attributes may be inappropriate for describing discrete survey data.

Figure 3 in the main text illustrates how populations with dissimilar response distributions can share a similar potential for conflict, such that development practitioners need more than standard graphical techniques to identify conflict potential; they need visualizations that interpret the interactions between mean moments and modalities in the context of disagreement potential. Similar to other survey response indices, $PCI_2$ achieves this interpretation by using the distribution of differences, or distances, between survey respondents.

$PCI_2$ compares the average distance between survey responses to the maximum potential difference. The resulting statistic is analogous to a t-statistic. Vaske et al. (2010) derives $PCI_2$ indirectly, by calculating and averaging individual conflict potential coefficients (A.1), and directly, by dividing the sum of all individual distances by the greatest possible sum of all distances for that response scale (A.2). As conflict is unlikely to exist between respondents with answers on the same half of a bivariate scale, $PCI_2$ does not include distances between those responses. $PCI_2$ calculates distances between -1 and 1, for example, separately from distances that represent a lower conflict potential (e.g. -2 and -1). The equations presented here are edited slightly for clarity and for easier comparison with other distribution statistics. *n* is the size of the population, *r* is the vector of Likert-scale response choices, and *x* is the vector of survey responses:

$$PCI_2 = \frac{\sum d_{x,x+i}}{n \cdot \left| r_{max} - r_{min} \right|}$$

$$PCI_2 = \frac{\sum n_r n_{r+i} d_{r,\ r+i}}{\frac{n^2}{2} \cdot \left| r_{max} - r_{min} \right|}$$

Equation 2. $PCI_2$ calculation

with $r < 0$ and $r + i > 0$. The equations used to calculate $d_{x,x+i}$:

$$d_{x,\ x+i} = \begin{cases} \left| r_x - r_{x+i} \right| & x<0\ \&\ x+i>0 \\ & r<0\ \&\ r+i>0 \\ 0 & \text{otherwise} \end{cases}$$

Equation 3. $PCI_2$ distance calculation

The resulting index ranges from 0 (all responses the same) to 1 (responses evenly split between opposing extreme scale values).

$PCI_2$ allows for multiple calculations of $d_{x,\ x+i}$ to reflect social science theory on consensus and conflict. A respondent with a neutral attitude towards an issue is unlikely to engage in conflict around that issue, such that a distribution containing a high frequency of neutral responses may erroneously indicate a low conflict potential (Vaske et al., 2010). The neutral answer can therefore be subtracted from $d_{x,\ x+i}$ and the greater distances weighted more heavily:

$$d_{x,\ x+i,\ p} = \begin{cases} \left( \left| r_x - r_{x+i} \right| - \left( d_{x,\ x+i} - 1 \right)^p \right) & x<0\ \&\ x+i>0 \\ & r<0\ \&\ r+i>0 \\ 0 & \text{otherwise} \end{cases} \quad \text{(A.4)}$$

The neutral answer is also subtracted from the maximum possible score in the denominator if the PCI_2 statistic. Vaske et al. (2010) also provide additional distance formulas for non-neutral and univariate scales. Vaske et al. (2010) and Heeseman et al. (2010) show that $PCI_2$ statistics are consistent when calculated with at least 400 simulations from populations with an absolute skewness < 1.0.

## References


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## APPENDIX C: MEANS AND $PCI_2$ SCORES FOR DEMOGRAPHIC SUPBROUPS

Table A. 6 Means and PCI2 scores for demographic subgroups by variable

*Notes: Levene test significance (p < 0.15) implies inhomogenous variance. If the Levene test is insignificant, the ANOVA (p < 0.15) is reliable; if the Levene test is significant, ANOVA is unreliable and a post-hoc test (Tukey Honestly Significant Difference, p < 0.15) is necessary. If the ANOVA is significant, we use Tukey HSD to locate between-group differences (p < 0.15). Insignificant Tukey HSD results are listed as N/A.*

| PCA Factor | Demographic Characteristic | Level | PCI | Mean | Levene Test Significance Values | ANOVA Between-Group Significance Values | Tukey HSD Between-Group Significance |
|---|---|---|---|---|---|---|---|
| Social Institutions | Subregion | North | 0.09 | 0.19 | 0.986, 0.756 | 0.332 | N/A |
| | | South | 0.12 | 0 | | | N/A |
| | Employment | Unemp. | 0.05 | -0.3 | 0.602, 0.665 | 0.214 | N/A |
| | | Part-time | 0.14 | 0.15 | | | N/A |
| | | Full-time | 0.1 | 0.05 | | | N/A |
| | | Retired | 0.12 | 0.13 | | | N/A |
| | Years in Region | Recent/ Seasonal | 0.11 | -0.26 | 0.682, 0.488 | 0.108 | 0.089 |
| | | Estd. | 0.04 | 0.27 | | | 0.089 |
| | | Long-time | 0.12 | 0.07 | | | N/A |
| | Business Ownership | Owner | 0.1 | 0.02 | 0.491, 0.577 | 0.835 | N/A |
| | | Non-owner | 0.12 | 0.05 | | | N/A |
| | Income | < $40,000 | 0.12 | 0.11 | 0.862, 0.844 | 0.469 | N/A |
| | | $40,000 - $75,000 | 0.12 | 0.11 | | | N/A |
| | | > $75,000 | 0.13 | 0.02 | | | N/A |
| Economic | Subregion | North | 0.08 | 1.07 | 0.036, 0.170 | 0.194 | N/A |
| | | South | 0.15 | 0.81 | | | N/A |
| | Employment | Unemp. | 0.14 | 0.65 | 0.015, 0.037 | 0.397 | 0.483 0.968 0.632 |

