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Forest Biomass Feedstock Availability and Economic Contribution of Biopower Facilities in the Lake States Region

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Abstract

The Lake States (MI, MN, WI) region holds 54.8 million acres of forest and offers the potential to meet the increasing demand for sustainable energy through forest biomass. The objective of this study is to estimate the annual availability of biomass, after considering the sustainability threshold, for a wood price and its economic impact in the Lake States region. This study identified twenty-seven active power facilities using biomass in addition to oil, gas, and coal, with a total capacity of 3.85 million MWh per year. They consumed 2.80 million dry tons of biomass in 2019. At the current delivered wood price, an additional 9.72 million dry tons of biomass is economically available, which, if used, would generate an additional 11,112 jobs (1,583 direct and 9,529 indirect and induced), $1.54 billion in value added ($803 million direct and $733 million indirect and induced), and $2.71 billion ($1.46 billion direct and $1.25 billion indirect and induced) in total output. Operating at least one-third of the existing capacity for biomass-based power generation would add 1,969 jobs, $293 million in value added, and $413 million in total output. The expansion of the biomass biopower industry has the potential to significantly increase economic impact, especially in rural areas.

Study Implications: Mapping procurement zones for resource allocation using delivered wood prices for biomass helps identify the economic availability of biomass for electric power production in the Lake States. Our results establish the market extent for biomass and identify potential areas where investment in biopower production or capacity upgrade is feasible. This study also provides insight into the economic impacts of additional biomass utilization to produce power. Most of these impacts would come about in rural areas, improving economic growth in these communities. A combined analysis estimating the potential supply and demand and the economic effects of biopower industry expansion provides valuable insight into decision-making for state forest action plans and private sector forest management plans. Furthermore, the findings from this study will help inform effective regional policy and investment decisions on biomass power industries. The method used can also be tailored to a specific facility to estimate its procurement zone, feedstock availability, and economic impacts.

Keywords: bioenergy, delivered wood price, economic impacts, electricity, procurement zone, sustainability

Increasing demand for energy consumption coupled with the awareness and concerns over adverse environmental, human health, and economic consequences of burning fossil fuels for energy have spurred interest in renewable energy resources, such as biomass. Also, the potential for economic growth in local and rural areas using biomass for energy has further fueled interest in woody biomass consumption (Dahal et al. 2020). According to the US Energy Information Administration (EIA 2022a), energy-related carbon dioxide (CO_2) emissions in the country rose by 296 million metric tons or 6% in 2021 compared with 2020 levels. Transportation and electric power sectors were the major contributors to this increase, with the former contributing 37% and the latter contributing 32% of total energy-related carbon dioxide emissions in 2021 (EIA 2022a). One approach to address this greenhouse gas (GHG) emissions crisis is through the expansion in the use of renewable energy sources for meeting energy demands (IPCC 2014). The use of renewables such as biomass in electric power generation, optimizing transportation costs of feedstocks, would reduce the use of fossil fuels for power production as well as for delivering biomass.

Over the past decade, the share of renewable energy in electric power generation has increased considerably in the United States, with impressive increments observed in the wind and solar energy sectors (EIA 2022b). For example, wind electricity generation increased from 1 to 25 million MWh from 2001 to 2022 in the Lake States (figure 1). In 2016, solar power generation began to gain popularity, and by 2022, production had reached 4 million MWh. From 2001 until 2016, the power generation capacity using wood and other biomass remained constant in the region, but it slightly declined after 2016. Biomass, which includes a variety of materials such as wood and wood processing waste, crops and waste materials, biogenic materials in municipal solid waste, as well as animal

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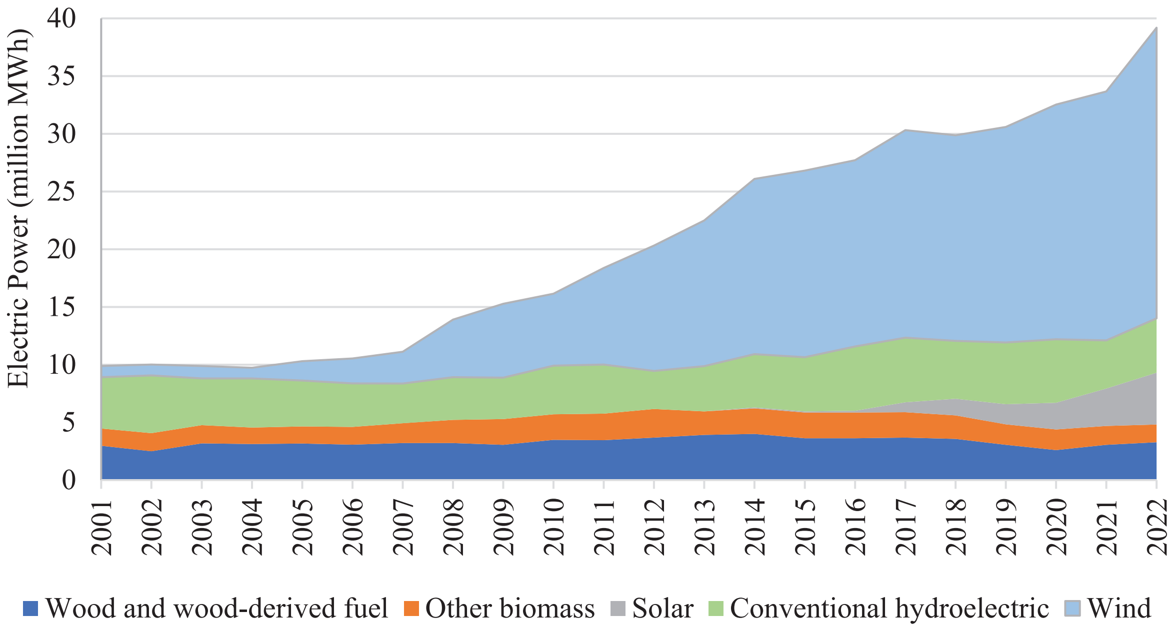

Figure 1. Trend of electric power generation from renewable energy sources in the Lake States (Source: EIA 2022b)

manure and human sewage (EIA 2022c), is another important source of renewable energy used mostly for facility heating, electric power generation, and combined heat and power generation. Biomass can be converted into electric power and heat through several methods, most commonly through direct combustion. Other methods include gasification, pyrolysis, and anaerobic digestion (EIA 2022c). Electricity generated from biomass accounted for 6.7% of the total electricity produced from renewable energy sources in the United States in 2021, with woody biomass contributing a major share of it (EIA 2022d). Approximately 67% of the electricity produced from biomass in 2021 came from wood and wood-derived fuels (EIA 2022d).

Supportive policies at both the federal (in 1978, 1992, and 2004) and state level (e.g., Renewable Portfolio Standards) have played a crucial role in promoting renewable sources for power generation across the country, particularly in the Lake States region. In Michigan, for instance, the state's renewable energy standard (RES) was enacted in 2008, requiring its retail electricity providers to obtain at least 10% of the electricity they sold from renewable energy resources by 2015. After meeting this goal, the state's RES requirement was increased to 15% of electricity sales by 2021 (EIA 2022e). Similarly, Minnesota's renewable energy portfolio standard (RPS) mandates that the state's electricity providers generate at least 25% of their electric retail sales from renewable sources by 2025 (EIA 2022e). Wisconsin's RPS required 10% of electric retail sales from renewable energy sources. On meeting this goal in 2013, the state's RPS required that each electric provider maintain, at a minimum, their 2015 percentage. Additionally, in 2019, the governor of Wisconsin signed an executive order that established a state office of sustainability and clean energy, which set a goal that all electricity consumed in Wisconsin be 100% carbon-free by 2050 (EIA 2022e). Energy generated from biomass qualifies as a renewable energy source for meeting the state's RPS in the Lake states region and can be promoted without negatively affecting the resource base as per current forest inventory and removals data. Regardless, power generation particularly from wood-based biomass can provide employment opportunities and much needed economic impetus in rural forest dependent communities.

Wood-based biomass for energy reduces GHG emissions over traditional fossil fuels (Gustavsson et al. 2011), generates income and employment opportunities in rural forest-dependent communities (Dahal et al. 2020), reduces the amount of waste wood ending up in landfill sites (2014, 2015), has positive effects on forests health (Vance et al. 2018), and displaces CO_2 emissions (Gan and Smith 2007). Because biomass-based electricity production uses local feedstock for energy production, compared with electricity generation using fossil fuel sources, they have greater impacts on local income (Dahal et al. 2020; Leefers 2011). Also, if managed sustainably, power generated from woody biomass may qualify as carbon neutral, because CO_2 released during power generation displaces CO_2 emissions from fossil fuels and can be sequestered through the production of additional trees (IEA 2022). However, to be considered truly carbon neutral, a full supply chain, including all emissions associated with the production, processing, transportation, and use of biomass for energy production, needs to be considered and can be achieved by conducting rigorous life cycle assessments (IEA 2022).

The Lake States region of Michigan, Minnesota, and Wisconsin is rich in forests and offers the potential to meet the increasing demand for energy through increased use of biomass, particularly wood and wood-derived fuels. Collectively, forests cover 54.8 million acres of land in these three states, and average annual net growth is almost double the removals in all three states (USDA Forest Service, 2020a, 2020b, 2021). This means that more wood can be removed from forests without affecting the sustainability of the resource base. In 2020, the percentage of the total energy produced from wood and wood waste was 30.3% in Wisconsin, 15.6% in Michigan, and 11.2% in Minnesota

(EIA 2022e). Wisconsin has the highest proportion of total energy production from woody biomass, as there are twelve operating facilities with a total nameplate capacity of 767 MW. In addition, Wisconsin ranks at the top in pulp and paper production nationwide (Jolley et al. 2020). Also, 12% of total manufacturing jobs in the state are from the forest products industry (Dahal 2021) and Wisconsin ranked second in total jobs nationwide (Pelkki and Sherman 2020). All these factors contribute to a larger proportion of energy from wood in Wisconsin. In Michigan, renewable energy contributed 11% of total in-state electricity generation in 2020, and biomass provided one-fifth or 2% of the state's net electricity generation from all sources (EIA 2022e). In Minnesota, biomass fueled more than 2% of the state's electricity in 2021, most of which came from wood and wood-derived fuels (EIA 2022e). In Wisconsin, the percentage of in-state electricity generated from biomass accounted for slightly less than 2% of the state's total net generation in 2020 (EIA 2022e).

Biomass is usually transported to a roadside landing during or after harvest and chipped to increase load density for transport. The final cost of the delivered biomass chips to the purchasing facility includes stumpage, harvesting, chipping, logging contractor profit margin, and trucking costs. Klammer (2017) found that a breakeven price of \$36–\$39 per green ton of biomass would be needed to supply 200,000 tons of timber residues in Michigan. Regions with lower chipping costs, like those that use whole-tree harvesting over the cut-to-length system and those with more dispersed demand points, have a better potential for residue supply. In addition, loggers would only consider biomass procurement with at least a 15% return on top of standard equipment investment (Klammer 2017). The amount of biomass harvested varies by different harvesting methods and so does the cost. The average onsite gathering and hauling cost of collecting residues is around \$8 per green ton under the cut-to-length method. However, the marginal cost of harvesting residues is minuscule, as low as \$2 per ton for the whole-tree method (Klammer 2017). The average transportation cost per ton-mile for a 100-mile radius is about \$0.13 per ton. In a different study, Leefers (2011) surveyed the biomass power plant in Michigan and found that the mean delivered price per ton for chips was \$21.50 (range: \$18–\$24). For sawmills and other mill residues, the price was \$17.90 (range: \$16–\$20); for logging residues, the price was \$21.60 (range: \$18–\$24). Leefers (2011) also reported that each plant employed 22 people on average to operate the facility with total estimated direct jobs of 132. In 2019, based on the seven biomass power plants surveyed, Leefers et al. (2020) reported 151 direct jobs in Michigan.

Identifying the existing capacity, mapping the procurement zones, and estimating available biomass within those zones are all critical steps in evaluating the economic contributions of the wood-based biomass power sector in a given region. By conducting such a study, one can emphasize the abundance of economically available biomass for power generation, as well as the ripple effects this sector can have on the regional economy, and advocate for its sustenance and expansion in the future. The study's objective is to estimate the available biomass at different prices and assess the region's economic contribution for various capacity conversion and biomass supply scenarios.

Materials and Methods

Data

We used eGrid2019 data from US Environmental Protection Agency (EPA 2021) to identify the location and capacities of all operating biopower facilities in the Lake States: Michigan, Minnesota, and Wisconsin. Twenty-seven facilities were operational in the region, with a total nameplate capacity of 1,465 MW (figure 2). We obtained detailed road network data from Esri (Esri Data and Maps 2017) to use in conjunction with biopower facilities to identify procurement zones at various delivered wood prices. The delivered wood price of biomass was obtained from a survey conducted by Michigan DNR in 2019 (Poudel 2021). We then overlaid procurement zones with 2019 FIA Inventory data (FIA 2021) to estimate the growth, removals, merchantable volume, and aboveground biomass within the procurement zones. Our I-O analysis used IMPLAN 2017 data with results reported in 2019 US\$. (IMPLAN 2019; Minnesota IMPLAN Group, 2004)

Procurement Zone Identification

To begin, we combined biopower facility locations and a road network database to determine the geographical extent of each facility's service area using delivered wood price, following the approach developed by Pokharel and Latta (2020) using the "Network Analyst" extension in ArcGIS (esri 2017). Using Euclidean, aerial, or road distance to map service areas can be erroneous where accessible biomass may have a greater economic distance from the power generation facility than the physical distance due to the lack of infrastructure and vice versa. As shown in figure 3, the time-based approach allows stretching service areas along high-speed roads and shrinking them along small arterial roads to represent the true regions where biomass procurement is possible at a given price.

To map the service area, we converted delivered wood price to haul time as a surrogate for transportation costs using equation 1

$$t = \left(0.5 * \frac{(p + (\Delta p * p) - p_h - p_s) * \ w}{r} * 60\right) - t_l \qquad 1$$

where t is the transportation or haul time supported by p, p is the current price of average mill delivered wood price, Δp is the % change in p for various scenarios, p_h is the cost of harvesting wood products, p_s is the stumpage price, w is the weight limit of a truck trailer to haul wood products, r is the cost of operating a truck for an hour, and t_l is the loading and unloading time.

Michigan Department of Natural Resources (DNR) reported that the average delivered price per ton for biomass chips was \$23.25/Gt (p) in 2019 (Poudel 2021). We removed the harvest and stumpage cost from the delivered wood price to determine the average net revenue for hauling biomass. The average harvest cost (p_h) of biomass was \$8.14/Gt, estimated at 33.33% of the delivered wood price following the finding of Steigerwaldt Land Services (2015). We assumed no stumpage (p_s) on biomass as it is a byproduct and waste from logging operations to harvest logs and pulpwood; then, equation 1 can be simplified to equation 2:

$$t = \frac{30\ p * (0.67 + \Delta p) * \ w}{r} - t_l$$
$$\text{when, } p_s = 0 \text{ and } p_h \ = 0.33 * p \qquad 2$$