Table A.6 continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Part-time | 0.23 | 0.77 | | | 0.968<br>0.815 0.638 |
| | | Full-time | 0.1 | 0.98 | | | 0.483<br>0.638 |
| | | Retired | 0.08 | 0.94 | | | 0.632 0.815 |
| | Years in Region | Recent/ Seasonal | 0.08 | 0.9 | 0.733, 0.964 | 0.065 | N/A |
| | | Estd. | 0.07 | 1.31 | | | 0.051 |
| | | Long-time | 0.15 | 0.79 | | | 0.051 |
| | Business Ownership | Owner | 0.11 | 1.1 | 0.712, 0.957 | 0.096 | N/A |
| | | Non-owner | 0.14 | 0.82 | | | N/A |
| | Income | < $40,000 | 0.12 | 0.92 | 0.502, 0.672 | 0.048 | 0.993<br>0.996 |
| | | $40,000 - $75,000 | 0.12 | 0.88 | | | 0.993 |
| | | > $75,000 | 0.13 | 0.88 | | | 0.996 |
| Personal Identity | Subregion | North | 0.12 | 0.35 | 0.519, 0.520 | 0.088 | N/A |
| | | South | 0.08 | 0.63 | | | N/A |
| | Employment | Unemp. | 0.18 | -0.05 | 0.829, 0.836 | 0.008 | 0.037<br>0.005<br>0.009 |
| | | Part-time | 0.09 | 0.56 | | | 0.037 |
| | | Full-time | 0.07 | 0.64 | | | 0.005 |
| | | Retired | 0.07 | 0.63 | | | 0.009 |
| | Years in Region | Recent/ Seasonal | 0.1 | 0.19 | 0.722, 0.921 | 0.072 | 0.048 |
| | | Estd. | 0.07 | 0.62 | | | N/A |
| | | Long-time | 0.09 | 0.62 | | | 0.048 |
| | Business Ownership | Owner | 0.09 | 0.64 | 0.651, 0.790 | 0.455 | N/A |
| | | Non-owner | 0.1 | 0.54 | | | N/A |
| | Income | < $40,000 | 0.18 | 0.44 | 0.001, 0.014 | 0.334 | 0.482 |

Table A. 6 continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | $40,000 - $75,000 | 0.04 | 0.63 | | | 0.482 0.769 |
| | | > $75,000 | 0.09 | 0.58 | | | 0.769 |
| Public Resources | Subregion | North | 0.1 | -0.25 | 0.422, 0.520 | 0.188 | N/A |
| | | South | 0.1 | -0.4 | | | N/A |
| | Employment | Unemp. | 0.18 | -0.3 | 0.275, 0.339 | 0.973 | N/A |
| | | Part-time | 0.09 | -0.38 | | | N/A |
| | | Full-time | 0.11 | -0.34 | | | N/A |
| | | Retired | 0.06 | -0.31 | | | N/A |
| | Years in Region | Recent/ Seasonal | 0 | -0.74 | 0.304, 0.503 | 0.009 | 0.139 0.390 |
| | | Estd. | 0.15 | -0.27 | | | 0.139 |
| | | Long-time | 0.1 | -0.31 | | | 0.390 |
| | Business Ownership | Owner | 0.08 | -0.36 | 0.263, 0.557 | 0.938 | N/A |
| | | Non-owner | 0.1 | -0.35 | | | N/A |
| | Income | < $40,000 | 0.1 | -0.31 | 0.605, 0.952 | 0.592 | N/A |
| | | $40,000 - $75,000 | 0.11 | -0.35 | | | N/A |
| | | > $75,000 | 0.09 | -0.35 | | | N/A |

## BIOGRAPHY OF THE AUTHOR

Mary Ignatiadis is originally from Huntsville, Alabama. She earned her bachelor's degree in 2016 from Williams College in Williamstown, Massachusetts, where she majored in geosciences. She served as an AmeriCorps volunteer at Teton Science Schools in Wyoming and worked as an environmental consultant in Massachusetts prior to joining the School of Forest Resources at the University of Maine. She is aiming to complete her master of science from the University of Maine in December of 2020.