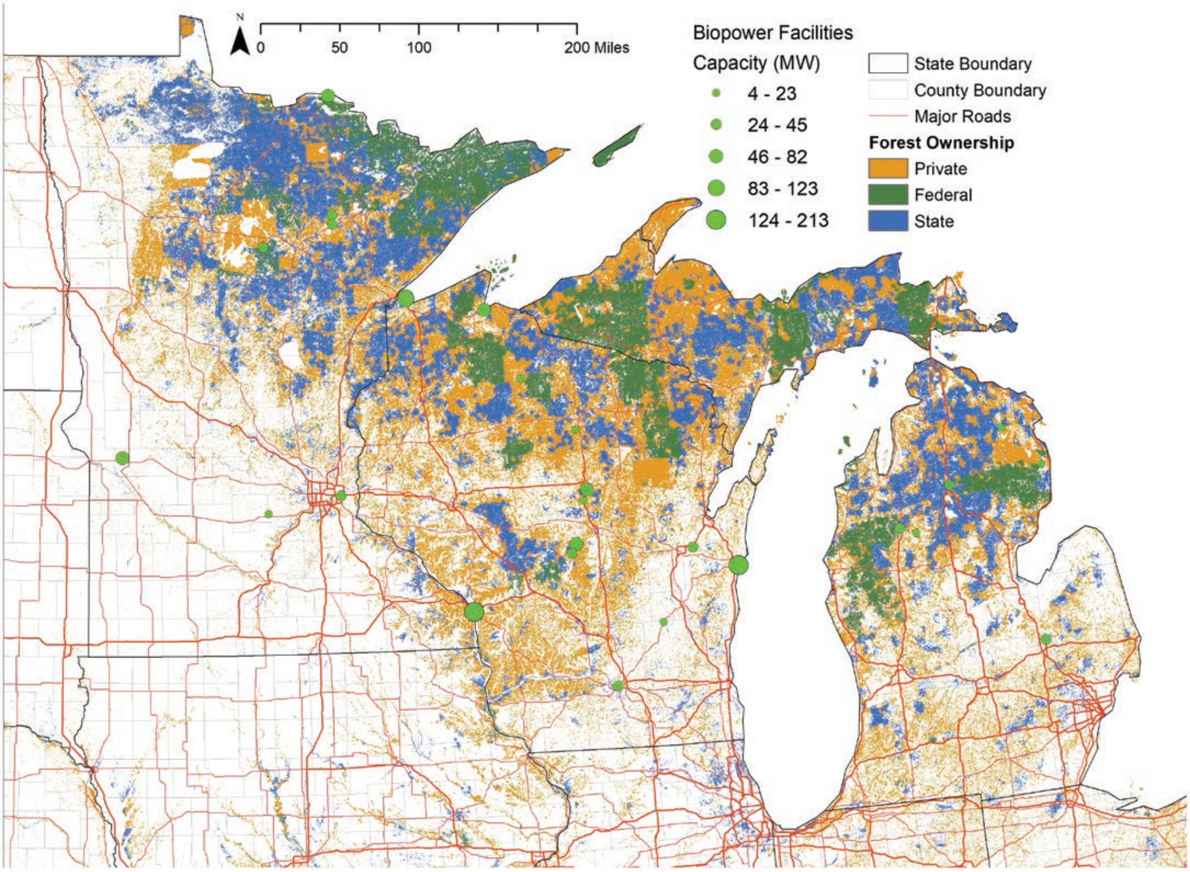

Figure 2. Biomass biopower facilities active in 2019 (EPA 2021) and forest ownerships (Hewes, Butler, and Liknes 2017) in the Lake States.

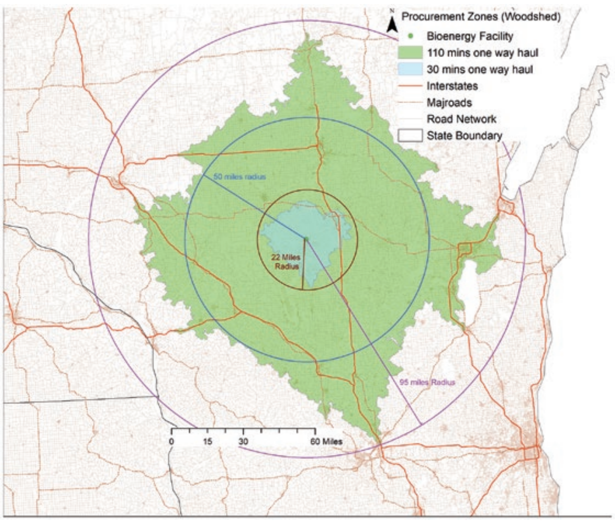

Figure 3. A representation of procurement zone around a bioenergy facility at different haul times.

Because a conventional truck hauls 25 tons (w) of chips (Geiver 2012), we multiplied the net revenue by 25 tons to expand the value to a truckload. The value of the truckload was then divided by the trucking rate (r) to determine the round-trip travel. The trucking rate was estimated from the method and values reported by Conrad (2018) using equation 3:

$$r = \frac{C}{(H * W)} \qquad 3$$

where $r$is the hourly trucking rate or the per-hour cost of operating a truck, $C$is the average annual cost to own and operate a log truck and trailer, and W is the total weeks the truck is operated in a year. Conrad (2018) estimated C, the average annual cost to own and operate a new (≤5 years) log truck and trailer to be $153,297 (2017 dollars) using trucker wages, diesel price, maintenance and insurance costs, taxes, and other truck operating costs. We adjusted for inflation and estimated the trucking cost for 2022 at $183,025. The average trucking rate (r) was estimated at $90/hour, assuming a truck is in operation for 40 hours every week $(H)$for 51 weeks in a year(W). The calculated rate was communicated with and verified by forest products industry stakeholders in Michigan. Then we divided round-trip travel by 2 to obtain a one-way haul time. Finally, a 60-minute average loading and unloading time (t_l) was subtracted from the hauling time to account for time spent at the landing and the facility. The average loading and unloading time were estimated based on communication with loggers, truckers, and Michigan DNR personnel. Hence, the one-way haul time (t) supported by $23.25/Gt is about 69 minutes. The resulting time is the farthest away from a facility where an average truckload of biomass chips can be procured at a given delivered wood price. The haul time–based service area drawn using the resulting time represents the wood basket for a biomass biopower facility. The outer boundary of this polygon represents the breakeven point, where net profit is zero for the sale of forest biomass.

Finally, the service areas of all twenty-seven biopower facilities were aggregated using the "Dissolve" tool in ArcGIS to create a single procurement zone for all facilities supported by the average delivered wood price for the Lake States region. The same process was repeated for 5%, 10%, 15%, and 20% increase and decrease in delivered wood prices (Δp) of biomass to map nine procurement zones supported by nine scenarios of changes in prices (Table 1).

The procurement zones, or wood baskets, for delivered wood prices were overlaid individually with 2019 FIA data (FIA 2021) using the rFIA package (Stanke et al. 2020) in R to estimate average annual growth, removals, merchantable volume, and aboveground biomass. We also included available biomass from neighboring states for further analysis, from where feedstocks at a given price would be available to biopower facilities in the Lake States. Table 1 shows the available biomass in each procurement zone (wood basket) of all biopower facilities in the Lake States and neighboring states. Figure 4 shows the growth, removals, total merchantable timber volume, and growth-to-removals (Growth-to-Drain) ratio in the Lake States. The volume and growth have continued to increase in the last 15 years, but the removals have remained almost constant. Hence, the growth-to-removals increased over time (figure 4) suggesting more volume could be sustainably removed after considering species composition.

Assessment of Sustainable Woody Biomass Availability

The annual sustainable availability of woody biomass identified as a net annual woody biomass increase (NAWI) is estimated using equation 4 following the method developed by Goerndt et al. (2013) and used in similar work by Stephen and Moser (2016) and Dahal et al. (2020). NAWI assesses the net availability of woody biomass in a year after considering growth, mortality, and extant removals

$$\text{NAWI} = \frac{V_g - V_r}{V_t} * W_B \qquad 4$$

where V_g is the estimated average annual growth volume on timberland within a procurement zone and V_r represents the estimated average annual removal volume on timberland before new demand for woody biomass within a procurement zone. Removals include cut and used trees, trees cut down during harvesting operations but not used, and live trees associated with land-use reclassification. V_t represents an estimated volume of live trees on timberland within a procurement zone and W_B represents estimated aboveground biomass in US short tons on timberland within the procurement zone. These estimates were derived from the FIA data with original units of cubic feet for volume and US tons for biomass. Volume and biomass estimates were from all live trees with diameter at breast height above 1 inch in timberlands, excluding reserved and other forestlands not accessible for commercial management.

Economic Contribution Analysis

IMPLAN

Economic contribution analysis is derived from the economic base theory and is an ex post analysis based on the existing economy as described by a social accounting matrix. The economic base theory describes contributions in terms of gross contribution (an industry selling its output to local industries and households keeping money in a region) and base contribution (an

Table 1. Total biomass available in the procurement zones at various delivered wood prices in 2019.

Delivered wood price ($/Gt)	Scenarios	Availability of aboveground biomass (million dry tons)						
	Change in delivered wood price	Illinois	Iowa	Michigan	Minnesota	South Dakota	Wisconsin	Total
27.90	20% increase	4.68	6.24	472.39	193.87	0.05	458.80	1,136.02
26.74	15% increase	2.30	5.17	423.65	167.11	0.05	419.40	1,017.69
25.58	10% increase	1.21	3.85	376.99	140.51	0.05	369.97	892.59
24.41	5% increase	0.69	2.16	331.57	113.34	0.05	321.73	769.55
23.25	**Current Average Price**	**0.20**	**0.94**	**277.19**	**85.78**	**0.05**	**272.87**	**637.03**
22.09	5% decrease	0.09		219.46	57.04	0.02	211.54	488.15
20.93	10% decrease			155.58	38.38		150.43	344.39
19.76	15% decrease			97.77	23.64		95.50	216.91
18.60	20% decrease			50.25	11.30		50.57	112.12
Total (∞)		173.11	72.12	678.44	332.01	29.20	505.91	1,790.79

Note: The bold text highlights the current price and economic contributions.

Table 2. Number of biomass power producers, their nameplate capacity and woody biomass consumption in the Lake States. (EPA 2021).

	Wisconsin	Minnesota	Michigan	Total
Number of facilities	12	9	6	27
Nameplate capacity in MW (*MW*)	767	518	180	1,465
Current power generation with coal, natural gas, and oil (million MWh)	1.51	1.51	0.83	3.85
Annual biomass consumption in million green tons	1.82	2.43	1.34	5.59

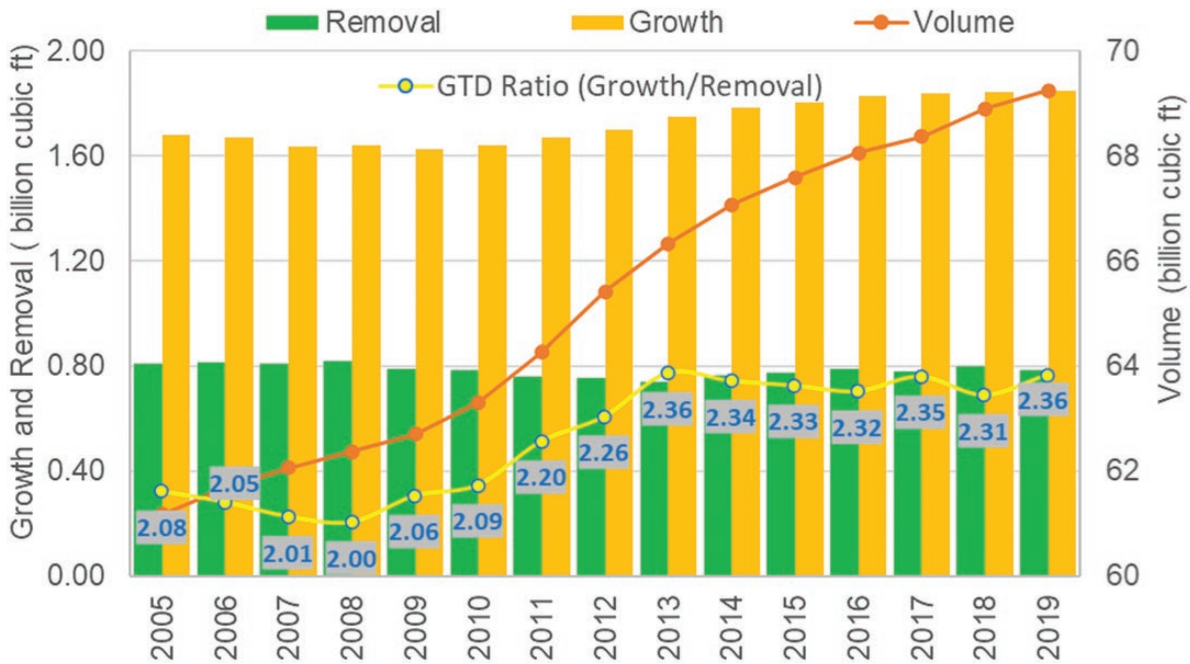

Figure 4. Growth, Removal, total merchantable timber volume, and Growth-to-Drain GTD)ratio in the Lake States.

industry's supply-chain expenditures bringing money into the region) (Watson et al. 2015). In other words, it estimates the relative importance of an existing industry to the regional economy. Impact analysis for planning (IMPLAN) (Minnesota IMPLAN Group 2004) is a widely used computer software package that allows users to estimate local input-output models and associated databases based on the interdependence among various producing and consuming sectors in the economy (Parajuli et al. 2018). The IMPLAN represents the flows of money in an economy among industries, government, and households within a region and imports into and exports out of the region (Dahal et al. 2020). In an I-O model, the flow of money among entities in the economy is arranged according to a set of input-output accounts where a portion of the output (i.e., sales) of one industry will appear as an input (i.e., purchases) of another industry. The accounts track the flow of money or jobs from one entity to the next and represent the interconnectedness of a region's industries, households, and government. An I-O model expresses how income or expenses in one part of the economy ultimately affects other parts based on purchasing and selling relationships. Economic contributions are generally reported as three components, depending on how they occur: direct, indirect, and induced. Direct effects are the result of initial spending in the study region by the business or organization under study. Indirect effects are the result of business-to-business transactions indirectly caused by direct effects as businesses increase spending on goods and services from other local businesses. Induced effects are the result of increased personal income generated by the direct and indirect effects as businesses increase payroll or hire more employees, and households, in turn, increase spending at local businesses. Induced effects measure the increase in household-to-business activity.

For this study, we used employment numbers collected from each powerplant to estimate localized economic contribution, including employment, labor income, gross output, and value added. Employment represents full-and part-time jobs and proprietors, gross output represents the value of production by the industry, and value added is the difference between gross output and intermediate input. The IMPLAN has been widely used in economic impact and contribution analysis of the natural resources sector. We used IMPLAN sector 47, electric power generation-biomass, and separated woody biomass based on employment numbers collected from each facility. This study included twelve powerplants from Wisconsin, nine from Minnesota, and six from Michigan. Our I-O analysis used IMPLAN 2017 data with results reported in 2019 US dollars.

Scenarios for Economic Impact Analysis

To capture the forest sector and labor market responses to additional biomass harvest and utilization, we used solutions of capacity conversion (demand related) and procurement analysis (supply related) to inform the economic contribution analysis. For this study, we used fifteen scenarios, including the base (current level of utilization) scenario, of which four are demand scenarios with capacity conversion and ten are supply scenarios with the availability of additional biomass at various delivered wood prices. The quantity of biomass demanded or supplied for these scenarios is presented in Table 3. Business as usual (*BAU)* is the base scenario that represents quantities of biomass used in 2019 to produce power reported in eGRID data. Demand scenarios with capacity upgrades include *BFG*, *B1K*, *B50*, and *B33* scenarios. The *BFG* scenario represents the biomass demand/usage if all coal, oil, and natural gas usage is converted to biomass power generation. The *B1K* scenario represents the biomass demand/usage if all total available nameplate capacity is used for biomass power generation. The *B50* and *B33* scenarios represent 50% and one-third of total nameplate capacity usage for biomass power generation. Supply scenarios with additional biomass availability at a given delivered wood price are *I20*, *I15*, *I10*, *I5N*, *AVG*, *D5N*, *D10*, *D15*, *D20,* and *TOT* scenarios. The *AVG* scenario represents the quantity of NAWI or additional sustainable biomass supply for biopower generation in existing facilities supported at the

Table 3. Biomass availability for demand and supply scenarios for biopower production in the Lake States region.

Description	Scenario (*s*)	Price ($/Gt)	Michigan	Minnesota	Wisconsin	Total
			Additional biomass in million dry tons(WB_s)			
Current annual biomass use	***BAU***	-	**0.67**	**1.22**	**0.91**	**2.80**
B.Demand scenarios with capacity conversion						
Biomass demand with current use and conversion of coal, oil, and natural gas to biomass	*BFG*	-	0.16	0.29	0.6	1.05
Biomass demand to operate at 100% nameplate capacity	*B1K*	-	0.9	3.32	5.81	10.03
Biomass demand to operate at 50% nameplate capacity	*B50*	-	0.12	1.05	2.45	3.62
Biomass demand to operate at 1/3 nameplate capacity	*B33*	-	-0.15	0.29	1.33	1.48
Supply scenarios with additional biomass availability						
20% increase in wood price	*I20*	27.90	7.08	2.68	7.59	17.50*
15%increase in wood price	*I15*	26.74	6.16	2.46	7.02	15.78*
10% increase in wood price	*I10*	25.58	5.55	2.07	6.35	14.05*
5% increase in wood price	*I5N*	24.41	4.75	1.65	5.54	12.01*
Average delivered wood price	**AVG**	**23.25**	**3.80**	**1.14**	**4.76**	**9.72***
5% decrease in wood price	*D5N*	22.09	3.08	0.68	3.69	7.44*
10% decrease in wood price	*D10*	20.93	2.01	0.42	2.59	5.00*
15% decrease in wood price	*D15*	19.76	1.09	0.34	1.74	3.16*
20% decrease in wood price	*D20*	18.60	0.45	0.20	0.88	1.51*
Total availability	*TOT*	-	9.73	5.14	8.41	28.84*

Note: The bold text highlights the current price and economic contributions.
*includes biomass from other states available for procurement at the given delivered wood price.

2019 average delivered wood price. The *I5N*, *I10*, *I15*, and *I20* scenarios represent the NAWI supply for power with 5%, 10%, 15%, and 20% increases in delivered price for biomass, respectively. The *D5N*, *D10*, *D15*, and *D20* scenarios represent the NAWI supply for biopower generation with 5%, 10%, 15%, and 20% decreases in delivered wood price for biomass chips, respectively. The *TOT* scenario represents the total NAWI biomass available in Michigan, Minnesota, Wisconsin, and neighboring states, irrespective of the cost of procurement. In all scenarios, we assume capacity upgrades will increase power production by using additional biomass without reducing or replacing current production levels. This approach can create additional economic impacts without diminishing the contributions of existing activities. The goal of this analysis is to present the technical potential for using biomass in power generation with the aim of stimulating local economic growth.

The total biomass demanded is estimated using equation 5 when all running capacity (capacity in use) is diverted to power generation using woody biomass instead of using coal, oil, or natural gas:

$$W_{BFG} = [(MWh_{coal} + MWh_{oil} + MWh_{NG}) * c] + W_{BAU} \quad 5$$

where W_{BFG} is the quantity of additional woody biomass demand from the current level of utilization if all running capacity dedicated to coal, oil, and natural gas is converted to biomass usage to produce biopower, W_{BAU} is the quantity of additional biomass used in 2019 to produce power from the current level of utilization, MWh_{coal} is the current level of megawatt-hour power generated using coal, MWh_{oil} is the current level of megawatt-hour power generated using oil, MWh_{NG} is the current level of megawatt-hour power generated using natural gas, and c is the conversion factor for biomass to power. Because 1 MWh of power is generated from 1 bdt biomass (Ashton et al. 2016), 1 bdt = 1 MWh. We estimate biomass demand when full, half, and one-third of existing nameplate capacities were dedicated to use biomass for power generation using equations 6–8,

$$W_{B1K} = 24 * 365 * MW * c \quad 6$$

$$W_{B50} = \frac{W_{B1K}}{2} \quad 7$$

$$W_{B33} = \frac{W_{B1K}}{3} \quad 8$$

where W_{B1K} is the quantity of additional woody biomass demand from the current level of utilization if all existing capacity or nameplate capacity is devoted to power generation using biomass running the facility 24 hours for 365 days, W_{B50} is the quantity of additional woody biomass demand from the current level of utilization if half existing capacity is devoted to power generation, W_{B33} is the quantity of additional woody biomass demand from the current utilization level if one-third of the existing capacity is devoted to power generation using biomass, and MW is the total nameplate capacity in megawatts in a state or region.

Impact Assessment for Different Scenarios

The economic contribution generated with different scenarios was estimated using equation 9,

$$EC_s = \frac{W_{B,s}}{W_{BAU}} * EC_{BAU} \quad 9$$

where EC_s is the economic contribution of scenario s, $W_{B,s}$ is the quantity of additional woody biomass demand at a capacity level or available at a given price for biopower generation in scenario s, EC_{BAU} is the economic contribution of business as usual or *Base* scenario, and W_{BAU} is the quantity of additional woody biomass used for biopower generation in the *BAU* or *Base* scenario.

Results

Descriptive Statistics

The total nameplate capacity available for biomass biopower generation in the Lake States was 1,464 MW, of which 767 MW was generated in Wisconsin, 518 MW in Minnesota, and 180 MW in Michigan in 2019. These facilities used 5.59 million Gt or 2.8 million bdt. Wisconsin biopower producers used 1.82 million Gt, Minnesota used 2.43 million Gt, and Michigan used 1.34 million Gt of biomass to produce power in 2019 (Table 2). Most of these facilities also used coal, natural gas, and oil for power generation in addition to biomass. Approximately 3.85 million MWh of power was produced using coal, natural gas, and oil in the Lake States. Michigan had the lowest number of facilities ($n = 6$) and available nameplate power (180 MW). Still, it used a considerably larger proportion of available biomass for power generation, over one-third of the existing capacity at 1.34 million Gt per year compared with the other states. Wisconsin had the largest number of active facilities ($n = 12$) and capacity (767 MW), whereas Minnesota consumed the largest volume of biomass (2.43 million Gt) and had the largest nameplate capacity (518 MW). If all biopower facilities were converted to biomass usage only instead of coal, natural gas, and other fossil fuels, the total consumption would be 3.85 million bdt, with an additional demand of 1.48 million bdt (Table 3). Operating at full nameplate capacities, if devoted to biomass biopower production, these facilities would use 12.83 million bdt.

Sustainable Availability of Woody Biomass: NAWI

The procurement zones for nine delivered wood price scenarios are presented in figure 5. The procurement region expands with an increase in the delivered wood price representing additional areas or regions available for biomass supply with additional dollars available for procurement. Figure 6 shows that the potential availability of feedstock changes significantly with the price change of about $10/Gt.

Approximately 28.84 million bdt of additional biomass (NAWI) was available annually for potential utilization to the biopower producers in the Lake States in addition to the current utilization level (2.80 million bdt) Table 4. This includes biomass available at the current delivered wood costs from neighboring states. At the delivered wood price of $23.25/Gt (current average price) additional 9.72 million bdt (29% of all NAWI) was economically available to the biopower industry. At a delivered wood price of $20.93/Gt, a 10% drop from the average biomass price in 2019, the NAWI is about 5 million bdt. If the price is further dropped to $18.60/Gt, 20% below the current price, only 1.51 million bdt of additional biomass becomes economically available annually. When the delivered wood price increases by 10% ($25.58/Gt) and 20% ($27.90/Gt), the NAWI increases to 12.01 million bdt and 17.50 million bdt, respectively. With these price increases, approximately 49% and 69%, respectively, of total NAWI in the region would

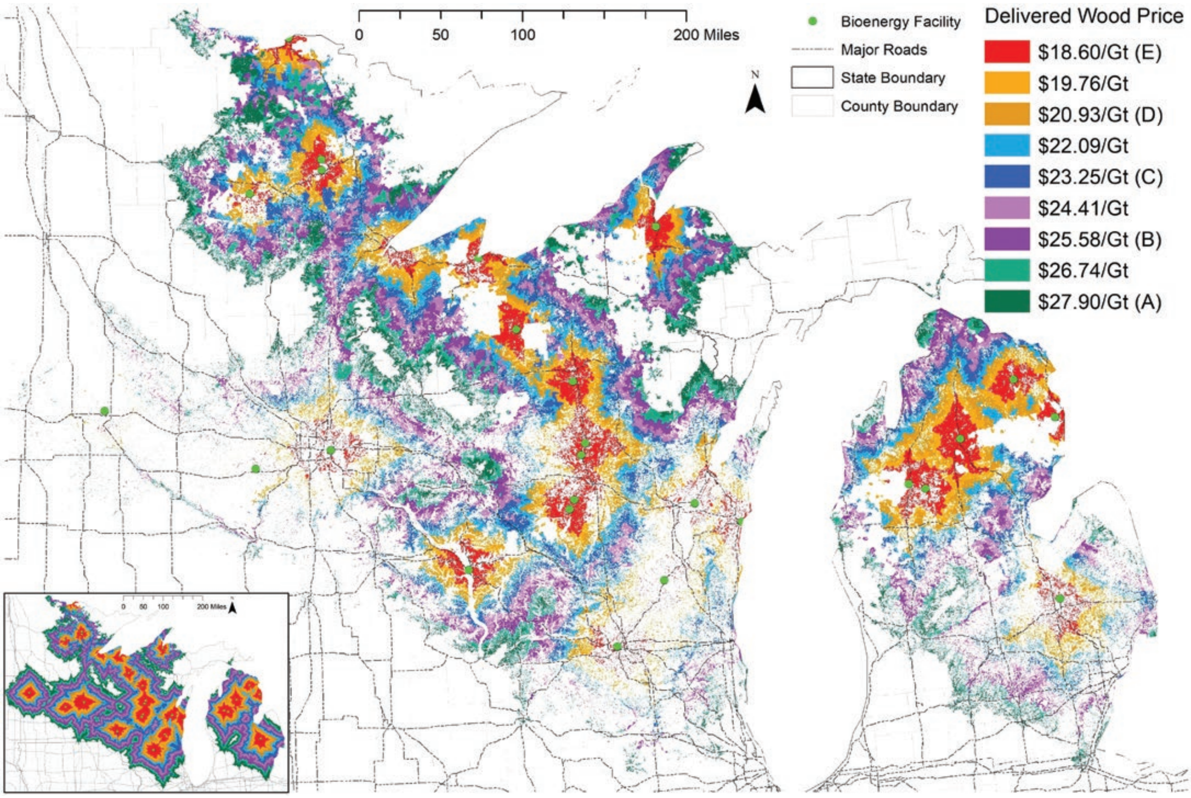

Figure 5. Biomass procurement zones at various delivered wood costs for state and private forestlands. (Inset: Biomass procurement zones without forest cover mask).

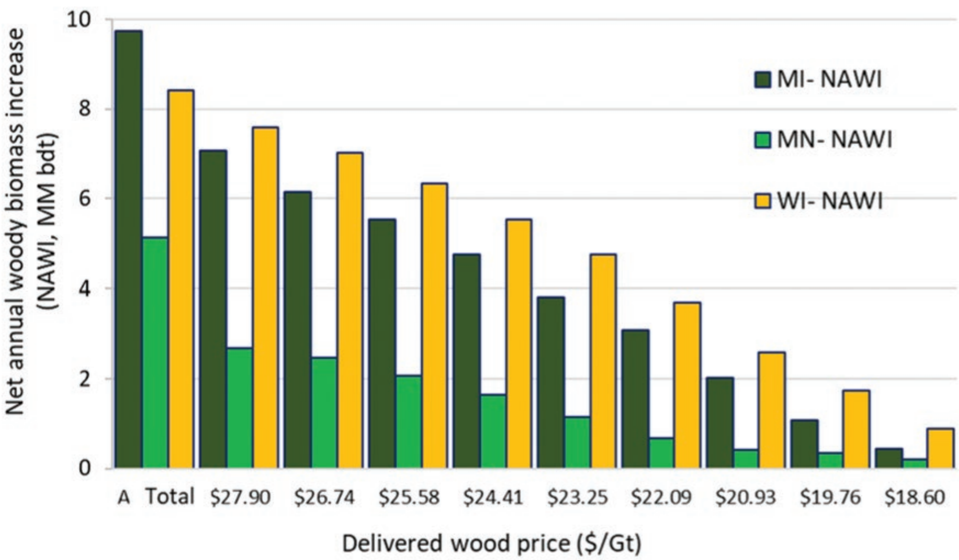

Figure 6. Total available biomass and net annual woody biomass increase (NAWI) in each procurement zones (wood basket) supported by a delivered wood price in the Lake States.

be economically available for the biopower sector. In all price scenarios, there is additional biomass available for utilization.

Economic Contribution of Biopower Production from Biomass

The economic contribution of biomass biopower generation is reported in Table 5. The biomass power sector contributed 3,201 jobs (456 direct + 2,745 indirect and induced), $442 million ($231 million direct + $211 million indirect and induced) in value added, and $781 million ($419 million direct + $361 million indirect and induced) in total output. In Michigan, the biomass biopower industry contributed 954 jobs (126 direct + 828 indirect and induced), $150 million ($86 million direct + $64 million indirect and induced) in value-added, and $247 million ($139 million direct + $108 million indirect and induced) in total output. As anticipated, the biopower industry in Minnesota created the highest

Table 4. Net annual woody biomass increase (NAWI) in the procurement zones at various delivered wood prices in 2019.

Delivered wood price ($/Gt)	Net annual woody biomass increase (NAWI, million dry tons)						
	Illinois	Iowa	Michigan	Minnesota	South Dakota	Wisconsin	Total
27.90	0.10	0.08	7.08	2.68	0.002	7.59	17.50
26.74	0.05	0.11	6.16	2.46	0.002	7.02	15.78
25.58	0.02	0.08	5.55	2.07	0.002	6.35	14.05
24.41	0.03	0.06	4.75	1.65	0.002	5.54	12.01
23.25	0.01	0.03	3.80	1.14	0.002	4.76	9.72
22.09	0.003		3.08	0.68	0.001	3.69	7.44
20.93			2.01	0.42		2.59	5.00
19.76			1.09	0.34		1.74	3.16
18.60			0.45	0.20		0.88	1.51
Total (∞)	3.86	1.70	9.73	5.14	0.22	8.41	28.84

Note: The bold text highlights the current price and economic contributions.

number of jobs (1,094) and generated the largest total output among the three states ($264 million). Nevertheless, despite having the smallest nameplate capacity (180 MW) and using the least amount of biomass (1.34 million Gt) of the three states, Michigan's biomass biopower industry contributed the largest direct ($86 million) and total value added ($150 million).

Economic Contribution with Additional Capacity Devoted to Biomass Utilization

Converting all current power generation capacity from coal, natural gas, and other fossil fuels to biomass fiber would add 1,204 jobs, $167 million in value added, and $293 million in total output. As a result, the total jobs supported by the industry would be 4,405 jobs (628 direct + 3778 indirect and induced), with value added of $609 million ($318 million direct + $219 million indirect and induced) and a total output of $1,074 million ($577 million direct + $ million indirect and induced) in the economy. If 33% of total nameplate capacity is dedicated to biomass biopower production, the total jobs will increase to 4,897 (1,696 more jobs than the current level), value added would become $677 million ($235 million more than the current level), and the total output generated would be $1,194 million ($413 million more than the current level). By dedicating 50% of total nameplate capacity to biomass biopower production, the total jobs would increase to 7,346 (4,145 more jobs than the current level), value added would become $1,015 million ($573 million more than the current level), and the total output generated would be $1,791 million ($1,010 million more than the current level). If 100% of the total nameplate capacity can be dedicated to biomass biopower production, the total jobs would increase to 14,692 (11,491 more jobs than the current level), value added would become $2,031 million ($1,589 million more than the current level), and the total output generated would be $3,583 million ($2,802 million more than the current level) in the economy.

Economic Contribution with Biomass Availability at Different Delivered Wood Prices

If all biomass available at the current average price is used, the biopower sector will contribute an additional 11,112 jobs (1,583 direct + 9529 indirect and induced), $1,536 million in value added ($803 million direct + $733 million indirect and induced), and $2,710 million ($1,456 million direct + $1,254 million indirect and induced) in total output in the economy compared with *BAU*. If total available NAWI were used irrespective of delivered wood prices, an additional 46,586 jobs (6637 direct + 39,949 indirect and induced), $6,439 million ($3368 direct + $3071 million indirect and induced) in value added, and $11,360 million ($6102 direct + $5258 million indirect and induced) in total output would be added in the economy in addition to the *BAU* scenario.

With a 10% reduction in prices, assuming all available biomass at this cost is used, the economic contribution would be still higher than that of the current level, the total jobs contributed will increase by 5,748, and value added will increase by $795 million with an additional $1,402 million in total output At 20% reduction below the current average price for average delivered wood prices, the industry would still contribute additional 1,739 jobs, $240 million in value added, and $442 million in total output, where about 1.51 million bdt of NAWI is available for biopower producers in addition to the current level of usage. So, in general, a significant amount of biomass is still available at lower prices than the current market price in the Lake States.

On the other hand, with a 5% increase in the delivered wood prices, the economic contribution increased significantly, where the total jobs number increased by 13,992 from *BAU* with additional value added of $1,890 million and $3,334 million of total output in the economy. This is slightly below what is required for running all facilities at the current nameplate capacity. With a 10% increase in the delivered wood price, the total jobs number increased by 15,992, value added by $2,210 million, and total output by $3,900 million ($3,119 million more than *BAU*). With an increase of 10% increase in the price of delivered wood prices of biomass, the biomass demanded would exceed the current nameplate capacity. Therefore, a new facility or an upgrade to the existing facility will be required. Further price increases will need added capacity in the region.

Discussion

Biomass power is an important part of the Lake State's forest-based economies and may be under-recognized for its role in providing market-based outlets for fuel materials,

Table 5. Economic impacts of biopower facilities to the state and regional economy under different scenarios (NAWI biomass, 2019 US dollars).

Scenario	Economic Impacts	Employment (#)				Value added (million $)				Output (million $)			
		MI	MN	WI	Region	MI	MN	WI	Region	MI	MN	WI	Region
BAU	Direct	126	179	151	456	86	63	71	231	139	145	125	419
	Indirect & Induced	828	915	507	2745	64	68	56	211	108	120	96	361
	Total	*954*	*1094*	*658*	*3201*	*150*	*131*	*127*	*442*	*247*	*264*	*221*	*781*
Additional Contributions to BAU scenarios													
Demand scenarios with capacity conversion													
BFG	Direct	30	43	99	172	20	15	46	87	32	35	83	158
	Indirect & Induced	194	223	334	1033	16	17	37	79	26	29	63	136
	Total	*224*	*266*	*434*	*1204*	*36*	*32*	*83*	*167*	*58*	*64*	*146*	*293*
B1K	Direct	170	489	964	1637	116	172	451	831	187	395	799	1505
	Indirect & Induced	1118	2500	3238	9854	87	187	356	758	147	326	612	1297
	Total	*1288*	*2989*	*4202*	*11491*	*204*	*358*	*808*	*1589*	*333*	*722*	*1411*	*2802*
B50	Direct	22	155	406	591	15	54	190	300	24	125	337	543
	Indirect & Induced	145	793	1365	3555	12	59	150	273	19	103	258	468
	Total	*167*	*948*	*1772*	*4145*	*27*	*114*	*340*	*573*	*43*	*229*	*595*	*1010*
B33	Direct	-27	44	221	242	-19	15	103	123	-30	35	183	222
	Indirect & Induced	-179	223	741	1455	-14	17	81	112	-23	29	140	192
	Total	*-207*	*267*	*962*	*1696*	*-32*	*32*	*185*	*235*	*-54*	*65*	*323*	*413*
Supply scenarios with biomass availability													
I20	Direct	1333	394	1260	2830	910	138	590	1436	1466	319	1045	2602
	Indirect & Induced	8757	2015	4232	17035	682	150	466	1310	1146	263	800	2242
	Total	*10090*	*2410*	*5492*	*19865*	*1592*	*289*	*1056*	*2746*	*2612*	*582*	*1845*	*4844*
I15	Direct	1161	362	1165	2552	793	127	546	1295	1277	293	966	2347
	Indirect & Induced	7625	1851	3915	15362	593	138	431	1181	997	242	740	2022
	Total	*8786*	*2212*	*5080*	*17914*	*1386*	*265*	*977*	*2476*	*2274*	*534*	*1706*	*4368*
I10	Direct	1045	305	1053	2278	714	107	493	1156	1149	246	873	2095
	Indirect & Induced	6865	1559	3538	13713	534	116	390	1054	898	204	669	1805
	Total	*7910*	*1863*	*4591*	*15992*	*1248*	*223*	*883*	*2210*	*2047*	*450*	*1542*	*3900*
I5N	Direct	895	243	919	1948	611	85	431	989	985	196	762	1791
	Indirect & Induced	5881	1240	3088	11726	458	92	340	902	769	162	584	1543
	Total	*6776*	*1483*	*4007*	*13674*	*1069*	*178*	*771*	*1890*	*1754*	*358*	*1346*	*3334*
AVG	**Direct**	**717**	**167**	**790**	**1583**	**489**	**59**	**370**	**803**	**788**	**135**	**655**	**1456**
	Indirect & Induced	**4708**	**855**	**2655**	**9529**	**366**	**64**	**292**	**733**	**616**	**112**	**502**	**1254**
	Total	***5424***	***1023***	***3445***	***11112***	***856***	***123***	***662***	***1536***	***1404***	***247***	***1157***	***2710***
D5N	Direct	580	100	612	1216	396	35	287	617	638	81	508	1118
	Indirect & Induced	3813	511	2058	7318	297	38	227	563	499	67	389	963
	Total	*4394*	*611*	*2670*	*8534*	*693*	*73*	*513*	*1180*	*1137*	*148*	*897*	*2081*
D10	Direct	379	62	429	819	259	22	201	416	417	50	356	753
	Indirect & Induced	2493	316	1441	4929	194	24	159	379	326	41	272	649
	Total	*2872*	*378*	*1870*	*5748*	*453*	*45*	*360*	*795*	*743*	*91*	*628*	*1402*
D15	Direct	205	49	289	516	140	17	135	262	225	40	240	474
	Indirect & Induced	1344	253	971	3106	105	19	107	239	176	33	184	409
	Total	*1548*	*302*	*1259*	*3622*	*244*	*36*	*242*	*501*	*401*	*73*	*423*	*883*
D20	Direct	84	29	145	248	57	10	68	126	93	23	121	228
	Indirect & Induced	553	147	489	1491	43	11	54	115	72	19	92	196
	Total	*637*	*176*	*634*	*1739*	*100*	*21*	*122*	*240*	*165*	*42*	*213*	*424*
TOT	Direct	1834	2605	2198	6637	1252	915	1029	3368	2017	2105	1822	6102
	Indirect & Induced	12046	13320	7383	39949	937	993	813	3071	1576	1739	1396	5258
	Total	*13880*	*15925*	*9581*	*46586*	*2190*	*1908*	*1842*	*6439*	*3593*	*3845*	*3218*	*11360*

Note: The bold text highlights the current price and economic contributions. The italics shows the totals.

low-value forest products, and mill residues. This study identified twenty-seven active biomass biopower producers in the Lake States with a total nameplate capacity of 1,465 MW. They used approximately 5.59 million Gt or 2.80 million bdt of biomass in 2019, which satisfied about 22% of their total power generation capacity. At present, all regional power producers use coal, oil, and natural gas. Switching the feedstock to biomass would increase the biomass demand by 1.05 million bdt. Raising the production to one-third of the available capacity for biomass-based power generation would increase the demand for biomass in the region by 1.48 million bdt from the current utilization.

The economic feasibility of using biomass for power generation has been a subject of much debate due to its perceived lack of availability. However, our research findings suggest that this perception is inaccurate. Specifically, our study estimates that the region has an additional 28.84 million bdt of biomass available, and a cost-optimal approach indicates that at least 9.72 million bdt of additional biomass is economically available at the current average delivered wood price of $23.25/Gt. These findings suggest that the feedstock available could satisfy approximately 96.96% of the existing capacity if all twenty-seven facilities in the region were used for power generation from biomass.

Despite the favorable economic availability of biomass, it is important to note that economic availability does not always translate into actual utilization. Even with cautious estimates of delivered wood prices of $18.60/bdt, a 20% decrease from the current price, 1.51 million bdt of additional biomass is available, which is more than enough to support one-third of production capacity in 27 facilities. Moreover, with favorable policy incentives and market forces, if the delivered wood prices are as high as $27.90/bdt, 20% above current prices, an additional 7.74 million bdt of biomass would be economically available above current availability. If all of this biomass is used, 17.50 million MWh of power would be generated in addition to existing power, increasing the biopower production by about 20 MW in the Lake States. Even a marginal increase in prices of 5% would create a larger wood basket, significantly increasing the available feedstock for biopower, with an additional 12.01 million MWh of power. Taken together, our findings indicate that the region is rich in biomass resources, and there is potential for new investments in the biomass biopower industry. Establishing new facilities would expand the procurement zones and increase the market extent, resulting in more economically available biomass. However, it is essential to address the existing challenges associated with the actual utilization of biomass, such as lower cost of power production from other sources, labor (loggers and truckers) and equipment (biomass harvester and chippers) shortages, less willingness to harvest and use biomass due to lack of information, and, most importantly, ill-informed stakeholders on the importance of removing biomass for both ecological and economic benefits. The capacity conversion does not happen in existing facilities due to economic, technological, supply chain, and other limitations. The cost of producing biopower has always been higher than power production from other sources, such as solar, wind, and especially fossil fuels (IEA 2020; IRENA 2012). Consequently, more than 9.72 million bdt of additional biomass within the economic reach of already existing facilities goes unused every year. This indicates huge potential for new investments in the biomass biopower industry in the region.

The procurement of biomass feedstock poses several challenges as it requires a well-established logistics process that involves harvesting, transportation, chipping, and storage. Many facilities may lack such a strong framework, which can lead to difficulties in procuring biomass feedstock. At the delivered wood price of $23.25/Gt and after considering the sustainable threshold for biomass availability, at least 9.72 million bdt of biomass is economically available within the woodsheds of existing facilities. However, about half of the private forest landowners in the region do not manage forests for harvesting or timber-related purposes (Butler et al. 2021), which limits the potential supply of biomass feedstock. On the other hand, landowners must comply with state rules, regulations, and best management practices, such as considering soil productivity, habitat, and forest health during harvesting. Timber harvesting is a complex process and may take significant time and cost. The Billion-ton Report (DOE 2016) indicated that up to 30% of biomass could be harvested without affecting the soil productivity, habitat, and health. Hence, capping the economically and ecologically available biomass at 30% of total NAWI estimates that within the procurement zones, at least 2.92 million bdt of additional biomass is already available and unused if procured at the current average delivered wood prices. This could satisfy about 76% of the feedstock requirement if facilities switched from coal, oil, and natural gas to forest biomass. However, capacity conversion to use a significantly larger volume of biomass, even if there is economic availability, is still farfetched.

In many cases, biopower producers consume mill residues from sawmills or pulp facilities to produce heat and power. These residues are generally seen as waste, and the primary purpose is to dispose of them. However, using logging residues for biopower incurs procurement costs, making it expensive compared with mill residues and other renewables. The biomass industry operates at narrow profit margins dues to the higher cost of power generation compared with fossil fuels, rendering it financially suboptimal (IEA 2020). Hence, any financial and policy incentives that reduce the cost of biomass procurement and production could facilitate the shift from fossil fuels to renewable biomass resources. Previous studies have suggested that logging residues can provide a wider source of additional feedstock to the power plant if procurement costs could be reduced (Pokharel et al. 2019). However, the cost of conversion is currently unjustified, as biomass biopower is not competitive with fossil-based power producers because of the relatively low cost of other fuels (Dahal et al. 2020).

The expansion of the biomass biopower industry has the potential to substantially affect economic contributions to states and regions, particularly in rural areas. Shifting power generation from natural gas, oil, and coal to biomass has the potential to generate 1,204 additional jobs, $167 million in value added, and $293 million in total output within the regional economy. A study by Dahal et al. (2020) found that wood-based power plants have a larger economic footprint (2.8) compared with coal (2.34) and natural gas (2.5), indicating that investing in wood-based power can produce a 20% greater economic contribution than coal and over a 15% greater contribution than natural gas. Thus, the net economic benefit of a wood-based power plant is larger than coal and natural gas if the same level of investment is made.

Table 6. Economic contribution of forest products industry in the Lake States region (MI, MN, WI), 2019 US dollars.

Impact type	Employment (#)	Labor income (million $)	Value added (million $)	Output (million $)
Direct	142,557	9,749	14,395	48,571
Total	344,893	21,651	33,534	82,805
Multiplier	2.42	2.22	2.33	1.70

Moreover, the economic benefits of the forest products industry are substantial to the rural economy of the Lake States. For example, in Wisconsin, the forest products industry accounts for 12% of total manufacturing jobs in the state, mostly in rural areas (Dahal 2021), and ranks second nationwide in terms of total forest products industry employment (Pelkki and Sherman 2020). The forest products industry in the Lake States generates 344,893 local jobs and approximately $82.81 billion in total output (Table 6). Given the heavy reliance of the Lake States economy on the forest products industry, particularly in rural communities, additional biomass usage would significantly improve rural economies by creating additional jobs and generating power.

Similarly, using forest biomass to generate at least one-third of the current power would support an additional 1,969 jobs, $235 million in value added, and $413 million in total output. If all the available biomass at the current prices is used in these existing facilities, well over 11,000 jobs, $1.5 billion in value added, and $2.7 billion in total output will be added to the Lake States economy. These findings suggest that shifting from fossil fuels to biomass in power production could generate a greater economic impact in the rural economy. Therefore, favorable policies and incentive programs targeted at biomass biopower production would not only help these facilities to achieve financial stability but also positively affect local economies. As stated above, Lake States already has the capacity and the feedstock to produce more power using biomass, but the real issue is the cost of production using biomass. Lowering the current price of biomass by 20% to reduce the production cost, there would still be additional biomass available, which can support 1,730 additional jobs, $240 million in additional value added, and $424 million in additional output in the region, indicating the potential for jobs and economic development in the region with biomass biopower production. If all of NAWI or available feedstock is used for power in those twenty-seven facilities, 46,586 jobs, $6.44 billion in value added, and $11.36 billion in total output would be added to the economy. Suppose power plants operate at maximum capacity to use biomass for power production. In that case, this industry could support over 11 thousand jobs, $1.6 billion in value added, and $2.8 billion in total output. This all indicates that there is available biomass and potential to develop a biomass biopower industry to increase economic contribution, especially in rural communities in the Lake States.

However, technical potential does not always translate to economic opportunities. Significant hurdles exist for the procurement of additional biomass for power generation. Some of the key factors limiting biomass procurement are equipment availability and upgrades to harvest biomass (Martinez-Valencia et al. 2021; Pokharel et al. 2017), lack of loggers and log truck drivers to procure biomass (Gc et al. 2017; Koirala et al. 2017; Vaughan et al. 2022), and high costs associated with collecting, sorting, and transporting biomass (Jones et al. 2013; Martinez-Valencia et al. 2021; Pokharel et al. 2019). The aging logger and trucker population and the younger generation's lack of interest in entering this business have created a labor shortage, which is essential to convert biomass utilization technical potential into an economic opportunity (Gc et al. 2020). Biomass procurement and utilization for power generation is labor intensive, less profitable, and requires operation changes. The forest products supply chain is already suffering from labor shortages. Therefore, changing operations and upgrading equipment to procure and use additional biomass may be demanding or even oversight, as loggers and truckers are already busy doing what they have been trained for and are accustomed to doing for many years. However, well-aligned policies and incentives could increase the demand for biomass among power producers, which could eventually encourage these businesses to procure biomass.

Notable limitations of this study are as follows. This study assumes no stumpage cost and a fixed harvesting cost (33% of the current delivered biomass price of $8.14/Gt). Including the stumpage costs for biomass and increasing the harvesting cost would either increase the delivered wood price for the same procurement zones or shrink procurement zones, lowering the available quantities of biomass at a given price. Also, we assume that capacity upgrades increase the additional utilization of biomass without compromising power production from other resources, thus creating additional economic impacts without reducing contributions from existing activities. This may not always be true, and some displacement may happen with large capacity conversions to produce a significant amount of electricity from biomass. Because our analysis only looked at facilities already using woody biomass, mostly in rural areas, and were likely candidates for upgrades, it was not possible to account for compromised economic contributions, if any, on other power production sectors. This study only considered capacity expansion in existing facilities using biomass for biopower production. Establishing new facilities at a distance from these facilities to deter competition would increase market extent or procurement zones such that more biomass could be hauled into new facilities. Procurement zones are based on delivered wood price converted to hauling time; therefore, results may change with each facility's preference and current contract with loggers and truckers. Also, this study does not consider biomass going out of the Lake States to neighboring states while accounting for biomass coming into facilities in the Lake States from these neighbors. This study does not explore the option to sell power, and this could be important in understanding the demand for power from renewables such as biomass and understanding how the transaction happens between the power producers and consumers. The IMPLAN, being a static model, does not account for the price change and other economic fluctuations over time. However, inter-industry relationships are subject to change over time. Also, NAWI estimates are based on FIA data, which is subject to sampling error.

Conclusion

This study estimates the economic availability of additional forest biomass in the Lake States region and its economic impacts on the local economy if used by wood-based power plants under various demand and supply scenarios. There were twenty-seven active biomass biopower producers in the Lake States region in 2019, with a total capacity of 1,465 MW. About 22% of the capacity in these facilities was dedicated for power production from woody waste and biomass, using 2.80 million bdt of woody biomass. Findings revealed that operating at a one-third level of nameplate capacity requires an additional 1.48 million bdt of biomass. At the current delivered wood price, 9.72 million bdt of additional biomass is economically available. This is enough to exhaust 96.96% of the existing power production capacity in these facilities. This indicates that a huge proportion of forest biomass is available for plants to operate at their maximum capacity or to make an upgrade in the existing facilities. Increasing the delivered wood price by 5%–20% would provide an opportunity to procure woody biomass from distant, growing wood baskets and create more jobs in the local economy. For instance, at delivered wood prices of $27.90/bdt, 20% above current prices, a capacity upgrade can produce an additional 7.74 million MWh per year of power using all available biomass after considering the sustainability threshold. Additional biomass utilization through capacity conversion, upgrade, and increase in delivered wood price has positive impacts on the economy, creating more jobs and value added. Because most of these biopower producers are located in rural areas, increased biomass-based power generation could be a significant economic stimulus for rural communities in the Lake States region. The biomass biopower sector supported 3,201 jobs, $442 million in value added, and $781 million in total output in 2019. Commissioning at least one-third of the existing capacity for biomass-based power generation would generate 1,696 jobs, $235 million in value added, and $413 million in total output in addition to the current production level. Using all biomass available at the current price would add 11,112 jobs, $1,533 million in value added, and $2,710 million in total output. Creating thousands of jobs and generating millions of dollars would benefit rural communities in many ways.

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Conflict of Interest

The authors declare no conflict of interest.

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